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Vegetace antropocénu

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Prohlášení

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1 ÚVOD

V období počátku neolitické revoluce, kdy člověk začal chovat zvířata, nastala potřeba zajistit pro ně zdroj potravy (WEISDORF, 2005; SCANES, 2018). Od vzniku pastevectví člověk využívá společenstva trav jako zdroje potravy pro přežvýkavce a koně (BOLES ET AL., 2019; SALVATORIET AL., 2019). Z počátku se člověk stěhoval na místa s dostatkem zelené biomasy trav (píce), aby zajistil dostatek zdrojů potravy pro chovaná zvířata (AMBROSE, 1991; MA ET AL., 2021). S usedlým způsobem života se pojí již trvalé využívání některých ploch jako pastvin (ARBUCKLE, HAMMER, 2019). Jednalo se především o plochy nevhodné pro ornou půdu. Ovšem i orná půda se využívala pro pasení v případě, že pole leželo ladem. Pastevectví a pastviny byly využívány především v pahorkatinách a horských oblastech (ARBUCKLE, HAMMER, 2019; DIETRE ET AL., 2020; GILCK, POSCHLOD, 2021). Později docházelo k využívání travnatých ploch jako zdroje sena pro píci v mimovegetačním období. Louky byly zakládány především v zaplavovaných nivách řek. Louky a pastviny jsou úzce spojeny se zemědělstvím a s některými činnostmi člověka (HEJCMAN ET AL., 2013; GILCK, POSCHLOD, 2021; LIU ET AL., 2021). Pravidelné a dlouhodobé spásání v případě pastvin a pravidelné sečení a sušení biomasy v případě luk vedlo k zastavení přirozené sukcese vegetace a k vytvoření netypického rostlinného společenstva (SIENKIEWICZ-PADEREWSKA ET AL., 2020; HOBOHM ET AL., 2021). Relativně druhově bohatá společenstva se skládají z dominantního zastoupení trav a víceletých bylin. Zastoupení jednotlivých druhů odráželo také půdní podmínky (pH, obsah humusu, obsah živin) a také klimatické podmínky odvislé především od nadmořské výšky.

Od začátku průmyslové revoluce docházelo ke změnám v chovu skotu (CHANG ET AL., 2020; LAURENT ET AL., 2020) a ke změnám v systému získávání píce. Celoroční ustájení skotu přineslo potřebu kvalitní píce bohaté na dusíkaté látky, a proto se pícniny začaly pěstovat na orné půdě. Pěstování jetelovin (jetele lučního, vojtěšky), případně jetelotravních směsí, dokázalo zajistit potřebu píce pro skot v průběhu celého roku (DIEKMANN ET AL., 2019). Následně klesla potřeba píce z lučních a pastevních porostů. Pícniny na orné půdě vytvářejí druhově chudá společenstva (KISS ET AL., 2021), složená z vysetých plodin a plevelů. Intenzifikace zemědělství po 2. světové válce vedla k rozorávání luk a pastvin (ELIÁŠ JUN. ET AL., 2021; RAVEN, WAGNER, 2021) a k dalšímu rozšíření pěstování pícnin na orné půdě. Pěstování pícnin bylo často spojeno s intenzifikačními prvky, jako je využívání průmyslových hnojiv, závlahových systémů

a pesticidů. Hlavní snahou byla produkce velkého objemu píce z orné půdy s vysokým podílem dusíkatých látek (Eliáš jun. et al., 2021; Raven, Wagner, 2021).

Lidé a plevel sdílejí dlouhou koevoluční historii. Nejranější agrární plevele vznikly, když se v historii lidstva objevilo samotné zemědělství. Mnoho z těchto druhů plevelů nás doprovázelo všude, kde jsme se usadili a pěstovali plodiny, přičemž plevele Starého světa následovaly západní kolonisty do Nového světa, ale také nové plevele z Nového světa zpět do Starého světa. V současné době plevele následují plodiny po celém světě. Plevele se přizpůsobují každé situaci a tato adaptace na celém světě je nyní podporována globálním vlivem lidstva (Clements, Jones, 2021). Plevele jsou potlačovány od počátku zemědělství, protože jsou hlavní biotickou příčinou ztrát na výnosu polních plodin (Delye et al., 2013; Chauhan, 2020; Hussain et al., 2021). K revoluci v regulaci plevelů došlo na počátku 50. let minulého století díky používání herbicidů, které daly základy průmyslovému zemědělství (Liebman et al., 2001; Merotto et al., 2022). V posledních letech byl v různých zemích zaznamenán nárůst používání herbicidů, jak vyplývá z vědeckých studií (Chauvel et al. 2011; Qu, 2021; Klingelhöfer, 2021; Thompson, Liu et al., 2023). Během 12letého monitoringu na pilotních farmách ve Švýcarsku bylo zaznamenáno zvýšení používání glyfosátu z 0,034 $kg.ha^{-1}$ na 0,141 $kg.ha^{-1}$ orné půdy (Dugon et al., 2010). V současné době dochází na některých místech k opouštění dříve zemědělsky využívaných pozemků (Levers et al., 2018; Yin et al., 2018). Náhlá absence lidských zásahů vede ke vzniku specifické vegetace (Zhang, Ye, 2021). Nevyužívané a opuštěné plochy dávají prostor pro rozvoj ruderální vegetace, při delší době sukcese křovinám a lesům (Sojneková, Chytrý, 2015; Chen et al., 2021), s výrazným zastoupením nepůvodních druhů (Zhang et al., 2010; Wang et al., 2013; Bravo et al., 2019).

Lidská činnost je často hlavním zdrojem znečištění a přináší potenciálně nebezpečné látky do atmosférických, suchozemských i vodních ekosystémů (Passariello et al., 2002). Nezanedbatelný vliv antropogenních faktorů na vývoj ekosystémů, rostlinných společenstev musí být součástí současného výzkumu v oboru botanika. Předkládaná práce shrnuje stávající poznání v oblasti koevoluce lidské civilizace a vegetace. Práce mapuje dopady lidské společnosti na vegetaci antropogenně ovlivněných stanovišť. Jejím cílem je popsat výsledky vzájemné koevoluční interakce mezi lidskou civilizací a vegetací a přispět k diskusi o antropocénu.

2 VEGETACE A ANTROPOGENNÍ PROSTŘEDÍ

2.1 Vegetace orné půdy

Orná půda patří mezi nejintenzivněji obhospodařovaná a vysoce modifikovaná antropogenní stanoviště a zároveň poskytuje základní stanoviště pro mnoho spontánně se vyskytujících druhů rostlin (STORKEY, CUSSANS, 2007). Změny v obhospodařování orné půdy ovlivnily mnoho aspektů biodiverzity, včetně rozšíření a hojnosti spontánně se vyskytujících rostlin (RICHNER ET AL., 2015; STORKEY ET AL., 2012). Obdělávání půdy se používá po tisíciletí pro přípravu seťového lůžka a hubení plevelů (Lal 2009; Mitchell et al., 2016). V současné době je podporováno omezené zpracování půdy jako alternativa k tradičnímu zpracování půdy (PEIXOTO ET AL., 2020; ZHANG ET AL., 2021). Omezené zpracování půdy zlepšuje kvalitu půdy a zmírňuje emise skleníkových plynů díky zvýšenému ukládání uhlíku do půdy a snížení spotřeby paliva při zpracování půdy (HOBBS ET AL., 2008; KASSAM ET AL., 2012; STOŠIĆ ET AL., 2021). Použití omezeného zpracování půdy se celosvětově zvyšuje (EL TITI, 2002) z důvodu kladných přínosů pro ochranu půdy a vody (HOLLAND, 2004; VOGELER ET AL., 2006) a také z důvodu snížení spotřeby paliva a nákladů na práci (DERPSCH, 2005). Uvádí se, že ve Spojených státech je 37 % orné půdy obhospodařováno bez obdělávání a 35 % půdy s omezeným obhospodařováním (NASS, 2019), zatímco ve světě je obhospodařováno bez obdělávání 11 % orné půdy (KASSAM ET AL., 2015). Podle COOPER ET AL. (2016) výhody omezeného zpracování půdy mohou převážit nad jakýmkoli zvýšením tlaku plevelů, protože zvýšení hustoty plevelů v systémech omezeného zpracování půdy není konzistentně spojeno s penalizací na výnosu plodin.

Jak je uvedeno v Tabulce 1, vegetace plevelů na zemědělské půdě, kde je uplatňováno její redukované zpracování, má vyšší biologickou relevanci, což přispívá k zachování a podpoře biodiverzity zemědělské krajiny. Plevele poskytují řadu zdrojů (pyl, nektar, plody, semena), které jsou zdrojem potravy pro různé druhy hmyzu, ptáků a savců (WILSON ET AL., 1999; PETIT ET AL., 2011, REQUIER ET AL., 2015; BRETAGNOLLE, GABA, 2015). Plevele jsou důležitým zdrojem potravy pro mnoho přírodních nepřátel škůdců pěstovaných plodin (parazitoidi, predátoři), (TYLIANAKIS ET AL., 2004; DITOMMASO ET AL., 2016).

Tabulka 1. Průměrný počet jedinců plevelů dle biologické relevance (BR) u jednotlivých variant zpracování půdy (WINKLER ET AL., 2023A)

Zpracování půdy	**Skupiny dle biologické relevance (počet druhů závislých na plevelích)**						
	BR1 (<6)	BR2 (6-12)	BR3 (13-24)	BR4 (25-50)	BR5 (51-100)	BR6 (101-200)	BR_bez (bez údajů)
CT	0,0	0,1	5,6	1,3	1,8	0,0	0,5
MT	0,0	0,1	3,3	1,1	2,0	0,0	1,2
NT	0,0	0,3	5,4	5,0	1,0	0,0	0,6

Vysvětlivky: CT – tradiční zpracování půdy, MT – minimalizační zpracování půdy, NT – technologie přímého setí do nezpracované půdy

Herbicidy spoluvytvářejí selekční tlak na vegetaci polí (KOLÁŘOVÁ ET AL., 2023). Různé druhy regulací plevelů vytvářejí na tuto vegetaci specifický tlak a v dlouhodobějším horizontu mění životní strategii rostlin (WINKLER ET AL., 2023A). Plevele, které jsou schopny tento tlak přežít, tuto niku obsazují a zůstávají součástí zemědělské krajiny, ovšem bohatost vegetace polí je důležitá pro bohatství ptáků (GEIGER ET AL., 2010; GUERRERO ET AL., 2012) a dalších živočichů schopných přiletět a usadit se na intenzivně ošetřovaných polích (CHIRON ET AL., 2010).

Změny v druhovém složení plevelů vyvolané omezením aplikací herbicidů vedou k prosazení specializovanějších plevelů (specialistů) na úkor obecně rozšířených druhů (generalistů), (WINKLER ET AL., 2023A). Podle CLAVEL ET AL. (2011) pesticidy, zejména herbicidy mohou přispět k procesu biotické homogenizace, což znamená zvyšování zastoupení plevelů odolných k používaným herbicidům. Zavedením omezení v aplikaci herbicidů roste heterogenita stanovišť v krajině. Především snížení dávek pesticidů je podle CHIRON ET AL. (2014) a LIU ET AL. (2021) v širším měřítku základním přínosem pro taxonomickou a funkční rozmanitost zemědělské krajiny.

Zemědělství je jedním z největších zdrojů emisí do povrchových vod a vodních ekosystémů (CARPENTER ET AL., 1998; HANIFZADEH ET AL., 2017). Vodní ekosystémy jsou často kontaminovány herbicidy (GILLIOM, 2007; LOOS ET AL., 2009; WITTMER ET AL., 2010; BRÜHL, ZALLER, 2021). Tato kontaminace závisí na mnoha parametrech, například na struktuře povodí a využití půdy (na antropické aktivitě, povrchu nebo sklonu), struktuře a složení půdy, na environmentálních faktorech a hydrologii (na

dešťových srážkách, průtoků vodních topků, větrů), na podmínkách vodního prostředí (na pH, organických látkách a suspendovaných částicích) a také na chemických vlastnostech herbicidů (BLANCHOUD ET AL., 2007; ULRICH ET AL., 2013). Mnoho evropských studií uvádí detekci účinných látek herbicidů ve vodním prostředí, jako jsou diuron, metolachlor, isoproturon, terbutryn a atrazin (MEYER ET AL., 2011; KÖCK-SCHULMEYER ET AL., 2012; DE SOUZA ET AL. 2020; BARBIERI ET AL., 2021; TÓTH ET AL. 2022). Vzhledem k jejich fytotoxickým účinkům tvoří jejich chování ve sladkovodních ekosystémech riziko pro necílové organizmy, jako jsou např. bentické diatomy (*Diatomeae*), (AKERBLOM, 2004). Herbicidy obecně inhibují různé životně důležité funkce u fotosyntetizujících organizmů (SINGH ET AL. 2020; HASANUZZAMAN ET AL. 2020). Účinné látky herbicidů, jako jsou triaziny (atrazin, terbutryn, irgarol) a fenylmočoviny (diuron, isoproturon), jsou známé působením na fotosyntetický systém II (PS II), zatímco metolachlor inhibuje biosyntézu mastných kyselin a aminokyselin (WAKABAYASHI, BÖGER, 2002).

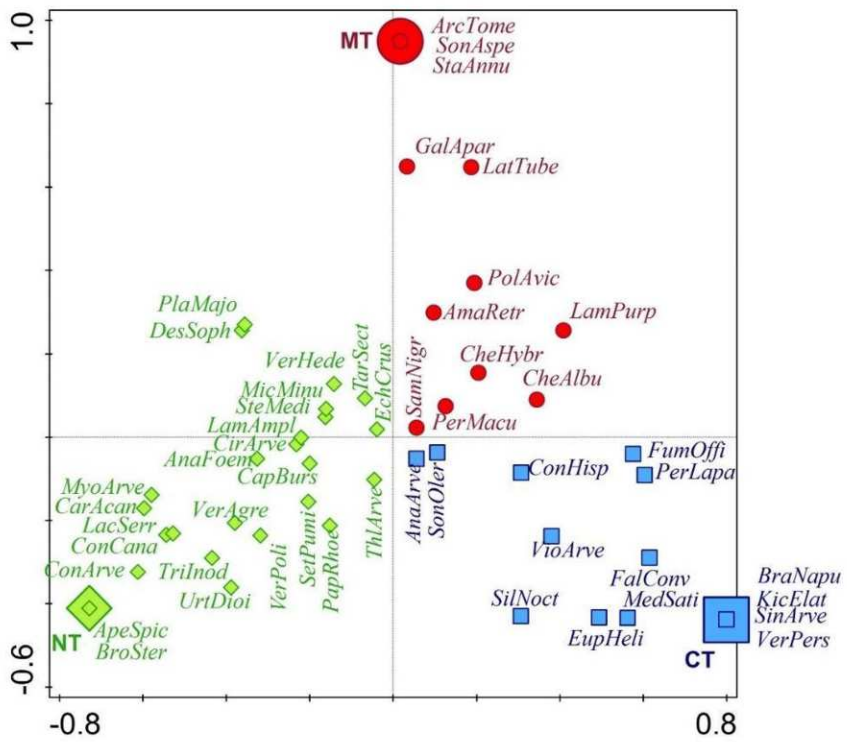
Používání pesticidů je jedním z nejdiskutovanějších aspektů intenzifikace zemědělství vzhledem k jejich potenciálním přímým i nepřímým důsledkům na úrovni jednotlivců, populací a ekosystémů (ARANCIBIA ET AL., 2020; BLETTLER ET AL., 2022). Přímé toxické účinky pesticidů se mohou objevit rychle po aplikaci (MITRA ET AL., 2011), zatímco nepřímé účinky se obvykle objevují po jednom nebo několika letech od aplikace (HOLE ET AL., 2005; BRUGGISSER ET AL., 2010). Toxicita pesticidů může být u jednotlivých zasažených organizmů výrazně odlišná (SERRÃO ET AL., 2022; TUDI ET AL., 2022) a ekologické dopady pesticidů mohou trvat i několik let po jejich aplikaci (CHIRON ET AL., 2014). Herbicidy mohou např. snížit dostupnost potravy, hnízdění a zredukovat úkryty ptáků hnízdících na zemi a živících se na orné půdě (KLEIJN ET AL., 2009; GUERRERO ET AL., 2011; DE MONTAIGU ET AL., 2023).

Únik herbicidů neboli koncepce ztrát herbicidů spočívá v prostorové heterogenitě, kde dominují hydrologické faktory prostředí, další faktory např. rychlost sorpce nebo degradace jsou méně důležité. Několik studií skutečně prokázalo, že faktory, jako jsou topografie a hydrologické vlastnosti půdy, vysvětlují prostorové vzorce ztráty herbicidů (LEU ET AL., 2004B; SHAVIT, 2022). Část herbicidů může být transportována ze zemědělské půdy do povrchové a podzemní vody, kde ovlivňují ekosystém (LIESS A VON DER OHE, 2005; DUGAN, ET AL., 2023; NAHAR ET AL., 2023).

V současné době patří pesticidy spolu s dusičnany mezi hlavní zdroje znečištění zdrojů pitné vody v Evropě (EEA, 2018). Ve snaze omezit nebo alespoň zmírnit negativa

emisí ze zemědělství do vody vyvinula Evropská Unie (EU) v posledních desetiletích rozsáhlý a regulačně-politický rámec, který zasahuje do hospodaření s vodou, do zemědělských postupů, do ochrany životního prostředí (ŽP), (WUIJTS ET AL., 2021). Například směrnice o dusičnanech 91/676/EHS (EC, 1991) navazuje na cíle směrnice o pitné vodě 98/83/ES (EC, 1998) a rámcová směrnice o vodě 2000/60/ES (EC, 2000) tvoří zastřešující rámec pro směrnice EU týkající se funkcí vody, používání chemikálií, jejich vlivu na ŽP a stav evropských vod. Základním právním předpisem v České republice, který upravuje ochranu vod, je zákon č. 254/2001 Sb. (vodní zákon), dalšími právními ustanoveními jsou mezinárodní smlouvy a právo EU. Přestože jsou směrnice EU propojeny s právním řádem ČR má jejich provádění vedlejší účinky, které brání účinné ochraně zdrojů pitné vody. Například pravidla pro používání hnojiv nejsou vždy prospěšná pro kvalitu podzemních vod a pitné vody (WUIJTS ET AL., 2021). Přijaté rámcové směrnice EU odrážejí rostoucí povědomí o ochraně vod a povodí (OECD, 2015A; OECD, 2015B). Nová ustanovení týkající se Směrnice o vodě vyžadují mezioborovou spolupráci, a to jak v rámci jednotlivých členských států EU, tak i mezinárodní spolupráci (WUIJTS ET AL., 2021). Regulační rámec o pesticidech v Evropě vytváří silné pobídky pro pěstitele, aby omezili aplikace herbicidů. Například v Dánsku vzrůstají od konce 80. let požadavky na snížení aplikací herbicidů, a proto bylo zahájeno několik akčních plánů pro pesticidy (JØRGENSEN, KUDSK, 2006).

Technologie zpracování půdy vyvolávají odezvu v druhovém složení plevelů, jak je uvedeno na Obrázku 1. Změny v zaplevelení vyvolané technologiemi pěstování plodin jsou součástí procesu, který můžeme označit za mikroevoluci (WINKLER ET AL., 2023A). Pokud bude chtít některý druh plevele uspět v podmínkách redukovaného zpracování půdy, musí, jak uvádí RAUP (1995), dělat něco lépe než ostatní druhy plevelů. Podrobnější studium vývoje vegetace plevelů nám může pomoci pochopit procesy vzniku a zániku druhů rostlin.



Obrázek 1. Vztah nalezených taxonů plevelů a odlišného zpracování půdy (výsledek analýzy CCA; celková vysvětlená variabilita = 11.8 %; F-ratio = 15.9; P-value = 0.001), (WINKLER ET AL., 2023A)

Vysvětlivky: CT (Tradiční zpracování půdy), druhy vyskytující se především na CT: *Anagallis arvensis (AnaArve), Brassica napus (BraNapu), Consolida hispanica (ConHisp), Euphorbia helioscopia (EupHeli), Fallopia convolvulus (FalConv), Fumaria officinalis (FumOffi), Kickxia elatine (KicElat), Medicago sativa (MedSati), Persicaria lapathifolia (PerLapa), Silene noctiflora (SilNoct), Sinapis arvensis (SinArve), Sonchus oleraceus (SonOler), Veronica persica (VerPers), Viola arvensis (VioArve).* MT (Minimalizační zpracování půdy), druhy vyskytující se především na MT: *Amaranthus retroflexus (AmaRetr), Arctium tomentosum (ArcTome), Galium aparine (GalApar), Chenopodium album (CheAlbu), Chenopodium hybridum (CheHybr), Lamium purpureum (LamPurp), Lathyrus tuberosus (LatTube), Persicaria maculosa (PerMacu), Polygonum aviculare (PolAvic), Sambucus nigra (SamNigr), Sonchus asper (SonAspe), Stachys annuam (StaAnnu).* NT (Technologie přímého setí do nezpracované půdy), druhy vyskytující se především na NT: *Anagallis foemina (AnaFoem), Apera spica-venti (ApeSpic), Bromus sterilis (BroSter), Capsella bursa-pastoris (CapBurs), Conyza canadensis (ConCana), Descurainia sophia (DesSoph), Echinochloa crus-galli (EchCrus), Lactuca serriola (LacSerr), Lamium amplexicaule (LamAmpl), Microrrhinum minus (MicMinu), Myosotis arvensis (MyoArve), Papaver rhoeas (PapRhoe), Setaria pumila (SetPumi), Stellaria media (SteMedi), Thlaspi arvense (ThlArve), Tripleurospermum inodorum (TriInod), Veronica agrestis (VerAgre), Veronica hederifolia (VerHede), Veronica polita (VerPoli).*

Lidská civilizace pomocí zemědělství utváří rostlinná společenstva, ovlivňuje erozi půdy, zvyšuje dostupnost živin, především dusíku a fosforu, a také obohacuje ŽP o uměle vytvořené látky používané jako pesticidy. Tyto civilizační faktory působí na ekosystém

celé krajiny i celé planety. Zemědělská činnost lidské civilizace díky svému rozsahu představuje vstup do nové etapy antropocénu. Toto téma je podrobněji rozpracováno v publikacích WINKLER, CHOVANCOVÁ A NEUDERT, 2015; CHOVANCOVÁ, ILLEK, WINKLER, 2020; HANUSOVÁ ET AL., 2022; WINKLER ET AL., 2022A; WINKLER ET AL., 2023A; WINKLER ET AL., 2023B.

2.2 Vegetace trvalých travních porostů

Druhová bohatost evropských travních porostů výrazně závisí na jejich prehistorickém původu, unikátní kombinaci místních abiotických faktorů a na regionálním druhovém fondu (BABAI, MOLNÁR, 2014). Dlouhodobá disturbance vyvolaná zemědělskou činností vede k vytvoření druhově bohatých travních společenstev na loukách a pastvinách. Tento způsob využívání trvá od počátku vzniku zemědělství až do dnešní doby (SIENKIEWICZ-PADEREWSKA ET AL., 2021). Tradiční systémy využívání půdy jsou důležité pro zachování druhové bohatosti travních porostů (BABAI, MOLNÁR, 2014). Louky hrají významnou roli ve využívání půdy v Evropě (DIEKMANN ET AL., 2019). V EU je více než 30 % zemědělsky využívaných ploch pokryto pastvinami (PANAGOS ET AL., 2020). Mezi zeměmi jsou velké rozdíly – od méně než 5 % pastvin ve Finsku, po více než 75 % v Irsku (ISSELSTEIN ET AL., 2005). Podmínky stanovišť, travních vegetací, managementu a produkčního potenciálu jsou velmi proměnlivé. Evropské pastviny významně přispívají k celkové biologické rozmanitosti venkovské krajiny (ISSELSTEIN ET AL., 2005; DIEKMANN ET AL., 2019). SIENKIEWICZ-PADEREWSKA ET AL. (2021) potvrdili, že středoevropské travní porosty podporují vysoký počet rostlinných druhů, což vyplývá především z heterogenity stanovišť, která obývají.

Intenzifikace produkce píce vede k tvorbě společenstev, která jsou druhově chudá (WANI ET AL., 2022). Tento proces započal v období průmyslové revoluce, po 2. světové válce a v druhé polovině 20. století zaznamenal vrchol. Cíl soběstačnosti v produkci potravin podnítil zkvalitnění a zintenzivnění obhospodařování travních porostů, případně jejich přeměnu na dočasné travní porosty či ornou půdu. V méně všestranných oblastech, jako jsou horské oblasti nebo vlhké nížiny, byly velké plochy travních porostů opuštěny nebo zalesněny (SCHILS ET AL., 2022). V současné době dochází v některých částech světa, včetně ČR, k odklonu od intenzifikace zemědělské produkce.

Snížení antropogenního tlaku je běžně považováno za přínosné pro biologickou rozmanitost (BOWLER ET AL., 2020; PRAKASH, VERMA, 2022). Ukončení určitého

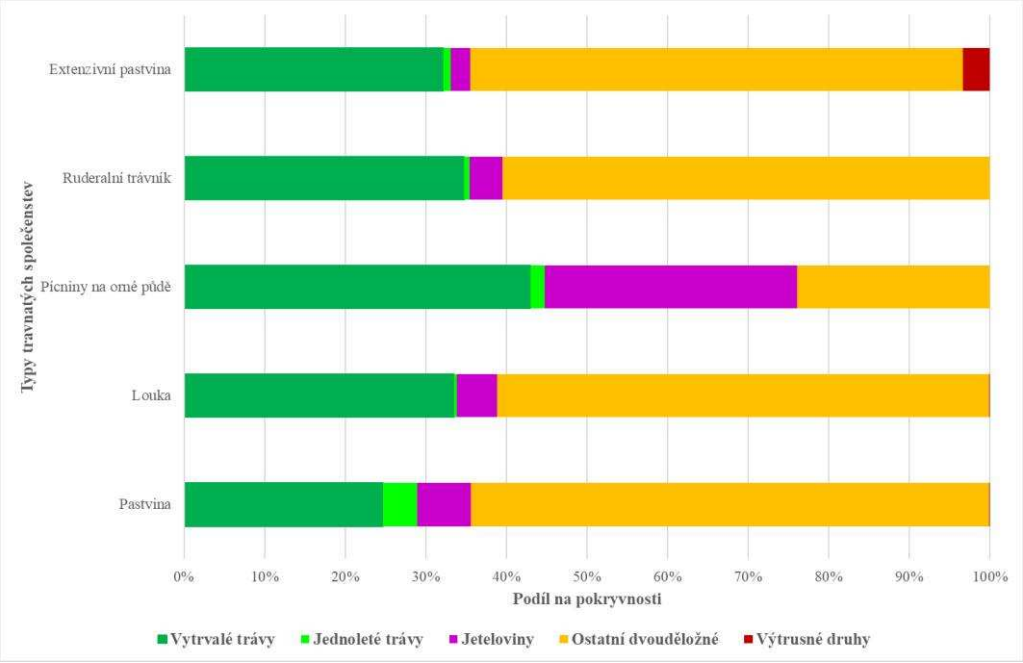
využívání půdy však může vést buď k obnově, nebo ke ztrátě biologické rozmanitosti v reakci na změny fyzikálních a biologických procesů (SITZIA ET AL., 2018). Extenzivní přístup nebo opouštění zemědělských postupů vyvolává změny v druhovém složení vegetace a mírný pokles počtu druhů rostlin (MARRIOTT ET AL., 2009). Tento proces, spojený s transformací zemědělství a se změnami v evropské zemědělské politice, započal v 90. letech minulého století. SITZIA ET AL. (2018) uvádějí, že spontánní zalesňování, které následuje po přerušení zemědělských postupů, je v současné Evropě běžné v důsledku socioekonomických faktorů. I když to přineslo obnovu divočiny, většina tradiční heterogenní krajiny a cenných otevřených stanovišť, jako jsou pastviny, extenzivní pastviny a louky, byla ztracena, nebo často prošla transformací na nové ekosystémy, složené ze směsi původních a cizích druhů (CHYTRÝ ET AL., 2009). V Evropě invaze cizích druhů rostlin na opuštěných zemědělských pozemcích ovlivňuje procesy v ekosystémech a určuje stanoviště pro ostatní organizmy (SITZIA ET AL., 2018). USTAOGLU a COLLIER (2018) zdůrazňují, že biodiverzita a postupy post managementu opuštěné zemědělské půdy hrají klíčovou roli v dynamice sekundárního biotopu, který se vyvíjí od doby, kdy byla půda opuštěna. Navíc v oblastech s dlouhou historií pěstování se druhy, které netolerují narušení, pravděpodobně z flóry vytratí (USTAOGLU, COLLIER, 2018).

Ekosystém travních porostů, které pokrývají až 40 % celosvětové půdy (SUN ET AL., 2022; STEVENS ET AL., 2022), představuje základní bariéru ekologické bezpečnosti ekosystémů a je také základem produkce píce pro hospodářská zvířata (BONTTI ET AL., 2009). V současné době jsme svědky velkého úbytku biodiverzity, označovaného jako krize diverzity (SHROFF, CORTÉS, 2020; KURTH ET AL., 2021; ERIKSEN, 2021).

Louky a pastviny patří k nejstarším typům zemědělských porostů využívaných lidskou civilizací. Dlouhodobá a stabilní disturbance travnatých společenstev lidskou civilizací vedla k vytvoření druhově bohaté, specifické vegetace v zemědělské krajině. Zvýšená intenzifikace produkce píce a pěstování jetelovin na orné půdě vede k druhově chudým rostlinným společenstvům. Omezení pravidelné disturbance a opouštění původně zemědělsky využívaných pozemků vede k ruderalizaci vegetace a ke změnám v druhovém složení. Podobně je tomu i u extenzivně využívaných travnatých společenstev. Je tedy patrné, že změny v disturbancích působených lidskou civilizací vyvolávají odezvy i ve složení vegetace travních společenstev, jak je patrné z Tabulky 2 a z Obrázku 2 (WINKLER ET AL., 2022B).

Tabulka 2. Počet druhů rostlin a průměrné indikační hodnoty charakteristik disturbance ve sledovaných typech travních porostů

Typy travnatých společenstev	Celkový počet nalezených druhů	Průměrný počet druhů	Indikační hodnota pro disturbanci bylinného patra (strukturní index)	Indikační hodnota pro frekvenci disturbance bylinného patra
Pastvina	63	14,25	0,66	-0,22
Louka	63	16,65	0,62	-0,30
Jetel luční na orné půdě	34	6,40	0,68	-0,22
Ruderální nevyužívaný trávník	40	8,35	0,62	-0,34
Extensivní pastvina	42	10,35	0,51	-0,41



Obrázek 2. Zastoupení skupin rostlin na pozemcích s odlišným charakterem využívání

Dopady lidské civilizace na ekosystémy, ale i na výskyt konkrétních druhů, jsou velmi výrazné. Ovšem působení lidské civilizace podléhá změnám, vývoji a evoluci. Pochopení koevoluce lidské civilizace a vegetace může přispět k predikci dalšího vývoje, včetně nové etapy antropocénu. Toto téma je podrobněji rozpracováno v publikacích WINKLER ET AL., 2021A; WINKLER ET AL., 2022B; WINKLER ET AL., 2024A.

2.3 Vegetace ovocných sadů

Zemědělské postupy v ovocných sadech mají velký dopad na řadu funkcí agroekosystémů (SCHAECKERMANN ET AL., 2015; GKISAKIS ET AL., 2016; DEMESTIHAS ET AL., 2017). Zejména management vegetace v ovocném sadu může změnit biotické interakce mezi škůdci ovocných stromů a jejich přirozenými nepřáteli, dále může omezit vyplavení dusíku a změnit vodní režim (SCHIPANSKI ET AL., 2014; DEMESTIHAS ET AL., 2017). Vodní režim je zásadní pro fungování ovocných sadů, především vodní stres může zmenšit plody a snížit jejich kvalitu (ETIENNE ET AL., 2013; WANG ET AL., 2019; YHONG ET AL., 2019). Velmi důležité je načasování vodního stresu. Pokud se objeví v pozdním jaru a začátkem léta, může mít dramatický význam pro násadu a růst plodů (LAKSO, 2003; YANG ET AL., 2018; HUESO ET AL., 2021).

Hospodaření s půdou v meziřadí ovocných sadů je zvláště důležité především pro vodní režim (VIGNOZZI ET AL., 2019; SIMONI ET AL., 2021; GONZÁLEZ-GÓMEZ ET AL., 2022). Preemergentní použití herbicidů, což je velmi běžné, vytváří holou půdu, čímž se snižuje infiltrace a zvyšuje odtok vody (MERWIN ET AL., 1994; DEMESTIHAS ET AL., 2017). Nicméně bylo zjištěno, že zatravnění půdy v meziřadí ovocného sadu snižuje výnos a růst stromů kvůli konkurenci o živiny a vodu mezi travami a ovocnými stromy (ATUCHA ET AL., 2013; GIACALONE ET AL., 2021; SIMONI ET AL., 2021). Z tohoto důvodu se doporučuje technika vyvinutá ve Švýcarsku a nazývaná „sendvič“ (Obrázek 3), která spočívá ve střídání pásu obdělávaného a zatravněného meziřadí, především ve srážkově chudých oblastech (SCHMID A WEIBEL 2000; MIA ET AL., 2020; MIA ET AL., 2021). Odlišný management vegetace vyvoláva odezvu v druhové složení vegetace ovocného sadu jak je patrné z Tabulky 3 (WINKLER ET AL., 2023C).



Obrázek 3. Tři pásy s odlišným obhospodařováváním vegetace v ovocném sadu: a) černý úhor (regulace vegetace pomocí zpracování půdy); b) zatravněný pás (mulčování); c) příkmenný pás pod stromy (mulčování a chemická regulace vegetace), (WINKLER ET AL., 2023C)

Tabulka 3. Skupiny rostlinných druhů preferujících odlišný management ovocného sadu (WINKLER ET AL., 2023C)

Preference managenetu	**Skupina druhů**	**Druhy rostlin**
Zatravněný pás	Jednoleté dvouděložné druhy	*Geranium pusillum, Polygonum aviculare, Veronica arvensis*
	Víceleté dvouděložné druhy	*Achillea millefolium, Artemisia vulgaris, Carduus acanthoides, Cichorium intybus, Cirsium arvense, Conyza canadensis, Echium vulgare, Eryngium campestre, Falcaria vulgaris, Plantago major, Potentilla argentea, Reseda lutea, Rumex acetosella, Silene latifolia, Tragopogon pratensis, Trifolium repens*
	Víceleté jednoděložné druhy	*Arrhenatherum elatius, Dactylis glomerata, Elytrigia repens, Festuca pratensis, Lolium perenne, Poa pratensis*
Zatravněný pás a příkmenný pás	Jednoleté dvouděložné druhy	*Capsella bursa-pastoris, Erigeron annuus, Erodium cicutarium, Holosteum umbellatum, Lycopsis arvensis, Veronica polita*
	Víceleté dvouděložné druhy	*Glechoma hederacea, Medicago lupulina, Taraxacum* sect. *Taraxacum*
	Jednoleté jednoděložné druhy	*Bromus hordeaceus, Bromus sterilis, Bromus tectorum*
	Víceleté jednoděložné druhy	*Festuca rubra*
Příkmenný pás	Jednoleté dvouděložné druhy	*Arenaria serpyllifolia, Epilobium adenocaulon, Filago arvensis, Fumaria officinalis, Lactuca serriola*
	Víceleté dvouděložné druhy	*Bryonia alba, Plantago lanceolata, Rosa canina*
	Jednoleté jednoděložné druhy	*Digitaria sanguinalis, Hordeum murinum*
	Víceleté jednoděložné druhy	*Festuca ovina*
Příkmenný pás a černý úhor	Jednoleté dvouděložné druhy	*Chenopodium album, C. pedunculare, C. strictum, Lamium amplexicaule, Lamium purpureum, Stellaria media, Veronica persica*
	Jednoleté dvouděložné druhy	*Convolvulus arvensis, Malva neglecta*
Černý úhor	Jednoleté dvouděložné druhy	*Amaranthus powelli, A. retroflexusma, A. albus, Anagallis arvensis, A. foemina, Chenopodium hybridum, C. pumilio, Portulaca oleracea, Senecio vulgaris, Sonchus oleraceus, Thlaspi arvense, Trifolium arvense, Tripleurospermum inodorum, Veronica hederifolia, V. triphyllos, Viola arvensis*
	Jednoleté jednoděložné druhy	*Echinochloa crus-galli, Panicum miliaceum, Poa annua, Setaria pumila, S. viridis*

Konkurence vegetace vůči ovocným stromům je zásadní otázkou managementu vegetace (WINTER ET AL., 2018; HALL ET AL., 2020; MIA ET AL., 2020; MIA ET AL., 2021). Mezi běžné a tradiční způsoby regulace patří sečení. Sečení vegetace sice reguluje růst rostlinných druhů, ale u vytrvalých druhů plevelů je nedostatečné pro jejich likvidaci. Naopak může přispět k posílení jejich kořenového systému, a tím podpořit jejich dominanci a konkurenci. Navíc, pokud je biomasa vegetace použita jako mulč, u mladých výsadeb farmáři riskují velké ztráty na výnosech způsobené konkurencí mulče o vodu (ŻELAZNY, LICZNAR-MAŁAŃCZUK, 2018). Proto je velmi běžná kombinace častého sečení a aplikace herbicidů (chemická regulace) jako efektivní způsob regulace vegetace (MERWIN, STILES, 1994; HERZ ET AL., 2019; PAUŠIČ ET AL., 2021).

Vysoká účinnost chemické regulace vyvolává obavy ze zvyšujícího se výskytu tolerantních populací vytrvalých plevelů, pozorovaných např. u *Taraxacum* sect *Taraxacum* Weber ex F. H. Wigg. a *Trifolium* spp. (LISEK, 2012; JEZOVA ET AL., 2014; LICZNAR-MAŁAŃCZUK, SYGUTOWSKA, 2016). Vedle této obavy je zde zvyšující se poptávka spotřebitelů po snížení agrochemikálií. Tyto trendy nutí ovocnáře k hledání alternativních způsobů regulace vegetace. Určitou alternativou může být mulčování, které má schopnost snížit zaplevelení ovocných sadů (GRANATSTEIN, SÁNCHEZ, 2009; MIA ET AL., 2020; MIA ET AL., 2021). Kromě regulace plevelů může mulč udržovat kvalitu půdy, podporovat biodiverzitu sadů a snižovat vyplavování živin (GRANATSTEIN, SÁNCHEZ, 2009; LEARY, DEFRANK, 2000; MIA ET AL., 2020; PAUŠIČ ET AL., 2021). Ovšem využití mulče nemusí být u některých typů podnoží ovocných stromů dostatečné z důvodu rozvoje vytrvalých plevelů (ŻELAZNY, LICZNAR-MAŁAŃCZUK, 2022).

Vegetace ovocných sadů plní řadu ekosystémových funkcí, které jsou často publikovány v řadě vědeckých prací (PFIFFNER ET AL., 2019; VIGNOZZI ET AL., 2019; DENAN ET AL., 2020; SOFO ET AL., 2020). Ovšem jedna funkce bývá stále opomíjena – funkce vegetace při vzniku a šíření požárů. Biomasa různých druhů rostlin v ovocném sadu v kombinaci se suchým a teplým počasím zvyšuje riziko vzniku požárů (FERNANDEZ-ANEZ ET AL. 2021; WINKLER ET AL., 2023C; PAGADALA ET AL., 2024). Požáry se v poslední době staly velkým problémem v řadě oblastí světa (APONTE ET AL., 2016; FERNANDEZ-ANEZ ET AL., 2021). Několik studií naznačuje, že četnost požárů byla způsobena změnou klimatu a také jinými faktory, jako jsou opatření na potlačení požárů, management vegetace ve městech a v zemědělské krajině, zalesňování a opouštění venkovských oblastí (DOERR ET AL., 2016; AGOSTON, 2018; WINKLER ET AL., 2021A; VAVERKOVÁ ET AL., 2022B). Stanovení nebezpečí požárů je založeno na fyzikálních

vlastnostech hořlavých materiálů, a to včetně biomasy vegetace, především trav, které mají vysokou výhřevnost (vyšší než 17 000 MJ.kg) a zvyšují riziko vzniku a následného rychlého rozvoje požáru (KEANE, 2015).

V zásadě platí, že čím je větší hustota bylinné vegetace, tím je lepší ochrana půdy a větší množství uhlíku, které se v půdě zachytí. Zvyšuje se však riziko konkurence o vodu a živiny, což může snížit výnos ovocných dřevin (RODRIGUES AND ARROBAS, 2020). V horkých a suchých podnebích s vysokým rizikem požáru trávy by měla být odpovídajícím způsobem upravena také regulace bylinné vegetace. Obhospodařování přirozené vegetace sečením vede k selekci porostů pro víceleté druhy, které lépe snášejí seč a stávají se obtížně regulovatelné (RODRIGUES, ARROBAS, 2020). Dynamika růstu biomasy (paliva) a dostupnost spalování (sucho) řídí trendy požárů (BRADSTOCK, 2010; KROFCHECK ET AL., 2019; GOMES ET AL., 2020). To znamená, že rozhodující pro vznik požáru je průběh počasí a také kumulace biomasy trav. Střídání různých typů managementu vegetace v rámci ovocného sadu mění druhové spektrum, množství biomasy a díky vysoké heterogenitě vegetace se snižuje riziko propuknutí plošného požáru.

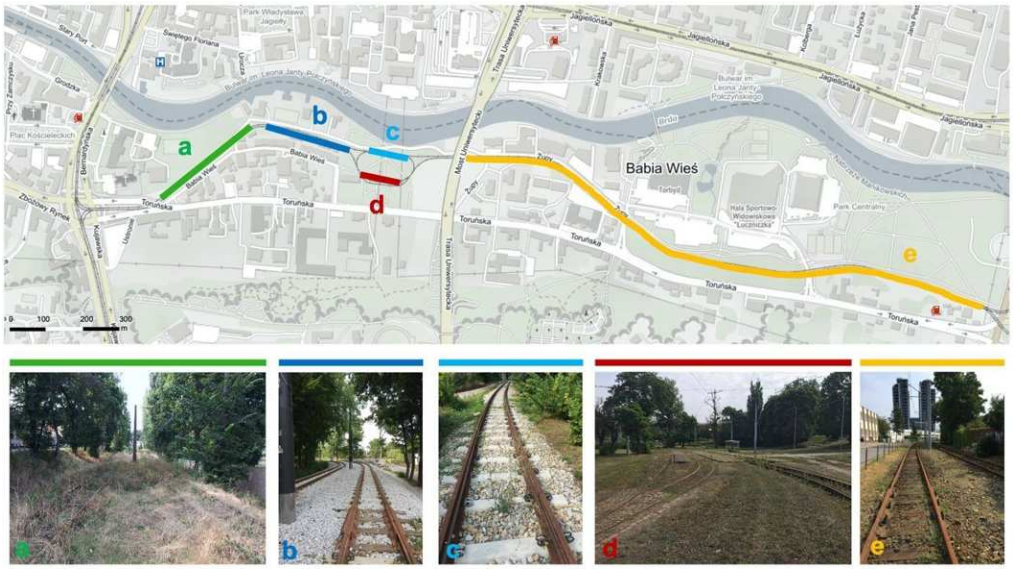
Požáry budou stále častějším jevem i v podmínkách mírného klimatického pásu a budou zasahovat do zemědělské krajiny (ROGERS ET AL., 2020; JONES ET AL., 2022; DMUCHOWSKI ET AL., 2022). Jednou z ekosystémových funkcí vegetace je zajistit vznik a šíření požárů, které jsou pro vegetaci přirozeným jevem. Pro lidskou civilizaci má požár především destruktivní a negativní charakter (FIDELIS, 2020; BERLINCK, BATISTA, 2020; MCLAUCHLAN ET AL., 2020), a proto máme snahu požár zcela eliminovat. Součástí snahy o eliminaci požárního rizika musí být také seznámení zemědělců s tímto rizikem a upravení managementuvegetace ovocných sadů.

Rostlinná společenstva ovocných sadů jsou tvořena stromy, které jsou vyšlechtěny člověkem, ale jsou zde zastoupeny i druhy rostlin, které můžeme považovat za plané. Lidská civilizace zde působí i na pedologické podmínky, které se mění pomocí hnojení, vápnění a kultivace půdy. Vztahy mezi pěstovanými a planými druhy jsou udržovány pomocí managamentu. Díky tomu existují rostlinná společenstva, která jsou udržována působením lidské civilizace. Jedná se o antropogenní ekosystémy, které můžeme považovat za prolínání holocénu a antropocénu. Toto téma je podrobněji rozpracováno v publikaci WINKLER ET AL., 2023C.

2.4 Vegetace měst a dopravních komunikací

Svět zažívá nejrychlejší růst měst v historii (MANSUR ET AL., 2022). Současná etapa lidských dějin bývá označována jako urban century (VEGA ET AL., 2021; REMME ET AL., 2024). Města jsou označována za největší vynález lidstva a za způsob života, který může přinést mnoho výhod, včetně vyšší ekonomické produktivity a inovací, lepších příležitostí ke vzdělávání, individuálnímu rozvoji a efektivnějšímu využívání přírodních zdrojů a energií (MCDONALD AND BEATLEY, 2020). Urbanizace vede k fragmentaci přirozených stanovišť a silně ovlivňuje ekosystém. Bohatost rostlinných druhů je z taxonomického hlediska mnohem větší ve městě než mimo něj díky přítomnosti exotických rostlin, které byly do míst vysazené náhodně nebo úmyslně kvůli okrasným účelům. Města mohou být bohatší i na původní druhy rostlin (BONTHOUX ET AL., 2014).

Lidská činnost vytváří mnoho stanovišť vhodných pro vývoj rostlin. Jedním ze synantropních stanovišť jsou tramvajové a železniční tratě, které hostí jen některé druhy rostlin (RENDEKOVA ET AL., 2020). Městská vegetace tramvajových tratích je buď záměrně vysévána, nebo se jedná o druhy, jejichž výskyt je spontánní. Tramvajové tratě představují specifické ekologické migrační koridory pro rostliny (WOŹNICA ET AL., 2016; RENDEKOVA ET AL., 2020). Tramvajové tratě vytvářejí velmi originální životní podmínky. Rostliny se musely tomuto civilizačnímu prostředí přizpůsobit, což vedlo k vývoji jedinečných vlastností (WOŹNICA ET AL., 2016). Příklad fragmentace stanovišť je uveden na Obrázku 4 (WINKLER ET AL., 2024B).



*Obrázek 4. Vymezení fragmentovaných stanovišť na příkladu tramvajové trati v části města Bydgoszcz: a) nevyužívaný úsek tramvajové trati (nevyužívaná trať); b) rekonstruovaný úsek tramvajové trati (nová trať); c) rekonstruovaný úsek tramvajové smyčky (nová smyčka); d) stará, udržovaná část tramvajové smyčky (stará smyčka); e) nevyužívaný, udržovaný úsek tramvajové trati (stará trať), (*WINKLER ET AL., 2024B*)*

Tramvajové tratě vytvářejí pro rostliny velmi specifická stanoviště (WOŹNICA ET AL., 2016; RENDEKOVA ET AL., 2020). Díky těmto podmínkám se zde mohou uplatit druhy specializované na tolerování stresu z vnějších podmínek. Rostlinné druhy, které zde mohou růst, musí nepříznivé podmínky snášet. Musí se také vypořádat se sešlapáváním a mechanickým narušováním automobilovou dopravou (SUDNIK-WÓJCIKOWSKA A GALERA, 2005; LIU ET AL., 2009).

Vytvoření tramvajové tratě dlouhodobě mění podmínky prostředí, fragmentuje druhové složení vegetace a ovlivňuje vývoj během sekundární sukcese vegetace. Je to v souladu s mnoha vědeckými pracemi, které poukazují na velký význam železničních stanovišť z hlediska výskytu a šíření cizích druhů rostlin (archeofytů a neofytů), (HANSEN, CLEVENERG, 2005; MÁJEKOVÁ ET AL., 2016; ČERVENKOVÁ ET AL., 2016; JEHLÍK ET AL., 2017), včetně invazních druhů (WRZESIEŃ ET AL., 2016; DENISOW ET AL., 2017; WRZESIEŃ, DENISOW, 2017), ale role tramvajových tratí v procesu invaze cizích rostlin zatím není tak dobře známa. V Tabulce 4 jsou druhy rostlin rozděleny dle původu a podle preferencí pro fragmentovaná stanoviště tramvajových tratí ve městě Bydgoszcz (WINKLER ET AL., 2024B).

Tabulka 4 Skupiny rostlinných druhů rostoucích na tramvajových tratích

Fragment trati	**Původní druhy**	**Zdomácnělé druhy**	**Invazní druhy**
Nová trať	*Acer platanoides, Agrostis stolonifera, Elymus repens, Equisetum arvense, Geum urbanum*	*Silene latifolia*	*Oenothera biennis*
Nová trať a nevyužívaná trať	*Acer pseudoplatanus, Epilobium hirsutum, Fallopia dumetorum, Festuca pratensis, Geranium robertianum, Lolium perenne, Plantago lanceolate, Taraxacum* sect. *Taraxacum, Ulmus laevis*	*Diplotaxis muralis, Chelidonium majus, Lactuca serriola, Lamium album, Senecio vulgaris, Setaria viridis*	*Epilobium adenocaulon, Parthenocissus quinquefolia*
Nevyužívaná trať	*Alliaria petiolate, Artemisia vulgaris, Bromus erectus, Corylus avellana, Dactylis glomerata, Holcus lanatus, Mycelis muralis, Poa pratensis, Populus nigra, Quercus robur, Sambucus nigra, Urtica dioica*	*Ballota nigra, Bromus sterilis, Echinochloa crus-galli, Geranium columbinum, Hordeum murinum, Lapsana communis, Melilotus officinalis, Prunus cerasifera, Sonchus oleraceus, Triticum aestivum, Viola odorata*	*Sisymbrium loeselii, Solidago canadensis*
Stará trať	*Artemisia campestris, Clematis vitalba, Glechoma hederacea, Hedera helix, Persicaria lapathifolia, Poa annua, Potentilla reptans, Stellaria media, Vicia tetrasperma, Viola arvensis*	*Arctium lappa, Atriplex patula, Lamium amplexicaule, Myosotis arvensis, Papaver dubium, P. rhoeas, Saponaria officinalis, Vicia villosa*	*Amaranthus albus, A. blitoides, Veronica persica*
Nová smyčka	*Medicago lupulina*		*Amaranthus retroflexus, Oxalis stricta*
Nová smyčka a stará smyčka	*Achillea millefolium, Arabidopsis thaliana, Arenaria serpyllifolia, Centaurea stoebe, Echium vulgare, Festuca rubra, Medicago falcate, Plantago major, Polygonum arenastrum, Potentilla argentea, Rumex acetosella, Trifolium arvense*	*Berteroa incana, Capsella bursa-pastoris, Convolvulus arvensis, Eragrostis minor, Erodium cicutarium, Geranium pusillum, Microrrhinum minus, Portulaca oleracea*	*Acer negundo, Conyza Canadensis, Galinsoga parviflora, Chenopodium strictum*
Stará smyčka	*Alyssum alyssoides, Cerastium holosteoides, Crepis biennis, Sedum acre, S. sexangulare, S. jacobaea, Trifolium repens, Bryophytes*	*Tanacetum vulgare*	*Matricaria discoidea*

Na podmínky tramvajových tratí reaguje vegetace tím, se fragmentuje druhové složení. Změny vyvolávají otázku prospěšnosti. Na jedné straně jsou tratě prostorem pro uplatnění a šíření invazních druhů (HANSEN, CLEVENERG, 2005; MÁJEKOVÁ ET AL., 2016; WRZESIEŃ ET AL., 2016; DENISOW ET AL., 2017; JEHLÍK ET AL., 2017; WRZESIEŃ, DENISOW, 2017; RENDELKOVÁ ET AL., 2020), na druhé straně vegetace ve městech je významným zdrojem biodiverzity a přináší další ekosystémové funkce pozitivně působící na život lidí (BASNOU ET AL., 2020; VEGA ET AL., 2021).

Je nutné věnovat pozornost druhovému složení vegetace a jejím funkcím, které mohou ohrozit zdravotní bezpečnost lidí ve formě alergických reakcí na pyl, ale patří mezi ně také riziko vzniku požárů v horkých a suchých obdobích roku. Lidské činnosti významně ovliňují strukturu městské vegetace, což mění ekosystémové funkce vegetace a následně funkce celého městského ekosystému a také dopady na lidskou civilizaci. Urbanizované oblasti mají výrazně pozměněné geologicko-pedologické podmínky, které jsou tvořeny použitím různých stavebních materiálů, průmyslovým znečištěním a působením dopravy. Urbanizované oblasti jsou na řadě míst planety uceleným geologicko-pedologicko-biologickým dílem lidské civilizace. Toto téma je podrobněji rozpracováno v publikacích ULDRIJAN ET AL., 2022; WINKLER ET AL., 2022C; WINKLER ET AL., 2023D; WINKLER ET AL., 2024B.

2.5 Vegetace a odpady produkované lidskou civilizací

Dramatický nárůst světové populace přímo zvyšuje produkci odpadu, včetně potravinového, kuchyňského, zahradního, rostlinných zbytků a zvířecího hnoje (FAN ET AL., 2021; WEI ET AL., 2021; KHAROLA ET AL., 2022). Organické odpady byly obvykle zpracovány skládkováním a spalováním, což je nákladné a poskytuje jen málo exportovatelné energie kvůli vysoké vlhkosti a nízké výhřevnosti (XIN ET AL., 2020).

Snaha o jiné využití organického materiálu vede k ekologičtějším metodám, jako je kompostování (WEI ET AL., 2017). Kompostování je metoda recyklace odpadu založená na biologickém odbourávání organické hmoty za aerobních podmínek, za vzniku stabilizovaného a sanitovaného kompostu (ZHANG ET AL., 2020; RASHID, SHAHZAD, 2021; THOMSON ET AL., 2021; CHOROLQUE ET AL., 2022). Výhody a nevýhody kompostování byly úspěšně prozkoumány ve světové literatuře (MEHTA, SIRARI, 2018; DHAMODHARAN ET AL., 2019; SELVAM ET AL., 2021; YIN ET AL., 2021; ZHOU ET AL., 2022).

Během procesu kompostování mohou vznikat environmentální problémy, včetně tvorby zapáchajících nebo toxických plynů (WEI ET AL., 2017; DHAMODHARAN ET AL., 2019; NGUYEN ET AL., 2022), bioaerosolů (ROBERTSON ET AL., 2019; FERGUSON ET AL., 2021) a prachu (SCHLOSSER ET AL., 2018; GAŁWA-WIDERA, 2021), což vede k ohrožení zdraví při práci nebo k obtěžování obyvatel v okolí. To se týká zejména kompostáren provozovaných na volném prostranství. Bioodpad a kompostování byly studovány z různých hledisek a několik studií se zaměřilo na environmentální otázky s využitím metod analýzy životního cyklu (NABAVI-PELESARAEI ET AL., 2019; WELIGAMA THUPPAHIGE ET AL., 2022; ZHOU ET AL., 2022), evidence a složení skleníkových plynů (PEIGNÉ, GIRARDIN, 2004; PAN ET AL., 2018; CHEN ET AL., 2019; YIN ET AL., 2021).

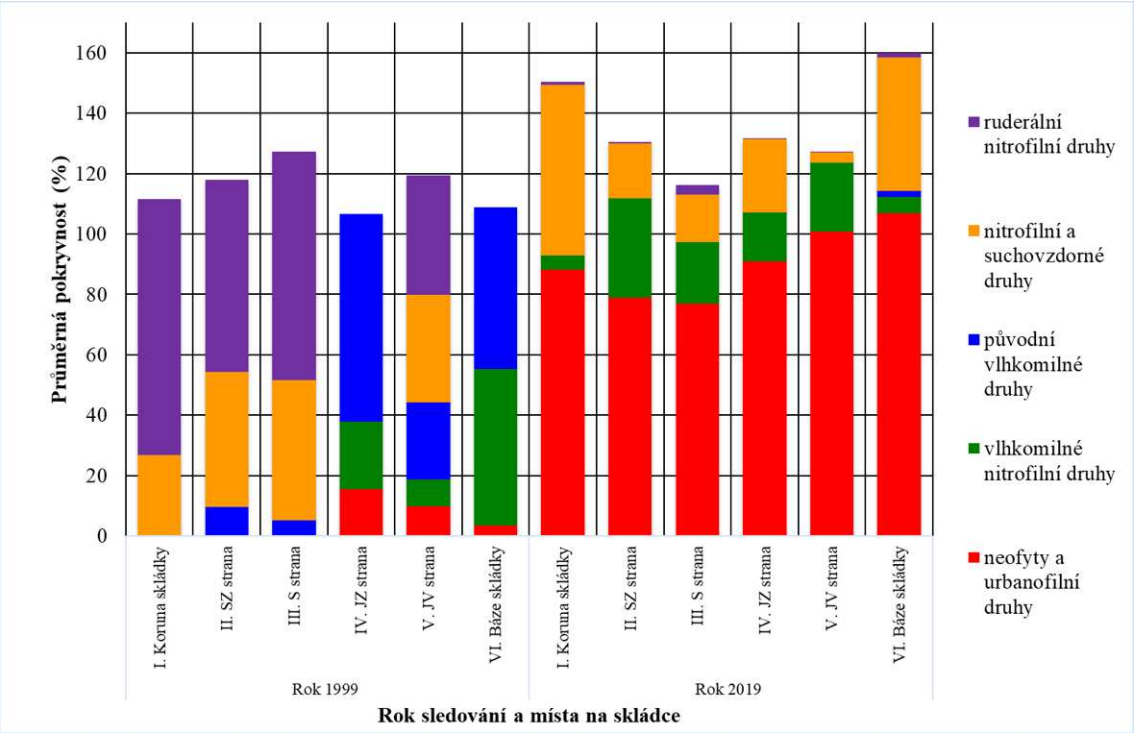
Mezi další rizika můžeme zařadit dovážení bioodpadu, který představuje zdroj diaspor rostlin (VAVERKOVÁ ET AL., 2019A; VAVERKOVÁ ET AL., 2020; WINKLER ET AL., 2021b) a podporuje změny v druhovém složení vegetace (VAVERKOVÁ ET AL., 2022A). Kompostovací zařízení se mohou stát novým místem šíření invazních taxonů rostlin (WINKLER ET AL., 2023E).

Mezi nejrozšířenější způsoby nakládání se směsmými komunálními odpady na celém světě patří skládkování (WONG ET AL., 2015; HAMID ET AL., 2018; RASAPOOR ET AL., 2020; SAUVE, VAN ACKER, 2020). Skládkování má řadu negativních dopadů na ŽP, a to v podobě degradace půdy (polutanty uvolňované z uložených odpadů, průsakové vody, aj.), což může vést ke kontaminaci půdy a vody (DĄBROWSKA ET AL., 2018; KODA ET AL., 2018; VAVERKOVÁ ET AL., 2018). Skládky komunálního odpadu mají závažný dopad na kvalitu a zdraví půdy (D'AMATO ET AL., 2018; WRIGHT ET AL., 2018). Kontaminovaná půda může následně znečišťovat vodu (KEESSTRA ET AL., 2016).

Existence skládek odpadů je vážným environmentálním problémem ve vyspělých i v rozvojových zemích. Dokládá to řada vědeckých prací, například výzkum provedený v Německu a Rakousku (ALLGAIER, STEGMANN, 2006), Irsku (DOAK ET AL., 2007), Francii (BIOTTO ET AL., 2009), Itálii (SILVESTRI, OMRI, 2008) a Srbsku (VASILJEVIĆ ET AL., 2012). Mezi potenciálně důležité signály patří přítomnost uhlíkatých částic v popílku (ROSE, 2015; SWINDLES ET AL., 2015), zbytky plastů (Zalasiewicz et al., 2016), další „technofosílie“ (ZALASIEWICZ ET AL., 2014A, ZALASIEWICZ ET AL., 2016) a přítomnost umělých radionuklidů (WATERS ET AL., 2015). Mnoho těchto změn a signálů zanechá v zemské vrstvě trvalý záznam (WILLIAMS ET AL., 2015; WATERS ET AL., 2014; EDGEWORTH ET AL., 2015; STEFFEN ET AL., 2016; WATERS ET AL., 2015; WATERS ET AL., 2016; WILLIAMS ET AL., 2016; ZALASIEWICZ ET AL., 2015). Degradace půdy se může

projevit také na složení vegetace rostoucí na skládkách odpadu (MAO ET AL., 2018). Na místech, kde jsou umístěny skládky odpadů, lze nalézt řadu netypických druhů rostlin. Celkově lze skládku charakterizovat jako stanoviště se synantropní flórou (ADAMCOVÁ ET AL., 2017; BRYANT ET AL., 2017).

Vegetace rostoucí na skládce odpadu se v čase vyvíjí a mění se druhové spektrum. Jak je patrné na Obrázku 5, v prvních letech po rekultivaci skládky jsou rozdíly v druhovém spektru viditelné na různých místech tělesa skládky. Po dvaceti letech dochází k ústupu původních a vlhkomilných druhů a prosazují se druhy, které patří k neofytům a jsou suchovzdornější. Specifické podmínky skládky komunálního odpadu spoluvytvářejí velmi unikátní druhové složení vegetace. Vysoký podíl mají především invazní neofyty (*Acer negundo, Solidago canadensis, Conyza canadensis, Erigeron annuus, Galinsoga parviflora, Iva xanthiifolia, Reynoutria sachalinensis, Robinia pseudacacia*), ale je zde také vysoké zastoupení druhů, které se mohou šířit na zemědělskou půdu nebo na jiná člověkem ovlivňovaná stanoviště (*Artemisia vulgaris, Calamagrostis epigeios, Elytrigia repens, Tanacetum vulgare, Oenothera biennis*). Vegetace skládek prochází specifickým průběhem sukcese vegetace a je základem nového typu ekosystému, který je vytvořen díky člověku a jeho činnosti (WINKLER ET AL., 2021B).



Obrázek 5. Zastoupení skupin druhů rostlin na sledovaných částech skládky Otwock v letech 1999 a 2019 (WINKLER ET AL., 2021B)

Vegetace skládek vytváří základ nového typu ekosystému, který vzniká díky člověku a jeho činnostem. Ovšem synantropní vegetace představuje potenciální riziko pro okolní ekosystémy a může tak přispět k jejich přeměně. Prvním rizikem je vysoké zastoupení invazních druhů rostlin, druhým rizikem je kontaminace rostlinných částí nebezpečnými látkami uvolněnými z odpadů.

Lidská civilizace vytváří nové ekosystémy, včetně geologicko-pedologických vrstev. Skládky komunálního odpadu a celý ekosystém skládek můžeme považovat za dostatečný a jednoznačný důkaz odlišnosti antropocénu od holocénu. Toto téma je podrobněji rozpracováno v publikacích WINKLER, RYPOVÁ A DVOŘÁK, 2017; VAVERKOVÁ ET AL., 2019B; WINKLER ET AL., 2021B; VAVERKOVÁ ET AL., 2022B; WINKLER ET AL., 2023E.

3 ROSTLINNÉ STRATEGIE

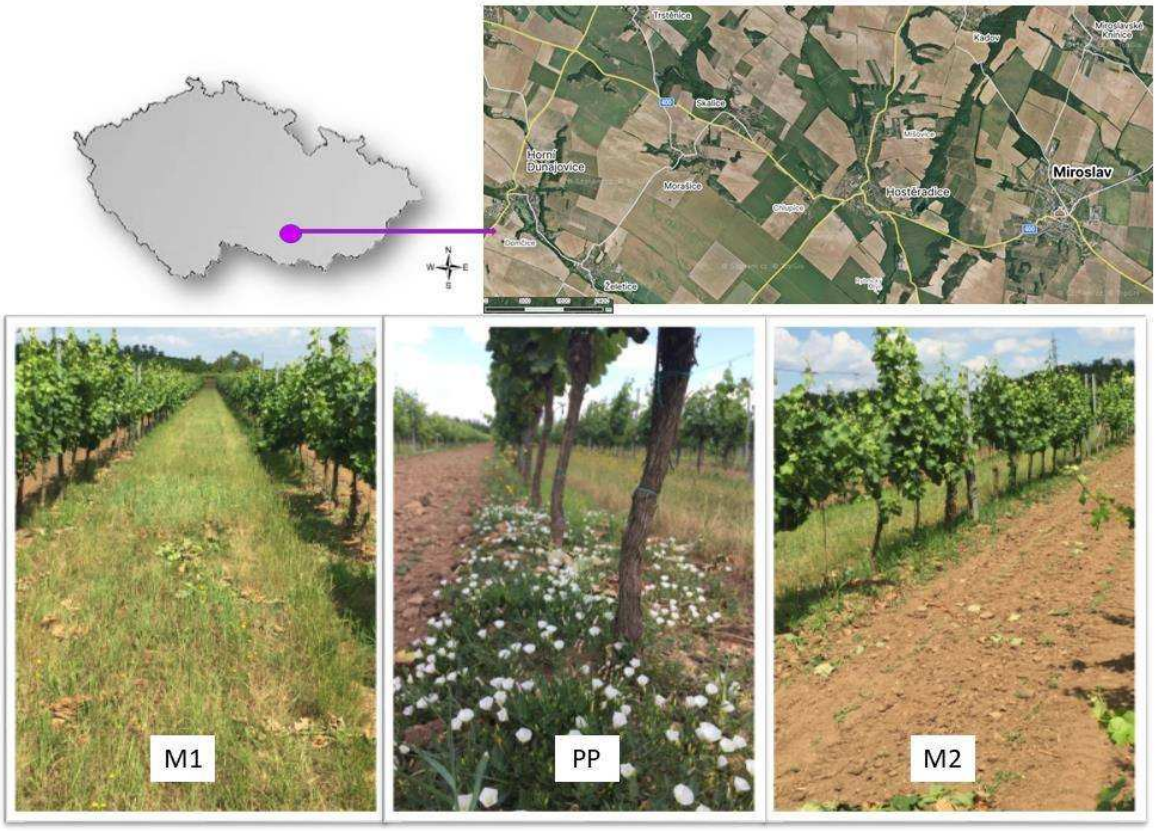
3.1 Fragmentace krajiny a vegetace

V zemědělské krajině je fenomén fragmentace spojen s celou řadou změn ve struktuře biodiverzity, složení společenstev, abiotických podmínkách a biotických interakcích (HADDAD ET AL., 2015; FAHRIG, 2017). Fragmentace ovlivňuje funkční skupiny organizmů (KÖRNER, JELTSCH, 2008; MAY ET AL., 2013) a mění složení komunit a konkurenční vztahy mezi populacemi. Fragmentace, zejména okrajové efekty stanovišť, mohou ovlivnit distribuci životních zdrojů, a tak způsobit změny v abiotických charakteristikách stanovišť (MURPHY, LOVETT-DOUST, 2004; RIES, SISK, 2004).

Změny abiotických a biotických environmentálních charakteristik vyvolané fragmentací mohou představovat selekční tlak na populace organizmů (SPENCE, TINGLEY, 2020; FAILLACE ET AL., 2021). Fragmentace stanovišť mění rozptyl semen v krajině u druhů, jejichž semena se šíří větrem (DENER ET AL., 2021). Fragmentace je často spojena se snížením velikosti populace rostlin a se sníženou dostupností pro opylovače (LIENERT, 2004; LAZARO ET AL., 2020). U populací rostlin to vyvolává snížení genetické diverzity a zvýšení inbreedingové deprese v populaci (LEGRAND ET AL., 2017). Ovšem většina reakcí organizmů na fragmentaci stanovišť je pozitivní a zvyšuje odolnost populací vůči široké škále podmínek prostředí (FAHRIG, 2017). Fragmentace má schopnost vytvářet trvalé a často nepředvídatelné výsledky, včetně překvapivých nárůstů hojnosti některých druhů. Pro plné pochopení důsledků fragmentace jsou nezbytná dlouhá časová měřítka, aby bylo možné plně ocenit vlivy fragmentace krajiny (HADDAD ET AL., 2015; IBANEZ ET AL., 2014).

Fragmentace ploch vinic a zvýšení rozmanitosti vegetace může udržet vyšší biologickou rozmanitost krajiny a poskytnout útočiště a zdroj potravy pro některé obratlovce a členovce, včetně těch, kteří omezují škůdce (SANGUANKEO, LEÓN, 2011; ARLETTAZ ET AL., 2012). Přestože jsou vinice intenzivně obhospodařovávanými agroekosystémy, mohou být hostiteli velké biodiverzity (FERNANDEZ-MENA ET AL., 2021; GELDENHUYS ET AL., 2021), poskytovat řadu ekosystémových služeb a díky své speciální struktuře stanovišť mají polopřírodní až přírodní charakter (WINKLER ET AL., 2017; GARCIA ET AL., 2018). Vegetace vinic může přímo i nepřímo poskytovat několik ekosystémových služeb pro produkci hroznů (GARCIA ET AL., 2018; WINTER ET AL., 2018) a může zvýšit biologickou aktivitu (QUECEDO ET AL., 2012), infiltraci vody

(GARCÍA-DÍAZ ET AL., 2017) a dostupnost organické hmoty (RUIZ-COLMENERO ET AL., 2011). Díky přítomnosti vegetace ve vinicích se zlepšuje stabilita půdní struktury, organická hmota stabilizuje půdní agregáty a kořenové systémy chrání půdu před erozí (RUIZ-COLMENERO ET AL., 2011). Vegetace vinic podporuje organizmy důležité pro vinnou révu (SÁENZ-ROMO ET AL., 2019) a zvyšuje úroveň biodiverzity (ALTIERI ET AL., 2005; WILSON ET AL., 2017B). Meziřádky vinic umožňují systém hospodaření, který podporuje trvalý nebo dočasný vegetační kryt neplodinovými druhy rostlin, buď jako směs osetých pokryvných plodin, nebo jako spontánní vegetaci. Pozitivní vliv krycích plodin na různé úrovně biodiverzity a související ekosystémové služby byl prokázán mnoha studiemi (SAENZ-ROMO ET AL., 2019; PAIOLA ET AL., 2020; GELDENHUYS ET AL., 2021; ZANETTIN ET AL., 2021). Ukázka hospodaření v meziřadí je na Obrázku 6.



Obrázek 6. Vinice ve vybrané oblasti a tři způsoby vegetačního managementu: M1 – zatravněné meziřadí; PP – příkmenný pás, M2 – kultivované meziřadí (HURAJOVÁ ET AL., 2024)

Heterogenní podmínky nacházíme také v solárních parcích (BLAYDES ET AL., 2021; LAMBERT ET AL., 2021; TAWALBEH ET AL. 2021). Díky heterogenním podmínkám může

docházet k fragmentaci prostředí, spojenou se zvýšenou biodiverzitou vegetace, která se následně projeví ve zvýšené biodiverzitě živočichů. Solární parky mají potenciál stát se ostrůvky biodiverzity v současné krajině (ULDRIJAN ET AL., 2021). Vegetace solárních parku má svou výraznou dynamiku, typ a vlastnosti vegetace nereagují na měnící se mikroklima způsobené solárními parky (WANG, ELTAHIR, 2000A; WANG, ELTAHIR, 2000B). Změny v prostředí otevírají také cestu pro invazi rostlin, proto je velmi důležitý monitoring, bioindikace a následný management vegetace solárních parků. Solární parky jsou dílem naší civilizace a představují pro rostliny nový životní prostor. Některé druhy zde nacházejí příznivé podmínky pro růst a rozmnožování, jiné se musí novým podmínkám přizpůsobit. Solární parky můžeme považovat za další stupeň v procesu koevoluce vegetace a lidské civilizace (ULDRIJAN ET AL., 2023).

Budování solárních parků představuje další pronikání průmyslové činnosti do ekosystémů. Výsledky lidské technologické tvořivosti označujeme jako technosféra. Jejím příkladem jsou solární parky, které propojují činnosti lidské civilizace a biosféry (ULDRIJAN ET AL., 2022).

3.2 Rozvrat klimatu a dopady na vegetaci

Klimatické změny jsou pro zemědělce velkým problémem z důvodu ohrožení výnosů polních plodin nepříznivým průběhem počasí (HARKNESS ET AL., 2020; HABIB-UR-RAHMAN ET AL., 2022). V období rychle se měnícího klimatu nemusí být regulace škodlivých činitelů, včetně plevelů, efektivní (WAGGONER ET AL., 1976). Klimatologové předpovídají, že bude pokračovat změna klimatu, která zahrnuje změny frekvence a distribuce srážek, změny směru a intenzity proudění větrů, zvyšování potenciální evapotranspirace, a že dojde k modifikaci dalších charakteristik počasí. Rychle se měnící klimatické faktory pravděpodobně budou způsobovat větší variabilitu počasí, což může vést ke zvýšení frekvence extrémních klimatických jevů (KATZ, BROWN, 1992; WALSH ET AL., 2020; SENEVIRATNE ET AL., 2021; CLARKE ET AL., 2022). Tyto změny samozřejmě mají vážné důsledky pro zemědělství. Analýza účinků meziroční klimatické variability na výnosy pšenice předpovídaná modelem CERES odhalila, že se zvyšující se variabilitou srážek a teplot budou výnosy pšenice výrazně kolísat (MEAMS ET AL., 1992; ZHENG ET AL., 2020; ZHANG ET AL., 2023).

Některé výsledky naznačují, že mnoho druhů rostlin reaguje na zvyšující se koncentraci CO_2 vyšší intenzitou růstu, ale pouze při dostatku ostatních živin. Při zvýšení

intenzity růstu biomasy plevelů dochází k omezení dostupnosti živin, což vede k zastavení nárůstu biomasy (BAZZAZ, 1990; LITTLE ET AL., 2021; WESTBROOK ET AL., 2022). Podle SINCLAIR (1992) i zde platí „zákon minima“ – růst rostlin je omezován faktorem, kterého je největší nedostatek. Podobné argumenty týkající se omezujících faktorů zdokumentovali WITTWER A ROBB (1964).

Změny kteréhokoliv faktoru (CO_2, teploty, vody, dostupnosti živin) ovlivňují konkurenci mezi plevely a plodinami a konkurenci mezi jednotlivými druhy plevelů navzájem (ZIMDAHL, 1980). Právě dopady změny klimatu mohou působit na konkurenční vztahy mezi plevely a plodinami, protože plodiny a plevele se často liší v typu fotosyntézy (PATTERSON, 1985). Například 14 z 18 „nejhorších plevelů na světě“ jsou rostliny typu C4 (HOLM ET AL., 1977), zatímco 12 z 15 hlavních plodin jsou rostliny typu C3 (HARLAN, 1975). V agroekosystému je růst a konkurenční interakce mezi plodinami (C3) a plevely (C4) synchronizována díky zpracování půdy a vysetí plodiny, což je okamžik, kdy klíčí také plevele (CHRISTIE, DETLING, 1982). Je zřejmé, že budoucí nárůst atmosférického CO_2 ovlivní konkurenční vztahy mezi plevely a plodinami, ale výsledky současných experimentů pocházejí pouze z kontrolovaného prostředí a nejsou k dispozici téměř žádné informace o dlouhodobém působení zvýšené koncentrace CO_2 v kontextu dalších změn (ZISKA, 2001).

Teplota a dešťové srážky jsou primárními faktory ovlivňujícími rozšíření plevelů v regionech (WOODWARD, 1992). Rozšíření mnoha druhů rostlin do severnějších oblastí může být urychleno právě globálním oteplováním (PATTERSON, 1993). Změny klimatu mají potenciál ovlivnit geografický výskyt plevelů a podporovat jejich pronikání do nových stanovišť (GALLAGHER ET AL., 2010; CLEMENTS, DITOMMASO, 2011; ZISKA ET AL., 2011). Změny klimatu, projevující se změnami teplot a koncentrace CO_2, povodněmi, požáry, intenzivními bouřemi a vlnami veder, mohou zapříčinit invazi nepůvodních druhů plevelů (THUILLER ET AL., 2008; DIEZ ET AL., 2012).

Klimatické důsledky skleníkového efektu (zvýšená teplota a sucho) jsou pravděpodobně příznivější pro rostliny typu C4 (PATTERSON, 1985). Hlavní překážkou předpovídání dopadů změn klimatu je nedostatek znalostí o vlivu těchto změn na vegetaci plevelů a plodin (PRESTIDGE, POTTINGER, 1990). Periodické a cyklické změny klimatických poměrů ztěžují identifikaci příčin a následků vztahů mezi průběhem počasí a vlivem na ekosystémy (ROECKNER, 1992). Globální klimatické modely jsou mimořádně složité, vyžadují mnoho předpokladů a mají řadu neznámých parametrů (SCHNEIDER, 1992).

Globální změny klimatu mají potenciál ovlivnit geografické rozšíření druhů rostlin a podporovat jejich invazi do nových lokalit (DUKES, MOONEY, 1999; GALLAGHER ET AL., 2010; CLEMENTS, DITOMMASO, 2011; ZISKA ET AL., 2011). Na druhé straně se rostliny mohou velmi rychle přizpůsobit změnám, různým podmínkám prostředí a různým biotopům (DENNILL, DONNELLY, 1991; GALLAGHER ET AL.; 2010; ROUGET ET AL., 2015). Změna klimatu ovlivňuje vodní a tepelný režim půdy, což má vliv na narušení dormance semen a na druhové složení vegetace (WALCK ET AL., 2011). Podle GLASER ET AL. (2024) nebylo možné za posledních 90 let prokázat vlivy změn klimatu na změny v osídlení rostlinných druhů na orných polích, ale jak dále uvádějí, antropogenní změna stanovišť měla velký vliv na rostlinnou biodiverzitu orné půdy ve střední Evropě.

Změny v druhovém složení vegetace probíhají relativně pomalu. Ústup běžných plevelů otevírá životní prostor pro invazi neofytů a ovlivňuje druhové spektrum plevelů v jarních obilninách. Změna v druhovém spektru plevelů vyvolává snížení účinnosti používaných herbicidů, a tím zvyšuje škodlivost plevelů a potřebu nových, efektivnějších způsobů regulace, včetně prognózy zaplevelení na orných půdách.

3.3 Mikroevoluce vegetace pod vlivem lidské civilizace

Mezi plevely a technologiemi pěstování rostlin se vytvářejí interakce, které jsou základní hybnou silou evoluce plevelů. Evoluční historie plevelů a ekologická dynamika plevelů jsou neodmyslitelně spojeny se zemědělstvím (MAHAUT ET AL., 2020). Zemědělství je možná nejrozšířenějším příkladem hnací síly vzniku nových stanovišť a ekosystémů (MOHLER, 2001). Zemědělské oblasti nyní pokrývají více jak 40 % zemského povrchu (FOLEY ET AL 2011). Díky krátkým životním cyklům a relativně jednoduchým genomům mohou plevele velmi rychle měnit své reakce na technologická opatření, a tím svoji škodlivost (MACLAREN ET AL., 2020; CLEMENTS, JONES, 2021).

Některým druhům plevelů nové podmínky technologií s redukovaným zpracováním půdy vyhovují nebo se na ně rychle adaptují. Díky tomu mohou na takových místech přežít a případně expandovat. Toto ovšem není trvalý stav, protože technologie a metody regulace plevelů se neustále vyvíjejí, což jednotlivé druhy nutí k adaptaci na nové neustále se měnící podmínky. V této souvislosti BRIGGS A WALTERS (2001) uvádějí, že snaha potlačovat plevele může působit jako selekční faktor a upřednostňovat jedince s vlastnostmi, díky kterýmž přežívají, a dokonce hovoří o tzv. mikroevoluci na orné půdě.

Jak dále píší, snaha potlačovat plevele je charakteristickým rysem člověkem utvářených biotopů.

Dále navazuje BARRETT (1983), který tvrdí, že selektivní vlivy vyvolané zemědělskými postupy vedou u plevelů k vytvoření zemědělských ras. Tyto rasy vytvářejí systém mimiker, kdy plevel připomíná v určitém stadiu svého života plodinu, a tím uniká regulaci. Jako příklad uvádí, že *Echinochloa crus-galli* tvoří formy, které se podobají rýži. Populace z rýžových polí vykvétá ve stejné době jako rýže ve srovnání s populacemi z jiných lokalit. Pokud by vykvetla dříve, zemědělci by ji vypleli.

Takovýto příklad zemědělské rasy plevelů v našich podmínkách dnešní doby nemá příliš velkého významu. Změny v habitu rostliny nastat mohou a je možné, že tyto změny probíhají u řady druhů a unikají naší pozornosti. Projevy nemusejí být vždy viditelné pouhým okem a mohou se týkat např. tloušťky a složení kutikuly na povrhu listu, která ovlivňuje účinnost herbicidů.

Dalším příkladem vytvoření zemědělské rasy může být druh *Senecio vulgaris*, u kterého byl zaznamenán rychlejší vývoj na místech, která byla pečlivě odplevelována ve srovnání se špatně ošetřovanými či neošetřovanými místy (KADEREIT, BRIGGS, 1985; THEAKER, BRIGGS, 1993). Zde odstraňování plevelů patrně působilo jako selekční faktor, který upřednostňuje jedince s co nejrychlejším vývojem.

Každá takováto změna u plevelů je ovšem vyvážena jinými změnami. Např. rezistentní rasy mají nižší fitness, pokud rostlina začne dříve tvořit plody (semena), dosáhne menšího vzrůstu a má nižší konkurenceschopnost. Vztahy mezi změnami jednotlivých znaků se pokusil zformulovat STEARNS (1992), který použil definici z oblasti monetaristické ekonomie, která se používá k modelování a měření nákladů, zisků a kompromisů (trade off). Jeho definice zní: Ke kompromisu dochází, je-li zisk způsobený změnou v jednom znaku spojen se ztrátou vyvolanou změnou znaku jiného. Aplikujeme-li tuto definici na příkladu druhu *Senecio vulgaris* na stanovišti pečlivě odplevelovaném, pak k přežití (kompromis) populace na tomto stanovišti dochází, pokud se zkrátí doba od vyklíčení po dozrání semen (zisk), což ovšem přinese nižší konkurenceschopnost jedinců (ztráta). Výsledkem je však přežití populace na stanovišti. Pochopení dopadů lidských činností na ekologickou a evoluční dynamiku bude vyžadovat přehodnocení ekologických teorií, které byly původně vyvinuty pro přírodní ekosystémy (MAHAUT ET AL., 2020).

Můžeme tedy konstatovat, že na orné půdě probíhá proces mikroevoluce agrofytocenózy, do níž člověk vědomě nebo nevědomě vstupuje. Činnost člověka zde

působí jako faktor či faktory, které výrazně ovlivňují druhy rostoucí na orné půdě. Technologie zpracování půdy je pouze jedním z mnoha faktorů, které působí nejen na plevele, ale ovlivňují i jiné organizmy a charakteristiky prostředí na polích. Tento proces není statický, ale dynamický, neustále se měnící na základě působení jednotlivých faktorů a reakce jednotlivých druhů plevelů.

3.4 Interakce mezi lidskou civilizací a vegetací

V současné době působí lidstvo jako globální hybná síla, která velmi rychle transformuje celé ekosystémy (ELLIS, 2011; ELLIS, 2015; WATERS ET AL., 2016; AGUILAR ET AL., 2020). Antropogenní transformace ovlivňuje utváření prostředí, včetně koloběhů a interakcí, mění využití půdy a celé krajiny, působí na klima a zvyšuje znečištění (BENÍTEZ-LÓPEZ ET AL., 2019). O to víc se projevuje vliv člověka na životní prostředí také při produkci a hospodaření s různými druhy odpadů (HOSSAIN ET AL., 2011; LESTARI, TRIHADININGRUM, 2019; GAUR ET AL., 2020; LI, ACHAL, 2020).

Působením selekčních tlaků vyvolaných lidskou civilizací dochází ke změnám v druhovém složení. Prvním trendem je výskyt jednoho výrazně dominantního druhu rostlin. Druhým trendem je výskyt skupiny druhů rostlin, které můžeme označit jako subdominantní. Třetím trendem je ohniskovitý výskyt s nízkým počtem jedinců u většiny ostatních druhů rostlin (WINKLER ET AL., 2015).

Lidská civilizace svým charakterem vytvořila civilizační ekosystém. Producenti a konzumenti jsou v lidské civilizaci velmi intenzivně provázáni. Avšak obě tyto skupiny produkují odpad a zde je náš civilizační ekosystém v nerovnováze, která se projevuje hromaděním odpadu, znečišťováním vod a produkcí plynných emisí. Jednou z cest udržitelného vývoje je omezení produkce odpadu, a tím zvýšení efektivity činností lidské společnosti. Tato cesta ovšem vede pouze ke snížení množství odpadů a neřeší jeho využívání a zpracovávání (WINKLER, VAVERKOVÁ A KODA, 2023).

Lidskou civilizací vytvořené ekosystémy umožňují prosadit se rostlinám splňujícím určitá kritéria, která jsou součástí antropogenní strategie. Mezi typické znaky antropogenní strategie patří tato kritéria:

Kritérium rozmnožování a tvorby semen: Většina domestikovaných plodin má tvorbu nové generace plně řízenou člověkem. Některé plodiny, odrůdy nebo formy se rozmnožují pouze za pomoci člověka. Typickým příkladem je *Zea mays*, která již ztratila schopnost uvolnit svá semena (obilky) z mateřské rostliny (VAN DER PIJL, 1982). Bez

člověka by tento druh přestal existovat. Podobně je tomu u okrasných plnokvětých odrůd růží (*Rosa* sp.). Řada kultivarů již ani netvoří pohlavní buňky a ve svém přežití je zcela odkázána na své pěstitele (ROBINSON, FIROOZABADY, 1993; MARCHANT ET AL. 1998; VON ARNOLD ET AL., 2002). Mnoho druhů rodu *Musa* sp. závisí výhradně na vegetativním rozmnožování. Tyto změny jsou často spojeny s domestikací rostlin a s dalším šlechtěním plodin. Samostatnou skupinou jsou GMO druhy rostlin. Zde člověk přímo zasahuje do DNA a skokově mění vlastnosti rostlin bez předcházejícího evolučního vývoje (HICKEY ET AL., 2019; ZAIDI ET AL., 2019; QAIM, 2020). Na základě tohoto kritéria můžeme konstatovat, že plodiny a řada šlechtěných kultivarů uplatňují převážně antropogenní životní strategii.

Kritérium rozšiřování diaspor: Lidská civilizace díky svým aktivitám, často i zcela záměrným, převáží diaspory druhů rostlin na vzdálenosti, které by byly pro rostliny přirozeně nepřekonatelné (AUFFRET, 2011; MACK ET AL., 2001; WICHMANN ET AL., 2009). Člověkem zprostředkované rozšiřování je hnací silou dálkové distribuce rostlin a stále více získává pozornost v ekologii šíření a invazí (VON DER LIPPE ET AL., 2013). V minulosti se často jednalo o jednorázové transporty, spojené s budováním živých druhových sbírek v botanických zahradách (DAMALAS, 2008; MACK ET AL., 2001; REICHARD ET AL., 2001; VAN KLEUNEN ET AL., 2018). Jedním z mnoha příkladů je druh *Galinsoga parviflora*, který byl přivezen z amazonských pralesů do řady evropských botanických zahrad (DAMALAS, 2008), následně se rozšířil po Evropě a dnes je součástí zahrádek a orné půdy jako běžný plevel. Důsledkem globalizace se často a opakovaně převáží velké množství rostlinných materiálů (zrna, bobů, bavlny atd.), (REICHARD ET AL., 2001; VAN KLEUNEN ET AL., 2018). Součástí těchto materiálů jsou také diaspory rostlin, které se díky tomu šíří do nepůvodních oblastí. Vlivem člověka překonávají rostliny obrovské, často i mezikontinentální vzdálenosti. Transport, ať už úmyslný, nebo neúmyslný, se stal základem pro novou kategorii rostlin, označovanou jako neofyty (VAN DER PIJL, 1982; ZISENIS ET AL., 2015; SANTINI ET AL., 2018).

Kritérium adaptace na zemědělské postupy: Od počátku zemědělské revoluce se začala formovat kategorie druhů rostlin označovaná jako plevele (ABBO, GOPHER, 2020; KOCH ET AL., 2016; MUELLER-BIENIEK ET AL., 2019). V současné době se jedná o samostatnou skupinu, adaptovanou na zpracování půdy, střídání plodin, hnojení organickými hnojivy a na další zemědělské postupy. Důležitou roli zde hraje délka vegetační doby, určovaná pěstovanou plodinou, dostatek živin a biologicky vysoce aktivní ornice (VAN DER PIJL, 1982). Specifické podmínky, vytvořené

člověkem-zemědělcem, dlouhodobě vytvářejí životní podmínky pro plodiny a plevele, tedy pro agrofytocenózu. Existence agrofytocenózy je plně závislá na lidské činnosti. Plodiny, ale i polní plevele jsou již na ornou půdu adaptovány natolik, že v přirozené vegetaci, bez zemědělských postupů dlouhodobě nepřežijí. Mezi zástupce těchto rostlin patří kromě plodin také polní plevele řazené mezi apofyty a archeofyty. Archeofyty, známé jako typické „plevele“, se přizpůsobily zemědělskému využití půdy (BAESSLER, KLOTZ, 2006).

Kritérium adaptace na chemické látky: Chemické látky vytvořené člověkem, jako jsou například pesticidy, ale také látky z petrochemického průmyslu i z domácností, mění životní prostředí velmi radikálně. Látky tohoto charakteru nejsou sice přírodního původu, ale v řadě případů jsou biologicky aktivní. Pokud se dostávají do prostředí, mění životní podmínky pro rostliny, jako je dostupnost živin nebo přítomnost toxických látek působících na metabolismus rostlin. Následkem toho dochází k ústupu citlivých druhů a k prosazení druhů, které jsou schopny změnu využít. Typickým příkladem je rozšiřování rezistentních populací plevelů v místech s vysokou herbicidní zátěží (HAWKINS ET AL., 2019; PEROTTI ET AL., 2020). Herbicidy jsou využívány k hubení plevelů (HEAP, 2017; SOMERVILLE ET AL., 2017). Pokud jsou herbicidy soustavně a nadměrně aplikovány na plevele, vede to k vymizení citlivé populace a přetrvávání jedinců rezistentních. Populace rezistentní k herbicidům následně nahradí v početnosti citlivou část populace. Herbicidy se stávají selekčním faktorem měnícím biologické vlastnosti druhů.

Kritérium řízené sukcese: Lesnické hospodaření je založeno na vysazování vybraných dominantních druhů stromů, které splňují určité pěstitelské parametry (HUI ET AL., 2019; LEIDINGER ET AL., 2019; SCHALL ET AL., 2018). Mezi tyto parametry patří snadné získávání osiva, rychlý růst, vysoká adaptabilita a další (YOUNG ET AL., 2020). V důsledku toho vznikají druhově chudé fytocenózy, tvořené stejně starými jedinci (GERVÉ ET AL., 2018; PUKKALA, 2018). Podle IEZZI ET AL. (2020) rychle rostoucích stromů celosvětově přibývá, což je skutečnost, která může mít silné regionální účinky na biodiverzitu. Biodiverzita hospodářských plantážních lesů je často považována za velmi nízkou a tvrdí se, že nenechá místo pro vzácné nebo ohrožené druhy (HORÁK ET AL., 2018). Díky člověku se dostávají druhy dřevin do nových lokalit, jak to vidíme například u druhu *Pinus pinaster*, který tvoří souvislé porosty v jižní Francii, ale také v jižní Africe (CAMINERO ET AL., 2018; VERGARECHEA ET AL., 2019). Dalším příkladem jsou rychle rostoucí dřeviny. Často se využívají člověkem vytvoření kříženci rodu *Populus* (*P. nigra*

× *P. maximowiczii*). Tito kříženci se rozmnožují pouze vegetativně, a to také výhradně za pomoci člověka (LI ET AL., 2021; TINSCHERT ET AL., 2020).

Kritérium změny geologicko-pedologických podmínek: Lidská civilizace přímo vytváří stanoviště pro vegetaci, jako jsou intravilány měst, průmyslové zóny, železniční a silniční komunikace, plochy pro těžbu nerostných surovin a skládky odpadu (DIJKSTRA ET AL., 2019; SEALEY ET AL., 2018; THOMSON, NEWMAN, 2020; WINKLER ET AL., 2021b). Problematika velkých stavebních projektů a těžby nerostných surovin je hodnocena především ve vztahu k negativním vlivům na životní prostředí (JACKA, 2018; SONDEREGGER ET AL., 2020; NASSANI ET AL., 2021). Všechna tato lidská díla a činnosti představují výrazný zásah do geologicko-pedologických podmínek, ale také do vodního režimu stanoviště. Podmínky stanovišť jsou tedy do značné míry určovány člověkem. Náhlé a výrazné změny představují výzvu pro rostliny, které se pokoušejí na tyto podmínky adaptovat a využít je ke své existenci. Druhy rostlin, schopné tyto podmínky využít, jsou velmi plastické ve svých nárocích na prostředí, mají vysoký reprodukční potenciál a vysokou regenerační schopnost. Mezi takové druhy můžeme zařadit například *Acer negundo, Calamagrostis epigejos* a *Robinia pseudoacacia* (PUCHAŁKA ET AL., 2021; TĚŠITEL ET AL., 2020; VESELKIN ET AL., 2021).

3.5 Adaptace rostlin

Rostliny jsou schopny se adaptovat na velmi různorodé a proměnlivé podmínky prostředí naší planety. Základní ekologické strategie rostlin popsal GRIME (1974, 1979), který definoval tři základní typy strategií: (i) kompetitivní strategii (C) – je výhodná na stanovištích, která mají dostatek zdrojů, podmínky nejsou extrémní a narušování je omezené; (ii) stres toleranční strategii (S) – je výhodná na stanovištích s nedostatkem zdrojů, extrémními podmínkami, ale omezeným narušováním; (iii) ruderální strategii (R) – je výhodná na stanovištích, kde je dostatek zdrojů, podmínky nejsou extrémní, ale úroveň narušování je značná. Mezi třemi základními typy strategií existují přechodné strategie (CR, CS, SR, CSR), které jsou uvedeny v databázi BiolFlor (KLOTZ, KÜHN, 2002). Metodu, která umožňuje přiřadit životní strategie konkrétním taxonům, navrhli PIERCE ET AL. (2017).

Odlišné strategie a jejich kombinace umožňují rostlinám žít a adaptovat se na rozličné podmínky svého okolí. Životní prostor rostlin je dán podmínkami prostředí, které

jsou určeny především klimatologicko-meteorologickými a geologicko-pedologickými podmínkami.

Transformace naší planety lidmi způsobuje bezprecedentní a zrychlující se změny v ekologii Země (CHAPIN III ET AL., 2011; DEFRIES ET AL., 2012). Lidé již přetvořili více než tři čtvrtiny pozemské biosféry (MARTIN ET AL., 2014). Rozvoj naší civilizace a lidská činnost mění jak podmínky prostředí, tak i přímo působí na životní cyklus rostlin. Obecně bývá popisováno pouze negativní působení lidské civilizace na jednotlivé součásti ekosystémů včetně rostlin. Některé druhy rostlin byly zcela vyhubeny nebo byl zničen či pozměněn jejich životní prostor. Opomíjenou skutečností však je, že člověk vytváří nová prostředí a pro řadu druhů rostlin je to nová výzva pro jejich životní strategii. Nový životní prostor, který se odlišuje od přírodních biotopů, nutí rostliny k vytvoření nových adaptací. Rostliny se však nejen adaptují na nové podmínky, ale dokáží je i aktivně využívat ke svému udržení na stanovišti a k dalšímu šíření. Nové adaptace pak zařazují do svých životních strategií druhy rostlin, které jsou úspěšné na člověkem vytvořených stanovištích. Díky rozvoji naší civilizace budou přibývat prostředí, která jsou pod silným vlivem člověka nebo budou člověkem přímo vytvořená. Tato antropogenní prostředí budou novým životním prostorem pro rostliny, ovšem pouze pro ty druhy, které změní svou stávající životní strategii.

Člověk a jeho činnost je studována především ve vztahu k degradaci prostředí a ničení původních rostlinných společenstev. Ovšem nové podmínky prostředí, jako je geologicko-pedologická činnost člověka, přítomnost chemických látek vytvořených člověkem, člověk jako rozšiřovač semen a člověk zajišťující rozmnožování, vedou nejen k adaptaci některých druhů rostlin, ale i k tvorbě nové životní strategie. Antropogenní životní strategie (A), umožňující druhům rostlin přežít na člověkem ovlivněných a vytvářených stanovištích, se značně vymezuje a odlišuje od původních tří strategií. Odlišnosti od stávajících strategií spočívají:

– ve vymezení ke kompetitivní strategii (C) – odlišuje se především extrémním narušováním, které způsobuje činnost člověka. Dostatek zdrojů pro rostliny je také spojen s činností člověka.

– ve vymezení k stres toleranční strategii (S) – odlišnost spočívá zejména v původu stresu, který opět pochází z lidské činnosti. Jedná se především o působení chemických látek vytvořených člověkem a změny v mikroklimatu stanovišť vytvářených člověkem.

– ve vymezení k ruderální strategii (R) – jeví se jako nejvíce nová v porovnání s antropogenní životní strategií, ovšem výrazné narušování (disturbance) je způsobeno

pouze člověkem. Disturbance se pravidelně opakují a nejedná se o nahodilý a jednorázový jev, jako je tomu u přírodní disturbance.

V současné flóře již existuje skupina druhů rostlin, které využívají a preferují antropogenní stanoviště. Mezi lidskou civilizací a některými druhy rostlin se začaly budovat vzájemně prospěšné vztahy. U těchto druhů rostlin došlo ke změnám v životní strategii. Vytvořily si strategii nového typu a můžeme hovořit o antropogenní životní strategii (A). Tato strategie má řadu identifikačních kritérií, která jsou úzce spojena s činností člověka a celé lidské civilizace.

4 DISKUSE

V 19. století geologové rozdělili historii Země do tří hlavních epoch, založených převážně na fosilních typech zachovaných v různých vrstvách jejího povrchu. Každá doba byla rozdělena na období a každé období bylo dále rozděleno na epochy. Mnohé z nich byly poznamenány hromadným vymíráním druhů (ELIAS, 2018).

Život rostlin je vždy silně ovlivňován podmínkami prostředí. V průběhu geochronologických jednotek se podmínky významně proměňovaly a byly doprovázeny poklesem nebo nárůstem biodiverzity rostlin. Příkladem nárůstu biodiverzity rostlin je devonská invaze suchozemských rostlin, která započala ve starším ordoviku, když se objevily rostliny odolné vůči vysychání (GIBBARD ET AL. 2022; STROTHER A FOSTER, 2021). Pokračovalo to zvýšeným výskytem cévnatých výtrusných suchozemských rostlin ve středním ordoviku a dále pak výskytem embryofytů v pozdním ordoviku (WELLMAN, 2010). Vývoj pokračoval a objevuje se pestřejší zastoupení hlouběji zakořeněných cévnatých rostlin v devonu (PAWLIK ET AL., 2020, PENG ET AL., 2020). Tento paleozoický (nejen devonský) vývoj suchozemských ekosystémů byl složitým a dlouhodobým procesem, pro nějž je termín „geologická událost“ jistě nesprávným pojmem (COLIN ET AL., 2022). Změny ve vegetaci měly doprovodné účinky na řeky, krajinu, suchozemské ekosystémy a změny se týkaly také klimatu a zvětrávání hornin (DAVIES A GIBLING, 2010; EDWARDS ET AL., 2015).

V posledním období se k přírodním podmínkám přidává vliv lidské civilizace, ať v podobě zemědělství, těžby nerostných surovin, urbanizovaných oblastí, dopravních komunikací, technosféry, tak i v podobě syntézy chemických látek, které jsou součástí potravních sítí. Epocha antropocénu může být užitečným dělením, pokud přiměje lidstvo, aby si uvědomilo, že jsme hlavními činiteli změn v dnešním světě a že musíme okamžitě podniknout kroky k zachování zdraví planety (ELIAS, 2018).

Termín antropocén byl zaveden atmosférickým chemikem Paulem Crutzenem a biologem Eugenem Stoermerem (CRUTZEN A STOERMER, 2000) a stal se poměrně populárním. Definice antropocénu má kořeny v přírodních vědách, která se odkazuje na „geologii lidstva“. Popisuje posun od předchozí geologické epochy, holocénu, do doby, kdy se lidstvo stalo geologickou silou (CRUTZEN, 2002). V červenci 2023 bylo jezero Crawford Lake vybráno pracovní skupinou pro antropocén AWG (Anthropocene Working Group) jako „golden spike“ a jako jasný ukazatel začátku epochy antropocénu,

a to na základě zachovaných vrstev sedimentů a přítomnosti radionuklidy ^{239}Pu, ^{14}C a pylu kulturních rostlin (kukuřice), (SORIANO, 2024).

Pro identifikaci nové epochy GTS (Geologic Time Scale) byl termín antropocén vybrán skupinou AWG (Anthropocene Working Group) a předložen Mezinárodní komisi pro stratigrafii (ICS International Commission of Stratigraphy) v říjnu 2023. V březnu 2024 byl tento návrh zamítnut, takže antropocén nebude formalizován jako jednotka GTS. Nicméně debata o antropocénu je stále otevřená a upozornila na několik problémů. V neposlední řadě je neformální využití antropocénu v geologii ponecháno otevřené, což umožňuje předložit v budoucnu podobný, byť upravený návrh. Tím může být následován příklad mnoha oficiálních jednotek GTS, jako je holocén, který byl dlouhodobě používán jako neformální jednotka (SORIANO, 2024).

Hlavní námitkou vůči formalizaci antropocénu, jak ji navrhuje AWG, je to, že neodráží časově transgresivní povahu lidského vlivu na Zemi. Zejména nezvažuje povahu lidských dopadů na globální environmentální systémy během pozdního holocénu, ale ani prostorovou heterogenitu těchto dopadů (WALKER ET AL., 2024). V důsledku toho by měl být antropocén chápán jako souhrnné účinky lidských činností, které transformovaly a nadále přetvářejí systém Země a ovlivňují biologickou rozmanitost, čímž vytvářejí podstatné, charakteristické a jedinečné záznamy v sedimentárních vrstvách a v člověkem modifikované půdě (GIBBARD ET AL., 2022). Hlavním problémem pro formalizaci je nejednoznačnost termínu antropocén (SORIANO, 2024).

Antropocén je sporný termín a vede k napětí v odborné debatě při přezkoumání vymezení geologických epoch (HEIKKURINEN ET AL., 2019). V podstatě se během několika posledních let vymezily dva protichůdné názory na formalizaci antropocénu. AWG podporuje formalizaci antropocénu jako poslední epochy kvartérního období po holocénu. Odpůrci formalizace antropocénu v GTS tvrdí, že antropocén by měl být považován za událost historie Země, jako je například Velká oxidační událost v proterozoiku, Velká ordovická událost biodiverzifikace a další. Vzhledem k tomu, že události jsou neformálními jednotkami, které nevyžadují standardizaci v GTS, tato možnost v praxi odmítá formalizaci antropocénu (SORIANO, 2024).

Kritici epochy antropocénu zpochybňují relevanci uvažování o lidstvu jako o činiteli, který způsobil a nadále způsobuje nežádoucí změny v biosféře (HEIKKURINEN ET AL., 2019). Chápání antropocénu je velmi odlišné. Pro někoho je antropocén krizí, ba katastrofou, zatímco pro jiného příležitostí, nebo je chápán jako vědecká hypotéza

opírající se o různá měření a technická vymezení, jindy může být vnímán jako volnější umělecká inspirace (POKORNÝ A STORCH, 2020).

Co je ovšem pro antropocén typické je, že vyvolává diskusi, která je základem vědecké práce a cestou k pochopení všeho neznámého. Ať už bude antropocén přijat jako epocha, událost, nebo krize, bude studován v řadě vědeckých oborů. Významnou skutečností je také propojení vědeckých oborů od gelogie, botaniky, zoologie, chemie až po ekonomii a sociologii. Studium antropocénu poprvé v historii lidstva otevřelo možnost pozorovat pozemské systémy v globálním měřítku a v reálném čase. To si vyžádá nové vědecké metody a také odlišný vědecký přístup.

Vymezení a definice antropocénu je předmětem rozsáhlé vědecké diskuse, která bude pokračovat ještě velmi dlouho a pravděpodobně nebude jednoznačně zakončena. Cílem této práce není zapojit se do této diskuse, ale shrnout zjištěné poznatky o vegetaci v období, které je pod silným vlivem lidské civilizace. Vegetace se vždy dokázala přizpůsobit, a dokonce využít všechny změny prostředí. Předkládané výsledky ukazují nejen výsledky působení lidské civilizace na vegetaci, ale také jako se vegetace s tímto působením vyrovnává a k jakým změnám ve složení vegetace dochází.

Spojitost výskytu některých druhů rostlin a konkrétních podmínek prostředí byla vědci využita k vypracování metod, ve kterých složení vegetace slouží k identifikaci půdních podmínek. V roce 1964 byla vypracována metodika indikace půdních typů v podmínkách tehdejšího Československa (KÜHN, 1964). Metoda vycházela z prací autorů, kteří se snažili vytvořit ekologické skupiny plevelů, jejichž výskyt je vázán na kombinaci stanovištních faktorů, jako je např. pH, zásobenost vodou, obsah dusíku apod. (EICHINGER, 1927; ELLENBERG, 1950; HILBIG ET AL., 1962). Od té doby naše zemědělství prošlo značnými změnami a vyvstala otázka, zda-li lze i za současných podmínek tuto slibnou metodu i nadále využívat. Při ověřování této metody došli WINKLER A ZELENÁ (2003) k závěru, že již není spolehlivá, a jako vysvětlení uvádějí, že spektrum druhů plevelů se neustále vyvíjí a mění jako reakce na plevelohubná opatření. Především používáním herbicidů dochází k potlačování citlivých druhů a na uvolněné místo se rozšiřují druhy odolné. Některé druhy rozšiřují svoji ekologickou amplitudu a je možné tyto druhy nacházet i v podmínkách, kde se dříve nevyskytovaly. Naopak jiné druhy nejsou schopny přizpůsobit se plevelohubným opatřením a ustupují (WINKLER ET AL. 2023B).

Aplikace herbicidů jsou součástí celé technologie pěstování plodin. Na vegetaci plevelů působí také zpracování půdy (WINKLER, ZELENÁ, 2005; WINKLER, 2008).

Vegetace plevelů při bezorebné technologii zpracování půdy měla vyšší hodnoty biologické relevance, jenž umožňuje vyšší výskyt závislých druhů organismů. Naopak vegetace plevelů při minimalizační technologii zpracování půdy měla nejnižší hodnoty biologické relevance, což omezuje výskyt organismů závislých na plevelech. Je tedy patrné, že technologie zpracování půdy ovlivňuje celý ekosystém na orné půdě.

Dalším fenoménem je výskyt nových druhů rostlin na orných půdách. WINKLER A ZELENÁ (2004) uvádějí, že vrbovka žláznatá (*Epilobium adenocaulon*) se vyskytuje na orné půdě. Frekvence výskytu vrbovky žláznaté v polních plodinách není zatím hospodářsky významná. V obilninách je její výskyt velmi malý a není schopna se zde rozmnožovat. V ostatních plodinách (cukrovka, kukuřice, vojtěška) nebyla nalezena vůbec, nebo jen velmi ojediněle. Její schopnost tvorby semen, nejvyšší výskyt a pokryvnost na orné půdě byly zjištěny v porostech řepky a kmínu. Podle zjištěného výskytu vrbovky žláznaté lze usuzovat na počátek její invaze na ornou půdu. V současnosti je schopna se na orné půdě, byť omezeně, rozmnožovat.

Sledování koevoluce lidské civilizace a vegetace se výrazně projevuje na druhovém složení luk, pastvin a ostatních travních porostů. V průběhu vývoje se mění účel travních porostů od produkce píce až k okrasným účelům a také se mění management údržby od pouhého sečení a spásání až i k velmi intenzivní údržbě, včetně použití závlahy, herbicidů a průmyslových hnojiv. Změny managementu i účelu využití se odrážejí v druhovém složení vegetace (RYSPEKOV ET AL., 2021; WINKLER ET AL., 2022B; WINKLER ET AL., 2024A).

Lidská civilizace vytváří i druhově bohatá rostlinná společenstva, jako jsou vinice a ovocné sady. Druhová bohatost je zde dána specifickým managementem vegetace. Ovšem složení vegetace většinou neodpovídá původní vegetaci a prosazují se zde preferované druhy rostlin (WINKLER ET AL. 2023D; RAGASOVÁ ET AL. 2020; RAGASOVÁ ET AL. 2021).

Urbanizované oblasti jsou na řadě míst planety uceleným geologicko-pedologicko-biologickým dílem lidské civilizace, zahrnujícím města, železnice, silnice, solární parky a průmyslové zóny. Pro řadu druhů rostlin jsou to nová místa pro život, kde se tyto rostliny musejí vyrovnávat s působení různorodého stresu, a pokud se s ním dokáží vyrovnat, otvírají se jim nové oblasti (VAVERKOVÁ ET AL., 2022A; WINKLER ET AL., 2022C; WINKLER ET AL., 2023D; WINKLER ET AL., 2024B).

Produkce a nakládání s odpadem představuje pro rostliny nový substrát, obsahující celou řadu biologicky aktivních technofosilií, které působí jako selekční faktor prostředí,

jenž je zcela vytvořený lidskou civilizací. Vegetace skládek představuje typickou ukázku vegetace antropocénu (VAVERKOVÁ ET AL., 2019B; VAVERKOVÁ ET AL., 2019C; VAVERKOVÁ ET AL., 2020; VAVERKOVÁ ET AL., 2022C; WINKLER ET AL., 2021B; KODA ET AL., 2022; KODA ET AL., 2023; WINKLER ET AL., 2023E).

Reakce vegetace na různorodé činnosti lidské civilizace, které působí na vegetaci přímo, jak je tomu na zemědělských půdách, ve městech, nebo nepřímo, jako tomu je v případě nakládání s odpady a budování skládek komunálního odpadu. Pomocí většiny činností je vytvářen selekční tlak, a tím se mění nejen druhové spektrum vegetace, ale mění se i druhy rostlin, které se přizpůsobují novým selekčním tlakům, nebo je přímo využívají. Lidská civilizace prochází svým vývojem, a tím mění charakter selekčních tlaků, které již dosahují globální úrovně. Na tento vývoj reagují i rostliny. Na základě reakcí rostlin byla definována antropogenní životní strategii (A), která druhům umožňuje přežít a využít podmínky, ve kterých působí lidská civilizace. Právě antropogenní životní strategie může být jednou z událostí, která přispěje k definici a ohraničení antropocénu (WINKLER, VAVERKOVÁ A HAVEL, 2023).

Další směr výzkumu by se měl zaměřit na hlubší porozumění koevoluci mezi lidskou činností a vegetací, zejména na dynamiku druhových změn v kontextu stále intenzivnějšího využívání půdy, urbanizace a změn klimatu. Jedním z klíčových cílů by mělo být sledování adaptivních strategií rostlin, které reagují na nové selekční tlaky, jako jsou herbicidy, technosféra či změny v půdním hospodaření. Důležité je rovněž zkoumat, jak se druhy vyvíjejí v urbanizovaných a technogenních prostředích, kde mohou vznikat nové ekologické niky.

Kromě toho je nutné se zaměřit na možnosti predikce budoucích změn ve vegetačních společenstvech, a to nejen na základě současných trendů, ale i potenciálních scénářů dalšího vývoje lidské civilizace a globálního klimatu. Výzkum by měl také zohlednit dlouhodobé dopady antropocénu, zejména jak lidská činnost ovlivňuje nejen místní ekosystémy, ale také biodiverzitu na globální úrovni. Klíčové je vytvářet nové metodiky pro monitorování a řízení vegetace v kontextu rychle se měnícího prostředí a přicházejících technologických změn.

Udržitelnost vývoje lidské civilizace představuje šanci na změnu a tvorbu nových postojů, vazeb a vztahů. Díky těmto změnám máme šanci vytvořit fungující civilizační ekosystém. Současné působení lidské civilizace není pouze přechodnou změnou, ale je klíčovým činitelem formujícím nový geobiologický řád. Antropocén jako nová epocha v historii Země není jen vědeckým konceptem, ale skutečným odrazem toho, jak naše

činnosti přetvářejí systémy naší planety. V tomto kontextu je nezbytné, abychom si uvědomili, že naše činnost není izolována a že ovlivňuje široké spektrum biologických a geologických procesů. Budoucnost naší planety bude závislá na tom, jakým způsobem budeme reagovat na tyto výzvy. Naše schopnost vytvořit udržitelný a harmonický vztah mezi civilizací a přírodními systémy je klíčová pro zachování zdraví a stability ekosystémů. Vyvstává tedy potřeba vyvinout a implementovat inovativní strategie pro ochranu a obnovu přirozených systémů, zajištění efektivního řízení odpadů a hledání nových cest k udržitelnému rozvoji. Vytvoření funkčního civilizačního ekosystému, který bude respektovat a integrovat přirozené procesy, se stává naší největší výzvou, ale také nadějí pro budoucnost naší planety.

5 ZÁVĚR

Lidská civilizace již globálně působí, zasahuje a mění nejen biosféru, ale i geologicko-pedologické vrstvy, klimatologicko-meteorologické podmínky a vodní režim krajiny. Odpady, technofosílie a odpadní látky jsou obrazem a stopou činnosti lidské civilizace, které se dlouhodobě projevující napříč sférami naší planety. Působení lidské civilizace zahájilo novou biologicko-geologickou epochu – antropocén. Lidská civilizace již určuje, jaké budou životní podmínky v antropocénu. Vývoj života na planetě je již pod vlivem antropogenních podmínek a určuje přežití organizmů na Zemi. Růst lidské civilizace v současném pojetí naší společnosti povede k postupnému vyčerpávání přírodních zdrojů a k hromadění odpadu a znečišťujících látek. Výsledkem budou stále se zhoršující životní podmínky nejen pro člověka jako biologický druh, ale i pro většinu živých organizmů. Změny ve vegetaci, například v rostoucí integraci neofytů a adaptaci rostlinných druhů na antropogenní podmínky, jsou jasnými indikátory, že naše civilizace vytváří novou ekologickou realitu. Probíhající procesy naznačují, že biosféra se neustále přizpůsobuje. Přizpůsobení však nemusí vždy znamenat zlepšení a často přináší i nové výzvy, jako je ztráta biodiverzity a degradace ekosystémů. Na silně antropogenně ovlivněných lokalitách můžeme pozorovat netypický průběh sukcese vegetace. V průběhu sekundární sukcese pod vlivem lidské civilizace dochází k ústupu původních a vlhkomilných druhů rostlin. Na jejich místo se prosazují druhy, které považujeme za neofyty, dále se více prosazují nitrofilní vytrvalé druhy a vyšší zastoupení mají také druhy suchovzdornější. Právě integrace neofytů do rostlinných společenstev je zásadní otázkou pro fungování celého ekosystému. Rychlost a úspěšnost integerace neofytů vyvolává řadu otázek pro fungování a další vývoj biodiverzity ale i pro vývoj a fungování civilizačních ekosystémů.

Budoucí výzkum může změny ve složení vegetace využít jako příležitost pro zodpovězení řady otázek. Zajímavou otázkou bude dynamika vývoje lidské civilizace a dynamika evoluce vegetace. Pozornost výzkumu si zasluhuje využití druhů rostlin v biomonitoringu životního prostředí. Další studium je nutné věnovat integraci neofytů a jejich ekosystémovým službám. Současná vegetace stále přináší nové příležitosti pro nová poznání a pochopení fungování ekosystému planety, které přispějí k obohazení botaniky jako nezastupitelné vědní disciplíny.

Studium vegetace může přispět ke studiu fenoménu antropocénu, ať ho budeme vnímat jako souhrn všech lidských činnosti, nebo jako geologickou epochu či

geologickou událost. Rostliny, jako bioindikátory změn podmínek vyvolaných lidskou civilizací, budou přinášet pozoruhodné a nové informace, které můžeme využít k pochopení fungování ekosystémů a vlivu činností lidské civilizace.

Činnost lidské civilizace působí jako selekční faktor, který vytváří a silně ovlivňuje celé ekosystémy a umožňuje přežití pouze těm druhům rostlin, které začnou uplatňovat kritéria antropogenní životní strategie. Nová antropogenní životní strategie je uplatňována především u zemědělských plodin, lesnických a okrasných druhů, ale také u plevelů, neofytů a u zástupců synantropní vegetace. Tyto skupiny vegetace jsou tvořeny druhy, které se začaly působení naší civilizace přizpůsobovat a také přímo využívat ke svému prospěchu. Ne zcela známou oblastí jsou ekosystémové funkce antropogení vegetace. Význam rostlin pro ostatní složky ekosystémů představuje zajímavé téma, jehož studium nám umožní lépe pochopit vztahy a souvislosti mezi rostlinami a dalšími organizmy. Z tohoto pohledu se jeví zajímavé vnímat rostliny jako prvek podporující biodiverzitu. Rostliny jsou součástí potravní sítě a zdrojem potravy pro hmyz a obratlovce, ale jsou také zdrojem potravy pro mikroorganizmy. Objasnění těchto vazeb by umožnilo využít rostliny jako indikátory života, udržitelnosti a stability ekosystémů.

Složení současné vegetace je výsledkem koevoluce rostlin a lidské civilizace. Člověk ve své evoluci již opouští hranice biologického druhu a vytváří lidskou civilizaci, která jako faktor (síla) mění podmínky prostředí na planetě a podílí se na vývoji druhů rostlin. Výsledkem koevoluce člověka a vegetace je nová antropogenní životní strategie, která nachází úspěšné uplatnění v podmínkách antropocénu.

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Příloha 1

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Trends in the succession of synanthropic vegetation on a reclaimed landfill in Poland

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ABSTRACT

The production and management of wastes clearly demonstrates a human influence on the environment. The most frequent method of handling waste worldwide is landfilling, which exerts a range of negative impacts on the environment. This study presents a twenty-year analysis into the vegetation of a closed municipal solid waste landfill in Poland. We assessed the composition of vegetation using the method of phytocoenological relevés. From monitoring 127 plant species, we created a floristic list of species found in the landfill. Detrended Correspondence Analysis enabled establishment of the covers of the plant species detected. Results indicated differences in the representation of native plant species and neophytes in the composition of vegetation. Landfill site environments differed from neighbouring ecosystems after twenty years, a high proportion of invasive neophytes have been identified on the landfill site. These differences suggest that the vegetation in the landfill has been changing, and the spectrum of plant species has been developing over time. Findings indicate that humans not only affect landscapes, but they directly create new ecosystems including geological-pedological layers. Landfills and the whole ecosystem of landfills therefore contain real and clear evidence of human influences on the surface layers of the lithosphere.

1. Introduction

Humankind is a global moving force that can transform whole ecosystems rapidly (Ellis, 2011, 2015; Waters et al., 2016; Aguilar et al., 2020). Anthropogenic transformation affects the environment and ecosystems (Benítez-López et al., 2019) including biodiversity (Hu et al., 2021). According to Keesstra et al. (2018) and Visser et al. (2019), pressure is increasing on the land. Due to improper use, land resources are quickly degrading, which creates even greater pressure on the remaining land.

The influence of humans on the environment also clearly shows in the production and management of wastes (Hossain et al., 2011; Lestari and Trihadiningrum, 2019; Gaur et al., 2020; Li and Achal, 2020). The most frequent method of handling waste worldwide is landfilling (Vaverková et al., 2012; Wong et al., 2015; Hamid et al., 2018; Adamcová, 2019; Rasapoor et al., 2020; Sauve and Van Acker, 2020). Landfilling has however a range of negative impacts on the environment in the form of soil degradation (pollutants released from deposited waste, leachates etc.), which may lead to soil and water contamination (Dąbrowska et al., 2018; Koda et al., 2020; Vaverková et al., 2012). Municipal solid waste landfills seriously affect soil quality and health (D'Amato et al., 2018; Wright et al., 2018), particularly illegal and old landfills without protection systems (Vaverková et al., 2019a). Contaminated soil can subsequently pollute waters (Keesstra et al., 2016). The existence of landfills represents an environmental problem both in advanced and in developing countries. The scale and scope of the transformation of the Earth's surface depends on the technical methods of protection systems of the landfill. This transformation has been demonstrated by many scientific works, for example by research conducted in Austria (Allgaier and Stegmann, 2006), Ireland (Doak et al., 2007), France (Biotto et al., 2009), Italy (Silvestri and Omri, 2008) and Serbia (Vasiljević et al., 2012), Czech Republic and Poland (Adamcová, 2019).

Degradation of soil can also show in the composition of vegetation

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growing on municipal solid waste landfills (Mao et al., 2018). Sites with landfills exhibit a number of non-typical plant species. Landfill can be characterized with typical synanthropic flora (Koda et al., 2013; Vaverková et al., 2019b; Bryant et al., 2017). According to Wania et al. (2006), these localities are usually colonized by plant species from the group of neophytes and archeophytes (Vaverková et al., 2019b). Previous studies of municipal solid waste landfills primarily focus on geographical aspects or on the causes of their origin (Jordá-Borrell and Ruiz-Rodrígez, 2014; Di Fiore et al., 2017; Carriero et al., 2018; Wright et al., 2018). Changes in conditions on the landfill surface and inside its body represent a challenge for vegetation, to which it must respond to during succession (Tintner and Klug, 2011; El-Sheikha et al., 2012; Koda et al., 2016; Rebele and Lehmann, 2016; Álvarez-López et al., 2020). Landfilling is increasingly restricted but cannot be eliminated. In the 1990s approximately 30 municipal solid waste landfills were active in the Warsaw area (Poland), whereas currently only a few are in operation. In Poland, over 2500 legal landfills and approximately 15,000 illegal landfills have been closed in the last twenty years (Koda et al., 2019). Closed landfills are persistent anthropogenic inclusions on Earth's surface. Therefore, to minimize disturbances to ecosystems caused by landfills, it is important to install a final cover and then to monitor the closed landfills. Although previous research (Vaverková et al., 2019b, 2020) found that closed landfill sites are suitable for the occurrence of invasive species and neophytes, such transitions have not been investigated in detail. This study, therefore, seeks to clarify the trends in the succession of such vegetation by answering following research questions. First, how do human activities condition the formation of new species composition in the landfill? We hypothesized that, even in the first years after reclamation of the landfill, differences in the range of species will be visible in different parts of the landfill body. Second, how will the native plant species return to the monitored locality after twenty years? We hypothesized that the native and hydrophilous plant species will withdraw from the landfill while the number of neophytes and drought-resistant species will increase. Third, to the extent does the vegetation in the landfill reflect the creation of a new anthropogenic ecosystem? We hypothesized that changed conditions of the landfill would facilitate the formation of a novel plant community.

2. Material and methods

To pursue the research questions, the overall approach to the study comprised several steps. First, we analysed proportions in the representation of native plant species and neophytes in the landfill vegetation composition. Second, we determined trends in the process of succession of municipal solid waste landfill vegetation on the space of more than twenty years. Third, we defined the character of the new type of municipal solid waste landfill vegetation. Fourth, we used the data obtained to assess landfills an indicator in general of human influences on the surface layers of the lithosphere.

2.1. Study site and landfills site description

The municipal solid waste landfill in the town of Otwock (near Warsaw, capital of Poland) is situated in the western part of the town at the end of Warsztatowa Street (Fig. 1). This street was the primary access to the landfill. The study landfill is in the catchment area of three rivers: the Vistula, the Jagodzianka and the Świder. In the immediate vicinity of the landfill, on the southern and south-western side, are reservoirs (backwaters) of the Jagodzianka that continues from the Bieliński Channel draining the marshy areas of the Masovian Landscape Park. Treated water from the municipal wastewater treatment plant located nearby also discharges into these reservoirs.

On the eastern side of the municipal solid waste landfill are agricultural lands and wastelands. Directly at the entrance to the landfill is a carpentry business with a wood drying plant. On the northern side a flood embankment of the Świder with adjacent forest areas. On the western side, the landfill borders road no. 801 Warsaw-Puławy, which runs in this section on an embankment constituting the flood embankment of the Vistula. Originally, the municipal solid waste landfill area was flat with numerous swampy depressions. Exploitation of municipal solid waste from the landfill and construction of the Warsaw-Puławy embankment, however, has transformed the area significantly.

The municipal solid waste landfill is also located close to the area protected by the Natura 2000 programme, in the vicinity of the Wyspy Świderskie nature reserve which was established to protect water ecosystems in the central part of the Vistula channel. Part of the ECONET-Poland network, this reserve includes numerous sandbanks, shoals in the area of the Świder's mouth as well as the Vistula. On the eastern side, within approximately 1 km, is a water intake station. Within ca. 3 km in an eastern direction from the municipal solid waste landfill are hospital facilities and a Lung Disease Treatment Centre. The municipal solid waste landfill studied is a special object for scientific considerations and analyses due to the close vicinity of environmentally protected sites and

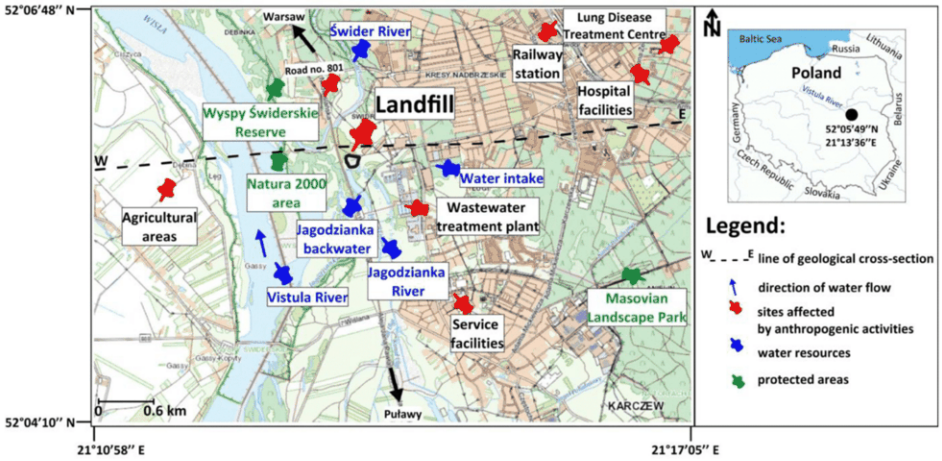


Fig. 1. The study area.

areas under pressure of anthropogenic activities.

The landfill became operational in 1961 as an illegal site. Initially, waste filled local terrain depressions nearby the Jagodzianka and Świder. Later, the site was legalized as a municipal solid waste landfill for the municipalities of Otwock, Karczew, Józefów, Wiązowna and Celestynów and received communal waste until 1991. In 1992, a project began to reclaim the now closed municipal solid waste landfill. Construction works were, however, launched as late as 1996. These works included the shaping of the landfill body (modelling of slopes with suitable gradients, covering them with the buffer sand layer and compost layer over the top), modification of access to the landfill from the east, a passive degassing system, an excavation of a ditch around the landfill and grass mixture sowing. The reclamation works ended in November 1998. In accordance with the regulations for waste landfills, monitoring of the quality of surface water and groundwater in the site of Otwock landfill has been carried out since it was closed. No significant impact in this respect, however, has been found (Porowska, 2019). We therefore omitted the analysis of these results from this study.

Currently, the landfill area is about 2.8 ha. The landfill body is elevated above the surrounding terrain by ca. 12.5 m in the southern part and by ca. 5.5 m in the northern part. Residents use the landfill surface for motocross, with several regularly used pathways across the landfill body. The closed landfill is considered reclaimed. A major problem is, however, the lack of protection against leaking pollutants. Therefore, the landfill may be a potential source of groundwater and soil contamination.

From the geological point of view, the research area is located within the Vistula valley, in the northern part of the Mazovian Gorge, where the Vistula opens into the Warsaw Basin (Wierzbicki et al., 2021). Geomorphologically, it is the Falenica II terrace, elevated about 90 m a.s.l. The Falenica over flood terrace, similar to the Otwock terrace, has been preserved on both Vistula banks as a narrow bench the width of which varies from several hundred meters to 1 km. On the geological profile (Fig. 2), apart from the analyzed landfill, other anthropogenic forms include: two large landfills (Łubna - closed, and Świerk - exploited), flood embankments of the Vistula and sewage sludge lagoons from wastewater treatment plant. Synanthropic vegetation succession also occurs in the region of these anthropogenic forms, especially in the area of large closed Łubna landfill (22 ha of area and 60 m high).

On an older Tertiary sediment (Pliocene), the top of which is at a depth of about 80 m, is a series of Quaternary formations (Pleistocene) in the form of boulder clays and water-glacial sands of the central Polish glaciation from the Mazovian-Podlasie and Maximal Stadiums, locally with sands or clayey beds. These formations are separated by interglacial or interstadial river accumulation sediments in the form of sands with gravel or silt. In the upper parts of the profile, directly beneath the Falenica terrace (up to a depth of about 50 m beneath the ground surface), there are river sands with Eemic interglacial and Pilica interstadial gravel. Underneath a thin layer of humus, there are small layers or lenses of muddy silt. They lie on sands of different granulation with lenses of gravel or river beddings of the Vistula (Quaternary - Pleistocene), bordering on humus sands, silt or peat of the Vistula bed, and the mouth of the Świder (Quaternary - Holocene) in the west of the area studied. The main hydrographic axis of the analysed area is the Vistula and its right tributary, the Świder, which flows into the Vistula in the northern part of the research area. From the south, floodplains of the Jagodzianka border the landfill, which passes under the embankment of the Warszawa-Pulawy road and joins the Bielinski Canal flowing into the Vistula.

2.2. Vegetation survey

Evaluation of the vegetation composition utilized the method of phytocoenological relevés. We conducted the survey in July 1999 and then again after twenty years in July 2019. The size of phytocoenological relevés was 25 m^2. We estimated the cover of detected plant species directly in percent. In each year of monitoring, we recorded 30 phytocoenological relevés —always on the same sites. The Pladias database of the Czech flora (Pladias, 2020) provided scientific names of individual plant species. The municipal solid waste landfill site was divided into six sections. Six phytocoenological relevés (Fig. 3) were recorded on each section each year: landfill crown (I - top), north-western (II - NW), northern (III - N), south-western (IV - SW), south-eastern (V - SE) sides and landfill base (VI).

We then processed data gained about the occurrence of plant species statistically using multidimensional analysis of ecological data and the Canonical Correspondence Analysis. The Monte-Carlo test assessed significance, during which 999 permutations were calculated. The Canoco 5.0 provided the programme to process the data (Ter Braak and Šmilauer, 2012). The cover of plant species detected was established using Detrended Correspondence Analysis. The length of gradient calculated by means of Detrended Correspondence Analysis was 5.34. Based on this calculation, we chose e Canonical Correspondence Analysis for further processing. The Canonical Correspondence Analysis defines the spatial arrangement of individual plant species in the given years, which is subsequently expressed graphically with the ordination diagram.

3. Results

The monitoring produced a floristic list of 127 plant species detected on the municipal solid waste landfill. The vegetation assessment using phytocoenological relevés revealed 58 plant species in 1999 and 104 plant species in 2019. Table 1 shows the numbers of plant species

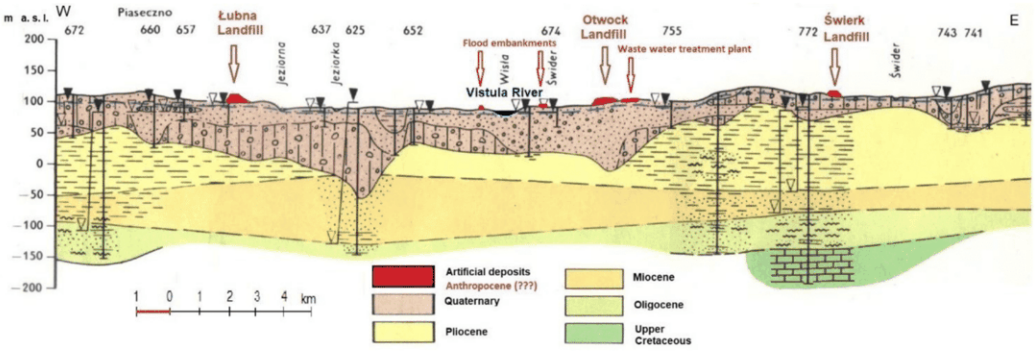


Fig. 2. Geological cross-section with anthropogenic forms.

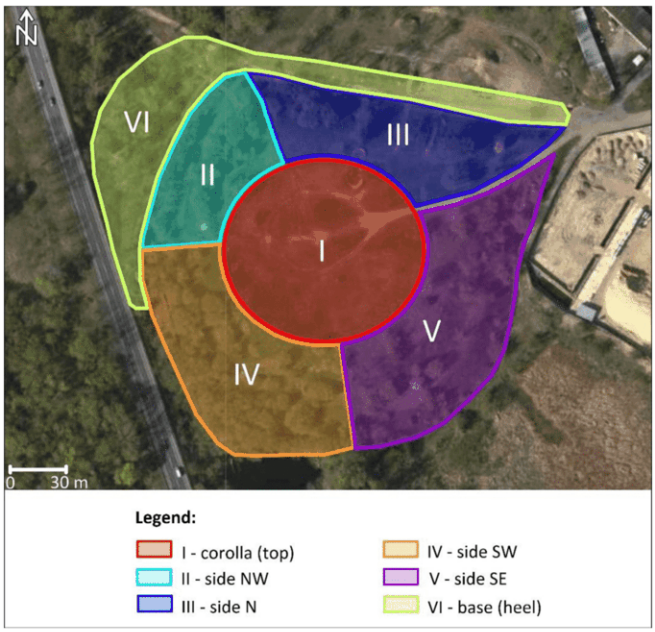


Fig. 3. Sections of phytocoenological relevés.

Table 1
Numbers of plant species found on landfill sections.

Habitat	Number of plant species found		
	year 1999	both years	year 2019
Corolla (top)	13	8	36
NW side	11	6	32
N side	15	8	32
SW side	13	4	36
SE side	15	9	37
Base (foot)	11	7	38

observed on the municipal solid waste landfill in the respective years (1999 and 2019).

Results of the Canonical Correspondence Analysis used to evaluate the vegetation cover of plant species in the respective years were significant at the level of $\alpha = 0.001$ for all canonical axes. Based on the Canonical Correspondence Analysis (Fig. 4), the recorded weed species can be divided into five groups.

Fig. 5 shows the representation of the respective groups and their share in the mean cover on the monitored municipal solid waste landfill sections

The analyses produced several key points. First, representation of native plant species and neophytes in the composition of landfill vegetation enabled classification of the plant species into the five groups. Group 1 was represented in the vegetation 1999, especially at the landfill base (Fig. 4) and consisted prevailingly of moisture-loving species. These species are also abundant in the native vegetation on neighbouring land. Species of significant cover percentage were *Phalaris arundinacea, Alnus glutinosa, Salix alba, Typha latifolia, Populus canescens, Typha angustifolia* and other. The text below will henceforth refer to this group as native hydrophilous species. *Alnus glutinosa* is a member of the group of deep-rooting plants. Group 2 includes the plant species that were represented mainly in 1999 and occurred particularly in the upper section of the landfill (Fig. 4). Most of the plants are weeds and strongly nitrophilous (*Atriplex sagittata, Chenopodium album, Setaria viridis, Apera spica-venti* and other). The text below will refer to this group as ruderal nitrophilous. Group 3 includes primarily the moisture-loving nitrophilous species that were present in both years of monitoring. They occurred particularly at the base of the landfill body (Fig. 4): *Urtica dioica, Sambucus nigra, Phragmites australis, Rubus* sp. and other. The group will be discussed as moisture-loving nitrophilous plant species in the text below. Group 4 represents the nitrophilous and more drought-resistant plant species occurring in the two years of monitoring particularly in the upper section of the landfill body (Fig. 4): *Elytrigia repens, Calamagrostis epigejos, Lolium perenne, Bromus inermis* and other. This group will be mentioned to in the text below as nitrophilous drought-resistant plant species. Group 5 comprises species found particularly in 2019: *Acer negundo, Chelidonium majus, Conium maculatum, Solidago canadensis, Polygonum aviculare* and other. These species are mainly non-native, ruderal and commonly widespread species. The text below will reference this group as neophytes and urbanophilous plant species.

Second, as shown in Fig. 4 and Table 1, the most obvious/important trend in the vegetation succession process in the municipal solid waste landfill is the increasing number of plant species present during the succession. Some native plant, particularly nitrophilous species are permanent members of the landfill vegetation (*Atriplex sagittata, Chenopodium album, Setaria viridis, Apera spica-venti, Urtica dioica, Sambucus nigra, Phragmites australis, Rubus* sp., *Elytrigia repens, Lolium perenne, Bromus inermis* and other). Another notable trend increasing the total number of species is the growing amount of invasive species and neophytes (*Calamagrostis epigejos, Acer negundo, Conium maculatum, Solidago canadensis* and other). Another trend observed is the withdrawal of hydrophilous plant species (*Phalaris arundinacea, Alnus glutinosa, Salix alba, Typha latifolia, Populus canescens, Typha angustifolia* and other).

Third, municipal solid waste landfill vegetation has a specific species composition. The municipal solid waste landfill vegetation type comprises nitrophilous species, urbanophilous species and neophytes. Nitrophilous plant species are the most abundant, which is a consequence of the release of nitrogen and other nutrients from the deposited

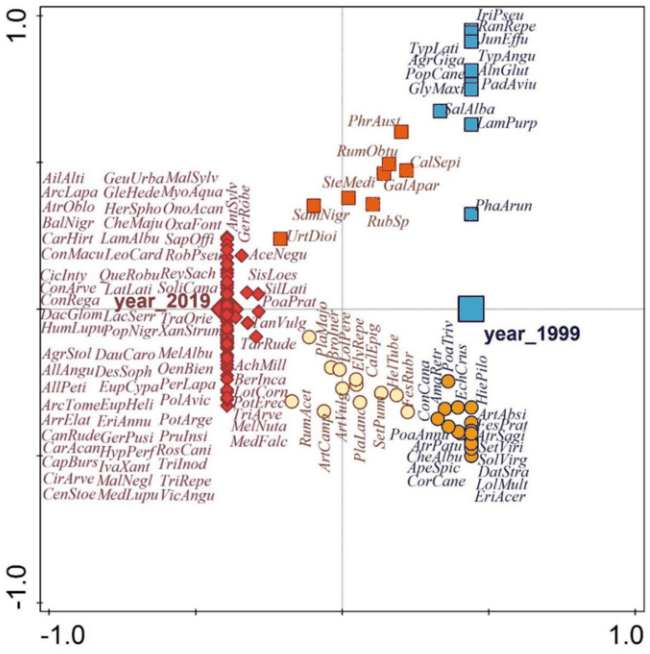


Fig. 4. Ordination diagram expressing the relation between the recorded plant species and the observation dates (overall explained variability = 21.2; F-ratio = 4.8; P-value = 0.001).
Legend: year_1999 symbol for year 1999; year_2019 symbol for year 2019.
AceNegu – Acer negundo, AgrGiga – Agrostis gigantea, AgrStol – Agrostis stolonifera, AchMill – Achillea millefolium, AilAlti – Ailanthus altissima, AllPeti – Alliaria petiolata, AllAngu – Allium angulosum, AlnGlut – Alnus glutinosa, AmaRetr – Amaranthus retroflexus, AntSylv – Anthriscuc sylvestris, ApeSpic – Apera spica-venti, ArcLapa – Arctium lapa, ArcTome – Arctium tomentosum, ArrElat – Arrhenatherum elatius, ArtAbsi – Artemisia absinthium, ArtCamp – Artemisia campestris, ArtVulg – Artemisia vulgaris, AtrOblo – Atriplex oblongifolia, AtrPatu – Atriplex patula, AtrSagi – Atriplex sagittata, BalNigr – Ballota nigra, BerInca – Berteroa incana, BroIner – Bromus inermis, CalEpig – Calamagrostis epigejos, CalSepi – Calystegia sepium, CanRude – Cannabis ruderalis, CapBurs – Capsella bursa-pastoris, CarAcan – Carduus acanthoides, CarHirt – Carex hirta, CenStoe – Centaurea stoebe, CicInty – Cichorium intybus, CirArve – Cirsium arvense, ConMacu – Conium maculatum, ConRega – Consolida regalis, ConArve – Convolvulus arvensis, ConCana – Conyza canadensis, CorCane – Corynephorus canescens, DacGlom – Dactylis glomerata, DatStra – Datura stramonium, DauCaro – Daucus carota, DesSoph – Descurainia sophia, EchCrus – Echinochloa crus-galli, ElyRepe – Elytrigia repens, EriAcer – Erigeron acer, EriAnnu – Erigeron annuus, EupCypa – Euphorbia cyparissias, EupHeli – Euphorbia helioscopia, FesPrat – Festuca pratensis, FesRubr – Festuca rubra, GalApar – Galium aparine, GerPusi – Geranium pusillum, GerRobe – Geranium robertianum, GeuUrba – Geum urbanum, GleHede – Glechoma hederacea, GlyMaxi – Glyceria maxima, HelTube – Helianthus tuberosus, HerSpho – Heracleum sphondylium, HiePilo – Hieracium pilosella, HumLupu – Humulus lupulus, HypPerf – Hypericum perforatum, CheMaju – Chelidonium majus, CheAlbu – Chenopodium album, IriPseu – Iris pseudacorus, IvaXant – Iva xanthiifolia, JunEffu – Juncus sp., LacSerr – Lactuca serriola, LamAlbu – Lamium album, LamPurp – Lamium purpurreum, LatLati – Lathyrus latifolius, LeoCard – Leonurus cardiaca, LolMult – Lolium multiflorum, LolPere – Lolium perenne, LotCorn – Lotus corniculatus, MalSylv – Malus sylvestris, MalNegl – Malva neglecta, MedFalc – Medicago falcata, MedLupu – Medicago lupulina, MelNuta – Melica nutans, MelAlbu – Melilotus albus, MyoAqua – Myosoton aquaticum, OenBien – Oenothera biennis, OnoAcan – Onopordum acanthium, OxaFont – Oxalis fontana, PadAviu – Padus avium, PerLapa – Persicaria lapathifolia, PhaArun – Phalaris arundinacea, PhrAust – Phragmites australis, PlaLanc – Plantago lanceolata, PlaMajo – Plantago major, PoaAnnu – Poa annua, PoaPrat – Poa pratensis, PoaTriv – Poa trivialis, PolAvic – Polygonum aviculare, PopCane – Populus canescens, PopNigr – Populus nigra, PotArge – Potentilla argentea, PotErec – Potentilla erecta, PruInsi – Prunus insititia, QueRobu – Quercus robur, RanRepe – Ranunculus repens, ReySach – Reynoutria sachalinensis, RobPseu – Robinia pseudacacia, RosCani – Rosa canina, RubSp. – Rubus sp., RumAcet – Rumex acetosella, RumObtu – Rumex obtusifolius, SalAlba – Salix alba, SamNigr – Sambucus nigra, SapOffi – Saponaria officinalis, SetPumi – Setaria pumila, SetViri – Setaria viridis, SilLati – Silene latifolia, SisLoes – Sisymbrium loeselii, SoliCana – Solidago canadensis, SolVirg – Solidago virgaaurea, SteMedi – Stellaria media, TanVulg – Tanacetum vulgare, TarRude – Taraxacum sect. Ruderalia, TraOrie – Tragopogon orientalis, TriArve – Trifolium arvense, TriRepe – Trifolium repens, TriInod – Tripleurospermum inodorum, TypAngu – Typha angustifolia, TypLati – Typha latifolia, UrtDioi – Urtica dioica, VicAngu – Vicia angustifolia, XanStrum – Xanthium strumarium.

waste. Dominant representation in the vegetation composition is that of neophytes, namely *Acer negundo* and *Robinia pseudoacacia* for the trees and shrubs. The herb layer is dominated by *Conyza canadensis, Solidago Canadensis* and *Oenothera biennis*.

Fourth, the municipal solid waste landfill body is a product of human civilization creating a specific geological-pedological layer. Specific conditions of municipal solid waste landfills are of long-term character and facilitate the development and continuance of a very specific vegetation type. This vegetation is dominated by invasive species (*Acer negundo, Calamagrostis epigejos, Robinia pseudacacia, Solidago Canadensis, Oenothera biennis* and other). These findings therefore suggest that the spread of these species changes the adjacent ecosystems.

4. Discussion

The results suggest that new conditions have provided living space for a specific type of vegetation. Originally, the landfill area was a wetland with typical vegetation, dominated by *Phragmites australis*. Along with the gradual deposition of waste, the changed conditions have altered the species composition of the vegetation. The processes have occurred over twenty years after the landfill was closed. These changes are due to active decomposition in the deposited wastes and related emissions into the environment. The analysis of species composition made in 1999 revealed the dominance of nitrophilous species. The landfill top as well as the northern and north-western sides exhibited a considerable predominance of nitrophilous ruderal and nitrophilous drought-resistant species. Some of them had been presumably brought here with compost used as an upper layer for the biological reclamation of the landfill. The species in question included *Amaranthus retroflexus*, *Chenopodium album, Atriplex sagittata* or plant species spread by windborne seeds (*Conyza canadensis*). According to Winkler et al. (2017), the application of composts may increase incidence of some annual weed species (*Amaranthus, Atriplex, Chenopodium*) and therefore the waste materials used for composting should be properly controlled

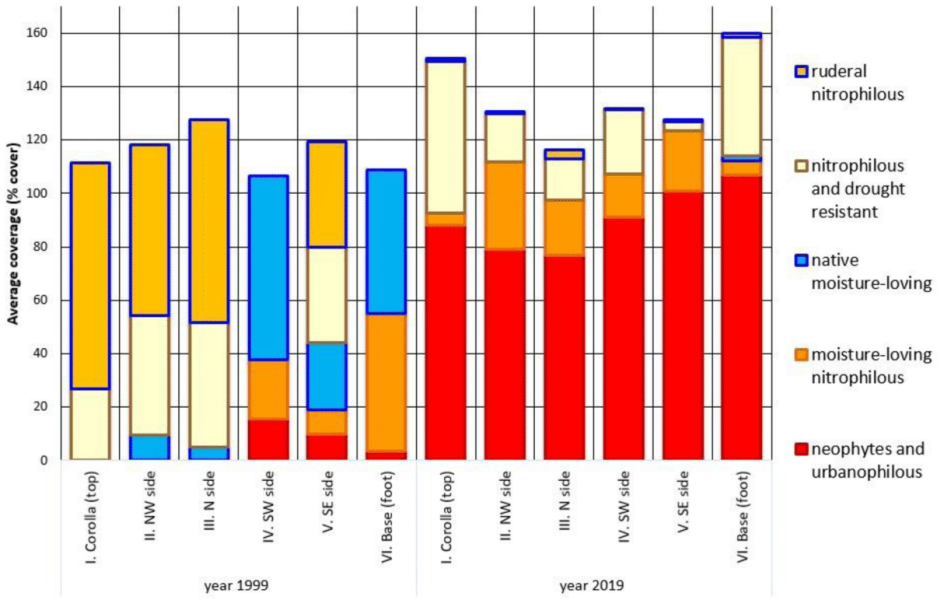


Fig. 5. Representation of the groups of plant species in the monitored landfill sections in 1999 and 2019.

(Vaverková et al., 2020).

The representation of grasses that presumably had been sown here (*Lolium perenne, Festuca rubra*), applied in compost or as a diaspora from the surrounding vegetation (*Elytrigia repens, Calamagrostis epigejos, Bromus inermis*) was also considerable. The occurrence of these plant species is important for the municipal solid waste landfill environment because of their erosion-control capacity. Vegetation at the landfill base and on the southern side consists mainly of moisture-loving and native species (*Phalaris arundinacea, Alnus glutinosa, Typha angustifolia*) or nitrophilous moisture-loving species (*Urtica dioica, Sambucus nigra, Phragmites australis*).

Twenty years after the reclamation, the vegetation composition exhibited marked differences on the landfill studied. Through succession, the number of species considerably increased – by 46. Spontaneous succession of vegetation in natural conditions has been currently well characterized, and there are efforts to use it in the process of reclamation (Rebele and Lehmann, 2016). Data about the course of succession in the environment created by humans, however, are so far missing. Analysing the composition of its vegetation, the reclaimed landfill can be considered rich in species with the dominant urbanophilous species and neophytes (*Acer negundo* accompanied by other perennial nitrophilous plant species such as *Conium maculatum, Urtica dioica*, *Chelidonium majus, Elytrigia repens* or *Solidago canadensis*).

These research results indicate that the native and moisture-loving plant species, as well as the annual nitrophilous species, withdrew during the twenty-year succession. Their ground has been gradually taken by plant species that are considered neophytes and the perennial nitrophilous species and the drought-resistant species. The trends suggest that the site has been experiencing water loss due to the construction of flood-control facilities and a road between the landfill and the Vistula. Climate change, however, may also play a role.

The high proportion of nitrophilous plant species indicates that the stored waste and reclamation materials on the landfill is still a source of nitrogen. When seeds from the local species pool arrive, germination, seedling establishment, growth, flowering, and seed setting depend on the soil productivity, which also has a great influence on interactions between plants, herbivores, and other ecological processes (Rebele and Lehmann, 2016). The composition of nitrophilous plant species exhibits certain changes. After the twenty years, the annual nitrophilous species recorded a considerable withdrawal as compared with the first year of the monitoring (*Amaranthus retroflexus, Apera spica-venti, Atriplex patula, Atriplex sagittata, Datura stramonium, Echinochloa crus-galli, Chenopodium album*). On the other hand, the perennial nitrophilous plant species exhibited a greater representation only in 2019 (*Acer negundo, Sambucus nigra, Elytrigia repens, Calamagrostis epigejos*, *Urtica dioica*). This withdrawal of annual and the onset of perennial plant species may be a natural consequence of succession. Natural colonization and composition of vegetation adapt to ecological conditions of the environment (Rebele and Lehmann, 2016). Nevertheless, the predominance of nitrophilous plant species on the site studied indicates that the landfill body is a source of nitrogen. According to research published by Porowska (2019), materials deposited in 1961–1991 still actively participate in hydro-chemical processes worsening water quality around the landfill. Thus, the waste is a source of substances that assimilate into plants or released into water in the landfill surroundings over an extended period.

During the landfill reclamation, a grass mixture was sown onto the surface. Although its composition was not recorded, the representation of some detected grasses may suggest the original composition of the reclamation mixture: *Festuca pratensis, Festuca rubra, Lolium multiflorum, Lolium perenne* and *Poa pratensis.* Some of these species, however, were present only in the first year of research (*Festuca pratensis, Festuca rubra, Lolium multiflorum*). We recorded *Lolium perenne*, nevertheless, in both years of the monitoring. *Poa pratensis* was more abundant in 2019 and its incidence on the reclaimed landfill is high. These two grass species may also play a role in biological reclamation of landfills.

The occurrence of invasive neophytes, namely *Acer negundo, Solidago canadensis, Erigeron annuus*, *Iva xanthiifolia, Reynoutria sachalinensis* and *Robinia pseudacacia,* is problematic from the phytosanitary point of view. The presence of other invasive species such as *Artemisia vulgaris, Calamagrostis epigeios, Elytrigia repens, Tanacetum vulgare* and *Oenothera biennis* may also pose problems. According to Cottet et al. (2020) the

spread of invasive species is considered worrisome. Moreover, the impact of invasive species is a major cause of biodiversity loss (Norder et al., 2020). These plant species on landfills may be sources of diaspora and their further spreading to nearby natural ecosystems or agricultural soils. According to Mooney (2005), invasive plant species change the functioning of ecosystems and disturb interspecific competition, which may lead to reduced biodiversity or to the loss of autochthonous plants and animals. As reported by Cottet et al. (2020) scientific communities alerted the public about the serious threats posed by biological invasions to biodiversity.

Through plants, hazardous substances from waste can contaminate the food chain or they may bioaccumulate. Entomophilous plant species (*Solidago canadensis, Sambucus nigra, Reynoutria sachalinensis, Robinia pseudacacia, Oenothera biennis*) can be problematic in this respect, as species spread by wind-borne seeds (*Acer negundo, Calamagrostis epigejos Solidago canadensis*). Nevertheless, a high cover of grasses may have a positive function especially *Calamagrostis epigejos*, which has a high root to shoot ratio. Because root litter provides a more recalcitrant carbon pool, higher root to shoot ratios may indicate increased soil carbon potential (De Deyn et al., 2008).

Humanity acts on the landfills as a pedological and geological agent, thus determining conditions for the vegetation. According to Zalasiewicz et al. (2017), a range of features may signal the "Anthropocene," including accelerated erosion and sedimentation. This signal is typical of landfills and shows in the descending height of the landfill body and erosion (sliding) of reclamation compost/soil layers. Other features include the presence of chemicals (Gałuszka et al., 2017) and failures of carbon, nitrogen, phosphorus, and other elements' cycles (Gillings and Paulsen, 2014; Zalasiewicz et al., 2018). these features are documented on landfills by analysing the composition of leachates and groundwater (Weng et al., 2015; Porowska, 2019). Landfill sites, especially modern ones with leak-proof seals, tend to mummify the material – even paper and foodstuffs – rather than encourage it to decay (Zalasiewicz et al., 2016). This means that the waste will not be decomposing on landfills for many decades.

Biotic changes represented by the invasion of new species are another feature (Bhagwat, 2018). Plant species that were historically moved by humans from one continent to another, be it intentionally or by chance, have multiplied in their new environments and cause extensive changes to ecosystems (Bhagwat, 2018). It is now widely acknowledged that the management of invasive species is a significant challenge and create the need to integrate socio-cultural sciences into research (Heger et al., 2013; Cottet et al., 2020). Research by Velez et al. (2021) showed that increased nutrient load and water level reductions caused by human activity resulted in the loss of native plants, whereas a few invasive, exotic species expanded and eventually came to dominate. According to Chin et al. (2017) understanding human and societal responses to anthropogenic environmental change are among the key challenges of an increasing population, climate change, and technology. Results of our study document the withdrawal of native plant species and the increasing abundance of allochthonous neophytes. These results converge upon the important point that landfills represent a human-made environmental change affecting the vegetation and surroundings.

5. Conclusion

In conclusion, this investigation of the succession of plants on municipal solid waste landfill in Poland over a period of twenty years produced answers to the research questions posed in this paper. First, analysis of changes in the composition of vegetation showed that the landfill site environments differ from the neighbouring ecosystems even after twenty years. In the first years after the landfill reclamation, visible differences in the range of species were present at various places on the landfill body. Native species and species tied to higher groundwater table occurred more in lower parts of the landfill. Upper landfill parts exhibited more abundant nitrophilous species, common weeds, and intentionally sown species. After twenty years, a high proportion of invasive neophytes were on the landfill. Second, the native plant species did not return to the study landfill and the species composition retained its specific character. A trend in the succession is obvious after twenty years; the native and hydrophilous plant species withdrew from the landfill while the number of neophytes and drought-resistant species increased. Third, the specific conditions of the landfill facilitated the formation of a novel plant community mainly consisting of neophytes and plant species of an invasive nature. The tree and shrub vegetation storeys consist mostly of *Acer negundo* and *Robinia pseudacacia*. The herb layer is represented by *Artemisia vulgaris, Calamagrostis epigeios, Conyza canadensis, Elytrigia repens, Solidago canadensis, Tanacetum vulgare* and *Oenothera biennis*. This specific combination of plants is a basis of landfill vegetation.

The findings show that vegetation in landfills can serve as an indicator of the anthropogenic ecosystem. Humans directly create new geological layers in the form of deposited waste. This interaction leads to the creation of a new type of geological environment and vegetation, based on allochthonous plant species introduced by human from other continents and plant species of an invasive character. These research results demonstrate that humans not only affect landscapes, but they directly create new ecosystems including geological and pedological layers.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.s

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Příloha 2

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Significance of Urban Vegetation on Lawns Regarding the Risk of Fire

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Abstract: Urban green infrastructure significantly influences the functioning of a city and the comfort of its residents. Lawns are an essential element of public greenery. They represent a live component, and if they are lacking, of low quality, or neglected, this will cause major problems in the urban environment. The vegetation structure of urban grassy areas changes under the influence of different management methods used for their maintenance. The main goal of this study was to evaluate the species diversity of urban lawns and to determine the influence of this vegetation on factors based on the representation of the species found. Three sites with urban lawns were chosen in a built-up city area where different types of vegetation management were applied: Typical management, in which grassy areas are mowed twice a year; intensive management, in which lawns are mowed several times a year and the biomass is removed; and extensive management, in which lawns are mowed irregularly, once a year at most, and the biomass is left unevenly on the site. Extensive management and unkempt urban grassy areas represent a high risk of fire due to the presence of plant species that produce great amounts of biomass. Combined with dry and warm weather, the dead biomass can lead to outbreaks of fire. Extensive management of urban grassy areas brings some benefits, such as lower maintenance costs and increased biodiversity and bioretention. On the other hand, intensive management reduces the risk of fire and the biodiversity of the plant community. Attention should be paid to the composition of vegetative species and their functions that could threaten the safety of residents, with the risk of fire being one of them. However, the vegetation biomass of grassy areas affected by management practices is only a precondition for the risk of fire because weather and drought occurrence play important roles as well.

Keywords: urban environment; green urban infrastructure; lawns; species diversity; fire risk

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1. Introduction

Urban green infrastructure (UGI), at both low and high levels, significantly influences the functioning of a city and the comfort of its residents. The impact of UGI includes its utilization as an element of the urban landscape and in the direct production of ecosystem services (ES), such as water management, heat reduction, species habitats, etc. [1,2]. Individual types of UGI differ in form, destination, composition, and structure [3]. Six main groups of urban ES can be distinguished: Air filtration, microclimate regulation,

noise reduction, rainwater drainage, initial wastewater treatment, and recreational/cultural value [4,5]. Recently, the main problem of cities is microclimate (air pollution and urban heat) and its negative impact on human health and comfort and energy consumption [2]. Urbanization transforms the natural land cover into engineered constructions (buildings, parking lots, streets, squares, etc.), leading to increased ambient temperature, commonly known as the urban heat island effect [6].

In recent decades, an increasing number of scientific reports have focused on urban vegetation and lawns with regard to their influence on cooling down the urban environment and the potential for saving energy [7]; in spite of that, urban lawns with very high potential remain insufficiently utilized in this respect [8]. The ability of vegetation to modify the local urban microclimate differs depending on the plant community composition [9]. Lawns are a significant element of public greenery [10]. They represent a live component, and if they are lacking, of low quality, or neglected, this will cause some of the main problems of the urban environment [3]. The potential of a positive or negative influence of lawns on urban ecosystems largely depends on the management practices, which can significantly differ [11]. Intense lawn management with herbicides, fertilizers, watering, and frequent mowing is associated with high aesthetic value [12,13], but results in unfavorable ES, such as intense water usage, nutrient runoff, and low species diversity [14]. Extensive lawn management is characterized by the use of less fertilizer and less frequent mowing [15], and these lawns are often composed of spontaneous species that can represent food for pollinators [16]. The third method comprises urban grasslands with extensive management, which can become habitats for a wide range of native plant and insect species [12]. They differ significantly from low-cut lawns in both appearance and utility functions [17]. Due to the lower management costs and higher biodiversity of urban grasslands, the need to increase their contribution in urban areas is constantly growing [18]. It should be noted that this also increases their acceptance by residents of cities for these types of solutions [19]. Considering the large number of small lawns in the urban environment and the variability of the applied management practices, the study of such habitats is a perfect opportunity to explain how plant assemblages are created and how they are modified by anthropogenic perturbations regarding taxonomy and function. Moreover, it is important to understand how their floral diversity can be enhanced and how functional lawn networks can be managed in cities.

UGI is monitored and managed with the application of remote sensing (RS) and a geographic information system (GIS) [20]. Multispectral images acquired from satellites, airplanes, or unmanned aerial vehicles (UAVs) supply rich information on the vegetation state, plant condition, and fire risk. The advantages of satellite imagery include the size of the acquired images, whereas the disadvantage is the low spatial and temporal resolution in comparison to aerial photographs [21]. Monitoring plant conditions and biomass changes using RS techniques include determining the plant vegetation index, which indicates the amount of chlorophyll in the green parts of plants. Areas covered by drying vegetation, with a low vegetation index, can become flammable, which increases the risk of fire [22,23].

Excess biomass that is not removed regularly from urban green areas can cause a risk of fire, particularly when surrounded by intense residential and service development. Ground fires, as they are usually called, can be of different intensities, depending on the humidity level, meteorological conditions, vegetation type, and topography [24]. Usually, the intensity is from 1 to 5 $m.min^{-1}$. However, in favorable conditions, such fires can reach a speed of 15 $m.min^{-1}$. Strong winds can increase the speed at which they propagate to over 20 $km.h^{-1}$ [25]. In the case of high wind speed, the fire front rapidly changes direction and gets out of control, becoming health- and life-threatening to people and causing damage to building objects. In ground fires, the fire itself is not high, usually reaching several centimeters to 2 m. In such cases, the fire propagates in all directions, with the fire front moving fastest in the direction where the wind blows [26]. The fire area is usually ellipse-shaped.

During the burning of surface grass, the temperature usually reaches 400 °C. However, in the case of burning trees or bushes, it can reach up to 600-800 °C. There is thus a significant difference between the development of surface fires and crown fires because essential oils are intensely burned during crown fires. A fire moving rapidly in tree branches will not entirely burn out all the essential oils secreted from the trees under the influence of high temperatures. Essential oils thus gather in the fire zone and cause explosions when accumulated in large quantities [27]. In surface fires, only the aboveground plant biomass is burned. Such fires do not significantly influence the soil properties due to the relatively low volume of burnt plant biomass. However, when grass areas are located on soil of peat origin, the situation is different. In such areas, sub-surface fires that cause burning out of the organic soil can occur. Sub-surface fires significantly change the habitat conditions of peatlands. During such fires, the content of easily accessible forms of phosphorus and potassium rapidly increases because these elements remain in the ash. In turn, the content of easily accessible forms of nitrogen in the soil decreases because, under high temperatures, this element is transferred into a gaseous form [28]. Regardless of the type of hazard, such as grass fire, it should be emphasized that sub-surface fires are particularly dangerous due to their intensity and unpredictability and there is a need to engage large forces and resources to neutralize them.

The main goal of this study was to evaluate the species diversity in urban lawns and determine the influence of such vegetation on factors based on the representation of the species found. The specific goals included the following: (i) To determine the influence of different levels of management of grass areas on the production of biomass that is dangerous with respect to fires; (ii) to assess the risks and benefits of different levels of management of urban grass areas; and (iii) to determine the plant species that increase the risk of fires in urban lawns. To the best of our knowledge, no study has yet linked the community composition and biomass production of grass with the flammability of urban lawns.

2. Materials and Methods

2.1. Characteristics of the territory

Trnava (48° 21′ 57.37" N, 17° 35′ 10.18" E) is the capital of the Trnava region and one of the most important cities in the Slovak Republic (Figure 1). It is situated in the Danubian lowland with altitudes ranging from 135 to 180 m above sea level (a.s.l.). The built-up city area lies almost entirely on a plain with altitudes ranging from 140 to 145 m a.s.l. (Trnávka River floodplain) and from 145 to 155 m a.s.l. (surrounding areas).

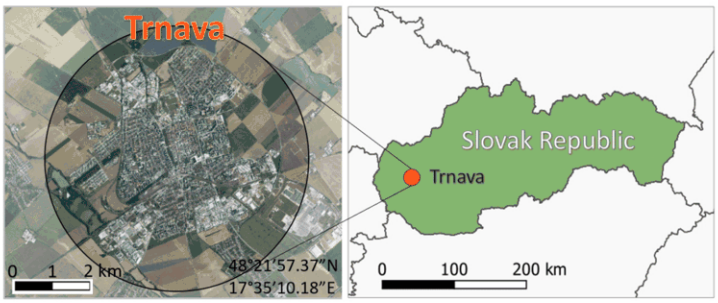


Figure 1. Trnava City location.

The city center is defined by walls on the east and west. The center directly neighbors a massively urbanized residential area, which is divided into six main city districts: Trnava Center (215 ha), Trnava East (1,066 ha), Trnava North (2,233 ha), Trnava West (2,060 ha), Trnava South (803 ha), and Modranka (776 ha). The city covers an area of 71.54

km², and its population is 65,596 inhabitants. It is situated in the vicinity of important European capitals such as Vienna and Budapest. Trnava is a Slovak regional capital with markedly few green areas. Its urban greenery and forests represent only 1.58% and 0.45%, respectively, of the region (Figure 2).

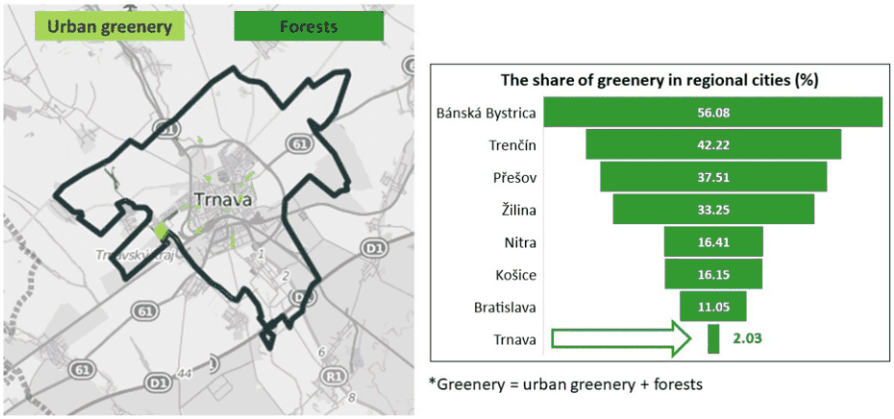


Figure 2. Urban greenery and forests (%) of Trnava; from [29].

The Trnava City cadastral area lies in a warm climatic region, characterized by a slightly dry to dry climate with mild winters, a mean annual temperature of 10.1 °C, and average total annual precipitation of 560 mm. The average day and night temperatures for individual months of the year in the period 1855–2018 are presented in Figure 3. Daily temperatures over 20 °C are recorded in May, June, July, August, and September.

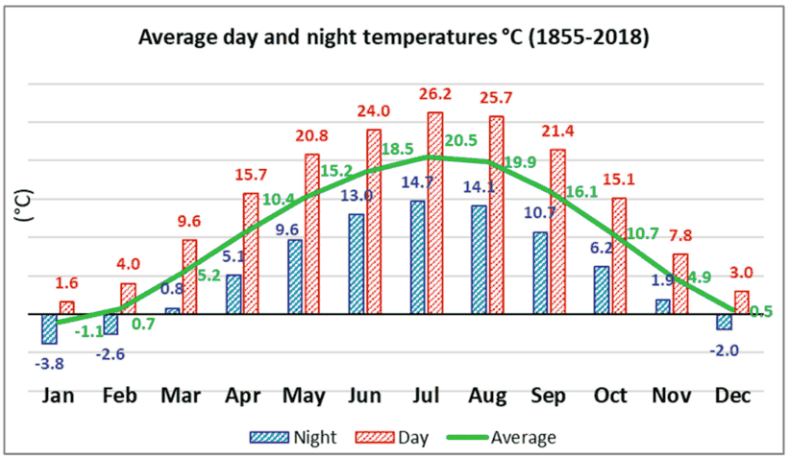


Figure 3. Average day and night temperatures in °C (1855–2018); from [30].

The number of summer days exceeds 50. The highest and lowest precipitation levels have been recorded in June–August and January–March, respectively. The mean annual temperature of the active soil surface is over 12 °C. The sun shines for 1800 hours per year on average, which is 40–45% of the maximum possible time. Snow cover occurs in Trnava

for only 30–40 days per year on average, and its thickness is over 50 mm for only about 20 days; the average snow cover thickness is 100 mm. NW winds prevail in the area. Other frequently occurring winds are from the SE and S. The mean relative air humidity is about 75%, with maximum (80–85%) and minimum (66–70%) values being recorded in winter and spring–summer, respectively.

In terms of hydrology, the Trnava City area belongs to the Váh River Basin and the Lower Dudváh watershed. In Trnava City, there are also catchments of the Parní, Trnávka, and Krupski Potok watercourses in the Little Carpathians. As for surface water, artificial water basins such as the Trnavské rybníky ponds play an important role. The small Trnávka River flows through the built-up area of Trnava City in a manmade, partly covered bed. According to the hydrogeological subdivision of Slovakia, Trnava City is situated in the Trnavská pahorkatina foothills. The mean height of the groundwater table near Trnava City is 134–145 m a.s.l. The chemical composition of the groundwater is characterized by high magnesium–calcium–bicarbonate concentrations.

Regarding land use, intensive agriculture in deforested areas predominates in the Trnava City cadastral area. Since the landscape is open with no massive vegetation, the soil has high erosion potential. The soil cover of Trnava City is relatively homogeneous in character, which results from the geological structure of the area, dominated by loess, on which Chernozem and Regosol soil types with high humus content developed. In terms of texture, the soils are medium heavy (loamy to sandy-loamy) and relatively insusceptible to chemical degradation (presence of carbonates), but their resistance to mechanical degradation and erosion is low. Phaeozems are common near Modranka along the Trnávka River. Hydromorphic soils are represented by Fluvisols and Gleysols. Fluvisols can be found along the Trnávka River watercourse in the south of the built-up area; the soils are light to medium heavy, with no skeleton. Clay soils occur locally in sites where the soil profile is under the long-term influence of groundwater. In the built-up area of Trnava City, anthropogenic soil types such as parks, gardens, and cemeteries occur as well.

In the past, vegetation in the Trnava City area was typically represented by various types of plant communities with high biodiversity, resulting from the geographical location, diverse geomorphology, and original hydrological conditions. The vegetation reconstruction map of climax plant communities indicates that the Trnávka River alluvia were populated mainly by ash, elm, oak, and alder alluvial forests (*Ulmenion* and *Alnenion glutinosa-incanae*). For the majority of the Trnava City area, continuous peri-Pannonian oak-hornbeam forests (*Querco robori-Carpinenion betuli*) and Pontic-Pannonia oak forests (*Quercion pubescenti-petraeae, Quercetum petraeae-cerri*) are reconstructed. In the flat part of the area, the contribution of wetlands was assumed to be much larger than today.

2.2. Sites of urban lawns

Three sites with urban lawn vegetation were selected in the built-up area, where different management types occur:

(1) Normal management: Grass areas are mowed twice a year, and biomass is taken away after the first mowing and mulched and left on the site after the second mowing. The site is part of the Na Hlíny housing estate, the most recent and smallest in Trnava City. Its construction began in the 1980s and ended in the 1990s. The housing estate covers an area of 1.1 ha (GPS, 48.3883103N, 17.5972586E) (Figure 4).

(2) Intensive management: The lawn is mowed several times a year and biomass are removed. The Calvary Park site is a place of reverence, situated on an original cemetery established in 1747. The Park has interesting historical monuments, memorials of important persons, the Trnava Calvary (built on the site of the first

historical Station of the Cross in the Austro-Hungarian Empire), and two massive lime trees, whose age is estimated at 260 years (GPS 48.3851289N, 17.5774719E) The housing estate covers an area of 2.1 ha (Figure 5).

(3) Extensive management: The lawn is mowed irregularly, once a year at maximum, and biomass is left unevenly on the site, which is part of a land property with a road behind the Tesco shopping centre and in the vicinity of the Trnava water reservoir protection zone, representing an area of 5.4 ha (GPS 48.3865733N, 17.6052408E) (Figure 6).



Figure 4. Sites of grassed areas with normal management: (**a**) Satellite image, (**b**) ground photo.

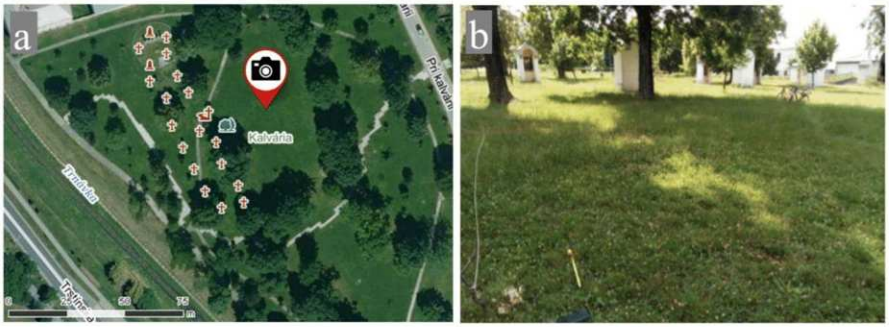


Figure 5. Sites of grassed areas with intensive management: (**a**) Satellite image, (**b**) ground photo.

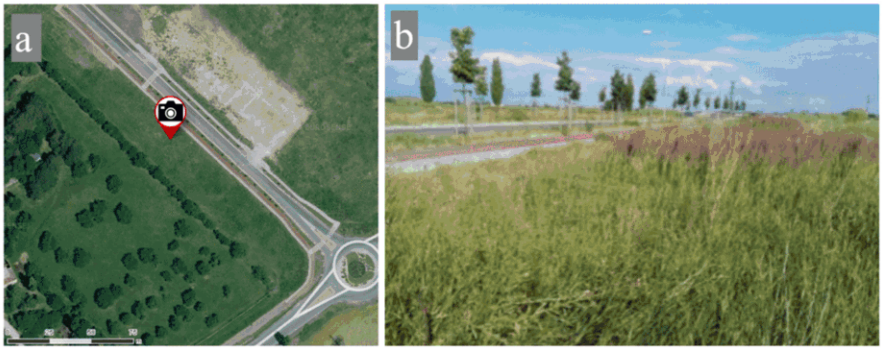


Figure 6. Sites of grassed areas with extensive management: (a) Satellite image, (b) ground photo.

2.3. Methodology of vegetation assessment

The vegetation was assessed using the method of phytocoenological relevés, with a relevé size of 20 m². On each site, 6 permanent plots were surveyed, on which vegetation assessment took place twice a year between 2015 and 2016 (in May and September). First, all plant taxa occurring on the permanent plot were identified, and then the cover of the aboveground biomass of individual taxa was estimated. Scientific names of individual plant species were from the database of Czech flora and vegetation [31]. Based on data from the Pladias database [31] concerning the height of the species and the determined cover, the plant species were classified into several groups according to the biomass produced. The species were also divided into groups based on the results of the CCA analysis according to the relationship with lawn management.

The values of the cover of individual plant species on the sites were processed using multidimensional analysis of ecological data. The choice of optimal analysis was governed by the gradient length determined by detrended correspondence analysis (DCA) of segments. In addition, canonical correspondence analysis (CCA) was applied. Statistical significance was established by means of the Monte Carlo test with the calculation of 999 permutations. The data were processed using Canoco 4.0. software [32]. A schematic of the experiment is presented in Figure 7.

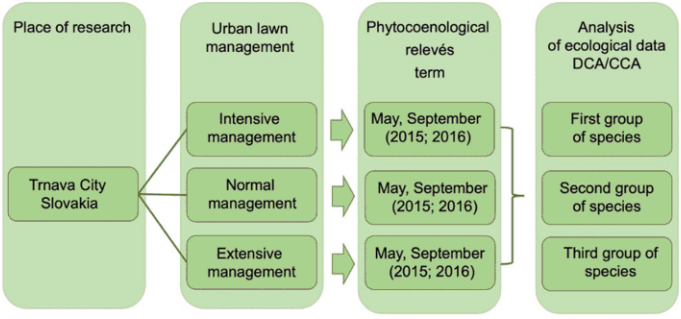


Figure 7. Schematic of experiment, showing the individual steps of the research.

3. Results

During the 2-year study interval, 56 plant taxa were found, 29 in the variant with normal management, 24 in the variant with intensive management, and 34 in the variant

with extensive management. The representation of plant taxa in the studied sites is graphically presented in Figures 8–10.

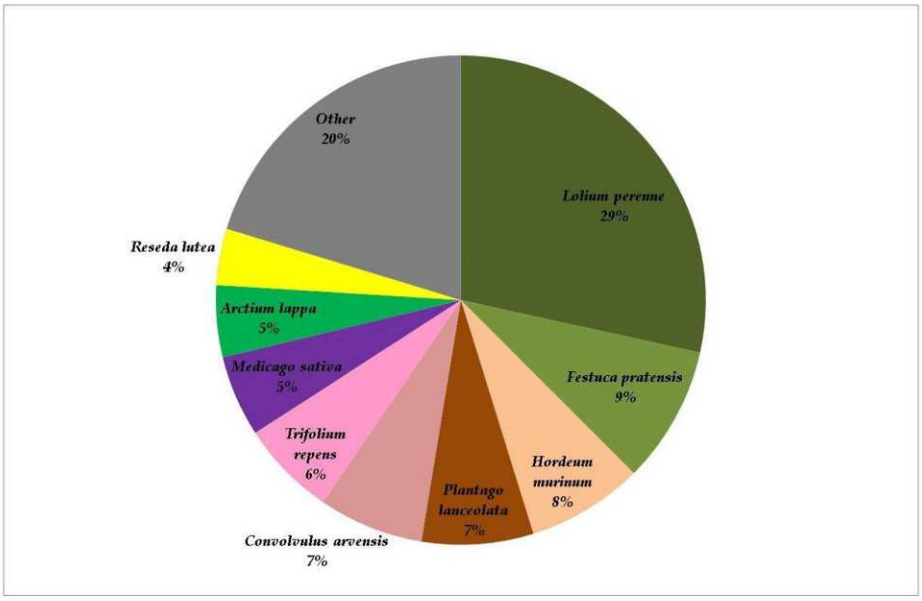


Figure 8. Species spectrum and distribution of vegetation of urban grassy areas in variant with normal management.

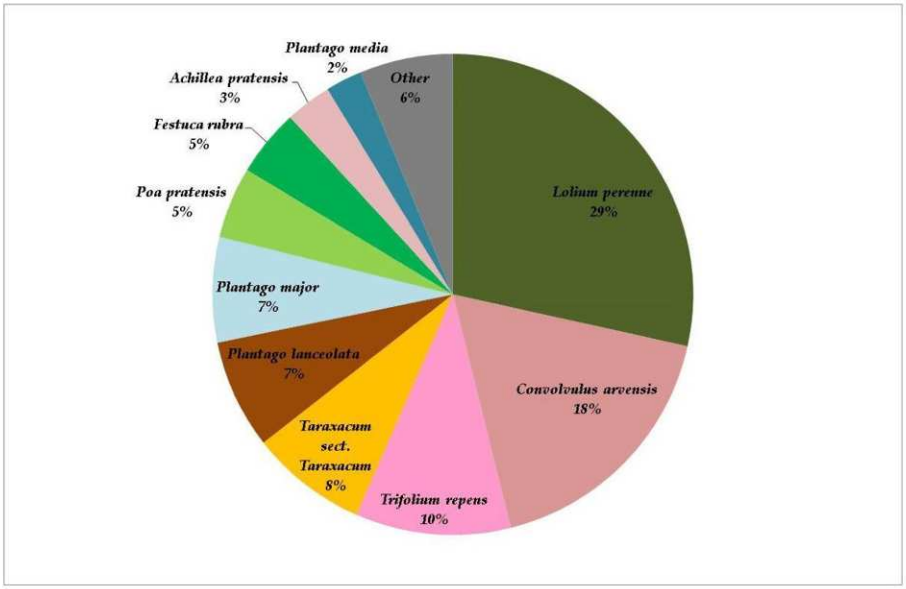


Figure 9. Species spectrum and distribution of vegetation of urban grassy areas in variant with intensive management.

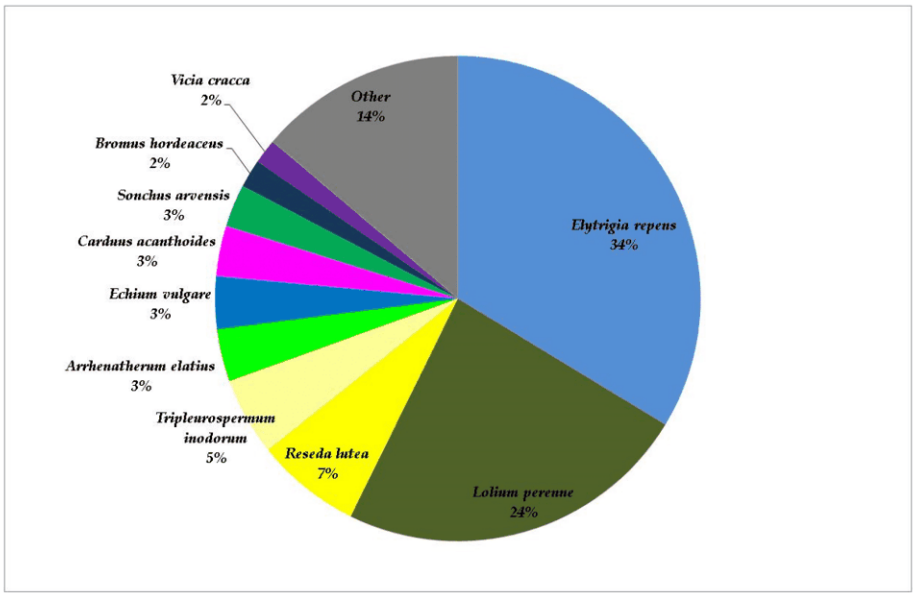


Figure 10. Species spectrum and distribution of vegetation of urban grassy areas in variant with extensive management.

Values of the cover of plant taxa recorded during the study were first processed using DCA. The calculated gradient length was 3.52. Then the data were further processed using CCA, which defined the spatial arrangement of individual plant species and sites with different types of lawn management. Results of the analyses are expressed graphically by means of the ordination diagram in Figure 11.

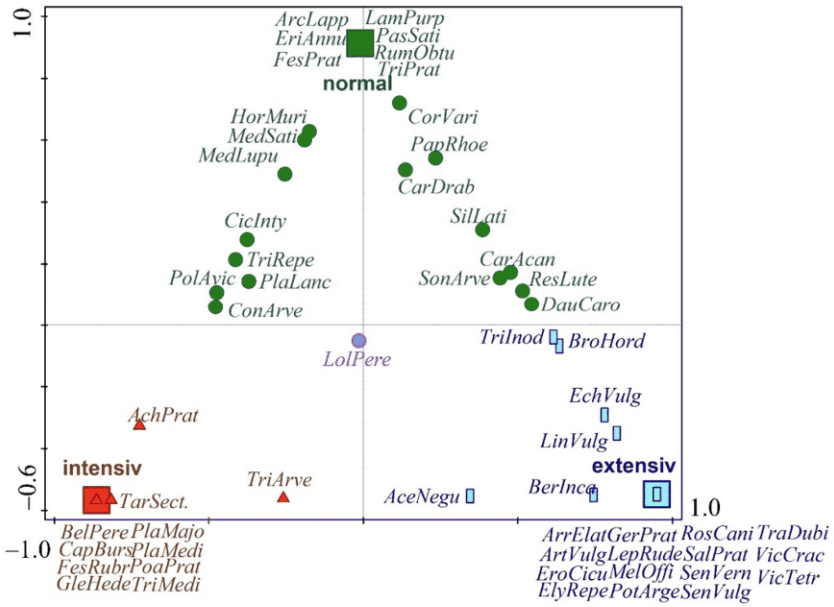


Figure 11. Reaction of plant taxa on sites with different types of management. Overall explained variability = 33.4%; F-ratio = 5.3; *p*-value = 0.001. *Intensiv, intensive management; normal, normal management; extensiv, extensive management; AceNegu, Acer negundo; AchPrat, Achillea pratensis; ArcLapp, Arctium lappa; ArrElat, Arrhenatherum elatius; ArtVulg, Artemisia vulgaris; BelPere, Bellis perennis; BerInca, Berteroa incana; BroHord, Bromus hordeaceus; CapBurs, Capsela bursa-pastoris; CarDrab, Cardaria draba; CarAcan, Carduus acanthoides; CicInty, Cichorium intybus; ConArve; Convolvulus arvensis, CorVari; Coronilla varia; DauCaro, Daucus carota; EchVulg, Echium vulgare; ElyRepe, Elytrigia repens; EriAnnu, Erigeron annuus; EroCicu, Erodium cicutarium; FesPrat, Festuca pratensis; FesRubr, Festuca rubra; GerPrat, Geranium pratense; GleHede, Glechoma hederacea; HorMuri, Hordeum murinum; LamPurp, Lamium purpureum; LepRude, Lepidium ruderale; LinVulg, Linaria vulgaris; LolPere, Lolium perenne; MedLupu, Medicago lupulina; MedSati, Medicago sativa; MelOffi, Melilotus officinalis; PasSati, Pastinaca sativa; PapRhoe, Papaver rhoeas; PlaLanc, Plantago lanceolata; PlaMedi, Plantago media; PlaMajo, Plantago major; PoaPrat, Poa pratensis; PolAvic, Polygonum aviculare; PotArge, Potentilla argentea; ResLute, Reseda lutea; RosCani, Rosa canina; RumObtu, Rumex obtusifolius; SalPrat, Salvia pratensis; SenVern, Senecio vernalis; SenVulg, Senecio vulgaris; SilLati, Silene latifolia; SonArve, Sonchus arvensis; TarSect Taraxacum sect. Taraxacum; TraDubi, Tragopogon dubius; TriArve, Trifolium arvense; TriMedi, Trifolium medium; TriPrat, Trifolium pratense; TriRepe, Trifolium repens; TriInod, Tripleurospermum inodorum; VicCrac, Vicia cracca; VicTetr, Vicia tetrasperma.*

Results of CCA, which were used to evaluate the cover of plant species in the years of study, were significant at a level of $\alpha = 0.001$ for all canonical axes. Based on CCA, the identified taxa of plants were classified into four groups.

The first group included species that occurred primarily in the grassy areas under intensive management: *Achillea pratensis, Bellis perennis, Capsela bursa-pastoris, Festuca rubra Glechoma hederacea, Plantago media, Plantago major, Poa pratensis, Taraxacum sect. Taraxacum, Trifolium arvense, and Trifolium medium.*

The second group included species mainly occurring in grassy areas under normal management: *Arctium lappa, Cardaria draba, Carduus acanthoides, Cichorium intybus, Convolvulus arvensis, Coronilla varia, Daucus carota, Erigeron annuus, Festuca pratensis, Hordeum murinum, Lamium purpureum, Medicago lupulina, Medicago sativa, Pastinaca sativa, Papaver rhoeas, Plantago lanceolata, Polygonum aviculare, Reseda lutea, Rumex obtusifolius, Silene latifolia, Sonchus arvensis, Trifolium pratense, and Trifolium repens.*

The third group consisted of plant species occurring particularly in grassy areas under extensive management: *Acer negundo, Arrhenatherum elatius, Artemisia vulgaris, Berteroa incana, Bromus hordeaceus, Echium vulgare, Elytrigia repens, Erodium cicutarium, Geranium pratense, Lepidium ruderale, Linaria vulgaris, Melilotus officinalis, Potentilla argentea, Rosa canina, Salvia pratensis, Senecio vernalis, Senecio vulgaris, Tragopogon dubius, Tripleurospermum inodorum, Vicia cracca, and Vicia tetrasperma.*

The fourth group was represented by plants of the species *Lolium perenne*, which formed the basis of all grassy areas in all management variants.

4. Discussion

The results show that the methods of managing urban grassy areas radically change the species composition of vegetation. Chollet et al. [8] confirmed that reduced mowing frequency offers the opportunity to switch from urban lawns to urban meadows. Changes in the vegetation structure also induce changes in the ecosystem functions of grassy areas [33]. As for the production of biomass, associated with the risk of fire are species that produce tall to medium-tall biomass (*Acer negundo, Arrhenatherum elatius, Artemisia vulgaris, Bromus hordeaceus, Elytrigia repens, Hordeum murinum, Lolium perenne, Medicago sativa, Melilotus officinalis, Rosa canina*). The largest share of these species was recorded in the variant under extensive management, in both the first and second terms of assessment (Figures 12 and 13), as well as in the variant under normal management, in the first term of assessment. The variant with intensive management was observed to have the smallest share of species producing biomass associated with the risk of fire. Moreover, according to Chollet et al. [8], low mowing frequency facilitates higher plant diversity compared to grassland with high mowing frequency. Frequent mowing facilitates the selection of species able to tolerate repeated disturbance and favors more disturbance-tolerant ruderal species. This is in line with the study of Socher et al. [34], demonstrating that mowing frequency had a stronger effect on plant species richness than fertilization.

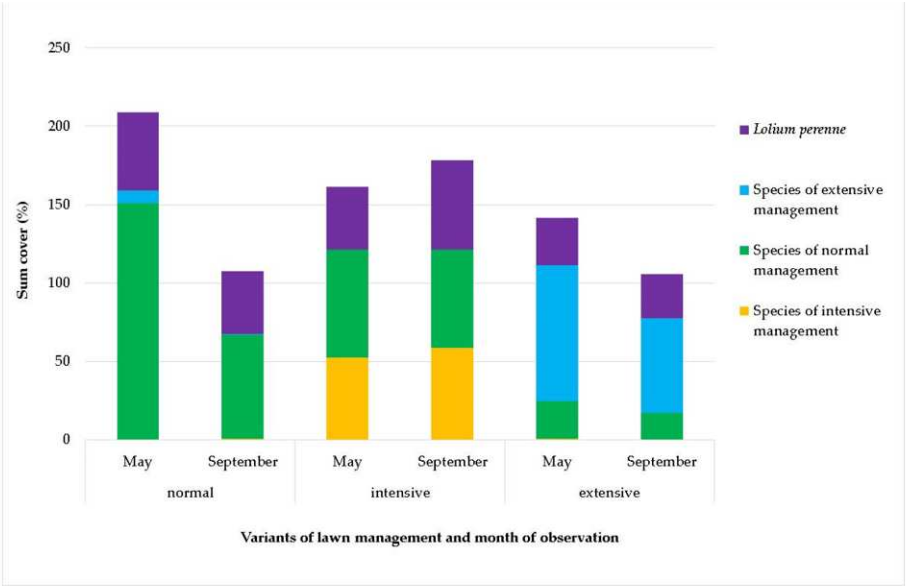


Figure 12. Representation of plant species groups according to their relation to the management of grassy areas (results of CCA).

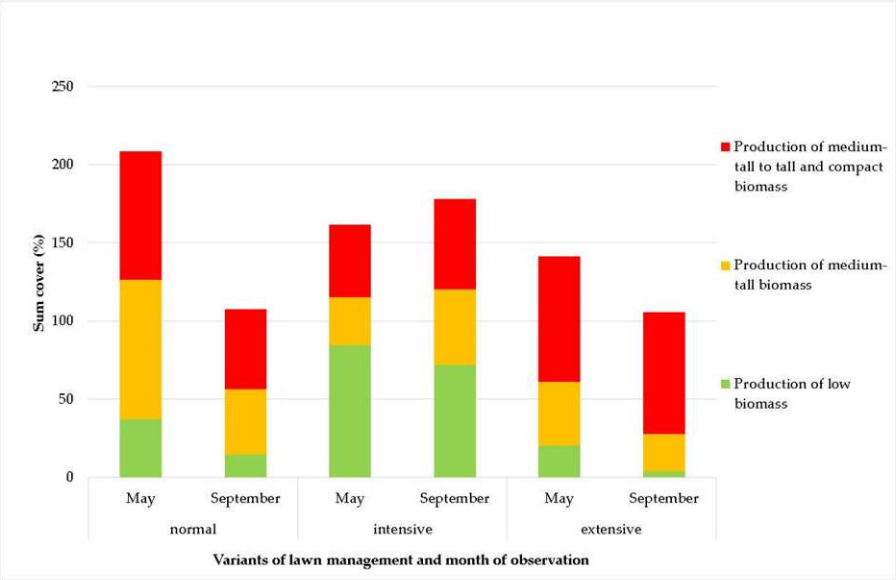


Figure 13. Representation of plant species groups according to the production of biomass important in case of fire.

According to Salemme et al. [35], grass was shown to increase the probability and intensity of fire by increasing loading, continuity, and flammability [36,37]. The results of this study show that the management method can alter the proportion of biomass and thus influence the risk of fire, which obviously changes over time. The risk of fire logically increases if the biomass of the vegetation of grassy areas dries out. Compared to forests, the availability of fuel is lower in grassy areas; however, this fuel is very dry [38]. Therefore, fire intensity in these areas is relatively low [39], but fires spread fast. The production of biomass over time is not identical in all plant species. Stavi [38] confirmed that the combination of large quantities of dry fuel and "suitable" meteorological conditions constitutes a "promising recipe" for fires. It should be stressed that fire seasons, due to global climate change, have altered fire seasonality (the timing of fire throughout the year) in many regions around the world [40]. If the biomass dries out at the end of spring and the beginning of summer, the share of annual winter grass species such as *Bromus hordeaceus* and *Hordeum murinum* will be particularly significant. These species are well adapted to urban ecosystems and readily spread in towns.

If the biomass dries out during the summer, the share of *Arrhenatherum elatius, Elytrigia repens*, and *Lolium perenne* will be important. These species produce great amounts of biomass [41–44]. Dead biomass of grasses forms a continuous layer [45], which is used by these species to protect themselves from unfavorable conditions (high temperature and evaporation). The dead biomass further provides a competitive advantage, preventing other plant species from accessing light. Thus, this layer of biomass plays a very important role in the species composition of phytocenosis [43,46,47], whereas it can become a cause of fire in urban conditions.

If the biomass dries out toward the end of summer and at the beginning of autumn in association with the end of the growing season, fruits and seeds ripen and aboveground parts of plants gradually die. In this period, the representation of dicotyledons such as *Acer negundo, Artemisia vulgaris, Medicago sativa, Melilotus officinalis*, and *Rosa canina* is particularly important [48–50]. The biomass of these species increases the risk of

fire. *Acer negundo* is classified as an invasive species and very often and quickly colonizes extensively maintained areas. Thanks to its rapid growth, even young *Acer negundo* plants pose a potential fire hazard.

Therefore, it is obvious that the presence of biomass of grassy areas affected by management practices is only a precondition for fire risk [35] because weather conditions and the occurrence of drought also play important roles [51–53]. It is commonly assumed that air temperature exceeding 24 °C, relative air humidity above 40%, a lack of precipitation, and a lack of clouds or low cloudiness are parameters that determine fire weather conditions [54–56], during which over 60% of plant biomass fires are produced. Biomass humidity at 30% is the boundary level, above which the development of fire from point heat sources and its propagation is rather improbable. At the same time, biomass humidity below 12% results in almost 70% of fires of all types. There is also the possibility of endogenic auto-flammability resulting from the auto-heating of material accumulated in heaps. According to various studies, the temperature of biomass auto-flammability is in the range of 150–210 °C. It should be emphasized that biomass auto-flammability usually takes place when the material is accumulated in heaps.

5. Conclusions

Changes in climate, land use, and landscape management impact the occurrence and severity of fires particularly in Europe, where ongoing changes have strongly modified fire patterns over the last decades [23]. This also applies to urban areas and the management of urban green infrastructure.

The results of our study confirmed that the vegetation structure of urban grassy areas changes under the influence of different management methods used (different anthropogenic management practices). During the 2-year study interval, 56 plant taxa were found, 29 in the variant with normal management, 24 in the variant with intensive management, and 34 in the variant with extensive management. Dead biomass, which poses a high risk of fire, is an important but neglected part of ecosystem functions. Extensively managed and unkempt urban grassy areas pose a high risk of fire due to the presence of plant species that produce great volumes of biomass. Combined with dry and warm weather, dead biomass can lead to fire outbreaks. Extensive management of urban grassy areas brings benefits such as lower maintenance costs and increased biodiversity. Intensive management reduces not only the risk of fire but also plant biodiversity. Grasses are particularly important in terms of fire risk. Increased attention should be given to annual winter grass species (*Bromus* sp., *Hordeum murinum*) and perennial grass species (*Arrhenatherum elatius*, *Poa pratensis* etc.), and some of them should even be regulated. Urban grassy areas are important sources of biological diversity in cities and bring further ecosystem functions that positively influence the lives of residents. In addition, attention should also be paid to the composition and functions of plant species that could threaten the safety of people, including the risk of fire. Human activities significantly change the vegetation structure of urban grassy areas, which subsequently modifies the species composition and ecosystem functions of these areas.

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Příloha 3

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INFLUENCE OF LAND USE ON PLANT COMMUNITY COMPOSITION IN VYSOCINA REGION GRASSLANDS, CZECH REPUBLIC

Human disturbance is an important factor in forming vegetation. According to our hypothesis, anthropogenic activity and changes in the species composition of grass communities occur in the process of co-evolution. Understanding co-evolution, to better predict future changes in the entire ecosystem. Five grassland sites were selected with different methods of use and hence different anthropogenic disturbance regimes. The results show that the composition of grassland communities responds to the methods of their use. The needs and demands of our civilization are changing. Humans co-create plant communities the preservation of which depends on their use by humans.

1. INTRODUCTION

At the beginning of the Neolithic revolution, when humans kept animals, a need arose to ensure food for them [1]. Since the period of pastoralism, people have been using grassland communities as a source of food for ruminants and horses [2]. In the past, they were moving to places with plenty of green grass biomass (forage) to have

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food for the animals [3]. Later, they settled down and started to use some sites permanently as pastures, particularly those inappropriate to become arable land. However, even the arable land was used for grazing if the fields lay idle (fallow). Later, grasslands started to be used as a source of hay for forage outside the vegetation period. Meadows were established primarily in flooded alluvia of rivers.

Grasslands are closely related to agriculture and some human activities [4]. Grassland management (grazing and mowing) is necessary to prevent succession leading to the formation of scrub and trees [5]. Semi-natural permanent grassland extensively managed is relatively rich in species and is dominated by grasses and perennial herbs. Plant species composition reflects soil conditions (pH, humus content, contents of nutrients) and climatic conditions which depend primarily on the altitude.

The dawn of the industrial revolution witnessed changes in livestock breeding and in the system of acquiring forage. Year-round cattle housing brought a need for high-quality forage, rich in nitrogenous substances. Fodder crops started to be grown on arable land. Clover crops (red clover, alfalfa) or clover grass mixtures could cover the need for forage for cattle during the whole year [6]. Subsequently, the need for forage from grasslands decreased. Fodder crops create communities poor in species on arable land [7] consisting of seeded crops and weeds. The intensification of agriculture after World War II led to the ploughing of meadows [8] and the expansion of growing fodder crops on arable land. The cultivation of fodder crops was often connected with intensification elements such as the use of industrial fertilizers, irrigation systems and pesticides. The aim was the production of high volumes of forage from arable land, with a high content of nitrogenous substances [8]. In some places, the lands formerly used for farming are currently being abandoned [9]. This sudden absence of human interventions leads to the development of specific vegetation [10]. Abandoned sites provide conditions favourable for the development of ruderal vegetation, after a long time of succession to shrubs and woods with a considerable representation of allochthonous species [11].

Understanding the factors and processes that influence the taxonomic and functional composition of biological communities is crucial for conservation ecology and biology [12]. The character of human disturbances (human activities) is an important factor in forming the vegetation species composition. Human activities are changing too, responding to the development of human civilization. According to our hypothesis: anthropogenic activity and changes in the species composition of grasslands occur in the process of co-evolution. Understanding the co-evolution of human civilization and vegetation will allow us to better predict future changes in the entire ecosystem. Therefore, our research aimed to i) determine how human management affected the plant species composition of studied grassland, ii) determine the share of plant species tolerant to diverse levels of disturbance on sites used for different purposes, iii) establish directions in changes in the species composition of vegetation as a result of human civilization.

2. MATERIAL AND METHODS

Study area. The study was situated in the Vysocina Region (Bohemian-Moravian Highlands), Czech Republic (CR) (Fig. 1). The region is located in the transport and population centre of the CR [13]. The economy of the eastern part of the region is influenced by the neighbouring Brno agglomeration, while the north-western part of the region is already the catchment area of the capital city of Prague (CR). The Vysocina Region is characterized by a high percentage of agricultural and arable land, the lowest population density of all regions in the country, and many small municipalities [14]. The region is typical of landscape degradation and the urgency of environmental problems. Extreme expansion and amalgamation of fields under the communism era resulted in large fields (frequently >100 ha) that are both erosion-prone and increase the risk of flooding. Much of the historical mosaic and species-rich habitat such as pasture was also destroyed [15]. In terms of the typology of rural space, it is underdeveloped countryside, characterized by poor civic amenities, small numbers of public transport connections, low municipal budgets, and negligible investment opportunities [16].



Fig. 1. The Vysocina Region; location of the study site

The region is a typical highland with a high share of grasslands in contrast to low elevations with prevailing arable lands. The Vysocina Region is characterized by the mean altitude of 500 m above sea level (ranging between 239 and 837 m a.s.l.), in the two distinct mountain ranges of Zdarske vrchy in the north of the region and Jihlavske vrchy in the south-west. The Vysocina Region is one of the colder regions of the CR. The long-term mean annual temperature ranges from 6 to 8 °C and the long-term mean total annual precipitation amount is 500–800 mm (Fig. 2) [13].

The original vegetation has been transformed by human activity into an undulating cultivated steppe with low hills and valleys and a wealth of forests and groves. The mass of cultivated forests covers most of the highest areas of the region. A large part of the stands are monocultures of Norway spruce (*Picea abies*), which have been seriously

damaged by the bark beetles since 2018 [13]. The lack of large ore deposits has spared the highlands from the devastation of mining activities.

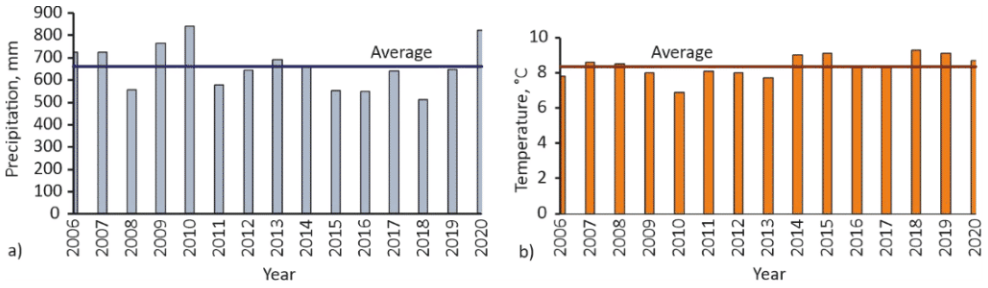


Fig. 2. Meteorological conditions of the Vysocina Region: a) average precipitation, b) average temperature



Fig. 3. Selected grassland sites: a) cattle grazing (Pasture), b) occasional sheep grazing (Extensive), c) arable land with the clover-grass forage mixture (Clover), d) mowed meadow (Meadow), e) abandoned ruderal grassland (Ruderal)

Characteristics of sites with different methods of use:

• Cattle grazing (Pasture, Fig. 3a): The site is situated in the Rovečné cadastral area (49.5841028N, 16.3685472E). It was ploughed in the autumn of 2016, and the compost was worked into the soil. In the spring of 2017, a presowing treatment was made, and a cover crop was seeded (oats). The seeding rate was 100 kg/ha; subsequently, a UNI-P-10 grazing mixture was seeded separately at 30 kg/ha. The seeding was followed by rolling and a collection of stones. In 2017– 2019, the site was used as a pasture for 20–30 heads of spotted cattle.

• Occasional sheep grazing (Extensive, Fig. 3b): The site is situated in the cadastral area of Vysoká u Jevíčka (49.6623514N, 16.8086858E). Since 2015, it has been used as a paddock and occasional pasture for hobby animals: four ouessant sheep, two sheep of meat type and two Cameroon goats. In 2015, self-seeded woody plants were removed, and the site was cleaned. Currently, there is no other site maintenance. The animals use the site only sporadically, and being additionally fed, they do not depend on grazing.

• Arable land with the clover-grass forage mixture (Clover, Fig. 3c): The site is situated in the Rovečné cadastral area (49.5919833N, 16.3662300E). In the autumn of 2015, it was ploughed with the incorporation of compost into the soil. In the spring of 2016, pre-sowing treatment was made, and the cover crop was sown. The sowing rate of spring wheat was 80 kg/ha. Then, the UNI-J-90 clover-grass mixture was seeded separately at a rate of 23 kg/ha together with a starting dose of nitrogen at 3 kg/ha. The sowing was followed by rolling and a collection of stones.

• Cut meadow (Meadow, Fig. 3d): The site is situated in the Ubušínek cadastral area (49.6159086N, 16.2867633E). The permanent grassland has been there for at least 40 years. During that period, it has been neither repeatedly seeded nor treated with additional sowing. Once a year, the site is fertilized with calcium nitrate at 150 kg/ha (40 kg of nitrogen per hectare). The permanent stand is regularly cut twice in the growing season with the first cut at the turn of May and June, and the second at the end of September.

• Abandoned ruderal grassland (Ruderal, Fig. 3e): The site is situated in the cadastral area of Bystřice nad Pernštejnem (49.5189211N, 16.2657394E), near a gardening colony. Formerly, it was mowed by gardeners who fed their rabbits. After 1989, the site was returned to its original owners. Since that time, it has not been used and no cultivation measures are implemented there.

Method of vegetation assessment. The vegetation was assessed using phytocoenological relevés. Five plots (Fig. 3) were chosen at each of the five studied sites for the phytocoenological relevés sized 10 m^2. The phytocoenological vegetation assessment took place twice each year in 2018 and 2019. The first one was before the first cut (if made on the site) from May to June. The second one was before the last cut in September. For each phytocoenological relevé, all species of plants growing in a defined area were recorded, and the total coverage of the herb layer and the cover of individual plant species were estimated directly in percent. Scientific names of plant species were unified according to the Pladias database of Czech flora and vegetation [17]. Plant species were divided into basic functional groups (perennial grasses, annual grasses, legumes, other dicots, and non-flowering plants). Other parameters evaluated in the detected species included indicative values for herb layer disturbance (structural index), frequency of herb layer disturbance, and intensity of herb layer disturbance [18].

Indicative values for disturbance express the relation of common taxa both to the frequency and to the intensity of disturbance. Individual types of disturbance are not

distinguished; however, the values cover a wide range of disturbance types such as timber logging, felling, grazing, trampling, use of herbicides, fires, windthrows, soil erosion, ploughing, digging by animals, the action of water (waves or flow) and floods. There are three types of indicative values for a disturbance [18, 19]:

• Indicative values for disturbance set up as structural index express disturbance regime through community parameters. The structural index is standardized for a range from 0 to 1 with higher values indicating a higher degree of disturbance.

• Indicative values for the frequency of disturbance are expressed as a reversed value of time between two disturbances on the logarithmic scale (in years, decimal logarithms). For example, value –2 means a hundred years between two disturbances, value –1 means ten years, while value 0 means a disturbance coming on average once a year. A unit difference corresponds to the ten-times increased frequency of disturbances.

• Indicative values for the intensity of disturbance are expressed on an arbitrary scale from 0 (mildest) to 1 (most intensive). They are based on an estimated share of removed biomass and the area share of soil surface affected by one disturbance. Although the indicative values for frequency and intensity partly correlate, they can serve to express these two components of the disturbance niche of taxa separately.

Values of the coverage of individual plant species on the observed sites were processed by the multidimensional analysis of ecological data. The choice of optimum analysis was governed by the length of the gradient determined by the segment-detrended correspondence analysis (DCA). Further, canonical correspondence analysis (CCA) was used. Statistical significance was determined using the Monte-Carlo test with 999 permutations calculated. The data were processed using the Canoco5 computer programme [20].

3. RESULTS

94 plant taxa were found during two years of monitoring. The numbers of species and average values of disturbance characteristics are presented in Table 1.

Table 1

Total numbers of species found, average numbers of species per plot area, and mean indicative values of disturbance characteristics in the monitored stand types

Site	Number of species		Indicative value of herb layer disturbance		
	Total	Average (per10 m^2)	Structural index	Frequency	Intensity
Pasture	63	14.25	0.66	–0.22	0.97
Meadow	63	16.65	0.62	–0.30	1.18
Clover	34	6.40	0.68	–0.22	0.76
Ruderal	40	8.35	0.62	–0.34	0.63
Extensive	42	10.35	0.51	–0.41	0.41

Shares of the coverage of the groups of taxa on the monitored sites are shown in Fig. 4.

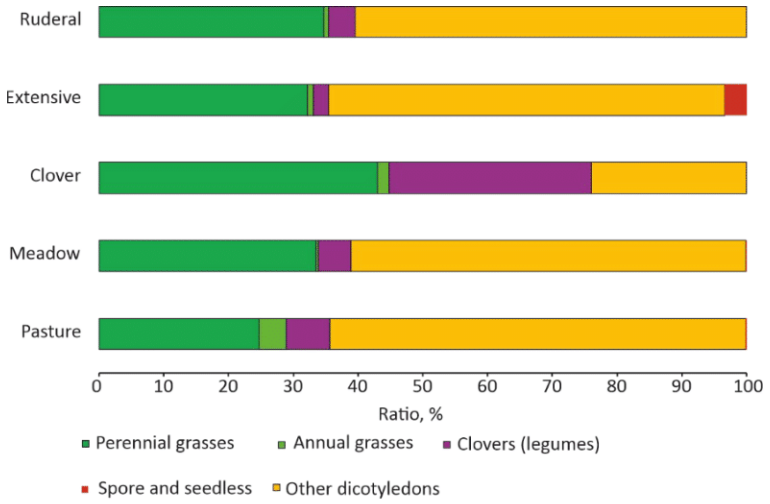


Fig. 4. Percentage of each group of plants on the sites of different use

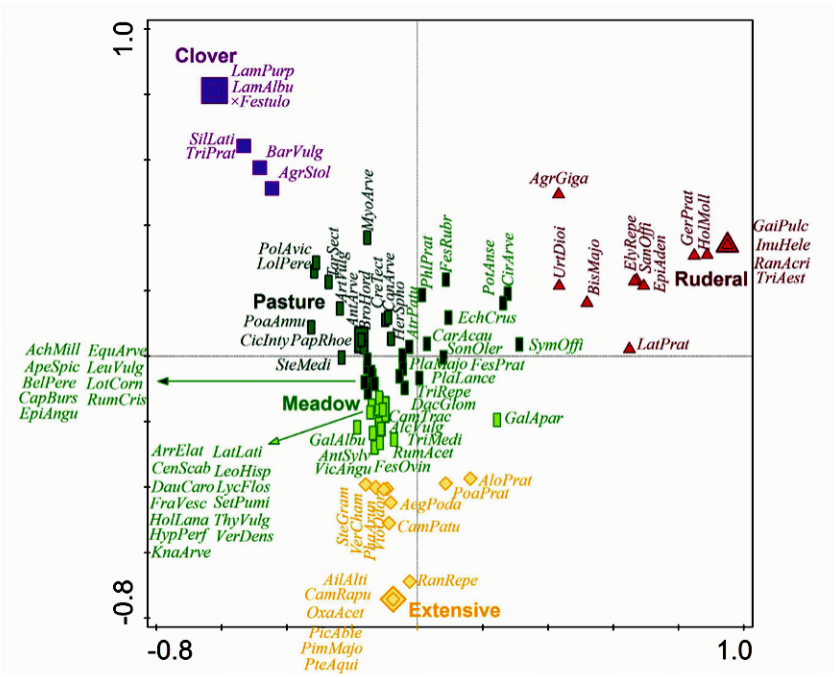


Fig. 5. Occurrence of plant taxa on the sites of different use;
Ruderal means ruderal site, Extensive – extensively used stand, Clover – clover crop on arable land, Pasture, Meadow – cutted grassland, overall explained variability 20.9%, *F*-ratio 6.3, *P*-value 0.001

Results of the CCA analysis which evaluated the coverage of plant taxa on the monitored sites were significant at a significance level $\alpha = 0.001$ for all canonical axes. A graphical illustration of the results is presented in Fig. 5. Based on the CCA analysis, the detected plant taxa can be divided into six groups. The division of taxa into groups according to CCA analysis is given in Table 2.

Table 2

Groups of plant species according to CCA analysis

Group	Plant species[a]	Taxon
1. Extensive	perennial grasses	*AloPrat – Alopecurus pratensis*, *PhaArun – Phalaris arundinacea*, *PoaPrat – Poa pratensis*
	other	*AegPoda – Aegopodium podagraria*, *AilAlti – Ailanthus altissima*, *CamPatu – Campanula patula*, *CamRapu – Campanula rapunculoides*, *PimMajo – Pimpinella major*, *Oxa acet – Oxalis acetosella*, *RanRepe – Ranunculus repens*, *SteGram – Stellaria graminea*, *VerCham – Veronica chamaedrys*, *VioOdor – Viola odorata*
	spore and non-flowering plants	*PicAbie – Picea abies*, *PteAqui – Pteridium aquilinum*
2. Clover	perennial grasses	*×Festulo – ×Festulolium*, *AgrStol – Agrostis stolonifera*
	legumes	*TriPrat – Trifolium pratense*
	other	*BarVulg – Barbarea vulgaris*, *LamAlbu – Lamium album*, *LamPurp – Lamium purpureum*, *SilLati – Silene latifolia*
3. Pasture	perennial grasses	*LolPere – Lolium perenne*
	annual grasses	*BroHord – Bromus hordeaceus*, *PoaAnnu – Poa annua*,
	other	*AntArve – Anthemis arvensis*, *ArtVulg – Artemisia vulgaris*, *CicInty – Cichorium intybus*, *ConArve – Convolvulus arvensis*, *CreTect – Crepis tectorum*, *HerSpho – Heracleum sphondylium*, *MyoArve – Myosotis arvensis*, *PapRhoe – Papaver rhoeas*, *PolAvic – Polygonum aviculare*, *SteMedi – Stellaria media*, *TarSect – Taraxacum* sect. *Taraxacum*
4. Pasture and meadow	perennial grasses	*DacGlom – Dactylis glomerata*, *FesPrat – Festuca pratensis*, *FesRubr – Festuca rubra*, *PhlPrat – Phleum pratense*
	annual grasses	*ApeSpic – Apera spica-venti*, *EchCrus – Echinochloa crus-galli*
	legumes	*LotCorn – Lotus corniculatus*, *TriRepe – Trifolium repens*
	other	*AchMill – Achillea millefolium*, *AtrPatu – Atriplex patula*, *BelPere – Bellis perennis*, *CapBurs – Capsella bursa-pastoris*, *CarAcau – Carlina acaulis*, *CirArve – Cirsium arvense*, *EpiAngu – Epilobium angustifolium*, *GalApar – Galium aparine*, *LeuVulg – Leucanthemum vulgare*, *PlaLance – Plantago lanceolata*, *PlaMajo – Plantago major*, *PotAnse – Potentilla anserina*, *RumCris – Rumex crispus*, *SonOler – Sonchus oleraceus*, *SymOffi – Symphytum officinale*
	spore and non-flowering plants	*EquArve – Equisetum arvense*

Table 2

Groups of plant species according to CCA analysis

Group	Plant species[a]	Taxon
5. Meadow	perennial grasses	*ArrElat – Arrhenatherum elatius, HolLana – Holeus lanatus, FesOvin – Festuca ovina*
	annual grasses	*SetPumi – Setaria pumila*
	legumes	*LatLati – Lathyrus latifolius, TriMedi – Trifolium medium*
	other	*AlcVulg – Alchemilla vulgaris, AntSylv – Anthriscus sylvestris, CamTrac – Campanula trachelium, CenScab – Centaurea scabiosa, DauCaro – Daucus carota, FraVesc – Fragaria vesca, GalAlbu – Galium album, HypPerf – Hypericum perforatum, Kna arve – Knautia arvensis, LeoHisp – Leontodon hispidus, Lyc flos – Lychnis flos-cuculi, RumAcet – Rumex acetosa,ThyVulg – Thymus vulgaris, VerDens – Verbascum densiflorum, VicAngu – Vicia angustifolia*
6. Ruderal	perennial grasses	*AgrGiga – Agrostis gigantea, HolMoll – Holeus mollis, ElyRepe – Elymus repens,*
	annual grasses	*TriAest – Triticum aestivum,*
	legumes	*LatPrat – Lathyrus pratensis*
	other	*BisMajo – Bistorta major, GaiPulc – Gaillardia pulchella, GerPrat – Geranium pratense, EpiAden – Epilobium adenocaulon, InuHele – Inula helenium, RanAcri – Ranunculus acris, SanOffi – Sanguisorba officinalis, UrtDioi – Urtica dioica*

[a]In column 2 (Plant species), "other" means "other dicotyledons".

4. DISCUSSION

The impact of humans on plant communities has been documented in the scientific literature [21–23]. According to Falcão et al. [21], human impacts, such as land use and habitat disturbance, can affect species composition and drive plant invasiveness. Changes in the species composition of vegetation generated by changes in human activities are documented also in other climatic zones [23].

The research result shows that the vegetation of the monitored site – Pasture creates a plant community rich in species, which is accommodated to the strong disturbance of the herb layer, with a high frequency of disturbance connected with the removal of most biomass. The Meadow site recorded the highest average number of taxa. The vegetation can be characterized as a community that is accommodated to the disturbance of the herb layer connected with the removal of most biomass – with a lower frequency of disturbance though. Clover crops create the poorest species community on arable land, which is best adapted to the strong disturbance of herb layer that is of high frequency and connected with the removal of most biomass. The Ruderal community had the second-lowest average number of plant species. The community is accommodated to the

herb layer's disturbance similarly to Meadows. It includes species indicating a less frequent disturbance, which relates to the removal of lower amounts of biomass.

The Extensive use site had a higher average number of species than the Ruderal site and the site of Clover on arable land but a lower average number of species than the Meadow and Pasture sites. This community was the worst tolerant to disturbance, requiring less frequent disturbances and removal of only a limited amount of biomass.

The results show that long-term management induced by agricultural activities leads to the development of rich-in-species grass communities on monitored Meadows and Pastures. It was confirmed that the intensification of land use practices reached the mountain meadows of alpine valleys [24]. The authors pay attention to the fact that the average number of species found in 2008 was lower than in the 1940s. This result supports a trend that has been frequently observed in managed grasslands over the last 60 years [24]. Long-term agricultural use of meadows and pastures leads to the creation of specific plant communities. The dominant plant species are those suitable for livestock food, such as the grasses *Lolium perenne*, *Festuca pratensis*, *Arrhenatherum elatius*, the clover *Trifolium repens*, *Lotus corniculatus* and the herbs *Daucus carota*, *Plantago lanceolata*. The representation of these and other plant species is significant in terms of the fulfilment of the productive functions of grasslands.

The species diversity of European grasslands considerably depends on their prehistorical origin, a unique combination of local abiotic factors, and the regional pool of species [25]. It was also shown that traditional land use systems are important for the preservation of species diversity of grasslands [25]. Agricultural grasslands are an important resource and biodiversity in the context of the European landscape. Species-rich grasslands can be a source of regional populations for many plant species. These populations can be used in the breeding of new fodder varieties with specific characteristics. However, the high level of biodiversity is linked to the nature of land management.

Intensification of forage production leads to the development of communities that are poor in species. The process started in the period of the industrial revolution, after World War II, and culminated in the second half of the 20th century. The massive use of industrial fertilizers and the sowing of mixtures of non-native species or new varieties are the main signs of intensification. Intensification leads to the dominance of supported grass species ×*Festulolium* (hybrid of genus *Festuca* and *Lolium*) and clover *Trifolium pratense*. Dominant species compete with other species, which will result in a decrease in vegetation biodiversity.

Reduction of anthropogenic pressure is generally considered as contributing to biological diversity. Nevertheless, termination of certain land use can lead either to regeneration or loss of biological diversity in response to changes in physical and biological processes [26]. Extensive approach or withdrawal from agricultural procedures induces changes in the species composition of vegetation and a slight decrease in the number of plant species. This process began in the 1990s and relates to agriculture's transformation and changes in the European agricultural policy. Sitzia et al. [26] inform that

spontaneous afforestation following the discontinuation of agricultural procedures is currently common in Europe due to socioeconomic factors. Although this brought a certain recovery to wildlife, a greater part of the traditional heterogeneous landscape and valuable open sites such as pastures, extensive pastures and grasslands were lost or often went through transformation into new ecosystems composed of a mixture of native and foreign species [27]. Nitrophilous species such as *Elymus repens*, *Urtica dioica*, *Geranium pratense* and possibly species that are easy to spread (*Epilobium adenocaulon*) are among the original species growing on nutrient-rich lands. Extensive farming can create space for Archaeophyte *Viola odorata* and/or agriculturally unsuitable species (*Aegopodium podagraria*). Changes in human activity provoke a response in the composition of vegetation.

A dramatic decrease in biodiversity can be observed as a diversity crisis. The impacts of humans on entire ecosystems but also the occurrence of specific species are very conspicuous. Humans and plants have a complex relationship extending far back into our joint evolutionary history. Understanding the co-evolution of humans and vegetation may contribute to the prediction of further development.

5. CONCLUSIONS

The results show that the vegetation of monitored pastures and meadows creates a species-rich plant community. This vegetation can be characterized as a community that is adapted to the disturbance of the herb layer and associated with the removal of most of the biomass. Less frequent disturbance and the removal of a smaller amount of biomass leads to lower species diversity, as was the case in the Ruderal and Extensive habitats. The poorest community was found with clover on arable land. Very frequent disturbance and removal of most of the biomass leads to a decrease in plant species diversity. The results show that species-rich grass communities are formed in monitored meadows and pastures. Pastures belong to the oldest ways of use, so we can assume that some plant species have already fully adapted to the conditions. On the contrary, the intensification or extensification of the use of grasslands causes changes in the species composition and a decrease in the species diversity of plants.

The long-term and stable management of grassland communities by anthropogenic activity led to the creation of species-rich and specific vegetation in the agricultural landscape. Changes in the use of grasslands caused by the needs of our civilization will lead to a decrease in the number of species and a change in the species composition.

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Příloha 4

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Responses of synanthropic vegetation to composting facility

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HIGHLIGHTS

- Composting plants are habitats where biodegradable materials are bio-oxidized.
- Compost becomes a vehicle for spreading weeds.
- Composting plants affect the surrounding areas and vegetation.
- The link between composting plants and vegetation must be included in the legislation.

GRAPHICAL ABSTRACT



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ABSTRACT

Composting facilities are habitats where biological materials are bio-oxidized. Biological waste represents a source of plant species diaspores and may promote changes in the species composition of the surrounding. The studied composting facility is situated in the Bohemian-Moravian Highlands, Czech Republic. Four sites, the composting pile and three habitats nearby were chosen of different use and disturbance conditions. Phytosociological plots were recorded in each of the habitat and the results were processed using multivariate analyses of ecological data. The information about plant species indication values was also analysed: (i) the relationship between soil disturbance and plant species occurrence, (ii) seed dormancy, (iii) seed bank, and (iv) vector of seed dispersion. During the research, 119 plant taxa were found in total. Conditions of the composting process (frequent disturbances, excessive available nutrients, enough water, and supply of new diaspores) represent a challenge for plant species. The presence of plant diaspores in the biowaste is a reason why the fundamental principle of appropriate composting process has to be adhered to. Another important task is to give attention to the methods determining the share of living diaspores in the final compost, which is still missing in practice. Compost might become a vehicle for spreading weeds. The capacity of vegetation to survive and multiply on the premises of composting facilities increases the importance of vegetation monitoring and control of the adjacent areas. The usual occurrence of rural brownfields near composting facilities increases the risk of diaspores being transmitted into biowaste or compost, thus increasing the share of undesirable viable diaspores. Composting facilities generate specific synanthropic conditions for the vegetation. Therefore, the composting facility projects should take into consideration the surrounding areas and vegetation management. It is recommended that the project should include semi-natural vegetation, which can create efficient barriers to the spreading of undesirable ruderal plant species. The novelty of this study is the confirmation that composting facilities

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and compost become a new factor affecting vegetation, which has been disregarded so far. The link between composting facilities and vegetation has to be included in the legislation related to parameters of compost quality. Moreover, the issue of weeds, their reproductive organs and their spread should be considered in the guidelines for the design, location, construction, and operation of composting facilities.

1. Introduction

Dramatically increasing world population directly increases production of organic waste including food and kitchen waste, garden waste, plant residues, animal manure, etc. (Fan et al., 2021; Wei et al., 2021; Kharola et al., 2022). Organic waste used to be processed by landfilling and burning, which is costly and provides only little exportable energy due to high moisture content and low calorific value (Xin et al., 2020). Increased attention has been recently given to the enhancement of managing the organic fraction of municipal solid waste (MSW). The traditional methods of organic waste management (WM) and disposal such as landfilling and combustion being unsustainable, a movement towards prevention, utilization and valorization of organic substances has been recorded, as mentioned in the hierarchy of WM (Thomson et al., 2021). Diversion of organic material from the waste flow, either by separation at the source or by centralized mechanized separation, is a precondition for its further processing using more environmental methods such as composting (Wei et al., 2017; Yasmin et al., 2022). Composting is a biotransformation process in which microorganisms and their related enzymes convert organic resources into stable and complex macromolecules (Zhang et al., 2020; Rashid and Shahzad, 2021; Thomson et al., 2021; Chorolque et al., 2022; Xu et al., 2022). The diversion of MSW from landfills by composting has many benefits for the environment, e.g. reduced emissions of greenhouse gases (GHGs) and reduced amount of leachate from landfills. As to the life cycle assessment (Laurent et al., 2014; Eriksson et al., 2015), there are other benefits that can be derived from the diversion of organic waste from landfilling or burning such as the production of compost which can be used as organic fertilizer or for land improvement (Wei et al., 2017; Toledo et al., 2018; Longhurst et al., 2019). The framework of the European Union directive on waste (no. 2008/98/EC, 2008) prefers the repeated use and recycling of materials rather than the use for energy and disposal. In this context, composting is a temporary solution and separated collection of biological waste is a measure that is supported by the European directive to make the member states move towards the strategies of circular bioeconomy (Marcello et al., 2021; Torrijos et al., 2021; Zhou et al., 2022). Composting is not only a temporary solution for treating biological waste but also has its limitations.

Advantages and disadvantages of composting were successfully investigated by many authors (Mehta and Sirari, 2018; Dhamodharan et al., 2019; Voběrková et al., 2020; Selvam et al., 2021; Yin et al., 2021; Zhou et al., 2022). During the process of composting, some environmental problems may occur such as development of bad odors or toxic gases (Wei et al., 2017; Dhamodharan et al., 2019; Nguyen et al., 2022), bio-aerosols (Robertson et al., 2019; Ferguson et al., 2021) and dust (Schlosser et al., 2018; Gałwa-Widera, 2021), which results in health hazards at work or discomfort of local population. This particularly applies to compost plants operated in the open. Biological waste and composting were studied from various aspects, and some studies were focused on environmental issues using methods of life cycle assessment (Nabavi-Pelesaraei et al., 2019; Weligama Thuppahige et al., 2022; Zhou et al., 2022), registration and composition of GHGs (Peigné and Girardin, 2004; Pan et al., 2018; Chen et al., 2019; Yin et al., 2021). Other authors explored theoretical and economic aspects of the recycling of biological wastes (Bong et al., 2017; Pai et al., 2019; Zulkepli et al., 2017). Nevertheless, the research on the influence of composting facilities on vegetation is still missing.

In a closed-loop bioeconomy, circularity of material cycles is emphasized (Vaverková et al., 2020a); therefore, composting facilities are established at very diverse places. Frequently used are abandoned industrial and agricultural brownfields (Navrátil et al., 2019; Navrátil et al., 2021), as well as other degraded sites. According to generally acknowledged rules, a correctly planned composting facility results from the interdisciplinary teamwork of several scientific branches – microbiology, construction industry, architecture, ventilation system, climatology and electrical engineering, geology, and landscaping. Reason is the principle of dividing the tasks to prevent failures (de Bertoldi-Schnappinger, 2007). However, the impact of composting facility itself on the environment (surrounding ecosystems) remains a neglected issue. Planning and operation of composting facilities is missing a dialogue with botanists and environmentalists. As far as it is known to the authors, the potential for spontaneous spreading of vegetation from composting facilities has been tackled only marginally in the scientific literature (Vaverková et al., 2020a). However, the Victoria Environment Protection Agency (EPA) suggested the issue of weeds, their reproductive organs, and their spread in guidelines for the design, location, construction, and operation of composting facilities (EPA, 2017).

Composting facilities are habitats created by humans, which are very specific environments for plants. Sites for the composting process (composting facilities) are places where biological materials of diverse properties are bio-oxidized. Bringing the biological waste represents a source of plant species diaspores (Vaverková et al., 2019; Vaverková et al., 2020a; Winkler et al., 2021) and may promote changes in the species composition of the surrounding vegetation (Vaverková et al., 2022). Through the conversion of the environment and building of structures, the anthropogenic activity enters the local ecosystems and forms new boundaries between the transformed and original environments. The vegetation continually adapts to human activities through changing the species composition. Some plant species make use of human civilization for their survival and dispersal including composting facilities. On their borders, composting facilities create an environment that can be referred to as ecotone (e.g., Walker et al., 2003), where the effects of the composting facility pas into surrounding natural, semi-natural or anthropogenic environment. Namely ecotones play an important role in the penetration and spreading of new species from one type of the environment to the another.

The novelty of this study is the confirmation that composting facilities and compost become a new factor affecting vegetation, which has been disregarded so far. The main aim of this research is the evaluation the impact of the composting facility on vegetation. According to our hypothesis, composting facilities generate specific synanthropic conditions for the vegetation. The goals to confirm the hypothesis are: (i) determination of plant species that are capable of surviving disturbances in conditions of the composting facility, (ii) evaluation of differences in the species composition of vegetation on different sites of composting facility, (iii) assessment of different sites within composting facility in respect of the seed bank dormancy, seed bank properties, possibilities of plant dispersion and relationship of plants to disturbances, with potential of plant species dispersion into the surrounding landscape.

2. Material and methods

2.1. Area characteristics

The studied composting facility is situated in the Jívoví cadastral area, Bohemian-Moravian Highlands, Czech Republic. Location of the composting facility in WGS84 coordinate system (Decimal Degrees) is 49.4098325°N, 16.0858692°E. The composting facility has been operated since June 2014, and an annual amount of processed biowaste is up to 2400 t. Supplier of biowaste is the Town of Velké Meziříčí, township Křižanov and other adjacent villages. The composting facility was constructed on land with mesobasic

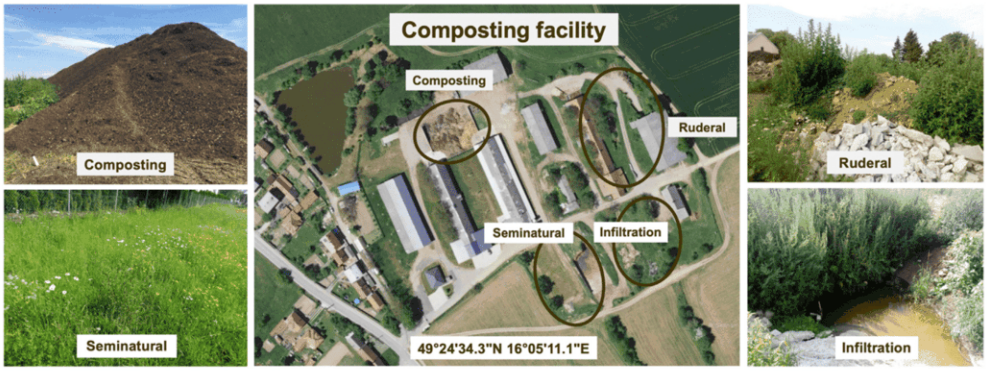


Fig. 1. Sites examined in the composting plant.

cambisols, formed by weathering on metamorphic rocks (mainly gneiss). Mean long-term annual precipitation amount is 666 mm and mean annual temperature is 6.7 °C (Culek et al., 1996; CGS, 2017, 2018).

2.2. Characteristics of sites at the composting facility

On the composting facility estate, four different sites (habitats) were chosen of different use and different disturbance conditions (Fig. 1): (i) Compost (Composting): place of biological waste disposal, digging through and compost storage. It is an area that is exposed to the most frequent and most severe disturbances. The biological waste contains plant diaspores of allochtonous origin, and the place is rich in nutrients; (ii) Grassland (Semi-natural): is a grassy meadow site which is regularly cut twice a year and biomass is removed. This site is very close to Semi-natural vegetation and is at the same time least directly affected by the composting facility operation; (iii) Ruderal vegetation (Ruderal): This is a so far unused and unkempt space on the composting facility premises. In the past, it was used to keep farm animals and for other agricultural purposes. Its character is that of rural brownfield; (iv) Polder (Infiltration): This is a terrain depression which developed after former terrain works. The site does not have a paved base and serves to capture and infiltrate rainfalls. A part of the site is contaminated with cement and gravel from construction works in the past.

2.3. Methodology of vegetation assessment

The vegetation was assessed on four sites situated on the composting facility premises (June 2019–2020) using phytosociological plots (relevés) according to the standard principles of the Zürich-Montpellier school of phytosociology (Braun-Blanquet approach). Plant species composition was recorded at twelve relevés, four square relevés (size 3 × 3 m) were situated at each study site (habitat). All of the present vascular plant taxa (mainly species) were recorded and their cover was estimated using modified Braun-Blanquet nine-grade scale (Westhoff and van der Maarel, 1978). Taxonomic nomenclature of plants follows Kaplan et al. (2019).

Results were processed using the multivariate analyses of ecological data. Cover values of plant taxa were square-root transformed. The first analysis performed was the segmental Detrended Correspondence Analysis (DCA), which calculates the length of gradient (Lengths of Gradient = 4.9). This was followed by the Canonical Correspondence Analysis (CCA). Statistical significance was tested using the Monte-Carlo test with 999 calculated permutations. All multivariate analyses were performed in CANOCO 5.0 (Ter Braak and Šmilauer, 2012).

The information about plant species indication values was taken from the database of Tyler et al. (2021): (i) the relationship between Soil disturbance and occurrence of plant species, which represents species dependence on soil disturbance, and does not distinguish between natural (e.g. wind, floods, ice movement or landslides) and anthropogenic disturbance (e.g. mechanical or caused by farm animals; range 1–9, Table 1); (ii) Seed dormancy (time needed from seeding/spread to germination; range 1–4, Table 2); (iii) Seed bank characterized the properties important for survival in the soil (range 1–4; Table 3); (iv) vector of Seed (fruit, vegetative) dispersion (10 vectors; Table 4; Tyler et al., 2021).

3. Results

119 plant taxa were found during two years of vegetation survey. The number of species on the monitored sites differed, though. On the Composting site, 50 plant species were found, of which annual dicotyledonous species exhibited the highest coverage (Fig. 2). On the Ruderal site, 57 species were recorded, of which dicotyledonous species had the highest coverage. The lowest number (45) of plant species was found on the Polder site (Infiltration area) and dicotyledonous species had the highest coverage. The highest number of species (63) was recorded in the Grassland site (Semi-natural) and the highest coverage was that of perennial plants (both dicotyledonous and monocotyledonous species).

Results of CCA analysis which was used to evaluate the presence and coverage of plant taxa on the monitored sites were significant at a α = 0.001 level of significance for all canonical axes. Graphical display of the

Table 1
Scale of soil disturbance.

Soil disturbance	Species characteristics
SoD1	Species colonize the already established vegetation and compete successfully; cause structural changes in the vegetation provided that soil disturbance is absent.
SoD2	Species colonize the already established vegetation which successfully competes for some time. However, in a long-term view they overcome the competition of the original vegetation and require absence of soil disturbance.
SoD3	Species multiplying even in undisturbed stands; they are however competitive only with difficulties and cannot win for a longer time.
SoD4	Species with only limited reproduction capacity in undisturbed and stable vegetation, the population of which does not survive in the vegetation permanently.
SoD5	Species requiring soil disturbance for reproduction; their individuals however survive for long.
SoD6	Species multiplying only in undisturbed soil or on bare soil; they can survive for tens of years but gradually disappear from the vegetation.
SoD7	Species multiplying exclusively on disturbed and bare soils can survive only several years and then gradually disappear from the vegetation.
SoD8	Species that are not competitive in closed canopy vegetation; they need soil disturbance at least every other year.
SoD9	Species that are not competitive in closed canopy vegetation; they need soil disturbance every year.

Table 2
Scale of seed dormancy.

Seed dormancy	Species characteristics
SeD1	Species with no dormancy, germinate within 10 days.
SeD2	Species with no dormancy, germinate within 10–30 days after sowing/dispersion.
SeD3	Species with moderate physiological dormancy germinate very slowly but independently on temperature and season, or requiring <35 days of cold stratification.
SeD4	Species with moderate to deep physiological dormancy germinate after at least one period of cold stratification longer than 35 days.

results of CCA analysis is in Fig. 3. Based on the CCA analysis, the detected plant taxa can be divided into five groups (Table 5). Each of the studied site compose of its own plant species composition, in addition, a group of species with a shared affinity for the Ruderal site and the Polder site.

The criterion of Soil disturbance shows what degree of disturbance on the site takes place in respect of vegetation species composition. The sites of Composting, Ruderal and Infiltration area were dominated by plant species that multiply exclusively on the disturbed and bare soil and have a limited capacity to survive in the closed canopy vegetation (SoD7; SoD8; SoD9). Species prevailing on the Semi-natural site were able to colonize the closed canopy of vegetation and could withstand a limited stand disturbance in the form of regular cutting (SoD2; SoD3; SoD4). The occurrence of most plant species on all sites is made possible by disturbances caused by human activities. Only the intensity and type of these disturbances differ. It is obvious that the Compost site experienced very similar disturbances as the Ruderal site and the Infiltration area (Fig. 4).

Seed dormancy is an important indicator for the germinative capacity of seeds of detected species and their potential to germinate on the sites. The Semi-natural site was dominated by plant species with no dormancy, which can germinate within 10–30 days after sowing/dispersal (SeD2). This means that species occurring on this site are able to germinate very quickly after maturation and other groups occur on the site only at a lesser extent. The representation is similar on the other sites where plant species without dormancy, germinating within 10–30 days after sowing/distribution (SeD2), species with moderate physiological dormancy (SeD3) and species with moderate to deep dormancy (SeD4) have a significant share. Thus, these three sites including Compost are occupied by plant species that are capable of immediate germination, but also by plant species falling into dormancy, thus enriching the soil seed bank (Fig. 5).

The Criterion of Seed bank is essential in terms of composting as it indicates how long the seeds can survive in the soil or in compost and then germinate. The sites Composting, Ruderal and Infiltration area are dominated by plant species with a long-term persistence in the Seed bank (SeB4), which are followed by plant species with a long persistence in the Seed bank (SeB3). The dominant plant species have a capacity of long survival in the soil. The Semi-natural site has the representation of these species slightly different. The share of plant species with the long-term persistence in the Seed bank (SeB4) decreases and the share of species with the temporary persistence (SeB1) slightly increases. The representation of respective groups according to the Seed bank is presented in Fig. 6.

The Criterion of Seed disperser is crucial in terms of plant species capacity to spread into the surroundings. All sites exhibit a dominant representation of plant species with the passive dispersal of diaspores (Passive). Nevertheless, the passive dispersal also includes the distribution by means

Table 3
Scale of seed bank.

Seed bank	Species characteristics
SeB1	Species with temporary persistence in the seed bank (1–2 years).
SeB2	Species with a short-term persistence in the seed bank (1–5 years).
SeB3	Species with long-term persistence in the seed bank ((5–25 years).
SeB4	Species with long-term persistence in the seed bank (>25 years).

Table 4
Scale of seed dispersion.

Seed disperser	Species characteristics
Adh	Fruits bent or sticky, easy to be captured by animal hairs or bird feathers.
AirD	Fruits very small and light, easy to be borne by wind.
AirP	Fruits downy with hairs easy to be dispersed by wind.
AirW	Fruits with wings easy to be dispersed by wind.
Bird	Fruits with coloured and nutrient-rich tissues attractive as food for birds (rarely also mammals).
Expl	Fruits with active explosive/ballistic dispersal mechanisms.
Myr	Fruits with tissues attracting ants which take the fruits away.
Pasivní	Fruits with no functional adaptation for vector of dispersal.
Veg	Fruits with the prevailing vegetative distribution by stolons, rhizomes, etc.
Voda	Fruits with spongy tissues and improved floating capacity to facilitate water dispersal.

of human activities and composts. Notable is also the higher share of plant species with fruits spread by ants on the Semi-natural site (Fig. 7).

4. Discussion

Many scientific studies claim that biological waste composting is an environmentally friendly WM method (Fan et al., 2021; Chen et al., 2022). Composting is perceived as one of means supporting the development of circular bioeconomy as well as environmental WM (Zhou et al., 2022). Biowaste and other organic materials very likely contain viable diaspores of weed plants (fruits, seeds, vegetative reproductive organs). Spreading of hazardous and harmful weeds can have a negative impact not only on the environment but also on human health. Spreading in connection with the activity of composting facilities can be a problem if the organic waste has not been processed properly or the resulting compost was repeatedly contaminated with the diaspores of weed plants before leaving the composting facility premises (Vaverková et al., 2020a). To minimize the spreading of weeds, biological wastes have to be processed according to basic principles and rules for composting process. Furthermore, it is necessary that biological wastes are spatially separated from the compost, and technologies used for biowaste, and compost management are not the same (which means additional costs and further equipment for the composting facility). This would prevent the transition of diaspores by the technology from the biological waste to the compost.

The composition of natural flora and fauna is continually changing. Species are dispersed and settled in new regions while in other regions they die out. Human activities often disturb these processes and cause great and rapid changes (Vaverková et al., 2020a; Winkler et al., 2021; Vaverková et al., 2022). The introduction of alien species and the development of human-made habitats are two types of activities, intended or unintended, which have great importance for changes in the species composition (Ødegaard and Tømmerås, 2000).

Based on the vegetation analysis it was found out that the Compost site is the least favourable for plants, which is given by the high number of disturbances connected with the composting process (digging, temperature, pH, time, and moisture content) (Mehta and Sirari, 2018; Ajmal et al., 2021). In spite of the fact, many plant species can adapt to the unfavourable and changing conditions (Mostofa et al., 2018; Fort and Freschet, 2020; Ma et al., 2020). Annual plant species that adapted to the Compost site include *Atriplex patula*, *Polygonum aviculare*, *Lapsana communis*, *Chenopodium album* and *Stellaria media*. These species feature long seed dormancy, high seed capacity to survive in the soil and passive dispersal of seeds, these features being problematic in terms of compost quality. If the seeds of these species get into the compost, they have a high probability to stay viable and to spread to new sites with the compost (Grundy et al., 1998). Vaverková et al. (2020b) notices about the occurrence of these species and their dispersal in composts, pointing out that basic principles of composting should be followed to curb the occurrence of weeds in the compost. Larney and Blackshaw (2003) point out that composting may reduce the number of viable seeds, but as highlighted by Hunková et al. (2011), the presence of

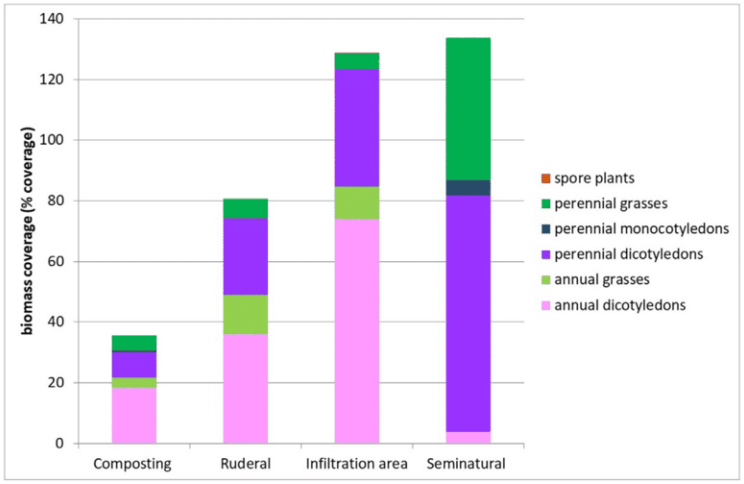


Fig. 2. Representation of life forms of plant species in different sites of composting facility.

seeds in the soil (compost) does not correlate with their presence in the vegetation. Therefore, it is not possible to estimate the presence of seeds in the compost according to growing plants. According to Winkler et al. (2017), the long-term application of organic fertilizers (compost) increases the weed infestation in field crops as well as the soil content of seeds of some species such as *Echinochloa crus-galli* or species from *Amaranthus* and *Chenopodium* genera.

On the Compost site, also perennial plant species were found that multiply vegetatively, e.g. *Aegopodium podagraria*, *Cirsium arvense*, *Elytrigia repens*. Vegetative reproductive organs of these species (Ringselle et al., 2021) were probably brought there with the biological waste. They obviously succeeded in surviving conditions at the composting facility, and it is a question if they are able to spread also to other localities by means of compost. Some plant species have a high regeneration potential and can

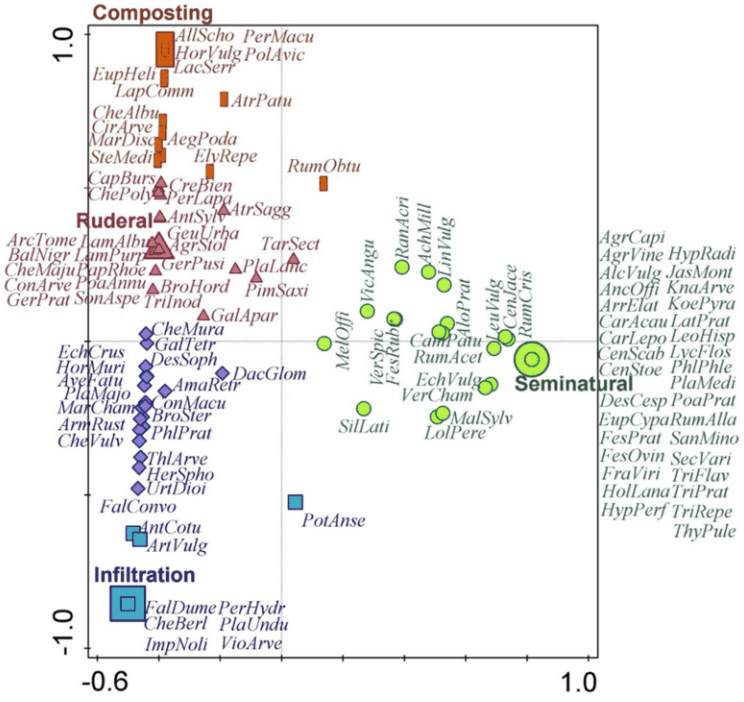


Fig. 3. Relationships of recorded plant taxa and different sites on the composting plant premises (result of CCA analysis; overall explained variability = 31.0 %; F-ratio = 1.8.; P-value = 0.001) Legend: Composting – Compost; Ruderal – Ruderal vegetation; Infiltration – Polder; Seminatural – Grassland).

Table 5
Groups of plant species according to CCA analysis.

Group according to CCA	Group	Taxa
Species preferring the Composting site	Annual dicotyledons	*AtrPatu – Atriplex patula, EupHeli – Euphorbia helioscopia, CheAlbu – Chenopodium album, LacSerr – Lactuca serriola, LapComm – Lapsana communis, MarDisc – Matricaria discoidea, PerMacu – Persicaria maculosa, PolAvic – Polygonum aviculare, SteMedi – Stellaria media*
	Annual grasses	*HorVulg – Hordeum vulgare*
	perennial dicots	*AegPoda – Aegopodium podagraria, CirArve – Cirsium arvense, RumObtu – Rumex obtusifolius,*
	Perennial monocotyledon	*AllScho – Allium schoenoprasum,*
	Perennial grasses	*ElyRepe – Elytrigia repens,*
Species preferring the Ruderal site	Annual dicotyledons	*AtrSagg – Atriplex saggirata, BalNigr – Ballota nigra, CapBurs – Capsella bursa-pastoris, GalApar – Galium aparine, GerPusi – Geranium pusillum, ChePoly – Chenopodium polyspermum, LamPurp – Lamium purpureum, PapRhoe – Papaver rhoeas, PerLapa – Persicaria lapathifolia, SonAspe – Sonchus asper, TriInod – Tripleurospermum inodorum,*
	Annual grasses	*BroHord – Bromus hordeaceus, PoaAnnu – Poa annua*
	Perennial dicots	*AntSylv – Anthriscus sylvestris, ArcTome – Arctium tomentosum, ConArve – Convolvulus arvensis, CreBien – Crepis biennis, GerPrat – Geranium pratense, GeuUrba – Geum urbanum, CheMaju – Chelidonium majus, LamAlbu – Lamium album, PlaLanc – Plantago lanceolata, PimSaxi – Pimpinella saxifraga, TarSect – Taraxacum* sect. *Taraxacum,*
	Perennial grasses	*AgrStol – Agrostis stolonifera*
Species preferring the site of Ruderal + Infiltration area	Annual dicotyledons	*AmaRetr – Amaranthus retroflexus, ConMacu – Conium maculatum, DesSoph – Descurainia sophia, FalConvo – Fallopia convolvulus, GalTetr – Galeopsis tetrahit, CheMura – Chenopodium murale, CheVulv – Chenopodium vulvaria, MarCham – Matricaria chamomilla, ThlArve – Thlaspi arvense,*
	Annual grasses	*AveFatu – Avena fatua, BroSter – Bromus sterilis, EchCrus – Echinochloa crus-galli, HorMuri – Hordeum murinum,*
	Perennial dicots	*ArmRust – Armoracia rusticana, HerSpho – Heracleum sphondylium, PlaMajo – Plantago major, UrtDioi – Urtica dioica,*
	Perennial grasses	*DacGlom – Dactylis glomerata, PhlPrat – Phleum pratense,*
Species preferring the site of Infiltration area	Annual dicotyledons	*AntCotu – Anthemis cotula, FalDume – Fallopia dumetorum, CheBerl – Chenopodium berlandieri, ImpNoli – Impatiens noli-tangere, PerHydr – Persicaria hydropiper, VioArve – Viola arvensis.*
	Perennial dicots	*ArtVulg – Artemisia vulgaris, PotAnse – Potentilla anserina*
Species preferring the Seminatural site	Annual dicotyledons	*JasMont – Jasione montana, VicAngu – Vicia angustifolia*
	Perennial dicots	*AchMill – Achillea millefolium, AlcVulg – Alchemilla vulgaris, AncOffi – Anchusa officinalis, CamPatu – Campanula patula, CarAcau – Carlina acaulis, CenJace – Centaurea jacea, CenScab – Centaurea scabiosa, CenStoe – Centaurea stoebe, EchVulg – Echium vulgare, EupCypa – Euphorbia cyparissias, FraViri – Fragaria viridis, HypPerf – Hypericum perforatum, HypRadi – Hypochaeris radicata,*
		KnaArve – Knautia arvensis, LatPrat – Lathyrus pratensis, LeoHisp – Leontodon hispidus, LeuVulg – Leucanthemum vulgare, LinVulg – Linaria vulgaris, LycFlos – Lychnis flos-cuculi, MalSylv – Malva sylvestris, MelOffi – Melilotus officinalis, PlaMedi – Plantago media, RanAcri – Ranunculus acris, RumAcet – Rumex acetosa, RumAlla – Rumex acetosella, RumCris – Rumex crispus, SanMino – Sanguisorba minor, SecVari – Securigera varia, SilLati – Silene latifolia, ThyPule – Thymus pulegioides, TriPrat – Trifolium pratense, TriRepe – Trifolium repens, VerCham – Veronica chamaedrys, VerSpic – Veronica spicata,
	Perennial monocotyledon	*CarLepo – Carex leporina,*
	Perennial grasses	*AgrCapi – Agrostis capillaris, AgrVine – Agrostis vinealis, AloPrat – Alopecurus pratensis, ArrElat – Arrhenatherum elatius, DesCesp – Deschampsia cespitosa, FesOvin – Festuca ovina, FesPrat – Festuca pratensis, FesRubr – Festuca rubra, HolLana – Holcus lanatus, KoePyra – Koeleria pyramidata, LolPere – Lolium perenne, PhlPhle – Phleum phleoides, PoaPrat – Poa pratensis, TriFlav – Trisetum flavescens,*
	Spore plants	*PlaUndu – Plagiomnium undulatum,*

successfully grow again from any plant fragment (Klimešová and Klimeš, 2007). For example, Melander et al. (2011) demonstrated that thermal destruction of *Elytrigia repens* is much less efficient. Energy calculations indicated that mechanical crushing of *Elytrigia repens* rhizomes is much more promising than thermal destruction. According to their findings, this perennial grass can be destructed only by temperatures above 70 °C, which are not reached at the open composting facility. Rusterholz et al. (2012) inform that biological waste may contain whole plants, plant fragments and seeds. Moreover, some plant species feature high regeneration capacity and can successfully regenerate even from tiny fragments of the parent plant. This was also confirmed by Krajšek et al. (2020) and Csontos et al. (2020).

Plant species that are able to succeed at composting facilities have several common properties, namely the relation to soil disturbances (Arshad et al., 2019). Species requiring soil disturbance every year have a great potential to succeed at composting facilities. To be able to survive in the environment of composting facilities for a long time, their diaspores have to have long dormancy and long-term persistence in the soil (Bajwa et al., 2022; de Aguiar et al., 2022). These properties make it possible to them to survive and maintain populations in the environment of composting facilities. If the plant species diaspores have a passive way of dispersal, they can use the created compost as material for spreading to other sites. It was confirmed by Gallandt et al. (1999), that composting does not eliminate fully the viable seeds of weeds, which suggests that longer composting periods should be tested, deeper heaps, supplementary irrigation, and frequent turning of heaps in order to reduce the density of weed seeds. It is therefore necessary to develop procedures and methods for detecting living diaspores of vegetation in composts. The presence of living diaspores ought to be one of parameters determining compost quality.

The results also show that the sites referred to as rural brownfields have a very similar vegetation composition as the sites with composting facilities. Therefore, such sites are inappropriate in the vicinity of composting facilities or on their premises. Some species have the potential to move from the brownfield to the composting facility and to enrich the resulting compost with their diaspores. In this respect, problematic can be for example *Amaranthus retroflexus*, *Atriplex sagittata*, *Descurainia sophia*, *Chenopodium* sp., *Poa annua*, *Tripleurospermum inodorum* and other. The

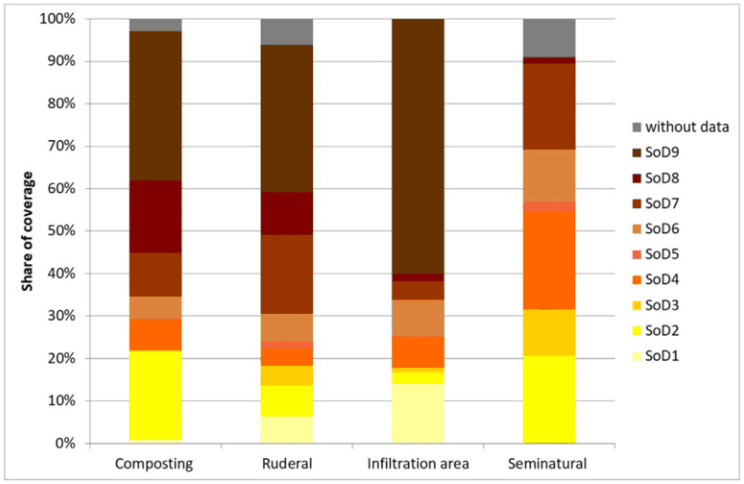


Fig. 4. Share in the coverage of plant species groups according to Soil disturbance.

potential of these species should be considered when selecting sites for the construction of composting facilities. Exactly the brownfields are often used for building composting facilities (Navrátil et al., 2021), although they are unsuitable due to bilateral dispersal of species including invasive species (plants) (Schröder and Kiehl, 2020; Mahammedi et al., 2022a; Mahammedi et al., 2022b). The site chosen for a composting facility should have known history (ecological load) and proposed appropriate way of reclamation. Surroundings of the composting facility can be significant in respect of the dispersal of neophytes and changes in the species composition of vegetation.

The vegetation species composition on the Semi-natural site is not problematic for the composting facility operation. The Semi-natural and regularly maintained site can feature vegetation suitable for neighbouring composting facilities. In the projects of composting facilities, attention should be given the composting process (Zhou et al., 2022), but also to the surroundings of composting facilities and management of adjacent areas. In the surroundings of composting facilities, an isolation space (biological barrier) should be designed, which would curb the dispersal of plant species. Semi-natural sites with the frequent and easy vegetation control are suitable in terms of limiting the spread of undesirable plant species. Semi-natural site is a species-rich community with a great potential to enrich biodiversity and ecosystem functions.

The vegetation of composting facilities interacts with the vegetation in the surrounding landscape. Ecotonal vegetation containing both semi-natural grassland and ruderal species originating from composting facility can serve as a migration path to the surrounding habitats. Vegetation unexposed to disturbances with high coverage and unsuitable environmental conditions for weeds in general (vegetation types of higher succession stages such as grasslands, shrubs, or forests) may create a sufficient barrier surrounding the composting facility preventing the dispersion of unwanted plants.

5. Conclusions

The specific conditions of composting facilities represent a challenge for a number of plant species. Frequent disturbances, excessive available nutrients, enough water, and supply of new diaspores create a very specific

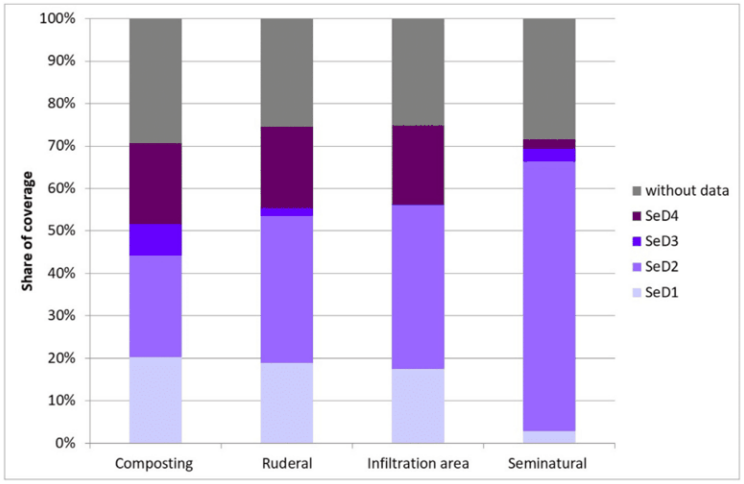


Fig. 5. Share in the coverage of plant species groups according to Seed dormancy.

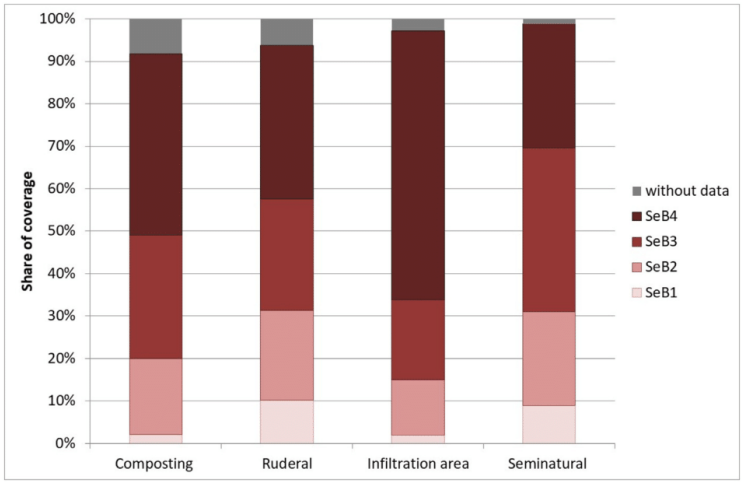


Fig. 6. Share in the coverage of plant species groups according to Seed bank.

environment for the vegetation. Some species are able to adapt to such conditions. Plant species that can survive them have some common properties: (1) resistance to the frequent soil disturbances, (2) very long dormancy of seeds, (3) high ability of seeds to survive in the soil, and (4) passive distribution of seeds. These properties create a high precondition for their surviving the process of composting and compost contamination with viable diaspores. The presence of plant diaspores in the composted biowaste is a reason why fundamental principle of appropriate composting have to be adhered to. Another important task is to give attention to methods determining the share of living diaspores in the final compost. These methods applicable in practice are still missing. Biowaste and compost are biological materials containing diaspores of living organisms including plants. Compost might become a vehicle for spreading undesirable plant species – weeds. It is necessary to change the view of biowaste, composting process and compost, and to perceive them as parts of living nature.

The capacity of vegetation to survive and multiply on the premises of composting facilities increases the importance of vegetation monitoring and control not only on sites determined for the process of composting but also on adjacent areas. The occurrence of rural brownfields near composting facilities increases the risk of diaspores being transmitted into biowaste or compost, thus increasing the share of undesirable viable diaspores. Projects for building new composting facilities should also consider the surrounding areas and vegetation management. It is recommended that project designs for composting facilities include biological ecotones with the semi-natural vegetation, which can create efficient barriers to the spreading of undesirable plant species. Dynamically developing composting facilities in recent years become a new factor affecting vegetation, which has been disregarded so far. The link between composting facilities and vegetation has to be reflected in the legislation related to parameters of compost quality, which also deals with regulations for the design of composting facilities.

It follows from the conducted research that composting facilities may become a new way for the spreading of some plant species and the source of their diaspores capable of further dispersal. The new ways and the sufficient amount of diaspores can alter the species composition of local vegetation. Whereas the plants represent a base of the food network, changes in

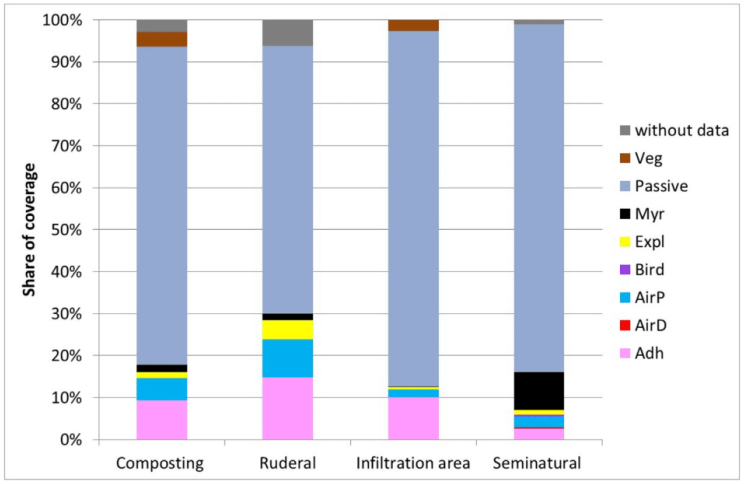


Fig. 7. Share in the coverage of plant species groups according to Seed disperser.

the vegetation species composition will cause a domino effect which may result in the transformation of biodiversity at all levels; the number of native species may decrease, and the number of invasive species may increase. The massive expansion of inappropriately designed and operated composting facilities can lead to the disturbance of vegetation biodiversity and the stability of ecosystems.

CRediT authorship contribution statement

Jan Winkler: Conceptualization, Methodology, Data curation, Writing-Original draft preparation. **Yasuhiro Matsui:** Formal analysis, Validation, Writing-Reviewing and Editing. **Jan Filla:** Data curation. **Lucie Vykydalová:** Data curation. **Martin Jiroušek:** Conceptualization, Data curation, Validation. **Magdalena Daria Vaverková:** Project administration, Conceptualization, Data curation, Writing-Original draft preparation, Visualization, Writing-Reviewing and Editing, Supervision.

Data availability

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Příloha 5

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Article

Impact of Conservation Tillage Technologies on the Biological Relevance of Weeds

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Abstract: Limited tillage provides a number of benefits, but a question remains how it affects weed community and biodiversity evolving from the weed community. Our field experiment was established in the cadastral area of Branišovice (South Moravian Region, Czech Republic). Three different tillage technologies were used in this field experiment: conventional tillage, minimum tillage, and no-tillage technology. In 2001–2004, infestation by weeds was evaluated in the stands of spring barley, winter wheat grown after a dicot pre-crop (rape, soybean), in the stands of wheat grown after wheat, and in stands of maize. The recorded weed species were divided according to the criteria of biological relevance. Based on the results of the four-year field experiment, it is possible to state that tillage technologies have only a limited influence on the intensity of weeding but substantially alter the species spectrum of weeds. Weed vegetation in the no-tillage variant exhibits higher values of biological relevance, which allows a higher occurrence of weed-dependent species of organisms. Weed vegetation in the minimum soil tillage variant has the lowest biological relevance values, which limits the occurrence of weed-dependent organisms. Alterations in weeding caused by different tillage technologies are part of the process of vegetation microevolution in the agricultural landscape.

Keywords: weed vegetation; soil tillage; conservation tillage; biodiversity

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1. Introduction

Land degradation is one of the most pressing challenges for global food security [1]. Causes of degradation lie in intensive agricultural activities, which include excessive use of synthetic fertilizers and pesticides, crop monoculture, and intensive soil tillage [2].

For thousands of years, soil cultivation has been used to prepare the seed bed and to control weeds [3,4]. Currently, reduced tillage, or minimum tillage, is promoted as an alternative to the traditional soil tillage. Reduced tillage improves soil quality and mitigates greenhouse gas emissions, through increased soil carbon sequestration and fuel consumption of conservation tillage [5,6]. The use of conservation tillage is increasing worldwide [7] because of its benefits for soil and water conservation [8,9], as well as for reducing fuel consumption and labor costs [10]. In the United States, 37% of arable land is reported to be no-till, and 35% is conservation tillage [11], while globally, 11% of cropland is no-till [12].

Despite the benefits, many farmers around the world have not adopted conservation agriculture practices yet [13,14]. A commonly cited concern is the difficulty of weed control in no-till technologies, especially in locations where resistant weed populations are predominant [15,16]. Minimum tillage induces a response in the weed community

composition and increases weed infestation, leading to greater reliance on herbicides compared to conventional tillage systems [4,17,18], but increased weed infestation is not always the case [19,20]. According to Nichols et al. [16], field studies of conservation tillage practices often provide inconsistent results, although most studies conclude that no-till practices in monocultures lead to the highest weed density, which does not necessarily result in reduced yields [16,21]. However, there is a considerable variation in the effect of different tillage practices on weed density in different studies [22–25]. According to Cooper et al. [21], benefits of conservation tillage may outweigh any increase in weed pressure, as the increased weed density in conservation tillage systems is not consistently associated with the reduced crop yield.

Cropland weed diversity is key to maintaining biodiversity and providing ecosystem services in agroecosystems [26]. In addition, weed communities can have specific effects on the composition of the soil microbial community. Some studies have shown substantial effects of weed species (e.g., *Centaurea maculosa*) on the abundance of soil microbial functional groups and community composition [27–29]. Soil tillage can change the conditions for both weeds and microorganisms in the soil. Tillage stimulates the germination of weed seeds [30,31] and different tillage systems affect the accumulation and distribution of weed seeds in different soil layers differently [32,33]. Tillage is a significant factor influencing soil microbial communities [34], but it also has a strong negative impact on weeds and, subsequently, also on the communities of specific soil microbial functional groups [35]. However, weeds are also important for other organisms. Some authors suggest that the decline in many species of insects and birds on farmland is related to changes in agricultural practices adversely affecting weeds [36]. The abundance of weeds and the intensity of weed infestation on arable land have drastically decreased in recent decades throughout Europe [37,38].

Minimum tillage is also part of conservation agriculture (CA), which is defined as a combination of three principles: minimal soil disturbance, permanent organic soil cover, and species diversification [39]. In addition to reducing costs, CA prevents some threats such as soil erosion [40–42] and improves several ecosystem services, namely, soil physical and chemical properties, soil organic carbon (SOC), and also biodiversity [43,44].

Conservation tillage brings a number of benefits; the question is, what is the impact on the weed community and weed-related biodiversity? According to our hypothesis, conservation tillage will increase the biodiversity of field weeds. Sub-goals leading to the confirmation of our hypothesis are to (i) determine the effect of different tillage on the species spectrum of weeds (ii); determine the effect of different tillage methods on the intensity of weed infestation (iii); determine the effect of tillage on the biological relevance of weed vegetation. Understanding the relationship between tillage and the biological relevance of weeds will facilitate better prediction of changes in agricultural landscape biodiversity.

2. Materials and Methods

The experimental plot is located in the cadastral area of Branišovice municipality of the South Moravian Region, Czech Republic. The terrain is mostly flat to slightly sloping. Average altitude is approximately 205 m above sea level. The area of interest falls into the Dyje River basin. The location belongs to the very warm and dry climatic region of the Czech Republic. Long-term average annual precipitation is 452 mm, the long-term average temperature is 9.4 °C. Soil types are chernozem and clay loam soil on the experimental plot [45–47].

The field semi-operational experiment was established in the autumn of 2000. The balancing crop before establishing the experiment was winter wheat (*Triticum aestivum*). The size of plots was 50 m × 36 m, individual plots were separated from each other by ten-meter strips.

The experimental crops were grown in a five-season crop rotation, in the following sequence: winter rapeseed (later soybean), winter wheat, winter wheat, corn for grain,

spring barley. Due to substantial damage of the winter canola stand by voles and consequences of winter at the turn of years 2002 to 2004, the crop was eliminated and replaced with soybeans.

Three different tillage technologies were used for each grown crop in this field experiment. Tillage variants were:

(i) Conventional tillage (CT): composed of the following work operations: undersowing (carried out with a Kverneland subsoiler to a depth of approximately 0.1 m), ploughing up to 0.22 m (Lemken rotary double-sided plough, ploughing depth varied ± 10%), pre-sowing soil preparation and sowing with a sowing combination (seeding combination accord);

(ii) Minimum soil tillage (MT): the soil was tilled up to a depth of ca 0.08 m. It consisted of the following work operations: mulching after pre-crop harvesting (carried out with a Kverneland subsoiler), application of total herbicide on emerged weeds, shallow tillage (made with Kverneland chisel subsoiler), and sowing with sowing combinations (carried out seeding combination accord);

(iii) No tillage (NT): tillage was skipped, a total herbicide was applied to the growing weeds after the pre-crop was harvested, and the crops were sown with a special direct seeding machine (carried out seeding combination accord).

In 2001–2004, weed infestation was evaluated in the stands of spring barley, winter wheat after a dicot pre-crop (rape, soybean), in the stands of wheat after wheat, and in the stands of corn. Weeds were evaluated using a numerical method. The number of weed individuals was determined on an area of 1 m², in 25 repetitions for each variant, crop, and year. The evaluation was made before the application of herbicides. The taxonomic nomenclature of plants was according to Kaplan et al. [48]. An overview of the herbicides applied is given in Table 1.

Table 1. Summary of herbicides applied in the crops monitored.

Crop	After Harvesting the Pre-Crops	Crops Prior to Sowing	After Sowing and Crop Emergence
Winter wheat (pre-crop: winter rapeseed)	Roundup Forte (*glyphosate*)	-	Aurora (*carfentrazone-ethyl*), Mustang (*florasulam; 2,4-D*)
Winter wheat (pre-crop: winter wheat)	Roundup Forte (*glyphosate*)	-	Aurora (*carfentrazone-ethyl*), Mustang (*florasulam; 2,4-D*)
Corn for grain	Roundup Forte (*glyphosate*)	Guardian (*acetochlor*, furilazole), Atrazin (*Metolachlor*)	Cobra (*lactofen*), Granstar (*tribenuron methyl*)
Spring barley	-	-	Aurora (*carfentrazone-ethyl*), Mustang (*florasulam; 2,4-D*)

The recorded plant species were classified based on the database of Tyler et al. [49] according to criteria for biological relevance (biodiversity relevance). Biological relevance is defined for each species as a number of other organisms that depend on that species or that use it as a food source, substrate, shelter, or reproduction site. The logarithmic scale of biological relevance for the recorded plant species is shown in Table 2.

Table 2. Biological relevance of found weed species.

Labeling	Number of Species Dependent on Plants
BR1	<6
BR2	6–12
BR3	13–24
BR4	25–50
BR5	51–100
BR6	101–200

The numbers of weed individuals of all species were statistically evaluated by multifactorial ANOVA and Fischer's LSD test. All data were subjected to homogeneity and normality tests. Data were not transformed prior to the statistical analysis.

The representation of individual weed species in the respective tillage variants was processed by the multivariate analysis of ecological data. The selection of the optimal analysis depended on the length of the gradient, determined by the detrended correspondence analysis (DCA), which was followed by the canonical correspondence analysis (CCA) was used. Statistical significance was determined using the Monte Carlo test where 999 permutations were calculated. The data were processed using the Canoco 5 computer program [50].

3. Results

During the four-year monitoring, 51 weed taxa were found. The average number of weed individuals was 9.3 per m² in the CT tillage variant, 7.8 per m² in the MT variant, and 12.1 per m² in the NT variant. Results of the statistical evaluation of weed infestation intensity are shown in Figure 1. Differences in the number of individuals between most variants are not statistically significant. A statistically significant difference was recorded in 2002 in the NT variant for wheat (s) grown after a dicotyledonous pre-crop, where weeding was the highest. Within the cultivated crops and tillage variants, statistically significant differences are rare. A statistically significant difference was detected in the no-tillage variant where higher weeding occurred.

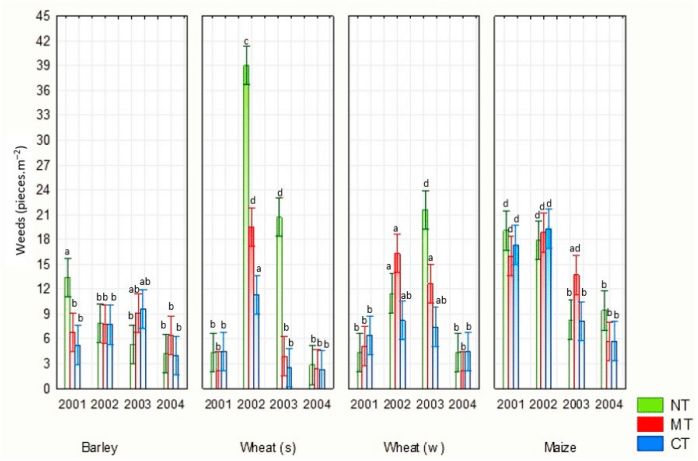


Figure 1. Intensity of weeding in the observed tillage variants, in the cultivated crops, and in the observed years. The results represent the mean of 25 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, whiskers

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represent the standard error, values with different letters (a, b, c, d) differ significantly. Variants of tillage technologies: CT—conventional tillage; MT—minimum tillage; NT—no tillage.

Based on the evaluation of biological relevance, it is evident that tillage creates favorable conditions for the growth of weed species from groups BR3 and BR4. The range of weed-dependent species varies between 13–50 species. Results of the evaluation of biological relevance are presented in Table 3. Weeds in the NT variant have the highest values of biological relevance and, thus, create a higher potential for the growth of other types of species on arable land. On the contrary, the weed vegetation in the MT variant has the lowest values of biological relevance.

Table 3. Groups of weeds according to the biological relevance of tillage variants.

Title 1	Soil Tillage Variant (Pieces.m^{-2})		
	CT	MT	NT
BR1	0.0	0.0	0.0
BR2	0.1	0.1	0.3
BR3	5.6	3.3	5.4
BR4	1.3	1.1	5.0
BR5	1.8	2.0	1.0
BR6	0.0	0.0	0.0
BR unknown values	0.5	1.2	0.6

The results of the CCA analysis, which evaluates the representation of individual weed taxa in the different tillage variants, are significant at the significance level $\alpha = 0.001$ for all canonical axes. A graphical representation of the results of the CCA analysis is presented in Figure 2. Based on the CCA analysis, the identified weed taxa can be divided into three groups. The division of taxa into groups according to the CCA analysis is shown in Table 4. The first group of species occurs mainly in the CT variant. The second group of species occurs mainly in the MT variant. The third group of species occurs mainly in the NT variant.

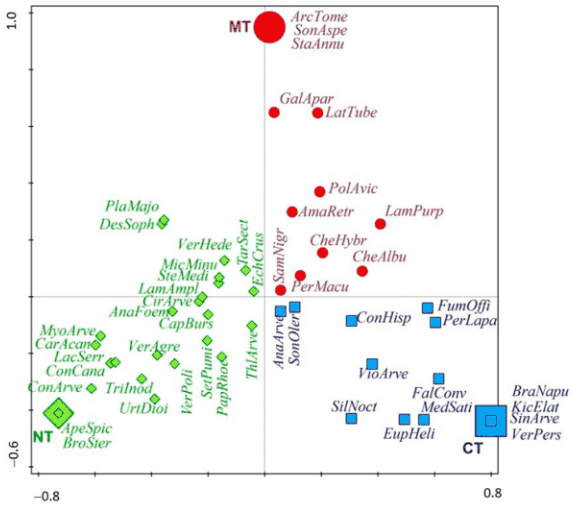


Figure 2. Relationship between identified weed taxa and tillage–result of CCA analysis (total explained variability = 11.8%; F-ratio = 15.9; *p*-value = 0.001).

Table 4. Groups of plant species according to CCA analysis.

Soil Tillage	Weed Groups	Weed Taxa
CT	Spring weeds	*Anagallis arvensis (AnaArve); Fallopia convolvulus (FalConv); Silene noctiflora (SilNoct); Sinapis arvensis (SinArve)*
	Summer weeds	*Euphorbia helioscopia (EupHeli); Kickxia elatine (KicElat); Persicaria lapathifolia (PerLapa); Sonchus oleraceus (SonOler)*
	Winter weeds	*Brassica napus (BraNapu); Consolida hispanica (ConHisp); Fumaria officinalis (FumOffi), Veronica persica (VerPers); Viola arvensis (VioArve)*
	Perennial weed	*Medicago sativa (MedSati)*
MT	Spring weeds	*Polygonum aviculare (PolAvic)*
	Summer weeds	*Amaranthus retroflexus (AmaRetr); Chenopodium album (CheAlbu); Chenopodium hybridum (CheHybr); Persicaria maculosa (PerMacu); Stachys annuam (StaAnnu)*
	Winter weeds	*Galium aparine (GalApar); Lamium purpureum (LamPurp)*
	Perennial weed	*Arctium tomentosum (ArcTome); Lathyrus tuberosus (LatTube); Sambucus nigra (SamNigr); Sonchus asper (SonAspe)*
NT	Spring weeds	*Anagallis foemina (AnaFoem)*
	Summer weeds	*Echinochloa crus-galli (EchCrus); Microrrhinum minus (MicMinu); Setaria pumila (SetPumi)*
	Winter weeds	*Apera spica-venti (ApeSpic); Bromus sterilis (BroSter); Capsella bursa-pastoris (CapBurs); Conyza canadensis (ConCana); Descurainia sophia (DesSoph); Lactuca serriola (LacSerr); Lamium amplexicaule (LamAmpl); Myosotis arvensis (MyoArve); Papaver rhoeas (PapRhoe); Stellaria media (SteMedi); Thlaspi arvense (ThlArve); Tripleurospermum inodorum (TriInod); Veronica agrestis (VerAgre); Veronica hederifolia (VerHede); Veronica polita (VerPoli)*
	Perennial weed	*Carduus acanthoides (CarAcan); Cirsium arvense (CirArve); Convolvulus arvensis (ConArve); Plantago major (PlaMajo); Taraxacum sect. Taraxacum (TarSect); Urtica dioica (UrtDioi)*

4. Discussion

Soil tillage has a statistically inconclusive or only a limited effect on the intensity of weed infestation of the monitored crops. These results are consistent with a number of studies that report inconclusive effects of different tillage systems on weed infestation [26,51]. Field studies dealing with minimum tillage practices often provide inconsistent results. Nevertheless, most studies conclude that no-till practices result in the highest intensity of weeds [16,21,22,24,].

The results show that NT tillage significantly increases weed infestation in some years, thus, creating a precondition for a higher weed infestation. It shows the largest differences between maximum and minimum weeding values. Findings of some research studies that indicate a higher weed infestation of crops grown under NT system conditions support this claim [52–55]. According to Benech-Arnold et al. [32] and Torreson et al. [56], conventional tillage distributes the weed seeds evenly within the tilled soil layer, while minimum tillage concentrates the seeds in the upper soil layer from where

they can germinate readily and at higher rates. The number of weeds is also significantly affected by the crop and weed species [57]. In the case of reduced technologies, the action of inhibitory substances has been proven, which can manifest itself in the limited germination of some species [58].

Based on the results, soil tillage significantly alters the species spectrum of weeds and the biological relevance of weed vegetation. Several studies draw attention to the influence of the species spectrum of weeds by the used tillage system [52,59,60].

The drying out of topsoil, which, according to Singh et al. [61], is faster for reduced systems, or the limited soil degradation, which was monitored for reduced technologies by Vakali et al. [62] and Siegrist et al. [63], may be the cause of the change in the weed species spectrum. Conventional tillage incorporates the weed seeds into greater depths, where their germination is inhibited, which results in a change in the species composition [64]. NT leaves the weed seeds on the surface; some species germinate better from the soil surface [65]. These changes in the soil environment can reflect in the species spectrum of weeds.

The results also demonstrate that NT creates more favorable conditions for grassy weed species, anemochorous species, and for species belonging to the group of winter and perennial weeds. Bilalis et al. [66] point out an increase in the perennial species (mainly *Convolvulus arvensis*).

Weed vegetation with the use of NT has a higher biological relevance, which contributes to the preservation and support of agricultural landscape biodiversity. Weeds provide a range of resources (pollen, nectar, fruits, seeds) that are part of the food for a variety of insects, birds, and mammals [67–70]. Weeds are important as a source of food and shelter for many natural enemies (parasitoids, predators) on pests of cultivated crops [71,72].

The MT variant creates more suitable conditions, especially for species from the group of summer weeds. A higher representation of summer weeds (*Amaranthus retrofexus*) was also observed by Nakamoto et al. [73], however, their representation varied between the observed years. MT weed vegetation has a lower biological relevance than the other monitored variants. MT tillage contributes only to a limited extent to the stabilization of biodiversity in the agricultural landscape.

An interesting question that would deserve further study is the interaction of tillage, weeds, and soil microorganisms. Studies comparing the effects of deep plowing and reduced tillage point to an increase in soil biological activity if the soil is not turned. There has been an increasing amount of information on the interaction between weeds (e.g., *Chenopodium album, Abutilon theophrasti, Amaranthus retroflexus, Thlaspi arvense, Setaria viridis*) and microbial communities in the soil [35]. The unique influence of weeds reflect in the composition of soil microorganisms, as well as in the representation of specific functional groups of microorganisms [27]. However, the effect of weeds on soil microbial communities is not consistent [27,29]. Moreover, changes in the microbial community structure increase the weed species' competitiveness [29].

No-till farming is a core component of CA and is considered preferable to conventional tillage. Reduced production costs, the ease of sowing seeds and fertilizer application, higher and stable production, soil erosion control, and higher efficiency of nutrient use are some of the advantages of minimum tillage [13]. However, there are also agronomic and ecological disadvantages associated with the no-tillage farming [74], which include soil compaction [75], unavailability of nutrients [76], and especially weed control [16]. Cooper et al. [22] claim that agronomic benefits of minimum tillage may outweigh increases in weed pressure, as the increased weed density is not consistently associated with reduced crop yield. On the other hand, Ali et al. [77] point out that the expanding popularity of MT and NT raises problems with the control of resistant weeds. The increased need for herbicide applications due to the increased weed infestation, frequently occurring with minimum tillage [78], causes negative impacts on the whole ecosystem.

5. Conclusions

Based on the results of our four-year field experiment, it is possible to state that tillage technologies have a limited influence on the intensity of weed infestation but significantly change the species' spectrum of weeds. The NT variant created more favorable conditions for the grass-type weed species, anemochorous species, and species belonging to the group of winter weeds and perennial species. The MT variant created more suitable conditions, especially for species from the group of summer weeds. It is the change in species composition that leads to changes in weed control, which will be reflected in a higher need for the chemical control of weeds.

MT technologies represent part of CA. One of the advantages of minimum tillage is the support of biodiversity. Weed vegetation in the NT method exhibit higher values of biological relevance; thanks to which, a higher occurrence of dependent species of organisms is possible. On the other hand, with the use of MT tillage, the vegetation features the lowest biological relevance values, limiting the occurrence of weed-dependent organisms. Therefore, there is a significant difference in the support of biodiversity between the minimum tillage methods. Minimum tillage cannot be always considered as a means of supporting biodiversity in the agricultural landscape. The importance of minimizing tillage and other conservation tillage methods will be assessed primarily in terms of environmental impacts. It is the importance for reducing CO_2 emissions, reducing erosion, and the importance for biodiversity that are the parameters that farmers will have to include in their practices.

Changes in weed infestation caused by soil tillage are part of a process we can call microevolution. If a weed species is to succeed under minimum tillage conditions, it must, as Raup [79] states, "*do something better than other weed species*". A more detailed study of the development of weed vegetation will help to understand the processes of genesis and extinction of plant species.

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Příloha 6

Urban Ecosystems
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Green space in an extremely exposed part of the city center "Aorta of Warsaw" - Case study of the urban lawn

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Abstract
The method of developing city centers is the responsibility of local authorities, which must reconcile the interests of investors applying for valuable land with the utility needs and expectations of residents regarding, inter alia, free squares and green enclaves. This study was conducted in Warsaw (Poland). In the study area, for 20 years there has been a discussion about how the area should be developed. So far, the area is used as lawns. During the monitoring period, 72 plant taxa were found. It is possible to state that an urban lawn is an ecosystem with relatively stable conditions, which is, however influenced by human disturbance and specific stress in the city. A city lawn is an oasis of greenery that is easy to set up and maintain, in the case of modernization, it does not generate large costs related to its restoration, unlike gardens. Maintaining an intensive lawn requires not only the selection of appropriate grass species resistant to the influences of the urban environment, but also the optimal way to us it. This research can be used to choose the optimal method for managing and maintaining greenery, considering the conditions of spatial development and environmental factors.

Keywords Warsaw · City development · Urban ecosystems · Urban greenery · Lawns · Vegetation heterogeneity

Introduction

Contemporary cities are characterized by growing density, while gradual overpopulation causes other problems in finding adequate apartments and exurbanisation (Cortinovis et al. 2019; Des Roches et al. 2021; Xi et al. 2022). The number of people inhabiting urban areas is estimated to increase by up to 70% by 2050 (Unhabitat 2009; Baldock 2020; Song et al. 2021). This fact affects city dwellers, exposing them to negative factors such as low air quality, noise, stress, traffic congestion, inefficient urban infrastructure, anonymity, and social pathologies (Fattah et al. 2022; Nieuwenhuijsen 2021; Khomenko et al. 2022; Xi et al. 2022). To counteract the adverse effects of city life and ensure optimum housing quality for residents, adequate number of biodiverse green areas should be ensured.

According to Meerow (2020), planning reflects decision-making processes that determine which outcomes are prioritized, where green areas are sited, and how. Plants and green spaces are key components in planning sustainable cities The environmental contribution of plants is important for the development of sustainability in cities and in the future (Ong 2003). Providing appropriate areas for well-functioning green systems is basic way to shape the spatial structure of city (Douglas et al. 2017). Urban green areas are often located in spaces that are attractive for investment; therefore, these areas are vulnerable to functional transformation (Dymek et al. 2021). Therefore, it is important to determine which Development Plans are the most valuable part of the urban greenery system.

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Sustainable development is of fundamental importance in these plans, ensuring the city's functionality with intensive development, including the planning of communication routes and places of temporary rest. Some elements of urban infrastructure are located underground (car parks, road and rail tunnels, underground passages, networks, and utilities transmission), which also makes development difficult. This also applies to the arrangement and maintenance of green urban areas.

Lawns in cities are an inseparable part of urban greenery. A large number of green areas in cities worldwide consist of traditional intensively managed lawns which form 15–30% of urban green areas (Hedblom et al. 2017; Pereira and Baró 2022). Traditional green lawn offers different options for recreation and leisure, which also have aesthetic values (Ignatieva and Hedblom 2018; Zinowiec-Cieplik 2020). In addition to aesthetic experience, lawns have a range of ecosystem functions, such as action on the micro-climate of urban space, retention and infiltration of rainwater, and source of food for animals (Hall et al. 2016; Tang et al. 2018). According to Bolund and Hunhammar (1999), lawns provide six main groups of services in urban ecosystems: air filtration, micro-climate regulation, noise reduction, rainwater drainage, recreation, and cultural value. The capacity of city lawns for carbon and nitrogen storage is also interesting, and can be higher than the capacity of other grass stands outside the urban space (Pouyat et al. 2006; Raciti et al. 2008; Sieczka and Koda 2016).

Intensively managed lawns maintained by herbicides, fertilizers, irrigation, and frequent mowing have a high aesthetic value (Ignatieva et al. 2017; Yue et al. 2017; Yang et al. 2019;). However, this value comes at the cost of considerable water consumption, outflow of nutrients, and low species diversity (Robbins and Sharp 2003; Fissore et al. 2012;). The extensive management of lawns reduces the consumption of fertilizers and the necessity of mowing (Hugie and Watkins 2016). Lawns often include spontaneous plant species that serve as food sources for pollinators (Larson et al. 2014; Lerman and Milam 2016) and provides refuges and corridors within some limits for native flora and fauna (Wheeler et al. 2017; Hu et al. 2022).

The maintenance of traditional lawns is costly; therefore, solutions are required, that would reduce the costs without limitations in providing ecosystem services for lawns (Smith and Fellowes 2015; Tempesta 2015). In general, this problem can be resolved by reducing the maintenance of lawns and the number of cuts, which would contribute to more environment-friendly actions (Chollet et al. 2018; Bonthoux et al. 2019).

Extensive management of urban grasslands brings benefits such as lower maintenance costs and increased biodiversity. Nevertheless, extensively managed, and unmaintained urban grasslands are places with a high risk of fire. Dry and warm weather, combined with dry plant biomass, can lead to fires ((Winkler et al. 2021a).

Urban green spaces must be planned and located like other land use and built environment features, and this inevitably requires negotiating conflicting priorities (Meerow 2020). However, there seems to be a gap between theory and practice. For 20 years there has been a discussion about how the study area should be developed. So far, this area has been used as a lawn. Urban lawns, as ecosystems created by humans (Thompson and Kao-Kniffin 2017) have to cope with unfavorable pedological conditions such as compaction of lower soil profile layers or disturbed water regimes of soils, including limited capillarity. Coping with stressful conditions determinizes the survival of plant species in urban lawns. Therefore, lawn vegetation management has a essential influence. There is a hypothesis that different management of lawns changes competitive relations among species in this ecosystem on the background of very specific stress conditions in urban spaces. Three goals were set up to confirm or disprove the hypothesis to: (i) define the species composition of lawn vegetation, (ii) identify functional groups of plant species in urban lawns, and (iii) determine the impacts of different lawn management practices on species composition and ecosystem functions. The results of research on existing lawns can be used to choose the optimal method of managing and maintaining urban greenery, considering the conditions of spatial development and environmental factors. Urban lawns are often the only green infrastructure alternative, particularly in places with high concentrations of other engineering networks and traffic restrictions. By their very nature, lawns enable a quick solution to emergency situations, they do not represent a traffic obstacle, and yet they bring a number of benefits.

Materials and methods

Site characterization

The study was conducted in Warsaw (Poland) an area of which is 517.2 km^2. It has a population of approximately 1.7 million. Warsaw is situated in the Mazovian Lowland in central Poland. The city spreads on two main geomorphological formations: the Vistula River valley and the moraine hilly land, which are divided on the left riverside by the Warsaw Escarpment (Czarnecka et al. 2021). The city has a system of green areas that is well developed in the long run (Kuchcik et al. 2016), which comprises urban forests, parks, squares, roads protected areas and dwelling green areas. A quarter of the city area is covered with residential development, and the same area is covered with

greenery (Kaczyńska 2020). Many urban green areas are situated along the Vistula River and its surrounding ares. Compared with other European cities, Warsaw is a city with riverine greenery and wood (Wilczyńska et al. 2021). However, in the center of Warsaw, the size of the green areas is very limited. The study locality in the center of Warsaw (area = 186.321 ha) is presented in Fig. 1.

The total green area in the selected area is approximately 14.8866 ha (including 2.8862 ha of lawns and 12.0004 ha of trees and lawns), which is approximately. 8% of the delimited center of Warsaw. The analyzed research lawns (L1; L2) are located above a tunnel that is part of the Warsaw Cross-City Line (Fig. 1), a 7 km railway underground line crossing the Central Warsaw in the east-west direction. A cross-city line is a key element of transport in Warsaw. The Warszawa Centralna Station is connected by underground passages to the Warszawa Śródmieście Station located entirely in an underground tunnel. The site is a typical urban space in which pedological conditions are strongly affected by building activities.

The development of the area where the studied lawns (L1; L2) are located has been extensively discussed by

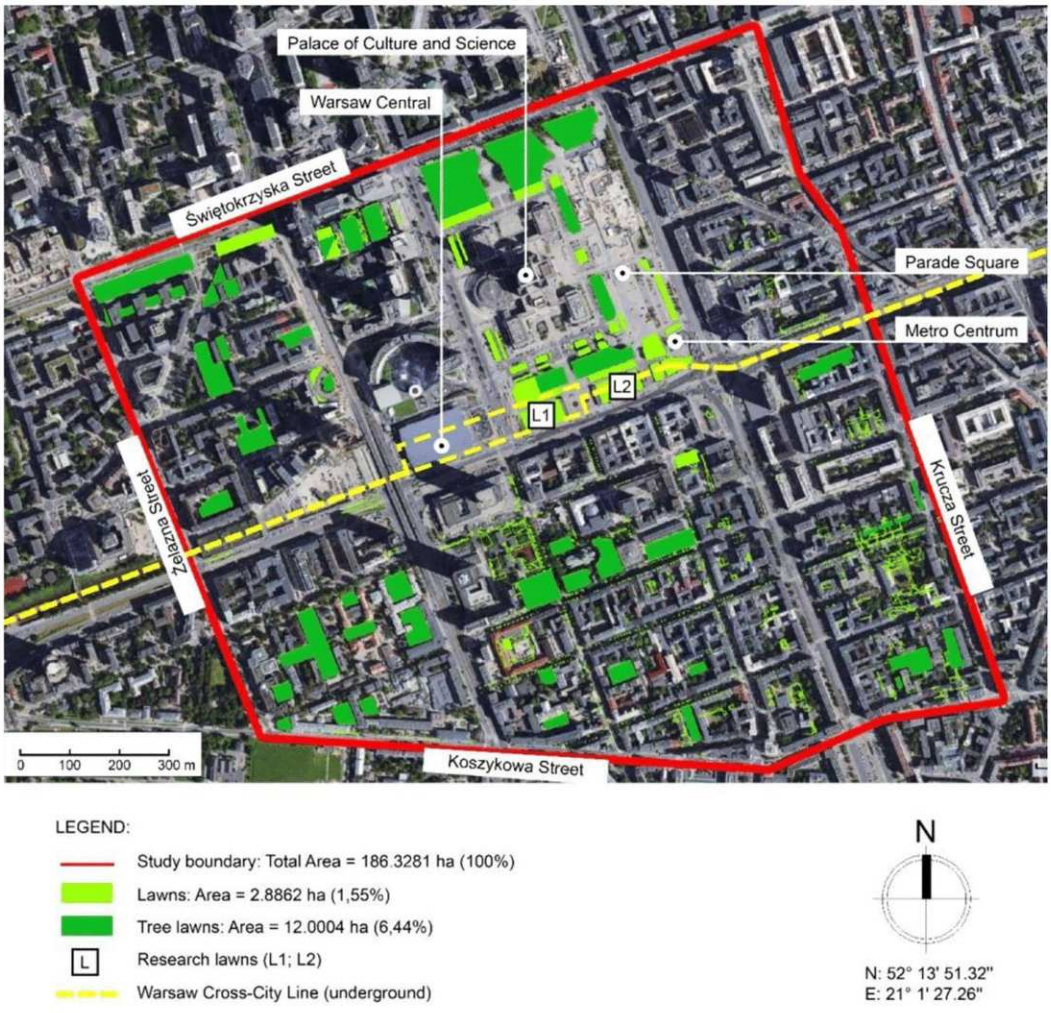


Fig. 1 The studied locality - current state on the orthophotomap (original study, based on https://polska.geoportal2.pl/map/www/mapa.php?mapa=polska, access: 8.08.2021)

local authorities, architects, and members of the community in Warsaw for over 20 years. The area is very attractive because of its communication location, an intense stream of people passing between the shopping center, Centrum metro station, and the above-mentioned railway stations, as well as active street trade and informal gatherings of people. An area lowered by the Centrum metro station is called Warsaw's Hyde Park, or "Patelnia" (ang. "The Pan"). Management of the Polish State Railways (PSR) was omitted in the discussions and plans for the development of the area, despite the fact that its main part is located above the railway tunnel, which condemned such plans to failure in advance. Permanent structures and water reservoirs cannot be established above the tunnel.

According to the current Master Plan, a significant part of lawns in this quarter will be removed because of planned investments (Resolution of the Warsaw City Authorities No. XCIV/2749/2010 of 9 November 2010), like the creation of a new City Centre, the construction of office buildings, commercial and cultural facilities. As a result, the lawn area will be reduced to 11.4732 ha, representing 6.16% of the demarcated center of Warsaw, (total area = 186.321 ha; lawns to be removed area = 3,4134 ha).

The examined lawns description

The monitored lawns (L1; L2) are located above the Warsaw Cross-City Line tunnel and are now part of the central public space (Fig. 2). The upper part of the study ground was made of soil-rubble fills. Pedological conditions can be characterized as anthropogenic with strongly altered and heterogeneous properties. The study site is an urban heat island, that is a place with a typical urban micro-climate. It is a locality with very specific stress conditions created by human civilization. In the immediate neighborhood, there are paved walkways for intensive pedestrian traffic between metro and railway stations.

Vegetation was assessed in lawns under two different management practices: (i) Traditional low lawn (TLL): The removal of biomass is performed 4–6 times during the growing season within traditional management. The number of cuts was determined based on the vegetation growth rate. The maximum height of the lawn is 0.4 m, then a cut follows. This is a common management practice applied to urban lawns over a long period (Fig. 3A). (ii) Tall city lawn (TCL): Here, management practice is applied with the goal of reducing costs related to urban lawns. The lawn was not

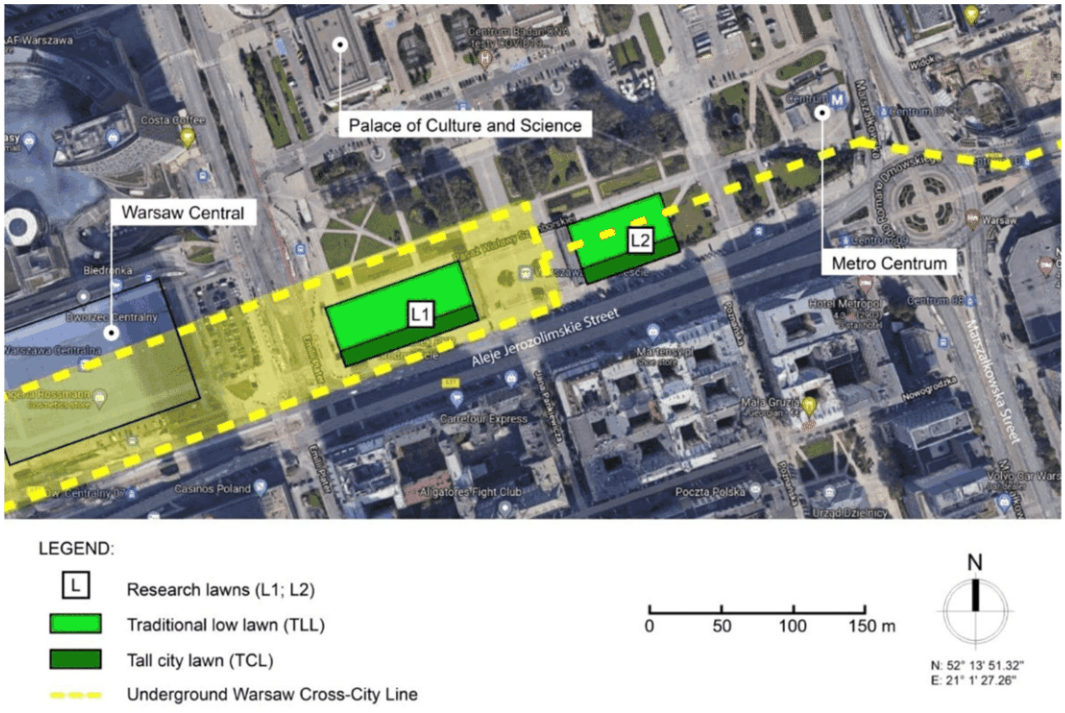


Fig. 2 The monitored lawns (traditional low lawn is marked in light green and high city lawn is marked in dark green), (original study, based on https://www.google.com/maps, access: 8.12.2021)

cut during the growing season or other cultivation measures (fertilization and, irrigation) were adopted. At the end of the growth, the biomass was mowed and removed (Fig. 3B).

Vegetation assessment

The vegetation was assessed using phytocoenological relevés sized 5 m^2. In each variant of the lawn, five plots were surveyed, on which vegetation assessment took place in July of years 2020 and 2021. First, all taxa of plants occurring in the phytocoenological relevé were identified, and then the degree of coverage was estimated for above-ground biomass of individual taxa. The scientific names of the plant species were obtained from the Pladias database of flora and vegetation (2021). The values of plant species coverage at the studied sites were subjected to a multidimensional analysis of ecological data. The choice of optimal analysis was ruled by the length of gradient identified by the Principal Component Analysis (PCA). The adjusted explained variation was calculated to be 48.6. Redundancy Analysis (RDA) was also used. Then, the data were processed using RDA to determine the correlation between plant species and lawn management. The RDA defines the spatial arrangement of individual plant species and variants of lawn management. Statistical significance was determined using the Monte Carlo test and 999 permutations were calculated. The data were processed using Canoco 5.0 computer program (Ter Braak and Šmilauer 2012).

Division of plant species into functional groups

Based on information from the Pladias database (2021), plant species were classified into several groups according to the selected characteristics: (i) Taxon origin: Taxa are divided into groups based on whether they are native or non-native in central Europe. The native taxon developed in the territory of Central Europe during evolution or appeared in Central Europe from the territory where it developed, without the contribution of humans. The non-native taxon has got to the territory of Central Europe from the territory in which it is native due to human activities, or by natural way from the territory in which it is non-native. Non-native taxa are classified as archeophytes and neophytes according to the time they were introduced in our territory. Archeophytes are non-native taxa introduced in the period between the beginning of Neolithic farming and year 1500, that is the time after the discovery of America, characterized by the development of overseas trade. Neophytes are non-native taxa that were introduced after 1500 years (detailed definitions see Richardson et al. 2000 and Pyšek et al. 2012). Non-native taxa that are cultivated more frequently in the Czech Republic (CR), but have not yet become wild, are presented separately. Data on the origin and time of introduction come from the Catalogue of non-native flora of the CR (Pyšek et al. 2012) where links are given to information sources about the origin of the taxa, which are complemented with some more recent findings. (ii) Plant height: Plant height is e related to the territory of Central Europe. They are presented in meters and applied to fully developed plants in a generative state growing in an open environment. Two values were mentioned for each taxon: minimum (common lower limit) and maximum (common upper limit). Data were obtained from the key to flora of the CR (Kaplan, 2019). (iii) Prevailing mode of pollen transfer: Pollen transfer onto the stigma is mediated by either abiotic vectors (carriers) such as wind (anemophilia) or biotic vectors such as insects (entomophilia). An alternative mechanism is self-pollination (autogamy), which can have various special forms, such as cleistogamy (self-pollination in incompletely developed, obligatorily autogamous flowers), pseudocleistogamy (self-pollination in flowers that are do not open due to unfavorable environmental conditions), or geitonogamy (self-pollination with pollen from the neighboring flower of the same plant when the pollen is not transferred by vector).

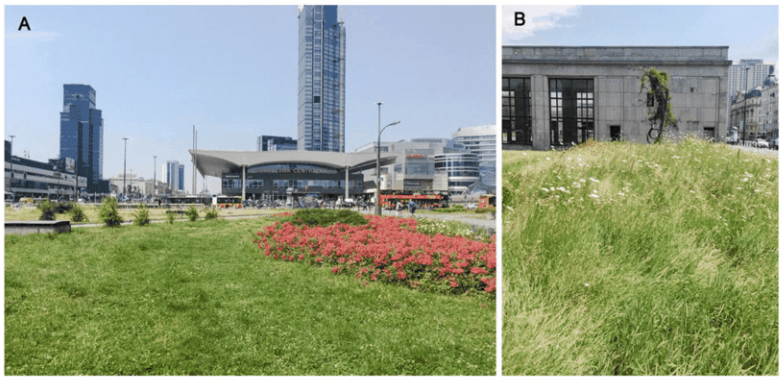


Fig. 3 The studied lawns in the center of Warsaw, year 2020: **A** - Traditional low lawn (TLL), **B** - Tall city lawn (TCL).

Information about the modes of pollination was obtained from the BiolFlor database (Durka 2002). (iv) Cultivation groups of plant species: Plant species were divided into three groups according to their properties and functions in the lawns. Group 1 includes grasses, which are representatives of the *Poaceae* family. This species forms the basis of lawn communities. Group 2 include legumes, which are representatives of the *Fabaceae* family. These plant species play important roles in nitrogen cycling. Group 3 represents other species, usually those that are undesirable in lawns and interfere with their function. (v) The share of life strategies: (Grime 1974, 1979) distinguished three basic ecological strategies of plants: competitive strategy (C), useful on stable sites with sufficient sources, not extreme conditions and limited interference; stress tolerant strategy (S), useful on sites with insufficient sources, extreme and very variable conditions but limited interference; and ruderal strategy (R), useful on sites with sufficient sources, not extreme conditions but with a frequently occurring interference. Taxa were allocated to life strategies using the method proposed by (Pierce et al. 2017). This method makes use of three key functional properties of leaves, which reflect differences in the investment of nutrients: leaf area (LA; is large in strongly competitive taxa), leaf dry matter content (LDMC; is high in taxa tolerant to stress) and specific leaf area (SLA; is large in ruderal taxa). These data were used to calculate scores that express the rate of C, S, or R selection on a percentage scale. The sum of the three scores for each taxon were 100%. Data on the properties of leaves for the calculations and/or directly calculated values were borrowed from the LEDA database (Kleyer et al. 2008) and other studies (Bjorkman et al. 2018; Dayrell et al. 2018; Findurová 2018; Tavşanoğlu and Pausas 2018). The Pladias database contains three scores for the C, S, and R strategies and the categorized life strategies. Values of the C-score, S-score, and R-score were examined for each taxon occurring in the phytocoenological relevé. The values were then used to calculate the mean values of the scores of life strategies for individual plant species in the relevé.

Results

A total of 72 plant taxa were identified during the survey, of which 39 were identified in TLL and 58 in TCL. The representation of the plant taxa on the monitored sites is presented in Appendix A. The results of the analysis were graphically expressed by means of ordination diagram (Fig. 4).

The results of the RDA which evaluated the coverage of plant taxa, were significant at a level of $\alpha = 0.001$ for all canonical axes. Based on RDA analysis, the identified plant taxa were divided into four groups (Table 1).

The representation of the respective groups of species in lawns with different management methods is presented

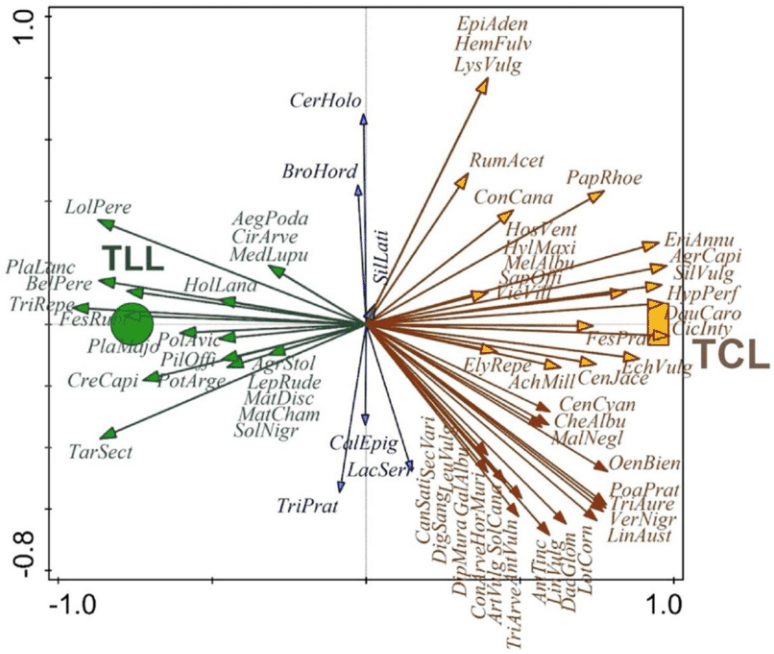


Fig. 4 Relation between the identified plant taxa and different lawn management methods (result of RDA; total explained variability = 48.6%; F ratio = 8.3.; P value = 0.001)

in Fig. 5. The species are divided into groups according to their origin, prevailing mode of pollen transfer and growing properties. The maximal height of plants was borrowed from the Pladias database (2021), and its average value was calculated. The average maximal height of species in TLL and TCL was 0.71 and 0.97 m, respectively. Figure 6 illustrates the shares of life strategies applied by the identified plant species.

Discussion

Urban green spaces play an essential role in the urban environment by providing a range of ecological, aesthetic, social, and economic benefits (Schrammeijer et al. 2022). Although cities are often considered "concrete jungles" (Hu et al. 2022), created natural enclaves, within urban areas can provide valuable ecosystem service. The role of lawns in the urban environment is multifaceted. From an ecological perspective, lawns provide several benefits. First, they can help reduce the urban heat island effect by reflecting solar radiation and cooling the air through evapotranspiration (Hu et al. 2021). Second, lawns can improve soil quality by promoting aeration and water infiltration, reducing soil erosion, and increasing organic matter content. Third, lawns can support biodiversity by providing habitat for a range of plant and animal species (Francoeur et al. 2021; Khare et al. 2021; Ervin et al. 2022).

Lawns play a significant role in different types of urban green spaces, such as parks, gardens, and public squares. lawns offer various recreational opportunities for urban residents, such as picnicking, sunbathing, and playing sports (Ignatieva et al. 2020). In parks, lawns are often used as a central gathering space for social activities and events such as concerts and festivals (Smith et al. 2021). They also provide an open space for physical activities such as jogging, yoga, and other fitness routines (Gaikwad and Shinde 2019). Lawns in parks can also contribute to the biodiversity of the area by providing habitats for insects and other small animals (Wenzel et al. 2020). In gardens, lawns are often used as a transitional space between the garden beds and borders. They can provide a neutral, green space that draws the eye and allows for easy movement through the garden. Lawns in gardens also offer a space for relaxation and contemplation, as well as a venue for social events, such as outdoor weddings and receptions (Hanson et al. 2021; Poniży et al. 2021). In public squares, lawns are often used to provide a calming oasis in the midst of the bustling city. They can offer a space for people to rest, relax, and enjoy the scenery. Lawns in public squares can also be used for small community events, such as outdoor concerts, art exhibits, and community meetings (Cao and Kang 2019; Carmona 2019; Deni et al. 2022).

Our results indicate that TCL featured 19 more species more than TLL and created phytocenosis richer in species. According to Bertoncini et al. (2017), lawns without the application of herbicides or other chemicals generally promote the occurrence of flowering plant species. Chollet et al. (2018) observed that a very low frequency of mowing has a beneficial effect on all aspects of species diversity, including functional and phylogenetic diversity. The reduced frequency of mowing offers an opportunity to convert of urban

Table 1 Groups of plant species classified based on the RDA analysis

Group	Species
Species of traditional low lawns (TLL)	*Aegopodium podagraria* (*AegPoda*), *Agrostis stolonifera* (*AgrStol*), *Bellis perennis* (*BelPere*), *Cirsium arvense* (*CirArve*), *Crepis capillaris* (*CreCapi*), *Festuca rubra* (*FesRubr*), *Holcus lanatus* (*HolLana*), *Lepidium ruderale* (*LepRude*), *Lolium perenne* (*LolPere*), *Matricaria discoidea* (*MatDisc*), *Matricaria chamomilla* (*MatCham*), *Medicago lupulina* (*MedLupu*), *Pilosella officinarum* (*PilOffi*), *Plantago lanceolata* (*PlaLanc*), *Plantago major* (*PlaMajo*), *Polygonum aviculare* (*PolAvic*), *Potentilla argentea* (*PotArge*), *Solanum nigrum* (*SolNigr*), *Taraxacum* sect. *Taraxacum* (*TarSect*), *Trifolium repens* (*TriRepe*).
Species of tall city lawns (TCL) – main group	*Agrostis capillaris* (*AgrCapi*), *Achillea millefolium* (*AchMill*), *Centaurea jacea* (*CenJace*), *Cichorium intybus* (*CicInty*), *Conyza canadensis* (*ConCana*), *Daucus carota* (*DauCaro*), *Echium vulgare* (*EchVulg*), *Elymus repens* (*ElyRepe*), *Epilobium adenocaulon* (*EpiAden*), *Erigeron annuus* (*EriAnnu*), *Festuca pratensis* (*FesPrat*), *Hemerocallis fulva* (*HemFulv*), *Hosta ventricosa* (*HosVent*), *Hylotelephium maximum* (*HylMaxi*), *Hypericum perforatum* (*HypPerf*), *Linaria vulgaris* (*LinVulg*), *Lysimachia vulgaris* (*LysVulg*), *Melilotus albus* (*MelAlbu*), *Papaver rhoeas* (*PapRhoe*), *Rumex acetosella* (*RumAcet*), *Saponaria officinalis* (*SapOffi*), *Silene vulgaris* (*SilVulg*), *Vicia villosa* (*VicVill*).
Species of tall city lawns (TCL) – subgroup	*Anthemis tinctoria* (*AntTinc*), *Anthyllis vulneraria* (*AntVuln*), *Artemisia vulgaris* (*ArtVulg*), *Cannabis sativa* (*CanSati*), *Centaurea cyanus* (*CenCyan*), *Convolvulus arvensis* (*ConArve*), *Dactylis glomerata* (*DacGlom*), *Digitaria sanguinalis* (*DigSang*), *Diplotaxis muralis* (*DipMura*), *Galium album* (*GalAlbu*), *Hordeum murinum* (*HorMuri*), *Chenopodium album* (*CheAlbu*), *Leucanthemum vulgare* (*LeuVulg*), *Linum austriacum* (*LinAust*), *Lotus corniculatus* (*LotCorn*), *Malva neglecta* (*MalNegl*), *Oenothera biennis* (*OenBien*), *Poa pratensis* (*PoaPrat*), *Securigera varia* (*SecVari*), *Solidago canadensis* (*SolCana*), *Trifolium arvense* (*TriArve*), *Trifolium aureum* (*TriAure*), *Verbascum nigrum* (*VerNigr*).
Species whose occurrence was affected by factors other than lawn management	*Bromus hordeaceus* (*BroHord*), *Calamagrostis epigejos* (*CalEpig*), *Cerastium holosteoides* (*CerHolo*), *Lactuca serriola* (*LacSerr*), *Silene latifolia* (*SilLati*), *Trifolium pratense* (*TriPrat*).

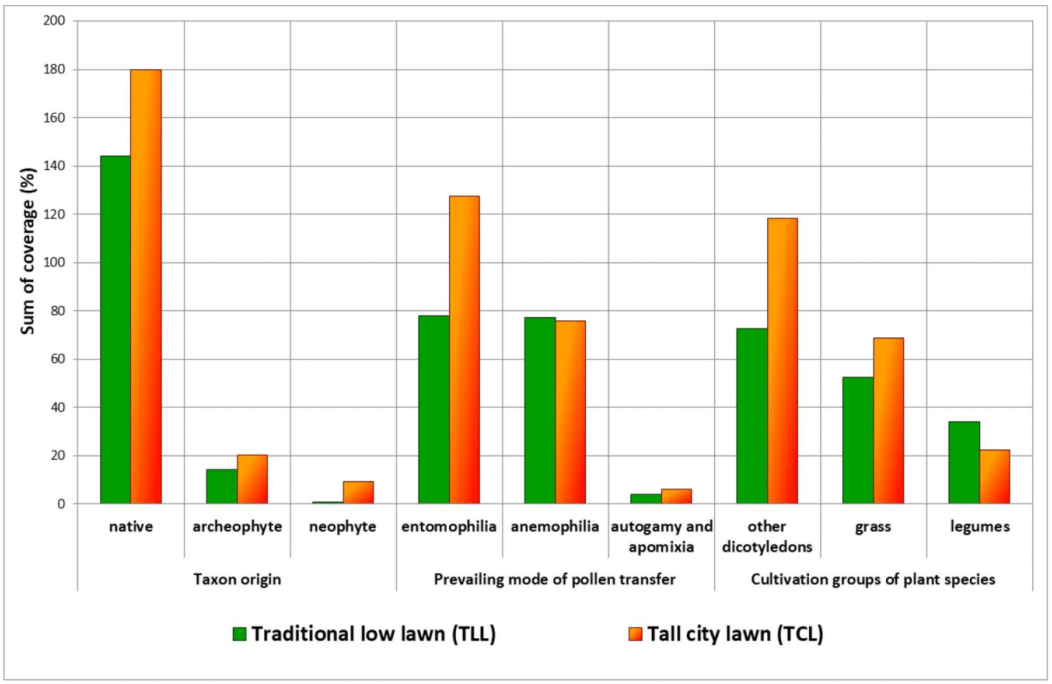


Fig. 5 Average degree of cover of the groups of species represented in the lawns

lawns into urban green fields/meadows. If we compare the number of species (39 plant species) in TLL, we can say that traditional low lawns are anthropogenic sites that are rather poor in species. The research findings were confirmed by Sikorska et al. (2020) who found that the number of species in the park lawns of Warsaw fluctuated from 16 to 25.

The results also showed that communities developing in lawns that are not cut differ in species. CCA analysis divided the species occurring in the TCL into two communities. Species of the subdominant position in the main group of species are *Agrostis capillaris, Daucus carota, Elymus repens, Achillea millefolium, Hypericum perforatum, Echium vulgare, Silene vulgaris* and *Festuca pratensis.* Species of the subdominant position in the subgroup were different and included *Poa pratensis, Linum austriacum, Trifolium aureum, T. arvense, Verbascum nigrum, Lotus corniculatus* and *Anthemis tinctoria.* Differences in species composition of vegetation are presumably a response to different soil conditions. Urban soils are increasingly being recognized as providers of ecosystem services (Delbecque et al. 2022). The soil profile in cities is often disturbed by construction work during which changes occur in the placement of individual soil layers or admixtures of building materials into the soil. These changes result in changes in the pedological environment in which the vegetation of urban lawns has to cope, which shows the distinctive heterogeneity of species composition.

Moreover, cities are centers of heavy metals (HM) emissions owing to intensive anthropogenic activities (Pan et al. 2018). Anthropogenic sources of HM in urban areas include industrial emissions, fertilizers, corrosion of construction materials, and coats (Kandic et al. 2019). After release, HM are transported by air and water streams, and finally deposited on soil surfaces owing to their high adsorbability on soil particles (Peng et al. 2022).

It has been confirmed that more frequent mowing is associated with a lower abundance and richness of bees in Tubingen, Germany (Wastian et al. 2016), lower butterfly diversity in Malmö, Sweden (Aguilera et al. 2019), and a decrease in native plant species in Xi'an, China (Zang et

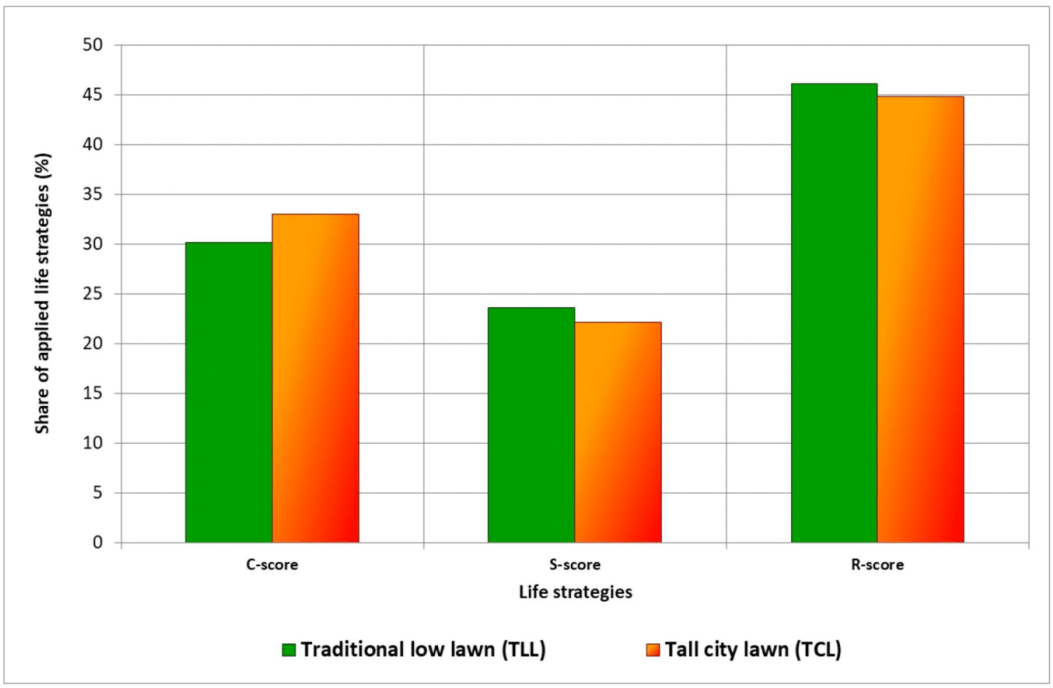


Fig. 6 Average share of the life strategies of species occurring in the lawn

al. 2019). Ecosystems with higher numbers of plant species provide insects and small vertebrates with multiple opportunities to get to food and maintain biodiversity in the urban environment. In general, lawns could serve as sources of food for fauna, including honeybees and butterflies living in urban environments (Öckinger et al. 2009; Matteson and Langellotto 2010; Zinowiec-Cieplik 2020). Globally, the occurrence of honeybees and other pollinators has recorded alarming reductions (Vanbergen et al. 2013; Baldock 2020). The small green areas in cities and towns could provide natural habitats for pollinators and mitigate the loss of diversity and its negative consequences (Goddard et al. 2010). Several scientific studies (Fischer et al. 2016; Harrison and Winfree 2015; Threlfall et al. 2015) indicate a surprising level of biodiversity and abundance of honeybees in towns. According to Baldock (2020), public greenspace areas, which are often managed by regular grass cutting, lead to the loss of most flowers. The potential impact of urban greenspaces was also investigated in four cities in the United Kingdom. the addition of flowers was found to increase the robustness of city-scale plant-pollinator communities (Baldock 2020).

The results indicated that both surveyed lawns were dominated by native plant species. The proportion of neophytes in the degree of coverage is lower than 10%. Similar results have been reported by Sikorska et al. (2020). According to their conclusions, the proportion of non-native species in Warsaw parks ranged from 2.7 to 8.7%. Therefore, it is obvious that urban lawns consist of phytocoenoses, with a low representation of neophytes. Different types of management promote the occurrence of native species. Despites this, attention should be given to the control of some neophytes such as *Conyza canadensis*, *Erigeron annuus*, *Oenothera biennis* and *Solidago canadensis*, particularly in TCL, where mowing is limited. Hu et al. (2022) pointed out that the origin of species is an important factor in judging the contributions to ecosystem services or biodiversity. According to Hufbauer (2018), an excessive proportion of neophytes and/or invasive species may weaken ecosystem stability. Adaptable invaders tend to establish vigorously in communities of native species and modify local ecosystems.

Studies have focused on the benefits of urban lawns; however, the fact that plants in lawns produce pollen may induce allergic reactions in sensitive persons. Studies on the allergenicity of urban green spaces are extremely important because a growing trend in the number of allergic sufferers has been observed (Jianan et al. 2007; Cariñanos et al. 2014; Kasprzyk et al. 2019). In this regard, anemophilic plant species are important, representing one of the adverse

effects on human health in urban environment (Dudek et al. 2018; Kasprzyk et al. 2019; Vaverková et al. 2019; Cristofori et al. 2020). In TLL, flowering and pollen production can be reduced by cutting stands. Nevertheless, cutting in the growing season is not carried out in TCL; therefore, anemophilic plant species represent a source of pollen, and a source of allergic reactions. Entomophilic plant species can represent a potential 'disservices' too (Meerow 2020); many pollinators are dangerous for sensitive persons with allergic response to insect poison.

Grasses are important in the vegetation of lawns, primarily owing to their tillering capability and capacity to create a closed continuous canopy. A very crucial plant species is *Lolium perenne*. The closed green canopy performs both aesthetic and erosion control functions. Legumes capable of binding atmospheric nitrogen play an important role in the sustainability of lawn ecosystems. The representation of other dicotyledons is typically perceived as undesirable. However, this group also plays a role in the functioning of lawn ecosystems. The shape and structure of their root systems create non-capillary soil pores, which increase the infiltration capacity of the soil and retain water. The higher representation of dicotyledons in the TCL creates the potential for higher infiltration capacity in these areas. Bolund and Hunhammar (1999) claim that lawns inhibit the surface runoff and only 5 to 15% of rainwater run off the surface while the remaining rainwater penetrates deep into the soil or is evaporated. According to this definition, TLL represents a living space primarily for plant species of low height. Regular mowing reduces the occurrence of tall herb species. In contrast, TCL is an ideal living space for tall herbs that pushes out lower plant species owing to undisturbed growth. Lower grass species are less exposed to fire hazards in cities ((Winkler et al. 2021a).

The two studied types of lawns represent living spaces in which individual plant species apply similar life strategies. Figure 5 shows that lawns are suitable for species with prevailing ruderal life strategy. This strategy allows them to survive human disturbances, such as mowing, biomass removal, and the supply of nutrients, namely nitrogen. The plants also significantly apply their competitive strategy, which points to the stability of urban lawns. Under conditions, plants then compete for life factors. The lowest share is that of the stress strategy, which still exceeds a 20%. Thus, it is obvious that plant species in urban lawns are exposed to specific stress conditions which include the microclimate of urban spaces characterized by high temperatures and lack of water surplus. Salting of pavements and the action of waste or dog excrement can also be considered as stress factors. Thus, urban lawns are environments with relatively stable conditions, that are strongly influenced by human disturbance under specific stress conditions. These specific environmental conditions form a self-contained phytocenosis, which is represented by urban lawns. The specific conditions of urban lawns can be a space for the application of a new life strategy of plants (Winkler et al. 2023) and can also block and change the course of vegetation succession ((Winkler et al. 2021b).

Changes in the management of lawns point to a new and creative approach leading to the support of biological diversity in cities and reconsideration of the role played by lawns in the enrichment of urban areas. Less frequent mowing is a practical, economical, ecological, and time-saving alternative to the traditional lawns. This alternative has the potential to be widely accepted, provided that it can overcome obstacles to social acceptance (Lerman et al. 2018). Several studies suggest that management methods friendly to wild animals have a certain backing on the public. However, these lawns are more prone to the occurrence of weeds as well as to the occurrence of native plant species (Frankie et al. 2005), which may interfere with preferred goals such as aesthetics and easy maintenance (Lerman et al. 2012; Van Heezik et al. 2012).

Globalization and urbanization are the main drivers of urban landscape homogenization worldwide. Therefore, the flora and fauna of cities are markedly similar in different parts of the world despite geographical and climatic differences (McKinney 2006). The alternation of TLL and TCL has the potential to successfully resist this trend and increase the biological diversity of urban ecosystems.

City lawns in the study area did not hinder the use of railway tunnel and pedestrian communication routes on the surface. They are a space available for the organization of small gatherings of people and periodic cultural and commercial events. Lawns are easy to maintain and can be recreated in the event of the need to carry out renovation, modernization, and maintenance work on existing equipment and facilities.

Conclusion

Based on the findings, it can be concluded that the study area in the urban environment has unique conditions and functions that should be respected while also allowing for the creation of a biodiverse oasis that enhances aesthetic appeal and positively influences the microclimate. Urban lawns are a suitable type of vegetation that can be purposefully included in highly trafficked areas, and they represent a new and specific type of vegetation that co-creates an urban environment.

The results of vegetation analysis indicate that urban lawns are ecosystems with relatively stable conditions but are strongly influenced by human disturbance and the specific stress conditions of cities. Changes in the management

of urban lawns can lead to changes in the species composition and affect the aesthetic perception of lawns. Tall city lawns can be an alternative approach to support biodiversity in the city and combat urban landscape homogenization. However, the heterogeneous composition of tall city lawns may lead to differing opinions among the city inhabitants.

The integrated planning of urban models that consider environmental and social trade-offs and synergies is essential for creating sustainable and diverse urban green areas. Findings of our study suggest that careful consideration and management of urban lawns can contribute to creating a more sustainable and biodiverse urban environment.

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Jan Winkler, Eugeniusz Koda, Jana Červenková, Igor Děkanovský, Aleksandra Nowysz, Łukasz Mazur, Aleksandra Jakimiuk and Magdalena Daria Vaverková. The first draft of the manuscript was written by Jan Winkler, Magdalena Daria Vaverková and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

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Příloha 7

fire

MDPI

Article

Fire Hazard: Undesirable Ecosystem Function of Orchard Vegetation

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Abstract: Fires will become an increasingly frequent perturbation even under the conditions of the mild climate zone and will interfere with the agricultural landscape. Fire is a natural phenomenon, and depending on ecosystems, vegetation may develop and contribute to the occurrence and spread of fire. Vegetation of the *sour* cherry orchard located in the climatically dry conditions of the South Moravian Region, Czech Republic (CR), was evaluated. Vegetation assessment was performed using phytocenological relevé. In each variant, 10 relevé were recorded. Coverage of the found species was estimated directly in percentages. Moreover, the maximum height in the stand was measured for each type of plant. Biomass of individual plant species was calculated, using the biomass index (*IB*) equation. The *IB* values of individual plant species in the treatments were processed by employing a multidimensional analysis of the ecological data. Different vegetation management practices in an orchard change the species diversity of the vegetation and thus the fire hazards in the orchard conditions. Grassy interrow has the most grass biomass during the entire vegetation season, and therefore represents the greatest hazard and spread of fire. The most important grasses include *Arrhenatherum elatius*, *Dactylis glomerata*, *Festuca pratensis*, *Lolium perenne*, and *Poa pratensis*. On the contrary, bare soil conditions in the interrow are most suitable for annual species, and this is the place with the highest changes in the number of species during the growing season. Biomass of the orchard vegetation combined with dry and warm weather increases the fire hazard. Annual and perennial grasses have very good potential for the production of biomass, which increases the hazard of fire. The nature of the vegetation in the orchards has the potential for the actual start of a fire and its subsequent spread, however, under other environmental conditions. During hot and dry weather, dead biomass may accumulate resulting in increasing the hazard of large wildfires. Varied orchard management practices lead to a higher diversity of vegetation and make orchards, islands of biodiversity in the agricultural landscape.

Keywords: fire; vegetation; orchard; ecosystem functions

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1. Introduction

Agricultural practices in orchards have a large impact on a number of agroecosystem functions [1–3]. Vegetation management can change biotic interactions in an orchard between fruit tree pests and their natural enemies and can also limit nitrogen leaching and

change the water regime [3,4], which is essential for the functioning of the orchards. Water stress can reduce fruit size and quality [5–7]. Moreover, the timing of the water stress is important, if it occurs in late spring and early summer, it can impact fruit set and growth negatively [8–10].

Interrow soil management in fruit orchards is especially important for the water regime [11–13]. The widespread use of pre-emergent herbicides results in bare soil, which reduces infiltration and increases water runoff [3,14]. However, grassing the interrow soil of an orchard has been found to reduce yield and tree growth due to competition for nutrients and water between grasses and fruit trees [12,15,16]. For this reason, the technique called "sandwich" (developed in Switzerland) is recommended. It consists of alternating cultivated and grassy interrow strips, especially in areas with poor rainfall [17–19].

Competition of vegetation with fruit trees is a critical vegetation management issue [18–21]. Common and traditional methods of control include mowing. Though mowing the vegetation controls the growth of plant species, it is insufficient for their eradication in the case of perennial weed species. On the contrary, it can contribute to strengthening their root system, thus supporting their dominance, and increasing their competition. In addition, if plant biomass is used as mulch, in the case of young plantings, farmers risk large yield losses due to mulch competition for water [22]. Therefore, the combination of frequent mowing and the application of herbicides (chemical control) is very common for controlling vegetation in fruit orchards as an effective way of vegetation control [23–25].

High efficiency of chemical control raises concerns about the increasing occurrence of tolerant populations in perennial weeds, e.g., observed in *Taraxacum officinale* Weber ex F.H. Wigg. and *Trifolium* spp. [26–28]. In addition to this concern, there is increasing consumer demand for a reduction in agrochemicals. These trends force fruit growers to look for alternative ways of vegetation control. Besides weed control, mulch can maintain soil quality, support orchard biodiversity, and reduce nutrient leaching [18,19,25,29,30]. However, the use of mulch may not be sufficient in the case of the use of certain types of rootstocks of fruit trees due to the development of perennial weeds [31]. Orchard vegetation performs a number of ecosystem functions that are often studied in a number of scientific works [11,32–34]. However, one function has been neglected, namely the function of vegetation in case of occurrence and spread of fires. Accumulated dead biomass of different types of plants in the orchard combined with dry and warm weather increases the hazard of fires. Fires have recently become a major problem in many areas globally [35,36]. Many studies show that the frequency of fires has been exacerbated by climate change as well as by other factors such as fire suppression measures, management of urban and agricultural vegetation, afforestation, and the abandonment of rural areas [37–40]. Fire hazard assessment is based on the physical features of combustible materials, including vegetation biomass. The presence of biomass of grasses, which have a high calorific value (higher than 17,000 MJ·kg), increases the hazard of occurrence and subsequently rapid development of fire [41].

As extreme weather has become more frequent in the Czech Republic (CR) recently, natural catastrophes such as floods, droughts, and wildfires strike correspondingly. A case in point is the summer of 2022 when a fire broke out in the Bohemian Switzerland National Park in the CR, marking it as one of the worst forest fires in the history of Czech history. While the scientific literature and media generally focus on forest fires, agricultural field fires also have had a significant economic impact over the past few years in the CR. According to the official records (Fire Rescue Service of the CR, 2020), over 600 fires occurred in the CR agricultural areas in 2019. Furthermore, among the recorded fires, 140 cases were caused by the self-ignition of crops in 2019 [42].

This study deals with the evaluation of the species structure of the sour cherry orchard vegetation under the climatically dry conditions of the CR owned and managed by the School Farm Žabčice (Mendel University in Brno). The aim of the study was: (i) to evaluate the composition of the vegetation associated with different management of the vegetation in the orchard; (ii) to identify plant species and groups of species that are tolerant to individual

management methods; and (iii) to indicate the fire hazard caused by the accumulation of vegetation biomass under different management conditions. It was hypothesized that: (1) The composition and amount of vegetation biomass in the orchard will vary under different management conditions, which will affect changes in the hazard of fire; (2) the vegetation management practices change the species diversity of vegetation and thus the hazard of fire hazards in orchard conditions.

2. Materials and Methods

2.1. Characteristics of the Territory

The area of interest (Figure 1), where the vegetation of the sour cherry orchard was evaluated, is located in the cadastral territory of the municipality of Žabčice (South Moravian Region, CR; coordinates GPS: 49.0132389° N, 16.5925986° E).

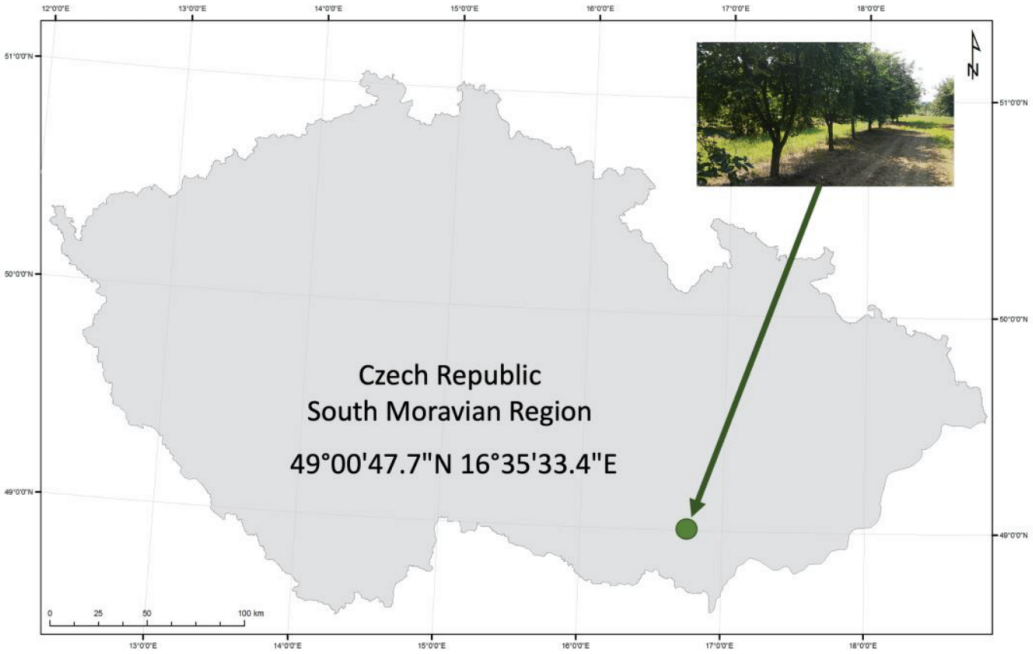


Figure 1. Location of the study area where vegetation of the sour cherry orchard was evaluated.

The *sour* cherry orchard is owned and managed by the School Farm Žabčice (Mendel University in Brno). The area of interest lies in the Graben Dyjsko-Svratecký basin, which rests mainly by Neogene sediments. The geological formation is composed of Quaternary gravels and partly of alluvial sediments. The soils here are neutral to moderately acidic with a lack of humus. The land contains black soil with a total skeleton content of up to 25%. The soil profile is deep to medium deep and consists mainly of sandy soils. The land is flat with an average altitude of 186.69 m above sea level. The long-term (years 1991 to 2020) average annual temperature is 9.2 °C and the long-term average annual rainfall is 481 mm. The data come from the Meteorological Station of the *Department of Agrosystems* and Bioclimatology—Žabčice, Mendel University in Brno. Drought in the area is caused by the uneven distribution of rainfall, drying winds, and rain shadow [43].

2.2. Characteristics of the Sour Cherry Orchard

The orchard is in the conventional farming mode. This regime allows the use of herbicides for vegetation control. The 'Fanal' and 'Morela late' varieties of sour cherries are

cultivated here. The orchard was established in 2005 on an area of 6.86 hectares. The *sour* cherry orchard has no irrigation, spacing of the trees is 12 × 4 m.

Three methods of vegetation management are applied within the orchard: (a) interrow with bare soil (Bare soil)—in the interrow the soil is regularly mechanically processed during the vegetation, and biomass of the vegetation is incorporated into the soil; (b) grassy interrow (greening)—in the interrow, there is a green strip that was not sown but was created by spontaneous succession, vegetation is mowed twice a year and biomass is taken away; (c) strip under trees (under trees)—the area is directly under the *sour* cherry trees around the trunk, vegetation is maintained here by chemical control and by mulching. Rows of trees are separated from each other by interrow. Bare soil regularly alternates with the greening in the interrow (Figure 2).

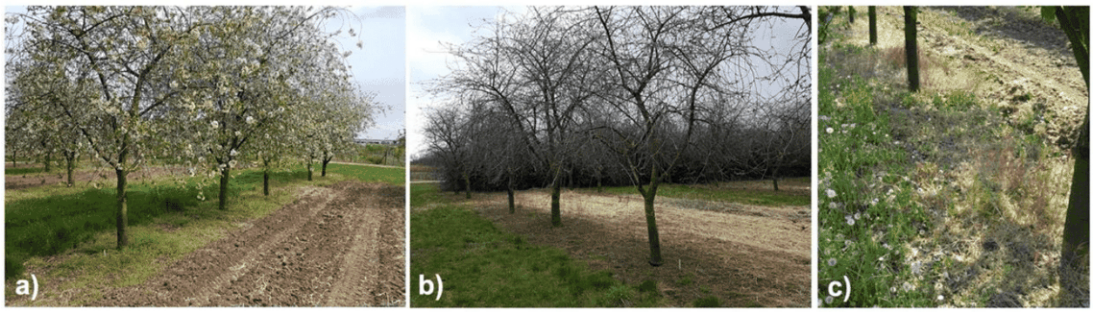


Figure 2. Orchard and three methods of vegetation management: (**a**) bare soil; (**b**) greening; (**c**) under trees.

2.3. Methodology of Evaluation of the Vegetation

Vegetation assessment was performed using the method of phytocenological relevé. Observation took place in the period of 2014 and 2015, each year in three terms (April, June, October). In each variant, 10 relevé were recorded, and their area was 2 × 4 m. The relevé were always recorded at the same location. Coverage of the found species was estimated directly in percentages. Furthermore, the maximum height in the stand was measured for each type of plant. Biomass of individual plant species was calculated, using the equation for the Biomass Index (*IB*), (Equation (1)):

$$IB = c \times hm \quad (1)$$

where *IB* is the biomass index given in % m, *c* (%) is the percentage of coverage, and *hm* is the maximum height measured in meters [40].

Plant species were divided into groups according to biological features (annual dicots, annual monocots, perennial dicots, perennial monocots). Scientific names of the identified plant species were taken from the Pladias Database of the Czech Flora and Vegetation [44].

The *IB* values of individual plant species in the treatments were processed by employing a multidimensional analysis of the ecological data. The first method was the detrended correspondence analysis (DCA), which provided the gradient length. DCA is a technique to summarize environmental changes over time and organize environmental data. Response data are compositional and have a gradient of 3.0 of the standard deviation (SD), i.e., a linear method is not appropriate. Further statistical evaluation was then conducted using the canonical correspondence analysis (CCA), where the time factors (i.e., month and year) were incorporated into the analysis as a covariate to avoid pseudo-replication. This shows the association between the selected factors (vegetation management). Multivariate analyses explain the relationship between the explanatory variables, and the relationship between the plant species found. This analysis was aimed at determining associations between vegetation composition and different types of vegetation management practices. Statistical

significance was further established using the Monte Carlo test, where 999 permutations were calculated. *IB* data were processed using the Canoco 5 [45].

Average water retention of the soil profile (AWR1) and normalized difference vegetation index (NDVI) were used to assess soil moisture and state of vegetation in the Žabčice location in 2014 and 2015. The SoilClim model provides information about current and reference evapotranspiration, and about the water content in the soil expressed as the average saturation of the soil profile with water. The soil moisture content values were recorded at 7-day intervals in the study location. The SoilClim model monitors the soil profile to a depth of 40 cm (topsoil). The core of the system is a dynamic model of soil water content [46,47]. This model is based on the work of Allen et al. [48]. An important role in assessing the impact of a potential drought episode on vegetation is played by satellite data databases (especially the NDVI of the state of vegetation) from the Aqua and Terra satellites. NDVI values provide information about the state of vegetation and can be used, among other things, to indicate places with physiological stress (e.g., as a result of a lack of moisture). NDVI values were used for our study location at a weekly interval.

3. Results

During the two-year monitoring, 79 plant taxa were found. The highest number of species for the different management of vegetation was found in the Greening interrow, and perennial plant species predominated here. Annual plant species predominated in the strips at trunks and in the interrow with Bare soil. During the period of monitoring, significant changes in the number of species for the different management of vegetation in the interrow with Bare soil were recorded. On the contrary, only minor changes in the number of species for the different management of vegetation were detected in the Greening interrow. Distribution of taxa into the groups according to the CCA analysis is presented in Table 1. Numbers of plant species and changes in the number of species for the different management of vegetation are presented in Figure 3.

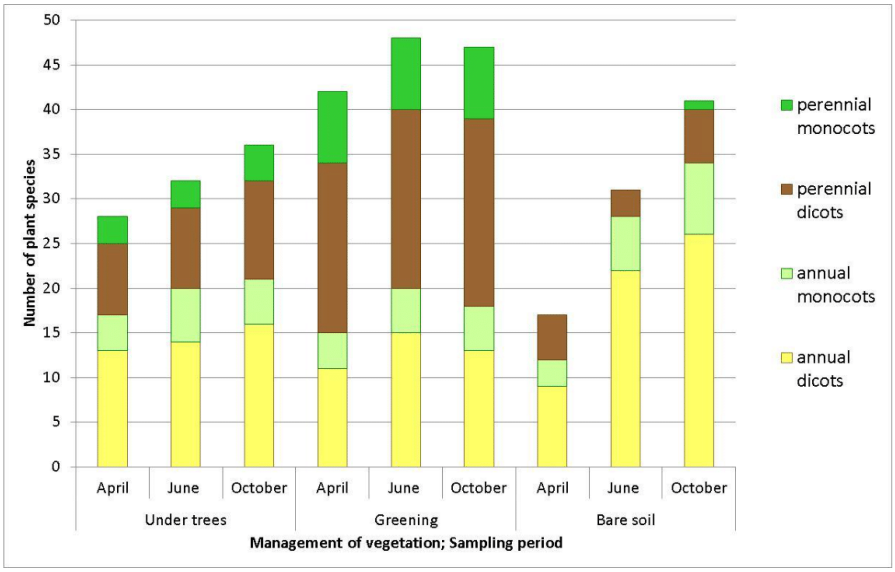


Figure 3. The number of plant species at different management and monitoring dates in the orchard.

Table 1. Groups of plant species according to CCA analysis.

Management Preference	Group of Species	*Taxa of Plants (Abbreviations)*
Greening	Annual dicots	*Geranium pusillum (GerPusi), Polygonum aviculare (PolAvic), Veronica arvensis (VerArve).*
	Perennial dicots	*Achillea millefolium (AchMill), Artemisia vulgaris (ArtVulg), Carduus acanthoides (CarAcan), Cichorium intybus (CicInty), Cirsium arvense (CirArve), Conyza canadensis (ConCana), Echium vulgare (EchVulg), Eryngium campestre (EryCamp), Falcaria vulgaris (FalVulg), Plantago major (PlaMajo), Potentilla argentea (PotArge), Reseda lutea (ResLute), Rumex acetosella (RumAcet), Silene latifolia (SilLati), Tragopogon pratensis (TraPrat), Trifolium repens (TriRepe).*
	Perennial monocots	*Arrhenatherum elatius (ArrElat), Dactylis glomerata (DacGlom), Elytrigia repens (ElyRepe), Festuca pratensis (FesPrat), Lolium perenne (LolPere), Poa pratensis (PoaPrat).*
Greening + Under trees	Annual dicots	*Capsella bursa-pastoris (CapBurs), Erigeron annuus (EriAnnu), Erodium cicutarium (EroCicu), Holosteum umbellatum (HolUmbe), Lycopsis arvensis (LycArve), Veronica polita (VerPoli).*
	Perennial dicots	*Glechoma hederacea (GleHede), Medicago lupulina (MedLupu), Taraxacum sect. Taraxacum (TarSect).*
	Annual monocots	*Bromus hordeaceus (BroHord), Bromus sterilis (BroSter), Bromus tectorum (BroTect).*
	Perennial monocots	*Festuca rubra (FesRubr).*
Under trees	Annual dicots	*Arenaria serpyllifolia (AreSerp), Epilobium adenocaulon (EpiAden), Filago arvensis (FilArve), Fumaria officinalis (FumOffi), Lactuca serriola (LacSerr).*
	Perennial dicots	*Bryonia alba (BryAlba), Plantago lanceolata (PlaLanc), Rosa canina (RosCani).*
	Annual monocots	*Digitaria sanguinalis (DigSang), Hordeum murinum (HorMuri).*
	Perennial monocots	*Festuca ovina (FesOvin).*
Under trees + bare soil	Annual dicots	*Chenopodium album (CheAlbu), Chenopodium pedunculare (ChePedu), Chenopodium strictum (CheStri), Lamium amplexicaule (LamAmpl), Lamium purpureum (LamPurp), Stellaria media (SteMedi), Veronica persica (VerPers).*
	Perennial dicots	*Convolvulus arvensis (ConArve), Malva neglecta (MalNegl).*
Bare soil	Annual dicots	*Amaranthus powelli (AmaPowe), Amaranthus retroflexus (AmaRetr), Amaranthus albus (AmaAlbu), Anagallis arvensis (AnaArve), Anagallis foemina (AnagFoem), Chenopodium hybridum (CheHybr), Chenopodium pumilio (ChePumi), Portulaca oleracea (PorOler), Senecio vulgaris (SenVulg), Sonchus oleraceus (SonOler), Thlaspi arvense (ThlArve), Trifolium arvense (TriArve), Tripleurospermum inodorum (TriInod), Veronica hederifolia (VerHede), Veronica triphyllos (VerTrip), Viola arvensis (VioArve).*
	Annual monocots	*Echinochloa crus-galli (EchCrus), Panicum miliaceum (PanMili), Poa annua (PoaAnnu), Setaria pumila (SetPumi), Setaria viridis (SetViri).*

The *IB* values are shown in Figure 4. The *IB* values change similarly at all monitored sites. The lowest values are in the first evaluation term (spring), the highest values are in the second evaluation term (summer), and the decrease is in the third term (autumn).

This trend corresponds to the vegetation period of the monitored area. In the Greening interrow, *IB* had the highest values and most of the biomass was comprised of perennial plant species. In the interrow with Bare soil, the *IB* values had the greatest difference between the observation dates. In the first term, the values were very low, in the second term they were 15 x higher. This growth is created mainly by the biomass of annual dicotyledonous species. In the under trees, the *IB* values are the lowest and the annual plant species predominate here.

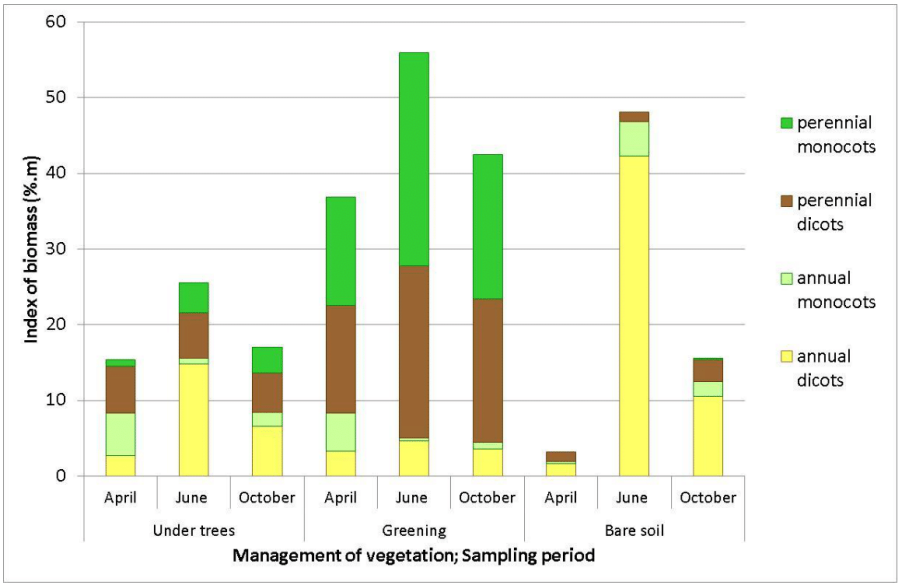


Figure 4. Values of biomass index at different sites in the orchard.

The results of the CCA analysis evaluate the coverage of plant taxa for the monitored sites. The results are significant, with a significance level $\alpha = 0.001$, for all canonical axes. A graphical representation of the results of the CCA analysis is presented in Figure 5. Based on the CCA analysis, the identified plant taxa can be divided into five groups (Table 1). Groups of the species correspond to the type of vegetation management where they have higher *IB* values.

The average water retention of the soil profile (AWR1) tends to decrease in the first half of the year. The trend changes from July to August when AWR1 despite certain fluctuations gradually grows. The amount of water in the soil profile is determined by the amount of water precipitation and by the intensity of water evaporation. AWR1 affects the NDVI values, which express the condition of the vegetation. The trend in the development of AWR1 is very similar to the trend of NDVI, as illustrated in Figure 6. Lower values of AWR1 and NDVI are considered to be suitable conditions for the occurrence of fires. This represents a state when the soil is dry, and the condition of the vegetation is poor. In the orchard, high biomass index values also contribute to the fire hazard. These conditions occurred in June 2014 and July and August 2015.

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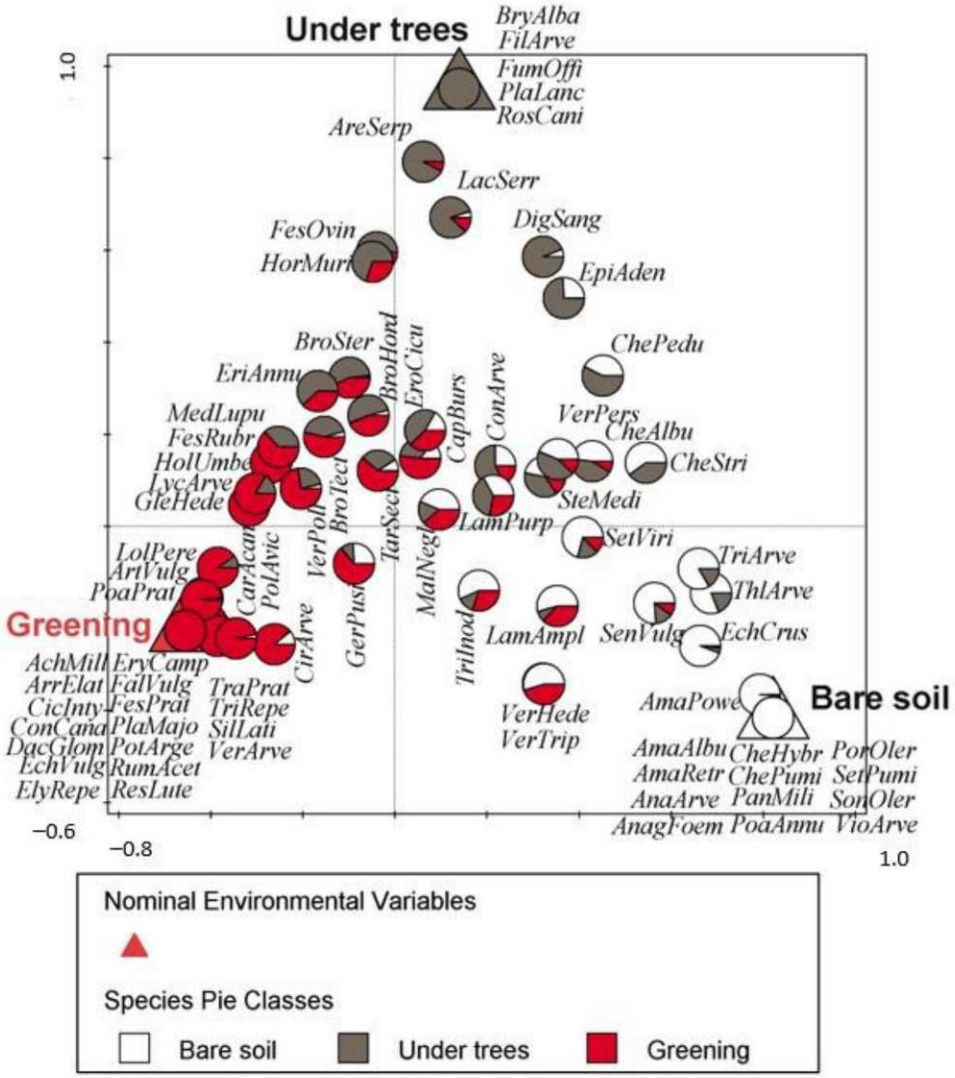


Figure 5. Occurrence of the plant taxa identified at the site with different management in the orchard. (Result of CCA analysis; total explained variability = 12.9%; F-ratio = 6.5; *p*-value = 0.001).

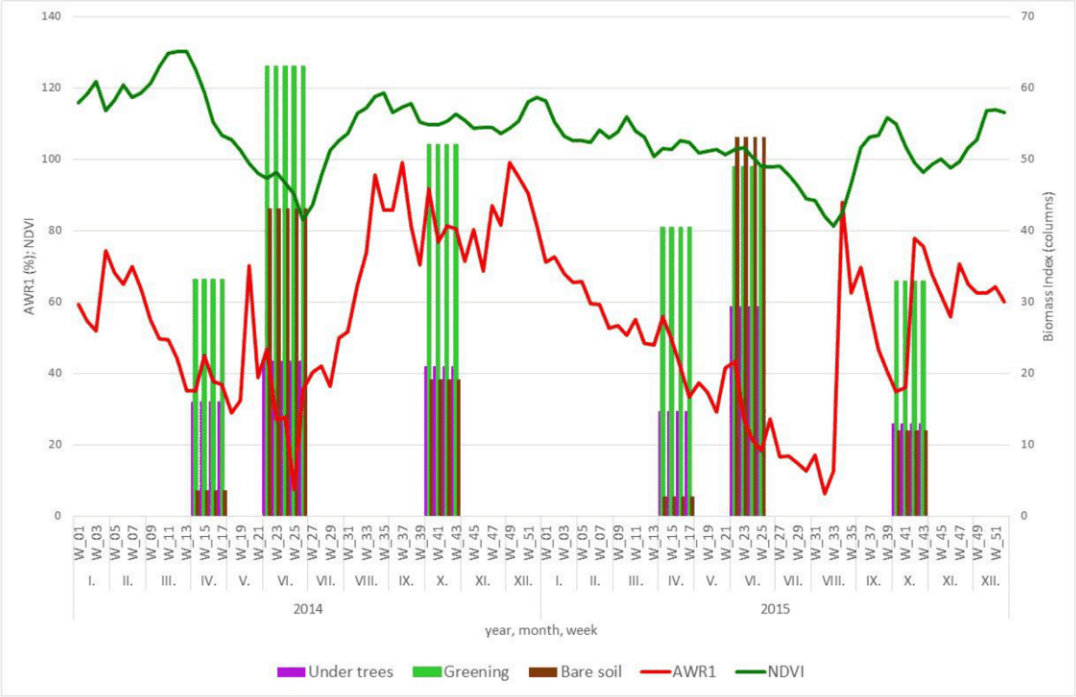


Figure 6. Development of AWR1, NDVI, and biomass index in the orchard.

4. Discussion

Fire is a natural phenomenon affecting biological processes and species composition of ecosystems, including the decomposition or accumulation of biomass [49]. On one hand, fires are an important and integral part of many ecosystems, affecting their distribution, biodiversity, and functioning worldwide. On the other hand, many current anthropogenic fire regimes are susceptible to catastrophic fires. This is especially relevant in ecosystems for which fire events were extremely rare throughout their evolutionary history, and for which fire regimes fall outside of the range of their historical variability [50].

Origin and outbreak of fire in the agricultural landscape are mainly determined by the course of the weather and especially by lack of water [51–53]. According to Lima et al. [54], fire can easily get out of control. According to Syswerd and Robertson [55], water availability in soil is most limited in July, which can vary by region. Under the conditions of the Czech Republic, drought is mainly expected from the end of July till the beginning of August [56]. During this period, it is necessary to monitor the biomass of vegetation as a possible cause of the fire. It is generally accepted that air temperature above 24 °C, relative air humidity below 40%, no precipitation, and no or low cloud cover are the parameters defining the so-called fire weather, in which more than 60% of plant biomass fires occur [39].

The amount of vegetation biomass is important for the origin and outburst of fires in the landscape [57,58]. Fire intensity generally rises with increasing vegetation cover due to fuel availability [59]. Moreover, fire behavior is largely driven by fuel flammability. Flammability can vary markedly between grass species and grass species composition. Excess biomass leads to an increased amount of fuel on both forest and non-forest land which is considered a key factor for fire hazard [58,60–63]. The intensity of the fire and, consequently, changes in soil features (such as soil structure, texture, porosity, wettability, infiltration rates, and water-holding capacity) [64] are determined not only by the quantity

but also by the type of vegetation [59]. While high-intensity fires tend to decrease site productivity, low-intensity fires can increase site productivity [64].

In the agriculturally used landscape, the amount of biomass and species composition of the vegetation determines the type of human-performed management [65,66]. The applied management of vegetation in the landscape impairs the natural course of vegetation succession [67]. Impairment of vegetation succession results in changes in the accumulation of plant biomass, and subsequently alters conditions for the outburst and spread of fires. In combination with dry and warm weather, the hazard of fires rises even in areas where fires are an exceptional phenomenon.

Fire is a natural disturbance for vegetation, which consumes the existing plant community and initiates a new phase of vegetation succession. Biomass from different types of plants has different importance for the outburst and spread of fires. The flammability of vegetation varies throughout the year due to differences in its chemical composition, moisture content, leaf biomass, and the dead-to-living plant parts ratio [59,68]. The intensity and duration of fire depend on the features of the vegetation [68]. Badia et al. [69] demonstrated that higher soil temperatures are reached in the case of woody fires than in the case of grass and shrub fires. Biomass of annual plant species plays an important role in the origin of fires. Grass biomass is important for the start as well as for the full fire spread. Biomass of woody plants has been shown to be important for high fire intensity. All these categories of plant species can be found in orchards. Representation of these categories of species and the amount of biomass is determined by the vegetation management in the orchard.

The grassed interrow has the most grass biomass during the entire vegetation season and therefore represents the greatest hazard for the origin and spread of fire. The most important grasses include *Arrhenatherum elatius*, *Dactylis glomerata*, *Festuca pratensis*, *Lolium perenne*, and *Poa pratensis*. Winkler et al. [39] state that as far as biomass production associated with fire hazard is concerned, the species producing high to medium-high biomass are significant (*Acer negundo*, *Arrhenatherum elatius*, *Artemisia vulgaris*, *Bromus hordeaceus*, *Elytrigia repens*, *Hordeum murinum*, *Lolium perenne*, *Medicago sativa*, *Melilotus officinalis*, *Rosa canina*). According to Salemme et al. [70], it has been proven that the biomass of grasses increases the probability of origin and intensity of fire due to the quantity, structure, and flammability of their biomass. Agricultural land management influences the share of biomass, and thus the fire hazard of the area. The fire hazard increases during periods of grassland vegetation biomass drying out [39].

A very rapid increase in the biomass of annual dicotyledonous species in the interrow with bare soil is another possible source of the fire. From this point of view, the problematic taxa can be as follows: *Amaranthus* sp., *Chenopodium* sp., and *Tripleurospermum inodorum*. However, the amount of biomass is mainly determined by the course of the weather. Sufficient water and favorable temperatures ensure a very rapid increase in biomass. Subsequent drought in the summer months ensures that the biomass dries up and thus the fire hazard increases. Based on the results, the interrow with bare soil is the place with the highest changes in species composition. Considerable dynamics of vegetation structure also change the amount of biomass and change the level of fire hazard during one growing season. This raises the need for more frequent control and evaluation of the degree of fire hazard.

In the strip at the trunks under the trees, mulching is used, which is a frequent method of vegetation control and biomass management. Mulching consists in covering the soil surface with organic or mineral products such as gravel, bark, straw, hay, sawdust, and wood shavings, or with a variety of synthetic materials such as polyethylene plastics [71]. Mulching is not usually used widely in fruit growing due to high costs and/or availability of materials but is important for specific fruit species or in organic farming. Mulching provides a variety of tasks, including weed control, soil temperature reduction, and water saving [72]. Despite numerous benefits, mulches can pose a fire hazard [73]. On the other hand, mulching and chemical control suppress the formation of vegetation biomass, thus

reducing the hazard of fire outbursts. However, chemical control is not applicable in organic farming and represents an unwanted burden for the environment. Among the found species that resisted mulching and chemical control well, was the species *Hordeum murinum*, which biomass can increase the fire hazard.

Cover cropping in the interrow of the orchard can be performed by mowing. The number of mowing should be adapted to the need and intensity of the vegetation control. A higher density of herbaceous vegetation provides better soil protection and greater carbon content in the soil. However, the risk of competition for water and nutrients rises in such conditions, which can negatively impact the yield of fruit trees [73]. In hot and dry climates with a high hazard of grass fires, control of the herbaceous vegetation should also be adjusted accordingly. Management of natural vegetation by mowing leads to a selection of stands for perennial species that tolerate mowing better and become difficult to control [73].

Biomass (fuel) growth dynamics and burning availability (drought) drive the fire trends [74–76]. This means that the course of the weather and the accumulation of biomass (grass species) are decisive for the origin of the fire. Alternating different types of vegetation management within an orchard affects the species spectrum and the amount of vegetation biomass, which contributes to a higher heterogeneity of vegetation and reduces the hazard of a widespread fire outbreak.

According to Trnka et al. [77], on average, 89.5% of all vegetation fires in the CR were recorded in the countryside and more than 65% of wildfires are recorded during the harvest periods. These authors emphasize that fires will become an increasingly frequent phenomenon even in the conditions of the mild climate zone and will intervene in the agricultural landscape. Although the CR, and Central Europe in general, has not been considered a wildfire hotspot compared to the Mediterranean area until recently (given the typical extent of fires, dedicated resources, or public perceptions), this situation has changed with the increase in dangerous fire weather. One of the ecosystem functions of vegetation is to ensure the occurrence and spread of fires, which is a natural phenomenon for vegetation. For human civilization, fire has primarily a destructive and negative character, which is why we strive to eliminate fire as a phenomenon in the landscape. Familiarization of farmers with this risk and modification of management of the vegetation of fruit orchards must become an integral part of the efforts to eliminate the fire hazard.

5. Conclusions

The results provide a different perspective on the relationship between orchard vegetation and potential fire hazard in human-managed ecosystems. It has been confirmed that different management practices applied in the orchard change the species composition of the vegetation. Grassed interrow creates the most favorable conditions for the occurrence of perennial species. On the contrary, bare soil conditions in the interrow are most suitable for annual species with the highest changes in the number of species during the growing season. The management applied in the strips under the trees, the combination of chemical control and mulching leads to the emergence of specific plant species (*Filago arvensis*, *Bryonia alba*, *Hordeum murinum*, *Festuca ovina*). It can be stated that varied vegetation management contributes to the high diversity and makes orchards islands of biodiversity in the agricultural landscape.

Biomass of the orchard vegetation combined with the dry and warm weather of the South Moravian Region increases the hazard of fire. Biomass of the annual and perennial grasses increases the hazard of fire. Green interrow has the most biomass of grasses during the entire growing season. Interrow with bare soil creates more suitable conditions for annual dicotyledonous species. These species have high biomass productivity. When the biomass dries up quickly due to specific climatic conditions and accumulates, the hazard of fires is increased. Therefore, it is necessary to perform regular monitoring in the interrow without vegetation and, if necessary, to incorporate the vegetation biomass into the soil on time. Mulching and chemical control suppress the formation of vegetation biomass, thus reducing the fire hazard. However, it is important to monitor the amount of biomass and

its accumulation together with the course of the weather in the relevant year. Based on the monitoring of AWR1 and NDVI, it is evident that from June to August, the conditions for the fire occurrence are favorable. Orchards are still being omitted in the fire hazard assessment. From the results, it is noticeable that the selected AWR1 and NDVI values together with the vegetation biomass represent a hazard. The amount of orchard vegetation biomass is regulated by management, which can substantially reduce the hazard of occurrence and spread of fires. Alternating the types of vegetation management in the orchard changes the species spectrum and the amount of vegetation biomass, thus compensating for the negative features of individual types of orchard vegetation management.

Changes in the nature of the climate and the variability of orchard vegetation can create new interactions that can also result in changes in fire hazards. Fires on agricultural land are still a neglected hazard, so scientific discussion and the search for new risk sites are of great importance.

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Příloha 8

water

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Article

Water Protection Zones—Impacts on Weed Vegetation of Arable Soil

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Abstract: The aim of this study is to evaluate the occurrence of weeds under conditions of limited herbicide use due to the protection zone of water resources. A total of 23 weed species were found in maize stands, 19 species were found in wheat stands, and 16 species were found in rapeseed stands. The redundancy analysis (RDA) results show significant differences in weed occurrence and composition due to herbicide regulation in each crop. Changes in weed composition induced by herbicide application limitations lead to a preference for more specialized weed species (specialists) at the expense of widespread species (generalists). Limiting the use of pesticides in sensitive and vulnerable areas, such as water sources, bodies, and watercourses, is justified from the perspective of protecting the aquatic environment and biodiversity. However, such measures can cause weed growth that is difficult to control, and therefore, it is important to search for new methods for weed control in field crops. Determining a balance between safeguarding water resources and addressing agricultural challenges remains crucial for sustainable land and water management.

Keywords: water protection; herbicides; biodiversity; agriculture; weed flora

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1. Introduction

Human activity is often the primary source of pollution, bringing potentially hazardous substances into atmospheric, terrestrial, and aquatic ecosystems [1]. Agriculture is one of the largest sources of emissions in surface water and aquatic ecosystems [2,3]. Hoever, aquatic ecosystems are often contaminated with herbicides [4]. This contamination depends on many parameters, such as watershed structure and land use (anthropic activity, surface, and slope), soil structure and composition, environmental factors, hydrology (rainfall, flow, and wind), aquatic environmental conditions (pH, organic matter, and suspended particles), and the chemical properties of herbicides [5,6]. Many European studies have reported the detection of active herbicides such as diuron, metolachlor, isoproturon, terbutryn, and atrazine in aquatic environments [7,8]. Owing to their phytotoxic effects, their behavior in freshwater ecosystems poses a risk to non-target organisms, such as benthic diatoms (*Diatomeae*) [9]. Herbicides generally inhibit various vital functions in photosynthetic organisms [10]. Weeds have been suppressed since the beginning of agriculture because they are the main biotic cause of yield losses in field crops [11]. A revolution in weed control started in the early 1950s, owing to the use of herbicides, which laid the foundation for industrial agriculture [12,13]. In recent years, increased use of herbicides has been reported in various countries [14–16]. During the 12 years of the monitoring of

pilot farms in Switzerland, an increase from 0.034 kg/ha to 0.141 kg/ha in glyphosate use in arable land was recorded [17].

The use of pesticides is one of the most debated aspects of agricultural intensification, given their potential direct and indirect consequences at the individual, population, and ecosystem levels [18,19]. The direct toxic effects of pesticides can appear quickly after their application [20], whereas the indirect effects of pesticides can occur one or several years later [21,22]. The toxicity of pesticides can vary substantially among affected organisms [23,24], and the ecological impacts of pesticides can persist several years after their application [25]. Herbicide use can also reduce shelter for bees, insects, reptiles, etc., in agricultural landscapes [26–28].

The leakage of herbicides, or the concept of herbicide loss, is based on spatial heterogeneity, where hydrological factors of the environment dominate, for example, the nature of the first rain event after herbicide application. Several studies have demonstrated that factors such as topography and soil hydrological properties can clarify the spatial patterns of herbicide loss [29]. Some herbicides can be transported from agricultural land to the surface and groundwater, where they can affect the ecosystem [30–32].

Pesticides, together with nitrates, currently form the main pollution sources of drinking water in Europe [33]. To limit or at least mitigate the negative effects of agricultural emissions on water, in recent decades, the European Union (EU) has developed an extensive and interconnected regulatory political framework that influences water management, agricultural practices, and environmental protection [34]. For example, the Nitrates Directive (91/676/EEC) [35] builds on the objectives of the Drinking Water Directive (98/83/EC) [36] and the Water Framework Directive (2000/60/EC) [37] to form an overarching framework for EU directives on the specific functions of water, the use of chemicals, and their effect on environmental protection and the state of European waters. Apart from international treaties and EU law, the basic legal regulation in the Czech Republic (CR) governing water protection is Act No. 254/2001 Sb. [38] (water law). Although the directives are linked, their implementation has side effects that prevent the effective protection of drinking water sources. For example, fertilizer use rules are not always beneficial to groundwater and drinking water quality [34]. The adopted EU framework directives reflect a growing awareness of the complexity of the water and river basin issue [39–41]. The new provisions related to the Water Directive require interdisciplinary cooperation within individual EU member states and international cooperation [34]. The pesticide regulatory framework in Europe creates strong incentives for growers to reduce herbicide application. In Denmark, since the late 1980s, the demand for herbicides has been increasing; therefore, several pesticide action plans have been initiated [42].

In CR water protection, the use of water and the right to access it are regulated by the Water Act [38]. The Water Act is specified or elaborated upon by subsequent regulations (government regulations and decrees) issued by the Ministry of the Environment together with the Ministry of Agriculture. Subsequent regulations have defined zones of hygienic protection for surface water sources, including rules and restrictions for the use of pesticides.

It should be emphasized that the pollution of aquatic ecosystems by herbicides and pesticides has far-reaching consequences for biodiversity, ecosystem services, and human health [43–45]. Pesticides can also negatively affect the environment in ponds, rivers, and other freshwater and marine habitats [46,47].

Restrictions on the application of herbicides in areas of surface water protection have led to a limited choice of herbicides. Different weed regulations create diverse selection pressures on weed vegetation. The aims of this study are (i) to assess the effect of herbicide limitations on the species composition of weeds in selected crops, (ii) to determine the weed species that meet the conditions of limited weed regulation, and (iii) to determine the proportions of neophytes and species with invasive status. Water surface protection based on herbicide use reduction can lead to challenges in the regulation of certain weed

species. Increased weed infestation by specific types of weeds without effective regulation can exacerbate conflict between farmers and water management authorities.

2. Materials and Methods

2.1. Study Area

Selected plots are in the cadastral territory of Zarazice (South Moravian Region, Czech Republic). The monitored agricultural holding operates over an area of 200 ha and includes flint maize (*Zea mays*), winter wheat (*Triticum aestivum*), winter rapeseed (*Brassica napus*), spring barley (*Hordeum vulgare*), and alfalfa (*Medicago sativa*).

The study plots are situated in two geomorphologically different parts. Plots in the southern part of the study area lie near the Morava River. The soil types are mainly fluvial soils formed from water sediments of the river, and the altitude is 170 m above sea level. This area falls within the groundwater protection zone, where the use of herbicides listed in the regulations is restricted. The plots in the eastern part of the study area are located at an altitude of 220 m above sea level. The most common soil types are cambizemes and regozemes. Both parts belong to the area, which is characterized by an average annual temperature exceeding 10 °C with an annual rainfall of up to 500 mm [48–50]. The Morava River flows through the center of the cadastral territory of Zarazice. Furthermore, there is an artificial water canal—the Bat'ův kanál on the right bank of the Morava—which is used for recreation purposes. The western border of the cadastral territory is formed by the relief arm of the Morava River, which was built in the 1930s to divert flood flows. The entire area between the relief arm and the Bat'a canal is delimited as a protection zone of the water source–Bzenec complex. In this complex, underground water is collected from wells and serves as a mass source of drinking water. The investigated plots in the southern part fall into the second degree Protection Zone, in which the requirements and prohibitions based on the Decision on the Determination of Water Resource Protection Zones from 1990 are respected.

No herbicide limitations (full regulation): In the plots, it is permissible to use all registered herbicides that are approved for the given crop, and their application is governed by general regulations for the use of plant protection products. Herbicides applied to maize crops include BALATON (Terbuthylazine) at a rate of 3.0 L/ha and STORY (Florasulam and Mesotrione) at a rate of 0.3 L/ha. Herbicides applied to winter wheat crops consist of GLEAN 75 PX (Chlorsulfuron) at a rate of 0.02 kg/ha and HURICANE (Aminopyralid, Florasulam, and Pyroxsulam) at a rate of 0.2 kg/ha. Herbicides applied to winter rapeseed crops include BUTISAN STAR (Chlormequat and Metazachlor) at a rate of 2.0 L/ha, GARLAND FORTE (Propaquizafop) at a rate of 0.8 L/ha, and GARLAND FORTE (Propaquizafop) at a rate of 0.5 L/ha.

Herbicide limitations (limitation): Within the designated protective zone plots, chemical weed control is restricted. Only herbicides with granted exceptions are allowed to be used on these plots. Herbicides applied to maize crops include EQUIP ULTRA (foramsulfuron) at a rate of 2.0 L/ha and STORY (Florasulam and Mesotrione) at a rate of 0.3 L/ha. Herbicides applied to winter wheat crops consist of HURICANE (Aminopyralid, Florasulam, and Pyroxsulam) at a rate of 0.2 kg/ha. Herbicides applied to winter rapeseed crops include GLEAN 75 PX (Chlorsulfuron) at a rate of 0.02 kg/ha and HURICANE (Aminopyralid, Florasulam, and Pyroxsulam) at a rate of 0.2 kg/ha.

2.2. Method of Vegetation Assessment

Weed assessments were performed in six plots. Three of these are located in the surface water protection zone. The other three plots were located in a zone in which herbicide use was not restricted. Flint maize, winter wheat, and winter rapeseed were grown in the plots. The plots' characteristics are listed in Table 1. Weeds were assessed using a numerical method. Eight sampling areas with a size of 1 m^2 were demarcated on each monitored plot. Sampling areas were evenly distributed in the plots. After demarcating the sampling area,

the weed species were identified and counted. The taxonomic nomenclature of the plants follows Kaplan et al. [51]. The observations were conducted between March and June 2018.

Table 1. Characteristics of selected plots.

Water Protection Zone	Crop	Surface Area (ha)	GPS
No herbicide limitations (full regulation)	Maize	7.12	48.9282369 N, 17.3842381 E
	Winter wheat	11.11	48.9334244 N, 17.3749683 E
	Rapeseed	9.08	48.9294775 N, 17.3726725 E
Herbicide limitations (limitation)	Maize	7.07	48.9418253 N, 17.3554419 E
	Winter wheat	15.95	48.9441083 N, 17.3509789 E
	Rapeseed	8.05	48.9502931 N, 17.3555419 E

The identified weed species were categorized into groups based on their biological characteristics. The spring weed group includes annual species that germinate at temperatures of 0–8 °C and do not survive the winter. The summer weed group encompasses annual species that germinate at temperatures of 8 °C and higher and do not survive the winter period. The winter weed group includes annual species that survive winter. The perennial weed group comprises species with multiple growing seasons over several years. The weeding crops group encompasses crops that behave like weeds and grow within other crops as a consequence of previous cropping.

The results were processed using multivariate analyses of ecological data. The first analysis performed was the segmental Detrended Correspondence Analysis (DCA), which calculated the length of the gradient (Lengths of Gradient) and was followed by RDA. Statistical significance was tested using the Monte Carlo test with 999 calculated permutations. All multivariate analyses were performed using CANOCO 5.0 [52]. The necessary calculations were performed using Canoco 5.0 computer program.

3. Results

A total of 23 weed taxa were identified in corn stands, 19 were identified in winter wheat stands, and 16 were identified in winter rapeseed stands within the assessment. The average number of weeds is shown in Figure 1. The representations of the individual weed taxa are shown in Figure 2 (for maize stands), Figure 3 (for wheat stands), and Figure 4 (for rapeseed stands).

The results of the RDA, which evaluated the number of individuals of weed taxa in wheat stands, were significant at the level of significance of $\alpha = 0.063$ for all canonical axes. However, the differences in weed abundance were statistically inconclusive. A graphical illustration of the RDA results is shown in Figure 6.

The results of the RDA, which evaluated the number of individuals of weed taxa in maize, were significant at the significance level of $\alpha = 0.023$ for all canonical axes. The differences in weed abundance were statistically significant. A graphical illustration of the results of the RDA is shown in Figure 5.

The results of the RDA, which assessed the number of weed taxa in rapeseed stands, were significant at the significance level of $\alpha = 0.023$ for all canonical axes. The differences in weed abundance were statistically significant. A graphical illustration of the RDA is shown in Figure 7.

Based on the RDA, the identified plant taxa were divided into three groups. The distribution of taxa into groups according to the RDA is shown in Table 2.

The results presented in Figure 1 demonstrate significant differences among the weed groups within the monitored crops. However, the representation of weed groups under the conditions of varied herbicide regulation limitations was not as pronounced.

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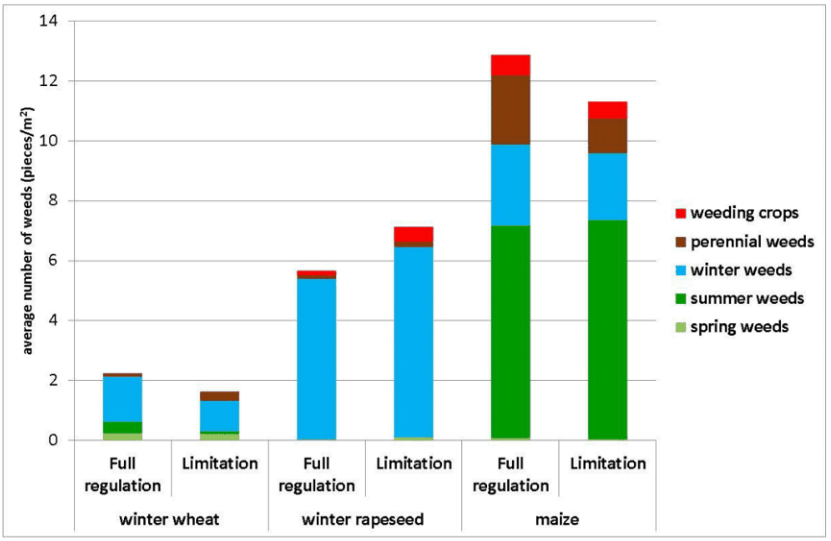


Figure 1. Average number of weeds in monitored crops.

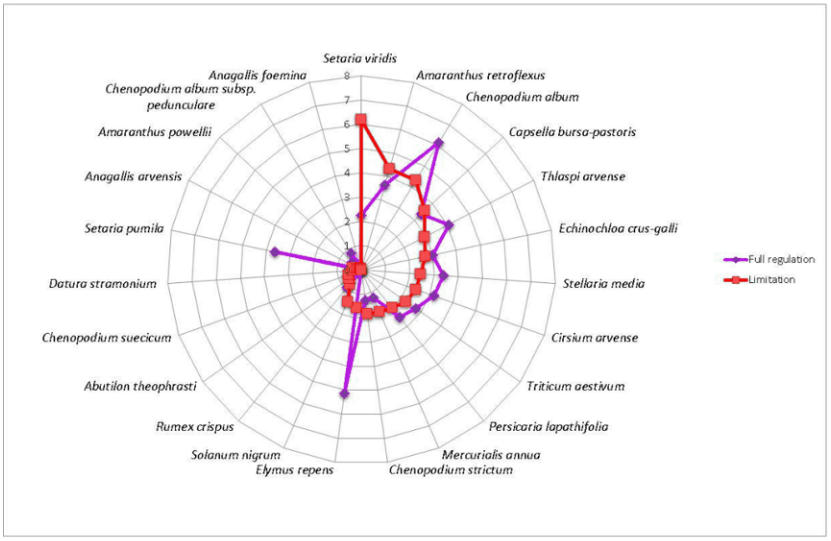


Figure 2. Representation of weed taxa found in maize stands (pieces/m^2).

From the results presented in Figures 2 and 5, it is evident that the limitation of herbicide usage alters the weed species composition in maize. In maize crops, the use of only specific herbicides (limitation) creates more favorable conditions for weed species, such as *Setaria viridis*, *Mercurialis annua*, *Chenopodium strictum*, *Solanum nigrum*, *Abutilon theophrasti*, *Datura stramonium*, and *Chenopodium suecicum*. Under full regulation conditions, weed species such as *Chenopodium album*, *Setaria pumila*, and *Elymus repens* find it easier to establish themselves.

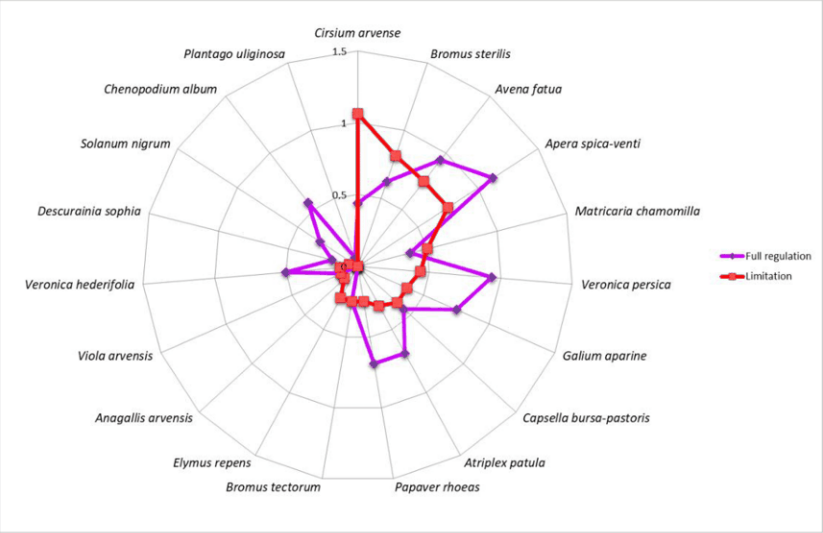


Figure 3. Representation of weed taxa found in wheat stands (pieces/m^2).

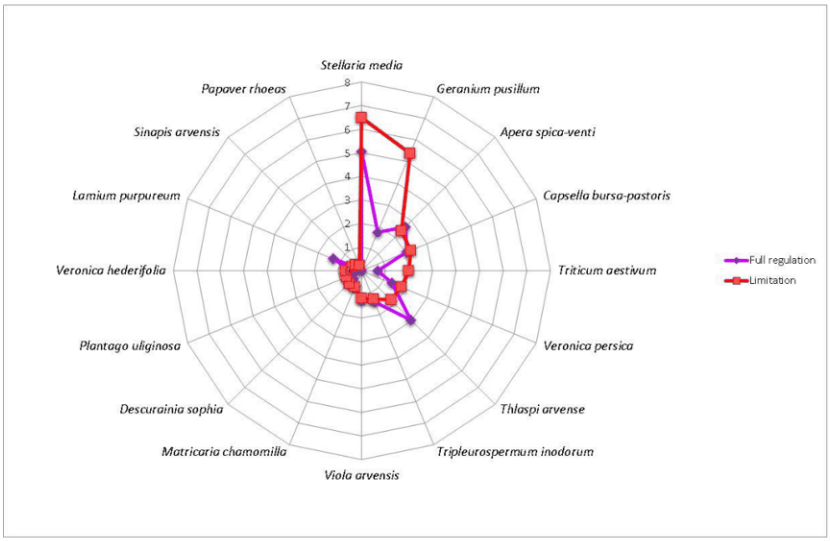


Figure 4. Representation of weed taxa found in rapeseed stands (pieces/m^2).

From the results depicted in Figures 3 and 6, it is evident that the limitation of herbicide usage also alters the weed species composition in winter wheat. The restricted use of herbicides (limitation) creates more favorable conditions for weed species such as *Cirsium arvense* and *Elymus repens*. Under full regulation conditions, weed species such as *Apera spica-venti*, *Atriplex patula*, *Avena fatua*, *Descurainia Sophia*, *Galium aparine*, *Papaver rhoeas*, and *Veronica persica* find it easier to establish themselves.

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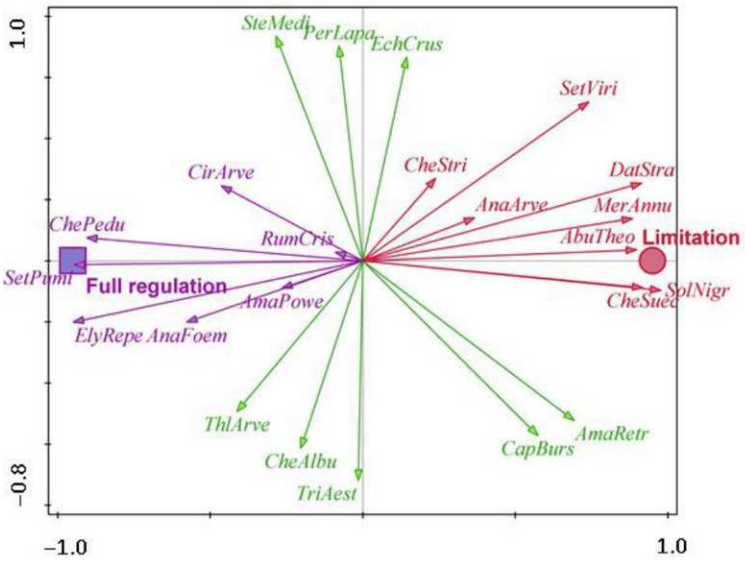


Figure 5. Response of weed occurring in maize stands to limited herbicide regulation (RDA result; F-ratio = 8.1; *p*-value = 0.023); purple color indicates species preferring full regulation, green color indicates species without preference, and red color indicates species preferring limitation.

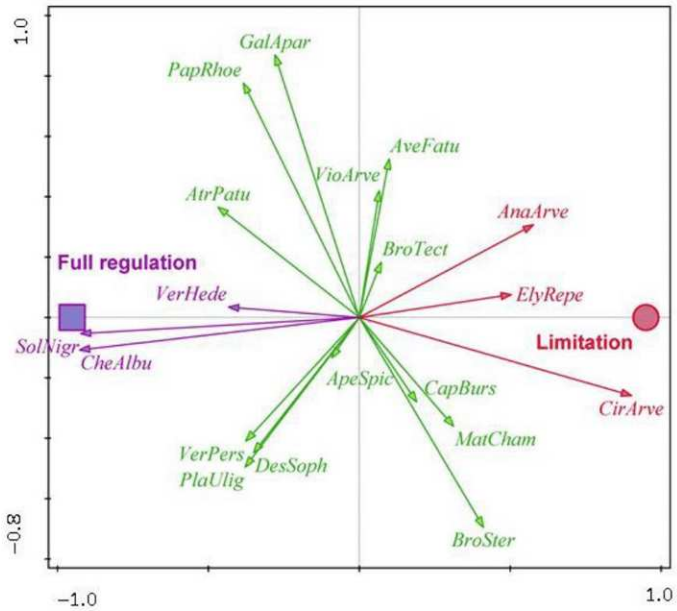


Figure 6. Response of weeds occurring in maize stands to limited herbicide regulation (result of RDA; F-ratio = 2.4.; *p*-value = 0.063); purple color indicates species preferring full regulation, green color indicates species without preference, and red color indicates species preferring limitation.

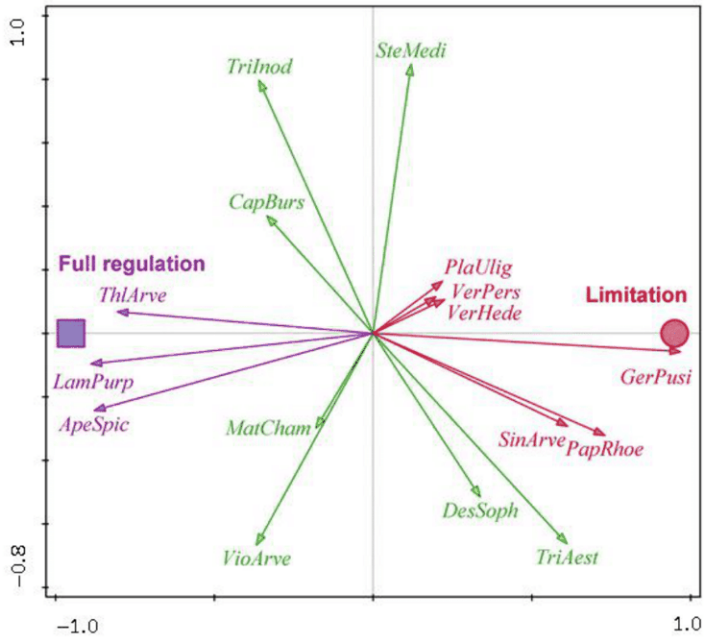


Figure 7. Response of weeds occurring in rapeseed stands to limited herbicide regulation (RDA result; F-ratio = 8.0.; *p*-value = 0.023); purple color indicates species preferring full regulation, green color indicates species without preference, and red color indicates species preferring limitation.

From the results presented in Figures 4 and 7, it is evident that the limitation of herbicide usage also alters the weed species composition in winter rapeseed. The restricted use of herbicides (limitation) creates more favorable conditions for weed species such as *Geranium pusillum*, *Papaver rhoeas*, *Plantago uliginosa*, *Sinapis arvensis*, *Veronica hederifolia*, and *V. persica*. Under full regulation conditions, weed species such as *Apera spica-venti*, *Lamium purpureum*, and *Thlaspi arvense* are established more easily.

Table 2. Groups of weeds according to their reaction to limitation of herbicide use (RDA).

Occurence in Crop Stand	Groups of Weeds		
	Species Preferring Herbicide Limitation	**Species without Any Preference, Affected by Other Factors**	**Species Preferring Full Herbicide Regulation**
Flint maize	*AbuTheo—Abutilon theophrasti*, *AnaArve—Anagallis arvensis*, *DatStra—Datura stramonium*, *CheStri—Chenopodium strictum*, *CheSuec—Chenopodium suecicum*, *MerAnnu—Mercurialis annua*, *SetViri—Setaria viridis*, *SolNigr—Solanum nigrum*	*AmaRetr—Amaranthus retroflexus*, *CapBurs—Capsella bursa-pastoris*, *EchCrus—Echinochloa crus-galli*, *CheAlbu—Chenopodium album*, *PerLapa—Persicaria lapathifolia*, *SteMedi—Stellaria media*, *ThlArve—Thlaspi arvense*, *TriAest—Triticum aestivum*	*AmaPowe—Amaranthus powellii*, *AnaFoem—Anagallis foemina*, *CirArve—Cirsium arvense*, *ElyRepe—Elymus repens*, *ChePedu—Chenopodium album* subsp. *Pedunculare*, *RumCris—Rumex crispus*, *SetPumi—Setaria pumila*

Table 2. *Cont.*

Occurence in Crop Stand	Groups of Weeds		
	Species Preferring Herbicide Limitation	**Species without Any Preference, Affected by Other Factors**	**Species Preferring Full Herbicide Regulation**
Winter wheat	*AnaArve—Anagallis arvensis, CirArve—Cirsium arvense, ElyRepe—Elymus repens*	*CheAlbu—Chenopodium album, SolNigr—Solanum nigrum, VerHede—Veronica hederifolia*	*ApeSpic—Apera spica-venti, AtrPatu—Atriplex patula, AveFatu—Avena fatua, BroSter—Bromus sterilis, BroTect—Bromus tectorum, CapBurs—Capsella bursa-pastoris, DesSoph—Descurainia Sophia, GalApar—Galium aparine, MatCham—Matricaria chamomilla, PapRhoe—Papaver rhoeas, PlaUlig—Plantago uliginosa, VerPers—Veronica persica, VioArve—Viola arvensis*
Winter rapeseed	*GerPusi—Geranium pusillum, PapRhoe—Papaver rhoeas, PlaUlig—Plantago uliginosa, SinArve—Sinapis arvensis, VerHede—Veronica hederifolia, VerPers—Veronica persica*	*CapBurs—Capsella bursa-pastoris, DesSoph—Descurainia Sophia, MatCham—Matricaria chamomilla, SteMedi—Stellaria media, TriAest—Triticum aestivum, TriInod—Tripleurospermum inodorum, VioArve—Viola arvensis*	*ApeSpic—Apera spica-venti, LamPurp—Lamium purpureum, ThlArve—Thlaspi arvense*

4. Discussion

The weeding of selected crops under real conditions varies based on chemical regulation limitations, which are given by the rules of the Water Protection Zones. The reactions of weeds are manifested primarily in species composition rather than in the intensity of weeding.

Higher weeding and a higher proportion of the weeds *Setaria viridis*, *Mercurialis annua*, *Chenopodium strictum*, and *Solanum nigrum* were observed in the maize stands where the use of herbicides was restricted. Species that are considered neophytes or species with an invasive status (*Abutilon theophrasti*, *Datura stramonium*, and *Chenopodium suecicum*) were also found in these stands to a greater extent.

The differences in the representation of weeds in the wheat stands were statistically significant according to the RDA. This might have been caused by the low weeding rate, which was implied by the high efficiency of the herbicides allowed in the water protection zones. Nevertheless, perennial weeds (*Cirsium arvense* and *Elymus repens*), which are difficult to control and very harmful in wheat stands, were more common in plots with herbicide limitations. The occurrence of perennial weed species is mainly associated with land. Although they spread slowly, there is a risk of spreading from a long-term perspective.

The winter rapeseed stands differed in terms of weed species composition. *Geranium pusillum*, *Papaver rhoeas*, *Plantago uliginosa*, *Sinapis arvensis*, *Veronica hederifolia*, and *V. persica* occurred more frequently in plots with herbicide limitation. These weeds are sensitive to common herbicides but are less sensitive to herbicides permitted in areas with herbicide limitations.

Changes in the species composition of weeds evoked by the limitation of herbicide applications lead to the promotion of more specialized weeds (specialists) and to the exclusion of generally widespread species (generalists). According to Clavel et al. [53], pesticides, especially herbicides, can contribute to the process of "biotic homogenization," which is the representation of weeds that are resistant to herbicide increase. The heterogeneity of habitats in the landscape is increasing by introducing limitations on the application of her-

bicides. The reduction in pesticide doses is a fundamental contributor to taxonomic and/or functional diversity in the broader agricultural landscape, according to Chiron et al. [25].

Herbicides co-create a selection pressure on field vegetation [54,55]. Different regulation creates a specific pressure on weed vegetation, to which the plants also respond in the longer term by changing their life strategy [56]. Weeds that can survive this pressure occupy this niche and remain part of the agricultural landscape. Field vegetation under herbicide regulation is important for the abundance of birds [27,57] and other animals that are capable of settling in intensively managed fields [58].

Limiting the use of pesticides in sensitive areas (near water bodies) appears to be justified from the perspective of water protection and biodiversity [59]. The ecosystem response of agricultural land to environmental changes remains understudied [60,61]. Biodiversity and soil fertility are crucial for humanity [62]; therefore, they must be given proper attention. The massive use of pesticides around the world leads to the stabilization and increase in crop yields, but also raises strong concerns about the impacts on biodiversity [63–65]. A recent review summarized the results of 394 studies and found that a large number of studies reported significant negative effects of pesticides on soil invertebrates [66,67], which constitutes a significant part of global biodiversity [60,68,69]. They are also an essential part of terrestrial food webs and play an important role in ecosystem services for many terrestrial animals, including vertebrates [70–74]. A loss of biodiversity destabilizes farmland ecosystems, which potentially threatens the sustainable intensification of agriculture [75].

A floristic analysis of the site is a well-known way of assessing the quality of the environment, because the entire flora of the site is a bioindicator [76]. According to Van Kleunen et al. [77], the presence of non-native taxa is an indicator of poor environmental quality. It can be assumed that a simple limitation of herbicide use is not a guarantee of improving the environment or water quality. Several studies have addressed the impacts of government measures and implemented management (for example, ES 2018 and EC 2019) on water quality [78], but little empirical research has been conducted to contribute to improving the quality of underground and surface water [79].

The limitations of chemical weed control resulting from regulations on water protection creates a need for non-chemical weed control in field crop stands. According to Melander et al. [80], research on direct non-chemical methods of weed control uses policy initiatives that aim to reduce the reliance on pesticides and promote organic crop production. The need for non-chemical methods of weed regulation can also be attributed to the lack of new active substances of chemical herbicides, which results from stricter requirements for the registration of pesticides and environmental regulations. This situation caused a drastic decrease in available pesticides, with the loss being the greatest in Europe, with 945 active substances in 1999 compared to 336 in 2009, which resulted in a 64% reduction [81]. Our results show that on plots with herbicide limitations in real conditions, there is an increase in difficult-to-control weeds (*Cirsium arvense*, *Elymus repens*, *Geranium pusillum*, and *Setaria viridis*) or new species of weeds (*Abutilon theophrasti*, *Mercurialis annua*, and *Solanum nigrum*). Their occurrence requires changes in weed regulation by farmers, which are often reluctantly accepted.

Regulations aimed at water protection are of paramount importance to safeguard the environment and human health. The impact on other ecosystem components must be monitored and evaluated. Limiting the use of herbicides reduces surface water pollution but simultaneously introduces challenges for farmers. Protective and regulatory measures must be understood on a broader scale of the entire landscape. These measures should be assessed not only from the perspective of water protection, but also by considering other landscape components influenced by these regulations. In formulating protective and regulatory measures, multidisciplinary discourse is necessary along with efforts to find collaborative solutions. To ensure the viability and effectiveness of these measures, it is crucial to avoid a scenario in which safeguarding one landscape element (water) significantly disadvantages the other (agriculture).

Therefore, it is essential to look for other techniques and methods to protect surface water. In the entire landscape, buffer zones are very important, and according to Mykrä et al. [82], they are very effective in protecting aquatic environments because of the diversity of plant communities in floodplain forests. Buffer zones or coastal zones are commonly considered to be effective filters of nutrients (N, P), as well as pesticides [83–86]. However, the relative effectiveness of these buffer zones depends on topography, vegetation and soil type, climate, and the extent of nutrient loading, and probably chiefly on their width [87–90].

Riparian vegetation affects stream water quality and biodiversity in several ways [87,91,92]. The vegetated riparian zone is important for the degradation of organic agrochemicals, including pesticides [93]. An appropriate design of the buffer zone based on site characteristics and landscape restrictions offers experts a tool to take steps to limit the negative effects of agriculture [94,95].

The need to feed billions of people necessitate reliable and predictable crop yields, with a parallel requirement to preserve conditions for biodiversity. This can be achieved using a model of agricultural production that includes water bodies and respects the multi-function use of productive landscapes [75].

5. Conclusions

Restrictions on weed management within water protection zones, as applied in the Czech Republic, led to alterations in the weed spectrum of the chosen crops. The reaction of field weeds can be seen primarily in the weed species composition. Changes in the vegetation composition were more evident in the stands of maize and winter rapeseed. In winter wheat stands, the differences in the weed composition were not statistically significant. Places with limited herbicide application are mainly suitable for weeds that are less sensitive to permitted herbicides, perennial species, and neophytes. The proportion of neophytes and invasive species was higher, especially in maize stands in plots with herbicide limitation. The responses of weeds to the reduction in pesticide use can help in planning appropriate weed control measures for individual crops.

Water protection rules can cause problems for the regulation of certain weed species. The limited assortment of herbicides leads to the repeated application of herbicides with the same active substance, which can result in the emergence of resistance in weeds. In areas designated for water protection, a complete ban on the use of pesticides appears to be more convenient, and in agricultural production areas, there is a transition to the organic farming regime.

The planning and implementation of appropriate measures for weed control in individual crops should consider specific conditions of a given location and the consequences of the chosen practices. A comprehensive approach to this issue should be based on scientific knowledge, monitoring of the development of weed resistence, and the ongoing optimization of strategies to control them. By adhering to this approach, sustainable agriculture that is in harmony with environmental protection and long-term sustainability can be achieved.

Alternative biological and physical weed control methods could represent a promising direction for further research. A thorough analysis of the economic and environmental aspects of these methods would help in finding a balanced and sustainable solution that would minimize negative impacts on the environment and agricultural production. Educating farmers about optimal weed control practices is also key to achieving sustainable agriculture and the long-term sustainable use of land and water resources.

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Příloha 9

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Perspectives and controversies

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Anthropogenic life strategy of plants

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Abstract

Plants can adapt to different conditions. They use different life strategies which allow them to adapt and survive. While humans and human civilization cause changes in the Earth's ecology, only negative impacts of human civilization on individual parts of ecosystems tend to be presented and described. One often omitted fact is that humans also create new habitats which, for many plant species, are new challenges necessary to trigger changes in their life strategies. In the contemporary flora, there is a group of plant species that use and prefer anthropogenic habitats, and beneficial relationships started to be established between the human civilization and certain plant species. These plants have developed a new type of strategy—the anthropogenic life strategy—as a result of the co-evolution of plants and humans. During their evolution, humans—as a biological species—have exceeded their biological boundaries and transformed into human civilization, which is a factor altering environmental conditions and contributing to the evolution of new species, including plants.

Keywords

anthropogenic habitats, changing environmental conditions, co-evolution of plants, human activities

Introduction

Plants are able to adapt to different and changing environmental conditions on our planet. Ecological strategies of plants were identified and characterized by Grime (1974, 1979) who defined three main strategy types: (i) competitive strategy (C) offering advantages in habitats with abundant resources, where conditions are not extreme and where disturbances are minimal; (ii) stress-tolerance strategy (S) offering advantages in habitats with limited resources, extreme conditions, but with limited disturbances; and (iii) ruderal strategy (R) offering advantages in habitats with abundant resources, without extreme conditions, but with significant disturbances.

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Between these main types, there are transient strategies (CR, CS, SR, CSR) which are presented in the BiolFlor database (Klotz and Kuhn, 2002). A method that makes it possible to assign life strategies to individual was developed by Pierce et al. (2017).

Our planet has been significantly transformed by human activities which result in unprecedented and accelerating changes in the Earth's ecology (Chapin et al., 2011; DeFries et al., 2012). There is no doubt, we live on a planet dominated by one keystone species—*Homo sapiens* (Kueffer, 2020). Humans have already transformed more than three quarters of the terrestrial biosphere (Ellis et al., 2010 ; Kennedy et al., 2018; Martin et al., 2014). Human activities change environmental conditions (Ebi et al., 2017; Ellis, 2020 ; Norder et al., 2020) and directly affect the life cycles of plants. So far, only negative impacts of human civilization on individual parts of ecosystems tend to be presented and described, including the impacts on plants. Some plant species were completely eradicated, or their living space destroyed or altered. However, one fact which is often omitted is that humans also create anthropogenic biomes (anthromes) (Ellis et al., 2010), and this is a new life strategy challenge for many species. A new environment which is different from their natural habitat forces the plants to adapt. Not only do the plants adapt to new conditions, but they can also actively use them to survive in the habitat and to multiply and spread. As our civilization develops, environments increasingly emerge that are either significantly influenced by humans or directly created by them. Such anthropogenic environments become new living spaces for plants (Fuentes and Baynes-Rock, 2017) but only for the species that can change their life strategies.

In the contemporary flora, there is already a group of plants that use and prefer anthropogenic habitats. Mutually beneficial relationships started to be established between the human civilization and certain plant species, with the latter creating a new type of strategy. These great changes led to the identification of a new type of strategy—anthropogenic life strategy (A). Many years of studies and observations made it possible for us to formulate a number of identifying criteria closely related to the activities of humans and human civilization. Typical anthropogenic life strategy characteristics comprise the following criteria.

Propagation and seed production

The production of new generations in most domesticated crops is fully controlled by humans. Some plants, varieties or forms can only reproduce with human assistance. One typical example is maize (*Zea mays*), which has lost its ability to release seeds (caryopses) from the mother plant. This species would have ceased to exist without humans. According to van der Pijl (1982) , deprived of its natural dispersal ability, the cultivated *Zea mays* seems an "impossible" plant in its domestication. In case of *Avena sativa*, the loss of the detachment of diaspores (present in natural forms) seems to have automatically promoted them from weeds to crop plants among other cereals (van der Pijl, 1982). This is also the case of some ornamental multi-petal varieties of roses (*Rosa* sp.). Many cultivars do not produce any reproductive cells and their survival fully depends on growers (Marchant et al., 1998 ; Robinson and Firoozabady, 1993 ; von-Arnold et al., 2002). Numerous species of the genus *Musa* sp. depend exclusively on vegetative reproduction. These changes are often linked to the process of plant domestication and further crop breeding.

Based on this criterion, we can state that crops and many artificially bred cultivars use a predominantly anthropogenic life strategy (Hickey et al., 2019; Qaim, 2020; Zaidi et al., 2019).

Spread of diasporas

Human activities result in the transport of plant diasporas over distances which the plants would not be able to cover naturally (distribution of species) (Auffret, 2011; Mack and Lonsdale, 2001;

Wichmann et al., 2009). Human-mediated dispersal (HMD) is a driver of long-range spread of plant species and is increasingly gaining attention in the dispersal and invasion ecology (von der Lippe et al., 2013). In the past, this included one-off cases related to the building of living species collections in botanical gardens (Damalas, 2008; Mack and Lonsdale, 2001; Reichard and White, 2001; van Kleunen et al., 2018). One of many such examples is the *Galinsoga parviflora* species, imported from Central America and planted in many botanical gardens around Europe (Damalas, 2008). It has spread across Europe rapidly and nowadays it is an omnipresent part of the vegetation covering anthropogenic habitats (gardens, arable land, etc.) as a common weed. Globalization means that large quantities of plant materials (grains, legumes, cotton, etc.) are frequently and repeatedly transported (Reichard and White, 2001; van Kleunen et al., 2018). These materials include diasporas of plants that spread to non-native areas, with human transport allowing them to cross long distances, often from one to another continent. This transport, both intentional and unintentional, has become the basis for a new category of plants referred to as neophytes (Santini et al., 2018; van der Pijl, 1982; Zisenis, 2015).

Adaptation to agricultural technologies

A new category of plant species—weeds—emerged with the beginning of the Neolithic agricultural revolution (Abbo and Gopher, 2020; Koch et al., 2016; Mueller-Bieniek et al., 2019). The species currently represent a specific group adapted to tillage, crop rotation, use of fertilizers and other agricultural techniques. Vegetation period duration is an important part of their strategy, and this depends on the specific crop, availability of nutrients, and highly biologically active topsoil. van der Pijl (1982) points out that a special group of weeds growing among the crop plants had to conform to these in many respects, compared with the wild forms (general habit, period and periodicity of germination and maturation, size of seeds). Archaeophytes, known to be typical "weeds," adapted to the agricultural land-use (Baessler and Klotz, 2006). On a long-term basis, the specific conditions created by humans have been creating living conditions for crops and weeds, that is, agrophytocenoses, the existence of which is fully dependent on human activity. Both crop and weed species are adapted to arable land so much that they survive with difficulty in a natural environment without the presence of agricultural practices.

Adaptation to chemicals

Man-made substances like pesticides, petrochemical industry and household products radically alter the environment. In many cases, these substances are biologically active. Entering the environment, they alter living conditions for plants, such as accessibility of nutrients or the presence of toxic substances affecting the plant metabolism. As a result, sensitive species decline while species that can benefit from the change thrive. A typical example is the spreading of resistant weed species populations in areas with high herbicidal loads (Hawkins et al., 2019; Perotti et al., 2020). If herbicides are systematically and excessively applied to weed populations, sensitive populations disappear while resistant individuals survive. Populations that are resistant to herbicides eventually replace the more sensitive ones. Herbicides are becoming a selection factor changing the biological properties of plants (Heap, 2017 ; Somerville et al., 2017).

A very common example of the effect of chemical substances produced by anthropogenic activities is the eutrophication of waters (Brolin and Kander, 2022; Gushulak et al., 2022; Häder et al., 2020; Wang et al., 2021). Due to the increased presence of nitrogen and phosphorus compounds, there are significant changes in the species composition of the aquatic flora (Ayele and Atlabachew, 2021; Kitsiou and Karydis, 2011; Zub et al., 2019).

Human-induced climate change is now affecting all regions of the world (Lima et al., 2022). Climate change affects vegetation patterns and plant physiology through spatial and temporal changes in temperature and humidity and increased atmospheric carbon dioxide (CO_2) and affects plant biology by providing more carbon for photosynthesis, biomass production and growth (CO_2 fertilization). These factors can affect the spread of invasive plants, the onset, duration, and intensity of pollination (Guo et al., 2022; Reinmuth-Selzle et al., 2017; Ziska, 2022).

Controlled succession

Forest management is based on planting selected dominant species of trees that meet certain target parameters defined by the growers (Hui et al., 2019; Leidinger et al., 2019; Schall et al., 2018). These parameters may include easy seed extraction, fast growth, high adaptability (Young et al., 2020). As a result, commercial plantation forests are species-poor phytocenoses comprising individuals of the same age (Grevé et al., 2018; Pukkala, 2018). According to Iezzi et al. (2020) fast-growing trees are increasing worldwide, a fact that can have strong local and regional effects on biodiversity. The biodiversity of commercial plantation forests is often considered to be very low, and it is claimed that they leave no place for rare or endangered species (Horák et al., 2019).

Human activity is resulting in woody species entering new habitats, such as *Pinus pinaster* which forms uniform dense growths in southern France but also in South Africa (Caminero et al., 2018; Vergarechea et al., 2019). Fast-growing trees are yet another example; the most frequently planted are for example intentionally created hybrids of the *Populus* species (*P. nigra* x *P. maximowiczii*) which reproduce only vegetatively (clones) and exclusively with the help of humans (Li et al., 2021; Tinschert et al., 2020).

Changes in geological and soil conditions

Humans create habitats such as urban areas, industrial zones, railways and roads, mines, and landfills (Dijkstra et al., 2019; Sealey et al., 2018; Thomson and Newman, 2020; Winkler et al., 2021). Large construction projects and the extraction of mineral resources is evaluated primarily in relation to negative environmental impacts (Jacka, 2018; Nassani et al., 2021; Sonderegger et al., 2020), the effects on plants are neglected. These activities significantly impact the geological, pedological and hydrological of habitats. The habitat conditions are therefore substantially determined by humans and are sudden and major from the perspective of plants. These conditions are an opportunity for certain plant species. Odoh et al. (2019) highlighted that the impact of natural resource mining has led to the invasion of alien species of plants, some of which had attained pest status. Plant species that thrive in these conditions are highly flexible in terms of their environmental requirements, have a high reproduction potential, and high regenerative ability. Such species include for example, *Acer negundo*, *Calamagrostis epigejos*, and *Robinia pseudoacacia* (Puchałka et al., 2021; Těšitel et al., 2020; Veselkin et al., 2021).

Conclusions

The new anthropogenic life strategy (A) allows plant species to survive in habitats impacted and/or directly created by human civilization. This new life strategy (A) differs from the original three strategies as follows:

- Difference from the competitive strategy (C): the difference is defined by the determining impact of human civilization on the availability of resources for the plants. Human activities also influence the plant reproduction processes.

Table 1. Comparison of existing strategies and anthropogenic strategies (A).

Strategies	Environmental conditions	Sources	The originator of stress
Competitive strategy (C)	Stable without disturbances	Abundant resources	Competition of plant species
Stress-tolerance strategy (S)	Limited disturbances	Limited resources	Extreme environmental conditions
Ruderal strategy (R)	Significant disturbance	Abundant resources	Significant disturbance
Anthropogenic strategies (A)	Regular disturbance	Sufficiency and scarcity of some sources	Human civilization

- Difference from the stress-tolerance strategy (S): the difference lies in the stress stemming from human activities such as the impact of chemical substances created by humans and changes in the microclimate of human-created habitats.
- Difference from the ruderal strategy (R): this seems to be a strategy most similar to the anthropogenic life strategy; however, the significant disturbance is caused by humans only. Such disturbance occurs regularly, and it is no random or one-off phenomenon as in the case of natural disturbance.

Anthropogenic life strategies are mainly adopted by agricultural crops, forest tree species and ornamental species, but also by weeds, neophytes, and synanthropic vegetation. These vegetation groups consist of species that have started to adapt to the impacts of our civilization and directly use them for their own benefit.

As a biological species, humans are already exceeding the biological species boundaries and transforming into human civilization, which is a factor altering the environmental conditions and contributing to the evolution of new species. The new anthropogenic strategy is a result of co-evolution between humans and vegetation.

Table 1 compares the existing ecological strategies of plants s and new type of strategy—anthropogenic life strategy (A).

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RESEARCH ARTICLE

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Fragmentation and biodiversity change in urban vegetation: A case study of tram lines

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Abstract

This study explores the vegetation composition along various tram line sections in Bydgoszcz, Poland, with a focus on understanding the impact of usage, maintenance, and historical development on urban vegetation dynamics. This study addresses this knowledge gap by investigating how these factors influence plant species composition, leading to variations in the prevalence of native and non-native species. The aim of this study is to contribute to urban ecological knowledge and inform vegetation management strategies. The investigation centers on five tram line sites representing different usage and maintenance scenarios: Unused line, New line, Loop rec, Loop old, and Old line. Through phytocoenological relevés conducted in 2020 and 2021, we measured the plant taxa coverage. Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) revealed relationships between plant species and tram line sites. The results indicated the presence of 107 plant taxa, with graphical representations highlighting the prevalent species on each tram line section. Older sections showed a higher representation of non-native plant species, whereas new sections exhibited native species dominance. Moisture-indicative values suggest an affinity for soils with average moisture content. CCA provides insights into the relationships between plant taxa and site variants and offers valuable implications for urban vegetation management and conservation strategies. The novelty of this study lies in its holistic approach for understanding how multiple factors interact to shape urban vegetation. By illuminating urban ecological dynamics and informing decision-making processes, this study contributes to urban planning, ecology, and biodiversity conservation. Additionally, this study fills a knowledge gap by providing insights into the unique ecological dynamics and species composition of tram lines in urban environments. Unlike previous research in Central European countries focusing on planted vegetation, this study explored the spontaneous spread of plants and successional patterns along tram lines, enhancing our understanding of the environmental conditions created by tram lines that influence vegetation composition and development.

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KEYWORDS
biodiversity, native and non-native species, transportation, urban ecology, urban vegetation dynamics, vegetation management

1 | INTRODUCTION

The world is experiencing rapid growth in towns (Mansur et al., 2022). The urban landscape is a backdrop for 55% of the world's population and this number is expected to grow (Guyot et al., 2021). The contemporary stage of human history is often referred to as the "urban century" (Vega et al., 2021). Towns are considered to be the greatest invention of mankind, a way of living that has many advantages, including higher economic productivity and innovation, better opportunities for education and individual development, and more efficient exploitation of natural resources and energy (McDonald & Beatley, 2020). The urban century also represents a challenge to the global environment, both directly by sprawling urban development, and indirectly by the consumption of energy and resources in towns (McDonald et al., 2018). Human civilization is forced to look for new ways to maintain the biological diversity of ecosystems in towns and cities (Elmqvist et al., 2019; Kueffer, 2020; McDonald et al., 2018). The Convention on Biological Diversity currently prepares a global framework for biodiversity after 2020, that aims to determine new global goals in the field of biological diversity in the coming decades. The goals are in line with the common vision of "mankind living in harmony with nature," which is to be achieved by 50 (Mansur et al., 2022).

Growing fear of the global loss of biological diversity and understanding of ecosystem functions and services creates space for the promotion and extension of urban green infrastructure (Andersson et al., 2014; Aronson et al., 2017; Fischer et al., 2018; Lepczyk et al., 2017; Winkler, Vaverková, & Havel, 2023). Contemporary towns represent a mosaic of different habitats, including urban greenery, in multiple forms: forests, parks, wastelands, ruderal sites, grasslands, ornamental plantations, and meadows (Knapp et al., 2012; Malkinson et al., 2018). Small green areas in towns are often neglected, and greater attention has been paid to large parks and nature reserves (Gallo et al., 2017). Small green areas such as tree alleys on streets and roadsides form the majority of urban green areas, particularly in densely inhabited town cores. Because of their linear character, they make it possible to interconnect urban green areas in individual towns. Small green areas have a much higher alpha and beta diversity than large green areas, such as parks or suburban greens, which suffer from the homogenization of biodiversity and isolation from other green areas (Muvengwi et al., 2022; Vega & Küffer, 2021).

Habitat fragmentation, as explained by many ecologists (Li et al., 2022; Nisi et al., 2023; Tan et al., 2023; Zaręba et al., 2022), typically leads to the isolation of species populations within smaller patches, resulting in restricted movement and gene flow. This can be detrimental to biodiversity by increasing the vulnerability of species to extinction and by disrupting ecological processes. Land fragmentation in agriculture often involves the division of large fields into smaller plots, which can affect the efficiency of agricultural operations. However, as shown by research, such as the study of farmland fragmentation in the Qilu Lake watershed (Yu et al., 2022; Zhang et al., 2023), it can have a positive impact on agricultural production efficiency, especially when managed at an appropriate scale. Smaller fragmented plots are sometimes more manageable and allow for more diversified crop rotations, which can increase productivity.

Fragmentation can also create habitats with different living conditions, which changes the structure of the vegetation and thus the entire ecosystem. The heterogeneity of living conditions allows new plant species to grow and enrich biodiversity. Sites with strong human influence are more often characterized by homogeneous living conditions. Fragmentation of anthropogenic landscape conditions can be a way to promote biodiversity.

In the Anthropocene, the extent of ecosystems in which human civilization had become a dominant ecological power expanded (Ellis, 2011; Vega et al., 2021). Human activity generates many specific habitats that are suitable for plant development. Tram and railway lines are synanthropic habitats that host specific plant species (Heneidy et al., 2021; Májeková et al., 2021; Rendeková et al., 2020). Urban vegetation of the tram lines was intentionally seeded, but some plant species occurred spontaneously. Tram lines represent specific ecological migration corridors for plants (Rendeková et al., 2020; Woźnica et al., 2016) under specific living conditions. Plants had to adapt to this special environment, which led to the development of unique properties in them (Woźnica et al., 2016).

Tram lines are more than just transportation infrastructure; they are essential components of urban infrastructure that serve important functional roles and possess unique properties (Gössling & McRae, 2022; Qiao et al., 2022). As a form of public transportation, tram lines provide efficient and sustainable mobility options within cities, contributing to improved accessibility and reduced reliance on private vehicles (Balaban & de Puppim, 2022; Coppola & Lobo, 2022). Tram lines are artificial biotopes (Dziuba et al., 2022) that create specific habitats for plants (Rendeková et al., 2020; Woźnica et al., 2016). The construction and maintenance of tram lines create unique environmental conditions that can foster the establishment and growth of plant communities (Saggau et al., 2023). These specific conditions provide an opportunity for plant species to adapt to external stress. Tram lines often form linear features that create edge effects between the track and the adjacent habitats. Edge effects refer to ecological changes and unique conditions that occur at the boundaries between different ecosystems (Papp et al., 2022). The transition zone between the tram line and the surrounding vegetation can provide niche opportunities for plant species adapted to intermediate light conditions and edge habitats (Dziuba et al., 2022; Rendeková et al., 2020). They must also deal with traffic trampling and mechanical disturbances (Liu et al., 2009; Sudnik-Wójcikowska & Galera, 2005). The specific conditions of tram lines provide an opportunity for non-native plant species (Rendeková et al., 2020) to spread to adjacent ecosystems. Species composition shows that tram lines also change moisture conditions (Dziuba

et al., 2022). Many plant species growing at these sites are tolerant of heavy mechanical disturbances and toxic substances. Although tram lines occur in many towns and cities, their flora has not been thoroughly investigated. Therefore, the aims of this study were to: (i) assess the taxonomic composition of vegetation growing on tram line sections under different conditions; (ii) determine the relationship between some plant species and functional plant groups under different tram line conditions: (iii) evaluate the ecosystem functions of tram line vegetation; and (iv) characterize trends in the fragmentation of tram line vegetation with different management strategies. Owing to their unique characteristics, the biotopes of tram lines should be included in urban botanical research to contribute to the understanding of the functions and changes in the vegetation of urban ecosystems.

This study contributes new global knowledge by shedding light on the unique ecological dynamics and species composition of tram lines in urban environments. While existing research on the flora of tram lines in Central European countries has predominantly focused on planted vegetation, this study delves into the spontaneous spread of plants and successional patterns observed. Tram lines create distinctive environmental conditions that influence the composition and development of vegetation.

2 | MATERIALS AND METHODS

2.1 | Description of the study area

The study was conducted in Bydgoszcz, Poland (53°07′27.6″N 18°00′31.1″E). Bydgoszcz is situated in the north of Poland on the Brda and Vistula Rivers. With 339,053 inhabitants (December 2021) and an urban agglomeration of more than 470,000 inhabitants, Bydgoszcz is the eighth-largest town in Poland (Taylor & Józefowicz, 2012). It is recognized for its green spaces and parks, historic mills, lush gardens, and walking paths (Sztubecka et al., 2019, 2020).

In terms of physical geography, the estate lies within the macroregion Pradolina Toruńsko-Eberswaldzka, in the mesoregion of the Toruń Valley and the microregion of the Urban Brda Valley (terraces I-III about 30–40 m above sea level). The southern outskirts of the estate are occupied by the Bydgoszcz Slope, with a relative height of approximately 27 m, carved by a system of small ravines and erosion indentations. Similarly, the western and eastern outskirts of the unit are natural boundaries formed by ravines, that lead to communication arteries (Kujawska Street, Jana Pawła II Avenue). The northern border is the Brda River.

Bydgoszcz was chosen as the study area because its urban characteristics and well-developed tram network make it a relevant context for studying the ecological dynamics of tram lines. This choice of location allowed us to study the impact of tram lines on urban vegetation in a diverse and ecologically relevant setting.

The communication system in Bydgoszcz mirrors the area-development system and has a linear character. It has a distinct section along the E-W axis and a relatively short N-S axis. Babia Wieś is an urban unit (housing estate) of Bydgoszcz, between the Brda River and downtown Bydgoszcz. The first trams in Babia Wieś were built in 1898, when the "green" line was extended from Zbożowy Rynek along Toruńska Street to Strzelnica (Żupy Street). In 1914, the tram line extended in the direction of Małe Bartodziejów to the Bełzka Street (Toruńskie roundabout). The work was interrupted due to the outbreak of World War I. After World War II, in the years 1952–1953, a new tram line "Brda" was put into use, connecting Old Town with Kapuściska and gnow. A tram loop was built in Babia Wieś, and the tracks were laid along Babia Wieś and Toruńska streets. The complex of tram lines called "Brda" from Babia Wieś to Łęgnowo, Kapuściska and Glinki was constructed in 1953 together with other five tram lines. In 1956–1959, a new tram depot was built. The Pomorski Bridge with tram lines was put into operation in 1970. In 1974, the comprehensive modernization of rails was carried out on the upper-town terrace, and a tram line was built into the Magnuszewska tram terminal, which was extended to Karpacka St. in 1984. The tram loop of Babia Wieś with the connected tram lines was operated until 2001. Subsequently, part of the tram loop and line was reconstructed and is currently not used for tram transport.

Five tram line sites were chosen in the studied section, which differs in the way they are used: (i) Unused line: the tram line section is not used for transport and is not maintained; continuous vegetation succession is on (Figure 1a); (ii) New line: the tram line section that was reconstructed but not used for transport; vegetation succession was disrupted by gravel boxing exchange (Figure 1b); (iii) Loop rec: the tram loop section that was reconstructed; the vegetation is maintained by mowing, and its succession is disturbed by vegetation management (Figure 1c); (iv) Loop old: the tram loop section that was not reconstructed; the vegetation is maintained by mowing and its succession is disturbed by vegetation management (Figure 1d); (v) Old line: the tram line section that is not used for transport; the vegetation is maintained by mowing and its succession is disturbed by vegetation management (Figure 1e).

In terms of water-related considerations, Bydgoszcz is situated in proximity to both the Vistula and Brda Rivers, with the Brda River running near the study area. According to the "Flood risk management plan" map from the Hydroportal-IT System for the Protection of the Country (Figure 2), our study area is close to areas susceptible to river flooding. This information highlights the proximity to potential flood-prone zones. Conversely, as indicated by the "Drought Effects Counteracting Plan" map from the same system, the entire study area falls within a zone characterized by a moderate risk of drought.

2.2 | Vegetation inventory

Vegetation was assessed using phytocoenological relevés measuring 5 m^2. The shape of the phytocoenological relevés areas was a rectangle of 1 × 5 m; the shorter side was directed to the tram line, and the longer side along the tram line. Phytocoenological relevés were conducted on three plots for each variant, and vegetation was assessed in August 2020 and 2021. First, all plant taxa that occurred in the phytocoenological relevé were identified, and then, the coverage was estimated for the aboveground biomass of individual taxa. The scientific names of the plant species were obtained from the Pladias database of flora and vegetation (Chytrý et al., 2021).

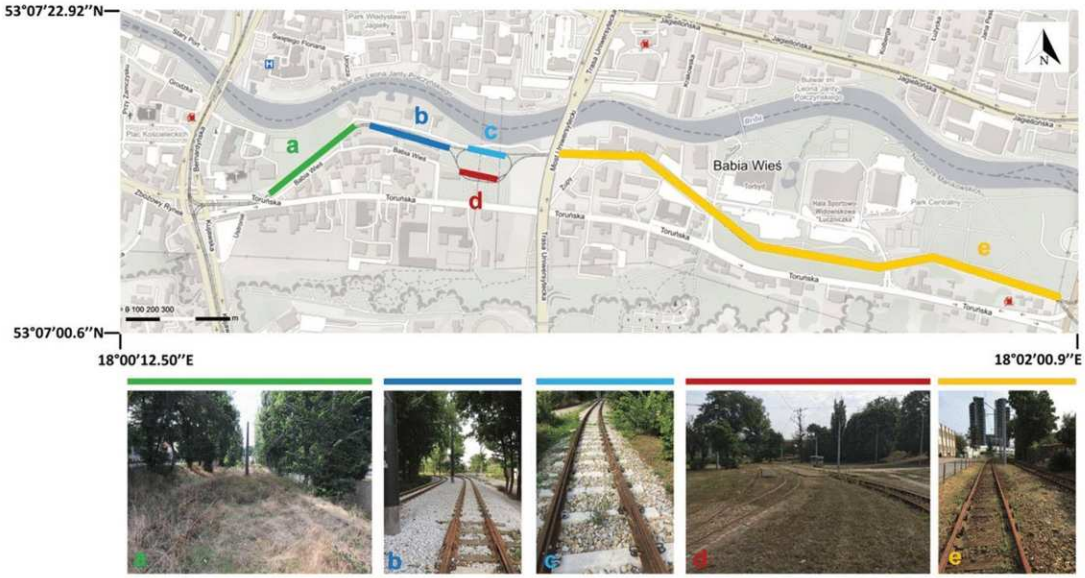


FIGURE 1 Demarcation of tram line and loop (a) unused and unused tram line section (Unused line); (b) newly reconstructed tram line section (New line); (c) newly reconstructed tram loop section (Loop rec); (d) old, maintained part of tram loop (Loop old); (e) unused and maintained tram line section (Old line). [Colour figure can be viewed at wileyonlinelibrary.com]



FIGURE 2 Map "Flood Risk Management Plan" in the study area (blue riverbed, red floodplain). [Colour figure can be viewed at wileyonlinelibrary.com]

Based on information from the Pladias database (Chytrý et al., 2021), plant species were classified into several groups according to the following characteristics: (i) Invasion status is the classification of non-native taxa into three groups depending on the degree of their engagement in local flora. Temporarily introduced taxa are those whose survival depends on the repeated supply of diaspores due to human activity. If they reproduce an outside culture, they are considered temporary. Domesticated (naturalized) taxa have multiplied regularly in the territory for a long time and are independent of human activities. Invasive taxa are domesticated taxa that spread rapidly in (usually extensive) territories, to a considerable distance from the mother population (Richardson et al., 2000, 2011). This classification was not used for the native taxa that were marked separately. The classification was obtained from the Catalogue of Non-native Flora of Czech Republic (Pyšek et al., 2012) with reference to the original sources of information. Categories: temporarily introduced, domesticated, invasive, and native. (ii) The indicator value for moisture was expressed on an ordinal scale from 1 to 12 (Table 1) as defined by Ellenberg et al. (1991). The values of individual taxa were adjusted and extended for the Czech flora by Chytrý et al. (2018).

TABLE 1 Indicative values for moisture.

1	Indicator of severe drought, viable on drought-prone sites and bound to dry soils
2	Transition between 1 and 3
3	Taxon missing on moist soils
4	Transition between 3 and 5
5	Indicator of fresh soils, bound to soils of average moisture content, missing on moist and often drying soils
6	Transition between 5 and 7
7	Indicator of moisture, bound to soils well supplied with water but not wet
8	Transition between 7 and 9
9	Indicator of wet, water-saturated and poorly aerated soils
10	Hydrophyte surviving for a longer time on unflooded soil
11	Hydrophyte rooting under water but with leaves above water surface at least temporarily, or plant flowing on water surface
12	Hydrophyte submerged in water constantly or nearly constantly

2.3 | Statistical analyses

The values of the coverage of individual plant species at the observed sites were processed using multivariate analysis of the ecological data. The selection of the optimal analysis was based on the length of the gradient determined by segment Detrended Correspondence Analysis (DCA). After DCA, Canonical Correspondence Analysis (CCA) was applied because the dataset was relatively heterogeneous, and therefore, the length of the ordination axes in DCA was relatively long. A Monte Carlo permutation test with 999 permutations was used to reveal the effect of the obtained explanatory variables (environmental in Canoco terminology) on plant species composition. Data were processed using the Canoco 5 computer program (Ter Braak & Šmilauer, 2012).

3 | RESULTS

3.1 | Plant taxa prevalence

In total, 107 plant taxa were identified during the monitoring period. The prevalence of these plant taxa along the monitored tram line sections is shown in Figure 3. These figures provide a graphical representation of the most frequently occurring plant taxa observed during monitoring. This information contributes to our understanding of plant biodiversity and ecological dynamics in the studied urban environments.

3.2 | Taxon coverage by invasion status

The share of taxon coverage according to the invasion status is shown in Figure 4. The older tram line sections exhibit a higher representation of non-native plant species with the "naturalized" and "invasive" status as compared with the new sections. The new and reconstructed tram line sections feature the dominant representation of native plant species.

3.3 | Taxon coverage by moisture indicative values

The share of coverage of taxa according to the indicative values for moisture is shown in Figure 5. All monitored tram line sections featured the dominant representation of species with indicative values of 4 and 5. The older tram line section exhibited a higher proportion of plant species with an indicative value of 2 or 3, that is, plant species were missing in moist soils. The unused tram line section shows an increasing share of species with indicative values of 7 and 8 (indicators of moisture bound to soils well supplied with water but not wet).

3.4 | Data analysis: DCA and CCA

The values of coverage by individual plant taxa obtained from the monitoring were processed using DCA. The adjusted explained variation was calculated as 4.05. The data were processed using CCA to establish the relationship between the plant species and tram line sites. CCA delineates the spatial arrangement of individual plant taxa and site variants. The results of the analysis are graphically expressed using an ordination diagram (Figure 6).

3.5 | Classification of plant taxa

The results of the CCA analysis, which was used to evaluate the coverage of plant taxa, were significant at a level of $\alpha = 0.001$ for all canonical axes. Based on CCA analysis, the identified plant taxa were classified into seven groups. The classification of the plant species into groups is presented in Table 2.

4 | DISCUSSION

Research on the flora of tram lines in Central European countries has primarily focused on planted vegetation (Klera & Bacieczko, 2013; Sikorski et al., 2018; Sudnik-Wójcikowska & Galera, 2005; Woźnica et al., 2016; Wrzesien et al., 2016). However, only a few studies have focused on the spontaneous spread of plants (succession) (Vaverková et al., 2018). According to Rendeková et al. (2020), insufficient research on the spontaneously growing flora of tram lines can be explained by the fact that in many cities, tram lines are still covered with concrete and maintained accordingly, which inhibits plant growth. The results of our study shed light on this topic. The results showed that the tram lines are habitats for a wide range of plant species. Different uses of tram lines affect the vegetation cover (Figure 4) and significantly change the species spectrum of the vegetation (Figures 3 and 6). Based on their preferences, the plant species can be

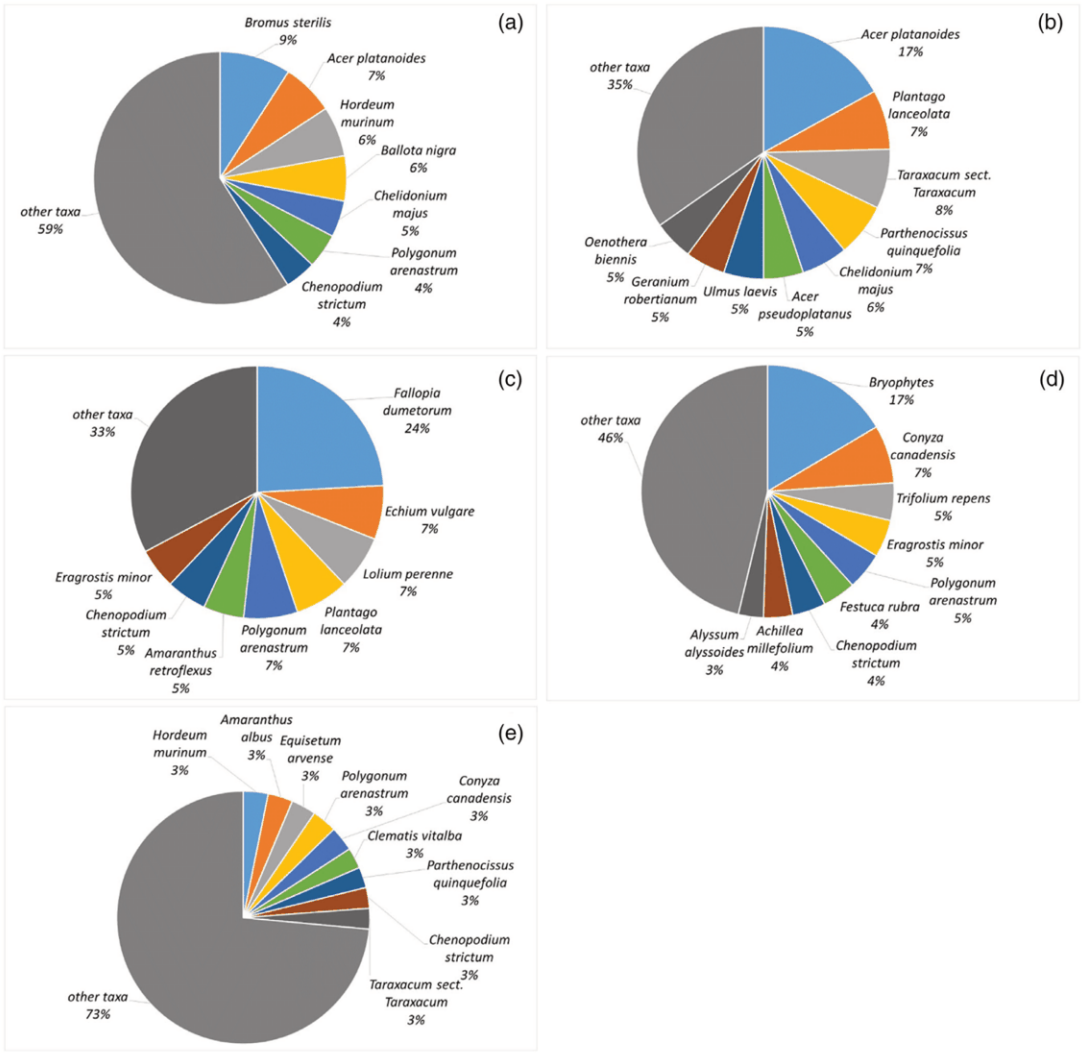


FIGURE 3 Representation of plant taxa occurring on the (a) unused and unkempt tram line section, (b) the newly reconstructed tram line section, (c) the newly reconstructed section of tram loop, (d) the old maintained section of tram loop, (e) the unused and maintained section of tram line. [Colour figure can be viewed at wileyonlinelibrary.com]

divided into groups (Table 2). Based on the species composition of vegetation, it is evident that the construction of tram lines changes the water regime, as can be seen in the different representations of plant species with different water succession requirements (Figure 5).

Commonly occurring in linear sections are taxa that are missing in moist soils, up to taxa that are considered indicators of moisture, bound to soils that are well supplied with water, but not wet. Owing to its linear character, it can be assumed that water is available from the surrounding area, which makes the survival of hygrophilous species possible. The tram line was more favorable for xerophytic plants. According to Májeková et al. (2016), stony and drained tram line sites provide suitable conditions for the growth of xerothermophilous synanthropic species that form an abundant part of the floristic spectrum of these habitats. As shown in Figure 2, the entire study site is in the vicinity of the river and the flood zone. This provides a prerequisite for the significant occurrence of wetland plant species. The vegetation composition of the evaluated tram lines did not correspond to this. The representation of wetland species was not significant and drought-adapted species were predominant. The conditions of the tram lines reduce the availability of water, thus

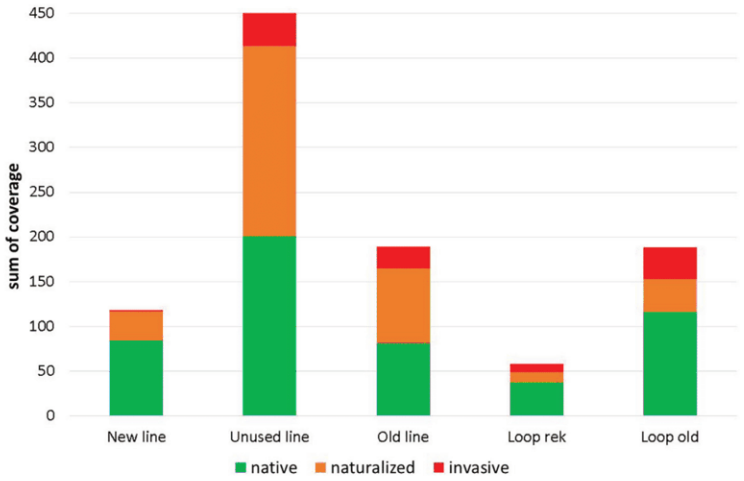


FIGURE 4 Sum of the coverage by individual taxa according to invasion status. [Colour figure can be viewed at wileyonlinelibrary.com]

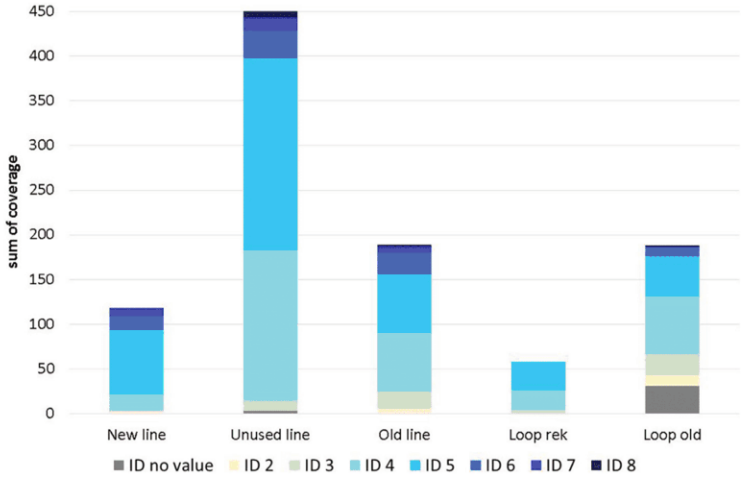


FIGURE 5 Sum of the coverage by individual taxa according to indicative values for moisture. [Colour figure can be viewed at wileyonlinelibrary.com]

creating habitats with different vegetation types. The construction of tram lines involves the placement of specific substrate materials such as ballast, gravel, or concrete (Connolly et al., 2016; Steckler et al., 2012). These engineered substrates may have distinct physical and chemical properties compared to the natural soils in the surrounding area. Variations in soil and substrate characteristics can influence the types of plants that establish and thrive along the tram lines (Heneidy et al., 2021; Łukaszkiewicz et al., 2018; Rendeková et al., 2020).

According to Dziuba et al. (2022), the species diversity of plants on tram lines depends on the succession processes in the surrounding areas. This should be considered when preparing recommendations for the authorities in urban areas. Regarding the significant differentiation of tram line biotopes, their role is irreplaceable in the preservation of urban biodiversity and in the fulfillment of the ecological functions of green areas with parks, gardens, and squares (Capotorti et al., 2020; Zaręba et al., 2022).

It follows from the results that the species composition of vegetation is subject to a certain level of development, which can be referred to as the succession of urban vegetation. This development is strongly affected by human civilization interventions (Dziuba et al., 2022). The initial stage of the succession of tram line vegetation can be seen in the new section (New line) or in the section of the reconstructed tram loop (Loop rec) (Figure 3). Typical signs include low vegetation cover and the predominance of native species whose diaspores are brought to the tram line from the surrounding area. The subsequent succession of vegetation follows a different course depending on the disturbance caused by human activity (Krzysztofik et al., 2022). The unused tram lines suggest that succession would occur without human interference. Compared with the initial stage of succession on the new

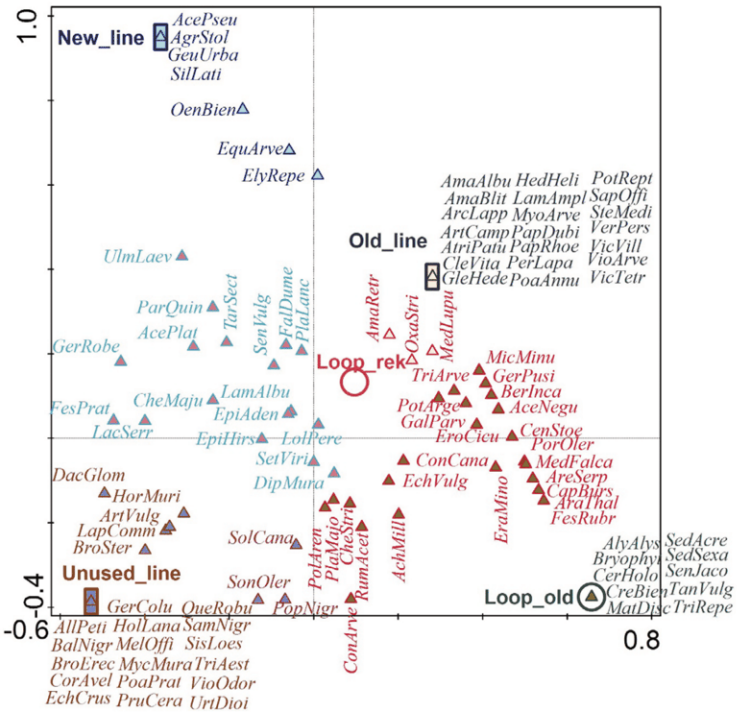


FIGURE 6 Relation of different sites on the selected tram line section and occurrence of plant taxa (total explained variability = 16.4%; the first canonical axis explains 14.59 variability, the second canonical axis explains 25.14 variability; *F*-ratio = 1.7; *p*-value = 0.001). [Colour figure can be viewed at wileyonlinelibrary.com]

line, the representation of non-native naturalized, and invasive plant species increases (Figure 4 and Table 2). The significant non-native species included *Ballota nigra*, *Bromus sterilis*, *Hordeum murinum*, *Chelidonium majus* and so forth. Plant species that are considered invasive include the following: *Epilobium adenocaulon*, *Parthenocissus quinquefolia*, *Sisymbrium loeselii*, and *Solidago canadensis*.

Tram line construction has changed environmental conditions for a long time, fragmenting the vegetation species composition and changing development during secondary vegetation succession. This is in accordance with numerous scientific studies that highlight the importance of railway habitats for the occurrence and distribution of non-native plant species (archaeophytes and neophytes) (Červenková et al., 2016; Dziuba et al., 2022; Hansen & Clevenerg, 2005; Jehlík et al., 2017; Májeková et al., 2016), including invasive species (Denisow et al., 2017; Wrzesien et al., 2016; Wrzesień & Denisow, 2017). However, the role of tram lines in the invasion of non-native plants remains unclear. If we change living conditions, we can change the vegetation, but which species can be considered non-native to the site? The construction of tram lines also changes the composition of vegetation, and a significant change must be expected.

The unused but maintained tram section suggests a different course of vegetation succession. Disturbances caused by tram line maintenance reduce the amount of vegetation biomass (coverage) and change species composition. The share of non-native naturalized, and invasive plant species is also increasing (Table 2). The most significant naturalized and invasive species were *Arctium lappa*, *Papaver dubium*, and *Amaranthus albus*. Specific changes in vegetation can be called cyclic succession. Repeated reconstruction of the tram line returned the vegetation to its initial stage.

A different succession course is expected in the tram loop. The beginning of succession, which is evident in the Loop rec habitat, showed low vegetation cover and a predominance of native plant species. In the old loop habitat, vegetation cover increased, and the proportion of native species was still dominant. The tram loop no longer exhibits a linear character, which is why the changes in conditions are more conspicuous, which also reflects the representation of specific plant species, such as *Alyssum alyssoides*, *Cerastium holosteoides*, *Sedum acre*, and *Sedum sexangulare*. These species would succeed in places where it is difficult for natural vegetation to grow. Distinct permanent changes in tram lines create specific conditions that are atypical for a given site. The specific development of vegetation can be referred to as a blocked succession.

Vegetation reacts to the conditions of tram lines by the fragmentation of species composition, which raises the question of its utility. On the one hand, tram lines provide space for the use and spread of invasive plant species, which can quickly spread and outcompete native species for resources such as water, nutrients, and light (Denisow et al., 2017; Hansen & Clevenerg, 2005; Jehlík et al., 2017; Májeková et al., 2016; Rendeková et al., 2020; Weidlich et al., 2020; Wrzesien et al., 2016; Wrzesień & Denisow, 2017). They create

TABLE 2 Groups of plant species according to CCA analysis.

Groups of plant species	Native	Naturalized	Invasive
Group 1 (New line)	*Acer platanoides* *Agrostis stolonifera* *Elymus repens* *Equisetum arvense* *Geum urbanum*	*Silene latifolia*	*Oenothera biennis*
Group 2 (New line; Unused line)	*Acer pseudoplatanus* *Epilobium hirsutum* *Fallopia dumetorum* *Festuca pratensis* *Geranium robertianum* *Lolium perenne* *Plantago lanceolate* *Taraxacum sect. Taraxacum* *Ulmus laevis*	*Diplotaxis muralis* *Chelidonium majus* *Lactuca serriola* *Lamium album* *Senecio vulgaris* *Setaria viridis*	*Epilobium adenocaulon* *Parthenocissus quinquefolia*
Group 3 (Unused line)	*Alliaria petiolate* *Artemisia vulgaris* *Bromus erectus* *Corylus avellana* *Dactylis glomerata* *Holcus lanatus* *Mycelis muralis* *Poa pratensis* *Populus nigra* *Quercus robur* *Sambucus nigra* *Urtica dioica*	*Ballota nigra* *Bromus sterilis* *Echinochloa crus-galli* *Geranium columbinum* *Hordeum murinum* *Lapsana communis* *Melilotus officinalis* *Prunus cerasifera* *Sonchus oleraceus* *Triticum aestivum* *Viola odorata*	*Sisymbrium loeselii* *Solidago canadensis*
Group 4 (Old line)	*Artemisia campestris* *Clematis vitalba* *Glechoma hederacea* *Hedera helix* *Persicaria lapathifolia* *Poa annua* *Potentilla reptans* *Stellaria media* *Vicia tetrasperma* *Viola arvensis*	*Arctium lappa* *Atriplex patula* *Lamium amplexicaule* *Myosotis arvensis* *Papaver dubium* *Papaver rhoeas* *Saponaria officinalis* *Vicia villosa*	*Amaranthus albus* *Amaranthus blitoides* *Veronica persica*
Group 5 (Loop rec)	*Medicago lupulina*		*Amaranthus retroflexus* *Oxalis stricta*
Group 6 (Loop rec; Loop old)	*Achillea millefolium* *Arabidopsis thaliana* *Arenaria serpyllifolia* *Centaurea stoebe* *Echium vulgare* *Festuca rubra* *Medicago falcate* *Plantago major* *Polygonum arenastrum* *Potentilla argentea* *Rumex acetosella* *Trifolium arvense*	*Berteroa incana* *Capsella bursa-pastoris* *Convolvulus arvensis* *Eragrostis minor* *Erodium cicutarium* *Geranium pusillum* *Microrrhinum minus* *Portulaca oleracea*	*Acer negundo* *Conyza Canadensis* *Galinsoga parviflora* *Chenopodium strictum*
Group 7 (Loop old)	*Alyssum alyssoides* *Cerastium holosteoides* *Crepis biennis* *Sedum acre* *Sedum sexangulare* *Senecio jacobaea* *Trifolium repens* *Bryophytes*	*Tanacetum vulgare*	*Matricaria discoidea*

entirely new environments and enable the survival of native plant species, thus enriching the species diversity in towns. However, some invasive plant species may have allelopathic effects, that is, they release chemicals into the soil, which can inhibit the growth of other plants (Kato-Noguchi & Kurniadie, 2021; Thiébaut et al., 2019). This can further reduce the diversity and productivity of vegetation on tram lines. The unique conditions of tram lines provide an opportunity for plant species to utilize elements of anthropogenic life strategies (Winkler, Koda, et al., 2023). Additionally, the presence of tram lines fosters the development of anthropogenic ecosystems (Winkler et al., 2021).

Nature conservation must move beyond the traditional notions of wild and cultivated nature (Kueffer & Kaiser-Bunbury, 2014) and embrace new hybrid approaches to protect biotopes that exhibit biological diversity, many of which have been shaped by human civilization (Burney & Burney, 2007; Higgs, 2003; Winkler et al., 2021). Respect for spontaneous vegetation can support biodiversity in urban environments (Reif & Kreß, 2014). Unfortunately, these new perspectives have little influence on the protection of biological diversity in urban areas (Vega & Küffer, 2021). However, towns and cities are hotspots for both endemic and endangered species (Goddard et al., 2010; Ives et al., 2016; Lewis et al., 2019). Rendeková et al. (2020) pointed out that, under local conditions, the habitats of trams and railway lines can serve as valuable refuges for some rare and endangered species. Understanding the role of vegetation on tram lines is crucial for effective urban and spatial planning, as it can have a significant benefit on: (i) Aesthetic value: Vegetation along tram lines can enhance the visual appeal of the urban landscape (Pochodyła et al., 2022; Sanchez et al., 2017; Sikorski et al., 2018; Vega & Küffer, 2021). Plants can create a natural and welcoming environment that softens the harshness of the urban infrastructure (Farrell et al., 2022; Teixeira et al., 2022). (ii) Environmental benefits: Vegetation on tram lines can provide a range of environmental benefits, including improved air quality (Bajçinovci & Bajçinovci, 2020; Jakubcová & Horváthová, 2020), reduced noise pollution (Akay & Önder, 2022), and mitigation of the urban heat island effect (Dian et al., 2019; Jakubcová & Horváthová, 2020; Leal Filho et al., 2021). Urban plants absorb CO_2 and other pollutants and provide shade and cooling effects that can help reduce the temperature in urban areas (Maksymenko et al., 2021; Piracha & Chaudhary, 2022). (iii) Ecological value: Vegetation on tram lines can provide habitats for a range of wildlife, from birds and insects to small mammals (Heneidy et al., 2021; Jakubcová & Horváthová, 2020; Łukaszkiewicz et al., 2021; Nilsson et al., 2014; Vega & Küffer, 2021). This can help support biodiversity in urban areas and contribute to the overall health of urban ecosystems.

The results evaluated have limitations due to the biological nature of the vegetation, and because of the case study in which the conditions of a specific city are evaluated. Despite these limitations, some general trends that can be observed in other areas can be identified. The urbanization activities of human civilization, including transportation structures, fulfill their primary functions. They also create new habitats and fragmented living conditions. Urbanized and fragmented conditions provide habitats for different plant species. The species structure of vegetation that is not intentionally planted provides feedback on the conditions created by human civilization. The use of vegetation to identify environmental conditions in biomonitoring has been well-established (Fusaro et al., 2021; Karmakar et al., 2021; Vaverková et al., 2023). However, it is not currently used in tram lines, even though vegetation provides information about environmental conditions.

Tram lines create conditions for the fragmentation of the urban environment and allow the survival of plant species that can better tolerate arid habitats and require low competition from vegetation. Human civilization is creating an ecosystem composed of specific plant species that provide specific ecosystem functions for other organisms, thus changing the composition of the urban ecosystem.

Further research investigating the impact of human activities and the microclimate on tram line ecosystems, as well as assessing the role of tram lines in urban development and the creation of green corridors, will contribute to a holistic understanding of these urban linear green spaces.

5 | CONCLUSIONS

The development of tram lines brings a number of transportation benefits to the urban landscape but also creates a new environment for plants. The linear nature of tram lines facilitates the entry of certain plant species into cities. This can increase biodiversity but can also lead to the spread of undesirable species. The linear nature of tram lines allows the introduction and spread of both native and non-native plant species. This study highlights the presence of hygrophilous species and xerophytic plants that thrive in response to specific conditions along tram lines, including the use of engineered substrates, such as ballast, gravel, and concrete. It is emphasized that the succession of urban vegetation is strongly influenced by human interventions, such as construction and maintenance, leading to different stages of development.

Tram lines in towns and cities allow for the species fragmentation of vegetation. Diverse species composition is beneficial for invasive species but also creates new environments and enables the survival of native species, thus enriching species diversity in towns. Tram loops exhibit a lack of water, indicating the occurrence of plant species with a transition value between indicators of severe drought and taxa that are missing in moist soils. The studied tram loop does not have a linear character and is therefore more suitable for the occurrence of drought-loving vegetation. The unused tram line section featured an increasing proportion of species considered indicators of moisture. Nevertheless, species with indicative values for soils with average moisture content had a dominant share in all the studied tram line sections. Distinct permanent changes caused by the construction of a tram loop create conditions atypical for a given locality.

This research also highlights the need for careful management and monitoring of tramway vegetation to balance its benefits and potential negative impacts. It provides valuable insights for urban and spatial planning by addressing the aesthetic, environmental, and

ecological significance of vegetation along tram lines. It also encourages a shift towards hybrid approaches to conservation that consider the unique habitats shaped by human civilization. This underscores the significance of tramways in bolstering biodiversity, and advocates for a more profound comprehension of their ecological functions in urban landscapes.

Tram lines change the environmental conditions for a long time, which affects the course of vegetation succession. The specific development of vegetation can be characterized as either blocked or cyclic succession. As a result of human civilization, tram transport affects not only the species composition of vegetation but also vegetation succession. Our research can be used for efficient management of biological diversity in urban habitats, monitoring, and developing measures to control the spread of non-native species. It can also be useful for the sustainable planning and management of urban landscapes. It should be stressed that to balance the benefits and potential negative impacts of vegetation on tram lines, it is important to implement careful management practices. This may include regular monitoring and removal of invasive species as well as the use of native plant species adapted to the local environment.

CONFLICT OF INTEREST STATEMENT

The manuscript was approved by all authors for publication, and they declare that they have no conflicts of interest.

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DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available within the article.

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Příloha 11

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Article

Nature-Based Management of Lawns—Enhancing Biodiversity in Urban Green Infrastructure

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Abstract: Urban green areas have multifunctional benefits that may mitigate unfavorable health and ecological effects. Green areas represent important biodiversity hideouts in anthropogenic regions. Lawns are the most common elements of urban greenery, covering a considerable number of green areas in cities. The aim of this analysis was to gain knowledge on urban greenery and elaborate recommendations related to management that favors grass lawn biodiversity. The established working hypothesis is that the limited intensity of management in urban grass areas is reflected in the modification of their species composition, as well as their potential ecological functions. An experiment on the management of city lawns was conducted in 2010 (still ongoing). There are three lawn variants under different management methods: ornamental, city, and permaculture lawns. Vegetation was assessed using the method of phytocoenological relevés. The coverage values of the individual plant species were processed using multidimensional analysis of ecological data. The results showed that human decisions and activities affected the species composition of these grassy areas. There were 46 plant taxa found during the monitoring: 12 in ornamental lawn variants, 24 in city lawn variants, and 31 in permaculture lawn variants. Permaculture lawns with extensive management represent the most environmentally friendly variant with respect to biodiversity and soil moisture content. However, changes in species composition have raised questions regarding the extent to which they may perform other ecosystem functions. Increasing the intensity of lawn management has resulted in lower plant diversity. Extensive management alters the aesthetic value of lawns and creates spaces for species that may spread in urban environments.

Keywords: urban green areas; biodiversity; grass lawns; management methods; species composition

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1. Introduction

Cities are responsible for significant negative environmental, economic, and health issues, but they also hold the key to a greener economy and sustainable future. According to [1], protecting and restoring urban ecosystems is important for sustainable urbanization. Cities are key to achieving the Sustainable Development Goals (SDGs), and there is a specific goal (SDG 11) for cities [2,3]. Urban green areas have multifunctional benefits that may mitigate unfavorable health and ecological effects [4–6]. They have several ecosystem functions, such as rainwater retention, urban heat-island effect mitigation, food supply, and air purification [5,7,8], particularly when they are located in the neighborhood of communication infrastructure [9]. Green areas are also important biodiversity hideouts in urban [10–12] and anthropogenic areas [13–17]. At present, lawns are the most common element of urban greenery, covering a considerable portion of all open green areas in

cities (up to 70–75%) [18–20]. They have a positive impact on human life in cities [21–24]. However, it is crucial to emphasize that a lawn is a deliberately created plant community consisting of a variety of grass species, including numerous nonnative species [25,26]. These lawns are meticulously cultivated to attain the visually appealing aesthetic of a lush green carpet [27]. Lawns are often created in habitats that are strongly affected by humans; therefore, appropriate species compositions should be selected. Due to their unique microclimate and urban environment, the conditions in cities often deviate from natural ecosystems. As a result, it becomes necessary to explore plant species that may not be typical for the local area but have the ability to thrive and perform the expected functions within lawns. Moreover, lawn management depends entirely on humans. The presence of lawns is currently a topic of controversy due to the potential negative environmental impact caused by the extensive use of pesticides and fertilizers, as well as resource-intensive maintenance practices like frequent mowing, watering, aeration, and reseeding [28–33]. These anthropogenic factors alter habitat conditions, subsequently influencing the species composition of lawns. Additionally, lawns have the capacity to modify urban microclimates, facilitate rainfall infiltration, and contribute to increased biodiversity [10,34–36]. Predominantly, lawns play an aesthetic role [37]. Evergreen, dense, and compact lawns are highly appreciated, particularly in decorative parks, gardens, and flowerbeds [25,38]. Grass lawns are showcases in most Western European cities and are appreciated by most people in terms of culture and aesthetics [18]. However, these lawns require intense and expensive management [39]. The high costs of lawn management have raised questions related to their impact on the environment, particularly the carbon footprint associated with mowing and water usage [35,40–42]. Therefore, lawns with functions other than aesthetics represent an alternative. The shift in city lawn management practices, aimed at reducing their detrimental environmental impact, has given rise to the concept of permaculture [43]. Permaculture lawns or urban meadows are designed to require minimal human intervention while fulfilling various ecosystem functions. Urban meadows, characterized by natural, non-mowed green areas with or without flowering plants, serve as an alternative land cover to conventional mowed green areas. Although their establishment in urban areas is on the rise, they still constitute a small fraction of urban greenery [44].

Exploring polycultures of diverse plant species, including both grasses and dicotyledons, that can thrive and reproduce under traditional lawn management practices, presents an avenue for grass-lawn alternatives. The long-standing and consistent disturbances inflicted on grassland communities by human civilization have resulted in the development of vegetation specific to certain species. These changes in disturbance, driven by human activities, are also reflected in the composition of grassland communities [45]. The authors of [28] propose that polycultures consisting of grasses and native plant species represent relatively untapped resources with great potential for landscape applications.

Natural-based solutions refer to approaches that integrate green spaces and nature-based management practices into urban environments to address environmental, economic, and social challenges. Specifically, the focus is on using natural elements, such as vegetation and soil, to manage water, enhance biodiversity, mitigate urban heat islands, and improve air quality [35]. Nature-based management, particularly water management, involves the utilization of natural ecosystems and processes to regulate water flow, enhance water quality, and manage stormwater runoff. This can include strategies such as green infrastructure (e.g., green roofs, rain gardens, and permeable pavements), restoring wetlands and riparian zones, and promoting the infiltration and retention of rainwater within urban areas [20].

Therefore, understanding the impact of lawn management on urban herbaceous vegetation is crucial. This study addresses four research questions. First, what is the effect of lawn management intensity on the species composition of the urban herbaceous vegetation? We hypothesized that low-intensity lawn management would increase the species diversity and proportion of native plant species. Second, what is the effect of low-intensity lawn management on the representation of the sown plant species? We hypothesized that intentionally sown species can be suppressed by nature-friendly lawn management. Third,

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different lawn management practices alter the representation of plant species, which is indicative of habitat moisture. We hypothesized that intensive management would increase evaporation and alter habitat moisture conditions, which would also affect the representation of moisture-loving plant species and cause them to decline. Fourth, does lawn management influence the proportion of nonnative species? We hypothesized that nature-friendly lawn management would reduce the representation of nonnative plants. By investigating these research questions, we aim to enhance our understanding of the impact of lawn management in urban environments and its implications for the provision of ecosystem services within a city's socio-ecological system.

2. Materials and Methods

2.1. Site Description

The Research and Educational Center—Water Center of the Warsaw University of Life Sciences (SGGW) is located at the main university campus in the southern part of Warsaw in the Ursynów district (Figure 1).

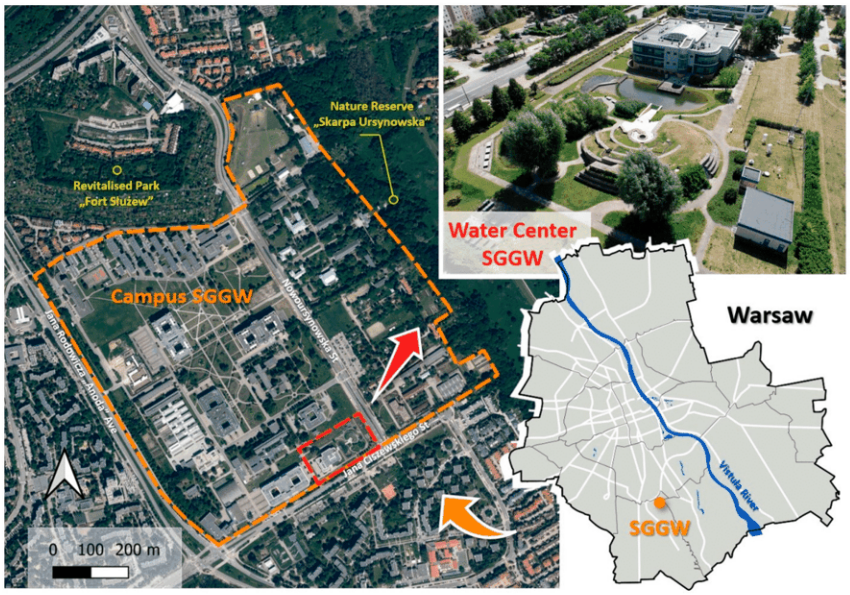


Figure 1. Location of the main campus and Water Center of SGGW.

The total project area is approximately 14,600 m^2. The Water Center is comprised of an educational and research facility with a development area of approximately 2000 m^2 and a total area of approximately 5600 m^2 (Figure 2). The Research Center—Water Center has the dual objective of enhancing the quality of education and promoting ongoing research and development among academic staff. This includes improving research methods and techniques and implementing practical experiences in various applications. The Water Center comprises a model of a watercourse connected with trophic reservoirs, with its outlet in the ultimate water reservoir. A large area of the Water Center is covered with lawns.

One notable feature of the water center park is a model watercourse interconnected with trophic reservoirs, ultimately leading to a water reservoir. To complement this design, a significant portion of the park area is covered with lawns. One of the lawns serves as an example of natural-based solutions, highlighting the benefits of incorporating green spaces and nature-based management approaches into urban environments.

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Figure 2. View of the Water Center of SGGW with the water park.

2.2. Characteristics of the Lawns

The experiment on the management of city lawns was initiated in 2010, with three distinct lawn variants being implemented, each employing different management methods. The specific management approaches for each lawn variant are as follows: (i) Ornamental lawn: This variant involves the cultivation of low-growing grass species under intensive management. Regular cutting is performed every 2–3 weeks during the growing season, with the cut biomass being removed. The lawn receives regular mineral fertilization and watering when precipitation is insufficient. (ii) City lawn: A city lawn represents the typical management approach found in most urban grass areas. It is mowed two to four times per year, depending on biomass growth. After mowing, the biomass is collected and removed, and neither fertilization nor watering is applied to the lawn. (iii) Permaculture lawn: This lawn variant follows a nature-based management approach that promotes semi-natural succession, with minimal human intervention. The grass stand is irregularly mowed once a year in the autumn. The cut biomass is left on-site, and the lawn receives no fertilization or watering. The management practices of permaculture lawns align with the long-term sustainability principles of the permaculture approach. By implementing these distinct management methods, this experiment aimed to assess the ecological and biodiversity outcomes associated with each lawn variant.

2.3. Methods of Vegetation Assessment

Vegetation was assessed using a remote sensor method. The study used the unmanned aerial vehicle DJI Matrice 600 with the multispectral camera Parrot Sequoia+. The camera allows images to be recorded in four spectral channels: green (GRE), red (RED), near-infrared (NIR), redge (REG), and RGB images in visible lights. The data collected allowed a visual assessment of the plants and an evaluation of plant health based on the chlorophyll index. The chlorophyll index allows the amount of chlorophyll in the green parts of plants to be determined. The Normalized Difference Vegetation Index (NDVI), which is the most commonly used index due to its ease of calculation, was used in the study. The NDVI index is based on the ratio of the NIR and RED channels and is expressed by the Formula (1) [46]:

$$NDVI = (NIR - RED)/(NIR + RED) \quad (1)$$

where:

NIR—near-infrared band
RED—red band

Vegetation was assessed using phytocoenological relevés with as size of 2 m^2. Four plots were surveyed for each lawn variant, on which vegetation was assessed in July 2020 and 2021. First, all taxa of plants that occurred on the phytocoenological relevés were identified, and then the aboveground biomass coverage was estimated for the respective taxa. The scientific names of the individual plant species were obtained from the Pladias database of flora and vegetation [47]. Based on the data from the Pladias database, plant species were classified into several groups according to the selected characteristics. The indicator value for moisture was expressed on an ordinal scale from 1 to 12, as defined by Ellenberg [48]. The values for the individual taxa were modified and extended by Chytrý [49].

The coverage values of individual plant species observed at each site were analyzed using a multidimensional analysis of ecological data. To determine the appropriate analytical method, the gradient length was assessed using segment Detrended Correspondence Analysis (DCA). Canonical Correspondence Analysis (CCA) was also performed. To assess statistical significance, a Monte Carlo test was employed, and 999 permutations were calculated. Data analysis was performed using Canoco 4.0, a computer program widely used for ecological data analysis [50].

3. Results and Discussion

3.1. Groups of Plant Species in Grasslands

There were 46 plant taxa found during the monitoring—12 of them in ornamental lawn variants, 24 in city lawn variants, and 31 in permaculture lawn variants. A representation of the identified plant taxa is shown in Table 1.

Table 1. The list of identified plant taxa with the average cover and plant species classification in groups.

Plan Species	Abbr.	Lawn Variants (Average Cover %)			Classification According to Groups:		
		Ornamental Lawn	City Lawn	Permaculture Lawn	Species Suitability for Lawns	Moisture Content	CCA Analysis
Achillea millefolium	*AchMill*	7.3	6.3	4.3	3	5	O/C
Armoracia rusticana	*ArmRust*			3.0	4	6	P
Artemisia vulgaris	*ArtVulg*		0.7	3.0	4	5	C/P
Bellis perennis	*BelPere*	6.7			3	5	O
Bidens tripartita	*BidTrip*			0.3	3	9	P
Calamagrostis epigejos	*CalEpig*			5.0	4	5	P
Carex hirta	*CarHirt*		1.3	1.7	3	6	C/P
Centaurea macrocephala	*CenMacr*			3.7	4	not specified	P
Cichorium intybus	*CicInty*		3.3	8.7	2	4	C/P
Cirsium arvense	*CirArve*		6.0	2.3	4	5	C/P
Convolvulus arvensis	*ConArve*		3.3		3	4	C
Conyza canadensis	*ConCana*		0.7		3	4	C
Cornus sanguinea	*CorSang*			0.3	4	5	P
Crepis mollis	*CreMoll*	3.0	0.7	0.7	3	4	O/C
Dactylis glomerata	*DacGlom*	4.3		13.3	1	5	P/O
Daucus carota	*DauCaro*		7.7	5.3	3	4	C/P
Equisetum arvense	*EquArve*			4.3	4	6	P
Erigeron annuus	*EriAnnu*	2.0		5.0	3	5	P/O
Festuca arundinacea	*FesArun*		1.3		1	7	C
Festuca pratensis	*FesPrat*			16.7	1	5	P

Table 1. *Cont.*

Plan Species	Abbr.	Lawn Variants (Average Cover %)			Classification According to Groups:		
		Ornamental Lawn	City Lawn	Permaculture Lawn	Species Suitability for Lawns	Moisture Content	CCA Analysis
Festuca rubra	*FesRubr*	25.0	58.3		1	5	O/C
Hypericum perforatum	*HypPerf*		1.3	6.0	3	4	C/P
Inula britannica	*InuBrit*			1.3	3	7	P
Lactuca serriola	*LacSerr*		0.3	2.0	4	4	C/P
Lolium perenne	*LolPere*	18.3	16.7		1	5	O/C
Lotus corniculatus	*LotCorn*		7.7		2	4	C
Lythrum salicaria	*LytSali*			1.7	4	9	P
Medicago falcata	*MedFalc*			2.0	2	3	P
Medicago lupulina	*MedLupu*	9.0	15.0		2	4	O/C
Medicago sativa	*MedSati*		4.0	6.7	2	4	C/P
Phalaris arundinacea	*PhaArun*			16.7	4	8	P
Plantago lanceolata	*PlaLanc*	10.7	7.0		3	5	O/C
Poa pratensis	*PoaPrat*		4.7	8.3	1	5	C/P
Potentilla argentea	*PotArge*	3.0			3	2	O
Potentilla reptans	*PotRept*			2.0	3	6	P
Rosa canina	*RosCani*			1.0	4	4	P
Rumex crispus	*RumCris*			0.3	4	6	P
Setaria viridis	*SetViri*	2.3			3	4	O
Silene latifolia	*SilLati*			3.0	4	4	P
Solidago canadensis	*SolCana*			1.8	4	5	P
Sonchus oleraceus	*SonOler*		0.3		3	5	C
Taraxacum sect. *Taraxacum*	*TarSect*		10.0	4.3	3	5	C/P
Trifolium pratense	*TriPrat*		7.7		2	5	C
Trifolium repens	*TriRepe*	11.7	6.0		2	5	O/C
Veronica maritima	*VerMari*			1.3	3	8	P
Vicia cracca	*VicCrac*		1.3		2	5	C

Legend: Groups according to suitability for lawns: 1—sown species, 2—useful species, 3—less suitable species, 4—undesirable species. Groups according to indicative value for moisture content: 2—transition between values 1 and 3; 3—missing on damp soil; 4—transition between values 3 and 5; 5—indicator of fresh soils, focus on soils of average moisture content, missing on wet soils and on soils that frequently dry out; 6—transition between values 5 and 7; 7—humidity indicator, focus on well-moistened, but not wet soils; 8—transition between values 7 and 9; 9—wetness indicator, focus on often soaked, poorly aerated soils. Groups according to CCA analysis: O—group consists of species which prevailingly occurred as part of the vegetation of ornamental lawns. O/C—group of species occurring predominantly in ornamental and city lawns. C—group of species which occurred predominantly in the city lawn variants. C/P—group of plant species recorded particularly in the city and permaculture lawn variants. P—group of plant species which dominated in permaculture lawns. P/O—group of plant species recorded in the ornamental and permaculture lawn variants.

Lawns represent a prominent component of green areas worldwide, regardless of regional climate variations. Despite their prevalence, lawns have not received extensive research attention [18]. Various definitions of a 'lawn' exist, but in this context, they are defined as an artificially created or modified plant habitat characterized by predominantly grass species (technically referred to as graminoids). Additionally, lawns may also contain spontaneous herbaceous species commonly known as 'weeds of lawn' [27]. These so-called 'weeds of lawn' play a vital role in fulfilling important ecosystem functions that hold significance for urban greenery as well as the lawn plant community itself. It is essential to recognize that lawns are dynamic plant communities, with their species composition shaped by human influence [51,52]. According to a study by Ignatieva [53], *Lolium perenne*, *Festuca rubra*, and *Poa pratensis* comprise the basic species composition of lawns in central Europe.

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In terms of human intervention, lawn plant species can be classified as (1) sown, (2) useful, (3) less suitable, and (4) undesirable. We assessed the criteria from a turf perspective only. Sown species are grasses that create basic and characteristic types of lawns. Useful species include leguminous plants that enrich the soil with nitrogen [54,55], thus supporting the growth of grasses and participating in improved rainwater infiltration into the soil [23,56]. Species that are less suitable for lawns are other dicotyledonous plant species, but only low-growth ones. Species that are undesirable for lawns are high-growth herbs or woody plants; that is, species that significantly alter vegetation characteristics [27]. The classification of the plant species in each category is presented in Table 1. Each species was assigned to only one group according to its predominant importance. The ratios in the representation of plant species groups based on their suitability for lawns are shown in Figure 3.

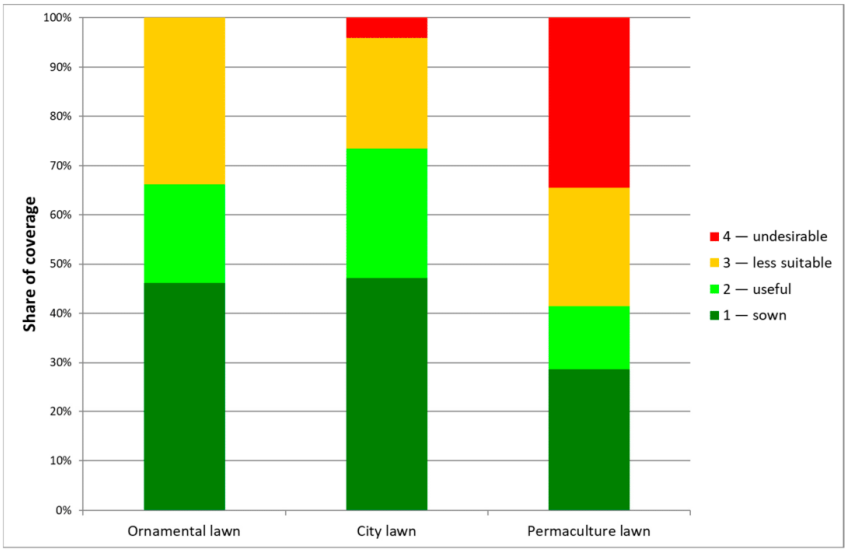


Figure 3. Lawn coverage shares by the groups of species suitability for lawns.

Sown species have the greatest cover contribution to cities and ornamental lawns. City lawns create a favorable ratio between sown grasses and useful species (family *Fabaceae*), which reduces their fertilization requirements (i.e., nitrogen). A considerably undesirable perennial species is *Cirsium arvense* with a sturdy root system, which occurs very unevenly. Therefore, local and targeted regulation is important.

Ornamental lawns have a lower contribution of useful species and a higher contribution of less suitable species. Although intensive management eliminates the occurrence of undesirable species, it also suppresses useful species (*Fabaceae*) and does not increase the contribution of the sown (grass) species. Our study indicates that intensive management significantly reduces plant species diversity and creates a category of species that can be characterized as 'turfgrass weeds'. Species that are less suitable for lawns include *Achillea millefolium*, *Bellis perennis*, and *Plantago lanceolata*. Our results are in accordance with those of Abu-Dieyeh [57], who confirmed that the occurrence of turfgrass weeds is rare in lawns mowed to a small height. According to Watson [58], intensive lawn management decreases plant and insect biodiversity, whereas frequent low mowing decreases plant structure and composition by favoring low-growth annual plants or grasses and decreases flower resources for pollinators by removing higher flower structures. Additionally, the results obtained by Watson [58] suggest that frequent mowing resulting from aesthetic requirements may cause other aesthetic problems by facilitating the increased invasion of weeds and

pests. Busey [59] and Norton [60] confirmed that intense mowing is an important factor that contributes to weed invasion in city lawns and meadows.

The studies performed by Chollet [51] indicate that lawns with low mowing frequency are characterized by higher plant biodiversity than green areas with high mowing frequency (+15% to 62%). Frequent mowing can only be tolerated by a few plant species, which may tolerate repeatable perturbations; thus, lawns are favored by ruderal species that are more tolerant to such perturbations [25].

The results indicate that mowing frequency is a key indicator of plant species diversity in urban spaces. This is in accordance with studies on semi-natural green areas, such as the study performed by Socher [61], who showed that mowing intensity had a greater impact on plant species richness than fertilization intensity in the analyzed green areas in Germany.

Permaculture lawns create space for the highest species diversity but also for undesirable species. In addition to common meadow plants, the species composition includes undesirable species of clearly ruderal or invasive character which spread in the landscape, such as *Artemisia vulgaris*, *Calamagrostis epigejos*, *Cirsium arvense*, *Erigeron annuus*, *Lactuca serriola*, and *Solidago canadensis*. The investigations performed by Bertoncini [62] have shown that surprisingly, less than 10% of species (seven species) noted on lawns in Paris represent invasive taxa. This is a relatively low amount, considering the common pattern observed in cities, which is usually about 15–20% of invasive species in urban and natural habitats.

The occurrence of *Centaurea macrocephala* (Figure 4) was also remarkable. The species was formerly cultivated as ornamental and its current potential to further spread in the built-up areas of towns and cities is high. Naturalized *Centaurea macrocephala* has been found in grass communities in the United Kingdom (UK). According to Hitchmough and Woudstra [63], sites yielding this species represent managed or abandoned gardens. Other localities where this plant is often naturalized are roadsides and the margins of railway tracks bordering suburban gardens. Regular botanic monitoring and targeted and local control would be adequate for the occurrence of these species. Permaculture lawns differ significantly in character from the aesthetic values of other variants. Therefore, this variant cannot be used at all sites determined for lawns.



Figure 4. Photo documentation of *Centaurea macrocephala* identified at the Water Centre of SGGW.

3.2. Moisture Bioindication Using Dew Species and NDVI in Grasslands

Urban ecosystems present transformed soil conditions as well as a rapidly changing and often hotter microclimate, generating numerous barriers to fostering native plants, or even predicting which taxa may survive in such an environment [25]. Based on the indicative values for soil moisture content, it was found that the species occurring in the study had values ranging from 2 to 9. Species with an indicative value of 5 (indicator of fresh soils bound to soils with the average moisture content, missing in moist and frequently drying out soils) had a dominant share of coverage in all lawn variants. However, the permaculture lawn variants exhibited species with indicative values ranging from 7 to 9 (7, indicator of moisture content, bound to soils with a good water supply but not wet; 8, transition between 7 and 9; 9, indicator of wet soils, saturated with water and poorly

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aerated). Thus, the permaculture lawn variants indicated a sufficient amount of water in the soil. In contrast, these species were missing in the ornamental lawn variants where species occurred with an indicator value of 2; that is, species missing on moist soils up to species bound to dry soils. As this variant is irrigated, it should have sufficient water. Therefore, we can assume that intensive management will change the hydrological situation of lawns, facilitating the occurrence of drought-resistant species and suppressing the occurrence of moisture-loving species. The indicative values of the individual species are presented in Table 1. The representation of species groups according to their indicative values for moisture in the respective lawn variants is shown in Figure 5.

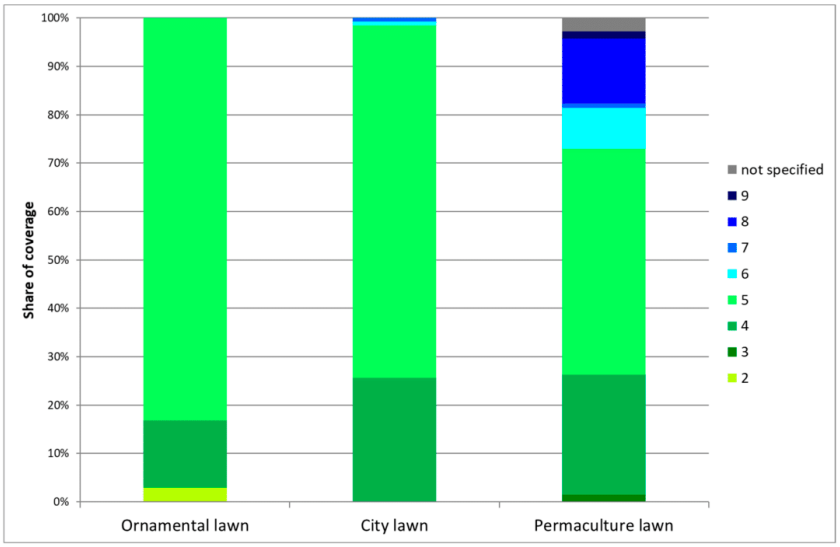


Figure 5. Lawn coverage share according to indicative values for moisture. Groups according to indicative value for moisture content: 2—transition between values 1 and 3; 3—missing on damp soil; 4—transition between values 3 and 5; 5—indicator of fresh soils, focus on soils of average moisture content, missing on wet soils and on soils that frequently dry out; 6—transition between values 5 and 7; 7—humidity indicator, focus on well-moistened but not wet soils; 8—transition between values 7 and 9; 9—wetness indicator, focus on often soaked, poorly aerated soils.

The NDVI index is based on the value of the contrast between the largest reflection (in the NIR band) and the absorption in the red band and contains in a range of values from −1 to 1. The value of the NDVI index increases as the reflection in the NIR band increases and the reflection in the red band decreases. A high value of the index corresponds to good plant health. The results of the analyses are shown in Figures 6 and 7.

The value of the NDVI index visibly differed between the three study areas. Statistical analysis of the study areas showed that the best condition was found in area (a) and the worst in area (b) (Figure 8).

According to the NDVI, the best condition for vegetation is the lawn of option a (ornamental lawn). Lawn vegetation that is frequently and regularly mowed can serve aesthetic purposes. However, this condition is provided by high external input (irrigation and fertilization). The species composition of the lawns with a higher proportion of species that tolerate drought in conjunction with irrigation suggests that water is likely to evaporate quickly.

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Figure 6. Orthophotomap with marked study areas (**left**). Spatial distributions of NDVI (**right**).

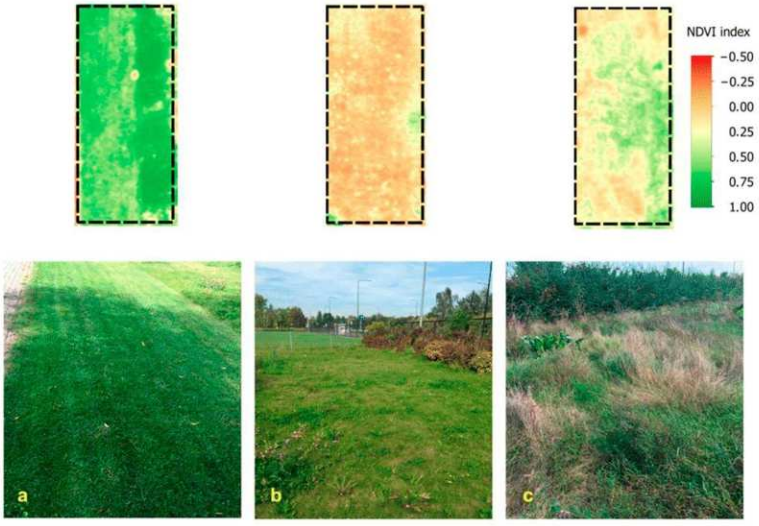


Figure 7. The lawn management variants in the Water Park and spatial distributions of NDVI (upper part): (**a**) ornamental lawn with intensive management; (**b**) city lawn with common management; (**c**) permaculture lawn with extensive management.

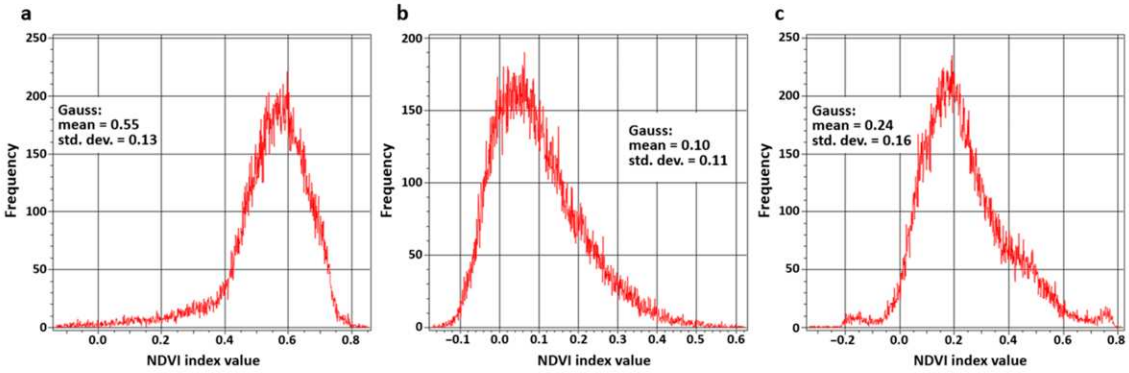


Figure 8. Histograms of the distribution of NDVI by area: (**a**) ornamental lawn with the intensive management; (**b**) city lawn with the common management; (**c**) permaculture lawn with the extensive management.

The vegetation in variant b (city lawn) exhibited the worst conditions. Most lawn species respond to unfavorable conditions (drought and high temperatures) during summer dormancy. A higher proportion of species tolerating drought point to more intense evaporation. Vegetation limitations allow plant species to survive adverse summer periods. City lawns do not require external inputs but lose their aesthetic value in some seasons.

NDVI analysis also showed that the highest heterogeneity in vegetation conditions was in variant c (permaculture land). The heterogeneity in vegetation conditions is due to high species diversity and the presence of dead biomass. The low vegetation condition was found at sites with dead biomass left in place. New biomass grows at sites with good vegetation conditions. Species composition with a higher proportion of wetland species indicates conditions with limited water evaporation. The management applied to permaculture lawns is reflected in the high heterogeneity of conditions and is close to natural grassland communities.

3.3. Plant Species Diversity in Grasslands

The values of plant taxa cover recorded during monitoring were first processed using DCA analysis. The calculated gradient length was 3.25. Based on this calculation, the CCA was used for further processing. CCA defines the spatial arrangement of individual plant species and the monitored lawn variants. The results of the analysis were graphically expressed using an ordination diagram (Figure 9).

The results of the CCA analysis which was used to assess the degree of coverage of individual plant taxa were significant at a level of $\alpha = 0.001$ for all canonical axes. Based on the CCA analysis, the found plant taxa can be classified into six groups (Table 1).

The first group (O) consists of species that prevailingly occur as part of the vegetation of ornamental lawns; that is, either poor competitors or those that are of annual character and gain ground only in low turfgrass. The second group of species (O/C) is represented by species occurring predominantly in ornamental and city lawns; that is, species less assertive against tall plant species and species that cope with regular cutting and removal of biomass. Plant species in the third group (C) tolerate regular cutting and do well under the lower competitive pressure of other species. Such species occurred predominantly in city lawn variants. The fourth group of plant species (C/P) was recorded particularly in city and permaculture lawn variants. These species were tolerant of regular cutting but was also capable of winning ground in competition with stronger species. The fifth group of plant species (P) dominated the permaculture lawns. These species were tolerant to extensive turfgrass management and were strong competitors. The sixth group of plant species (P/O) was recorded in ornamental and permaculture lawns. These species were

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tolerant to extreme variants and able to adapt to diverse environments. Different types of lawns under different management practices create different conditions that show a conspicuous change in the species spectrum of lawn vegetation. The consequences of human civilization activities have led to the development of a new plant community that changes and adapts to these activities [64–69].

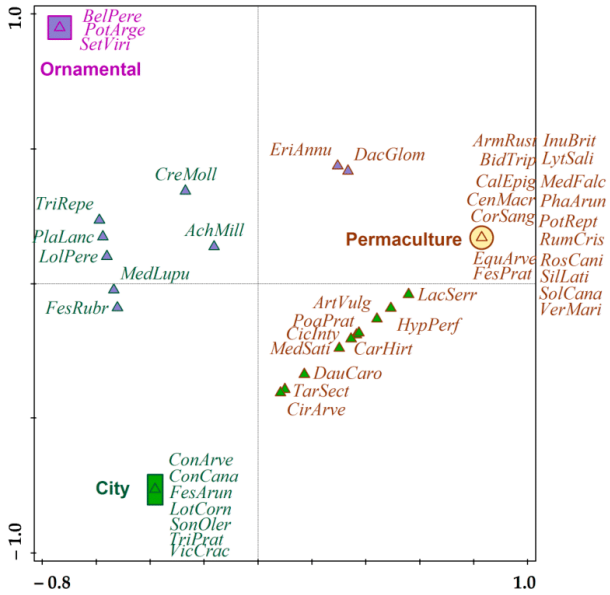


Figure 9. Relationships between the identified plant taxa and monitored lawn types (results of CCA analysis; F-ratio = 4.4; *p*-value = 0.001). Species Group O is indicated by purple font color and purple dots, Species Group O/C is indicated by green font color and purple dots, Species Group C is indicated by green font color and green dots, Species Group C/P is indicated by brown font color and green dots, Species Group P is indicated by brown font color and light yellow dots, Species Group P/O is indicated by brown font color and purple dots.

Increasingly, more studies indicate how aesthetics and ecosystem values influence landscape management and public policy, especially in urban ecosystems [70,71]. Lawns are close to everyday human habitats and are thus one of the most affected by human design. Intensive management is indispensable when the aim is to achieve a uniform and idealized lawn [62]. However, considering the significance of these green areas to city residents, it is necessary to find measures that may reconcile the presence of human societies with biodiversity management. According to Tabassum [4], cities are significant repositories of biodiversity; therefore, it is imperative to create resilient urban green spaces in the face of climate and environmental change.

4. Conclusions

The conclusions drawn from this study highlight the dynamic response of urban grass vegetation to various anthropogenic management practices. This reaction manifests as altered plant species composition, leading to shifts in the function and perception of urban grass areas. The trends observed in our study can be regarded as being universally applicable.

Our results highlight the significant influence of human decisions and activities on the species composition of urban lawns. First, we found that management intensity directly affects species richness, with intensive management resulting in lower plant diversity

compared to less intensive approaches. Second, nature-based management decreases the representation of intentionally sown plant species, facilitating the proliferation of undesired species that can alter the aesthetic appeal of lawns and potentially spread in the urban environment.

Third, intensive management practices exacerbate evaporation and surface drying, favoring drought-resistant species over moisture-loving ones. This shift in favorability towards certain plant types, such as grasses and drought-resistant species, comes at the expense of legumes and other high-growth plants. Notably, our analysis of permaculture lawns revealed high vegetation heterogeneity, suggesting differences in water regimes and potential reductions in evapotranspiration owing to the presence of dead biomass.

Furthermore, permaculture lawns managed with a nature-based approach exhibit the highest species diversity, including undesired species, surpassing the levels reported in the scientific literature. These undesired species, including neophytes and invasive species, underscore the complexity of managing urban grassy areas.

Given the pivotal role of lawns in urban ecosystems and their impact on biodiversity, achieving a balance between aesthetic appeal and ecological value is crucial. Our findings emphasize the urgency of developing resilient urban green spaces capable of adapting to climate and environmental changes while safeguarding biodiversity. Integrating nature-based solutions, such as permaculture lawns, offers sustainable alternatives for lawn management, and contributes to urban biodiversity conservation. Future research could delve into understanding human perceptions and preferences in shaping lawn management decisions and their consequent impact on biodiversity, providing valuable insights for sustainable urban landscape management.

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Research article

Vegetation structure of bio-belts as agro-environmentally-climatic measures to support biodiversity on arable land: A case study

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Abstract: Loss of biological diversity is one of the greatest challenges that our civilization must face nowadays. Reaction to the diminishing biodiversity of agricultural landscapes is various measures promoting free-living organisms. The study deals with the vegetation composition and structure of agro-environmental-climatic measures applied on arable land in operating conditions (intensively farmed regions of the Czech Republic). Additional study focus was applied to a popular measure of the feeding bio-belts. Bio-belts are not only hiding places for free-living animals but can provide them a rich food offer in the period from the harvest of main crops until winter. Thanks to the bio-belts, the landscape gains in biodiversity, and sloping sites can be protected from soil erosion. The vegetation of land parts used as bio-belts was assessed using phytocoenological relevés. Dominant plant species sown in the bio-belts were *Avena sativa, Panicum miliaceum*, *Brassica oleracea* var. *acephala, Fagopyrum esculentum, Phacelia tanacetifolia,* and *Pisum arvense*. Apart from the sown plants, there were also weeds occurring in the bio-belts, of which the most abundant were *Chenopodium album*, *Amaranthus retroflexus*, *Setaria verticillata*, *Cirsium arvense*, *Equisetum arvense*, etc. Risks connected with the realization of feeding bio-belts in respect of weeds occurring on arable land are negligible. Weeds from bio-belts have only a limited potential to spread to adjacent arable land. A potential spreading of weeds from the bio-belts to adjacent arable land was not demonstrated. On the contrary, thanks to its composition, the vegetation of bio-belts has the potential to extend the food offer

for animals. Thus, bio-belts are useful for supporting biodiversity in regions intensively used for agriculture.

Keywords: agricultural landscape; biological diversity; vegetation composition; weeds

1. Introduction

The biodiversity of native vegetation exhibited a dramatic decrease in the last four decades the agricultural landscape [1–4]. The decrease or total loss of biological diversity is currently conditioned primarily by human civilization activities such as the direct conversion of natural stands into cultivated farmlands [5,6] or land occupation for several types of construction [7]. Losses in the biodiversity of plants cause negative effects at further trophic levels of ecosystems [8,9].

Changes in technologies used for growing field crops resulted in the reduced occurrence of some weed species [10] and in the increasing occurrence of nitrophilous weed species [11,12]. According to Krähmer et al. [13] modern agriculture seems to favor nitrophilous species in principle. Several arable plant species have become endangered in Europe [13]. Consequently, once common annual weeds e.g, *Centaurea cyanus* and *Ranunculus arvensis* were practically eradicated from fields in the lowlands of England and endangered or extinct in many countries [14,15].

Weed richness and abundance in agriculture has indeed declined drastically over the past decades, as documented in Europe [10]. In fact, the occurrence of most field weeds is limited only to field edges where the competition of plants is lower due to the less efficient weed control management [16–19]. Thanks to the limited intensity of cultivation technologies on field edges, annual plants on arable land are promoted in their abundance and diversity [18–20]. The area between the field margin (edges) and first row of crop function as refugia for many weed species e.g, *Anthemis arvensis, Anthriscus caucalis, Papaver rhoeas* [18,19]. The limited use of pesticides and fertilizers on field headlands (protective headlands) increases the diversity of dicotyledonous plants with significant benefits for the populations of invertebrates and field avians [21,22]. Diversity of weeds on the protective headlands is higher when no fertilizers are applied, the degree of crop cover is lower thanks to which more light penetrates the stand that is used by weeds [17]. Another possibility is to retain the winter stubble when a part of the land is taken out of production thanks to which field birds have both food and hiding place on the site although the species diversity of plants usually does not increase [23]. Nevertheless, summer soil cultivation may increase potential for the germination of annual weeds [18]. In case of the prolonged absence of soil cultivation, the annual weed species will be gradually replaced by perennial species with the dominance of grasses [24–26].

Agricultural landscape represents a conflict of two directions. One of these directions is protection of the occurrence of living organisms-conservation [27,28]. The other direction is protection against harmful organisms in agriculture-phytopathology [29–31]. Weeds on arable land have an interesting position in this conflict, being problematic as competitors to field crops reducing their yields [3,32,33] and representing at the same time a source of food for many other taxa in agrosystems e.g, *Galium aparine, Fallopia convolvulus, Thlaspi arvense, Viola arvensis* [34–37]. Weeds deserve attention also thanks to significant heterogeneity of their occurrence [37–42].

It has been demonstrated that bio-belts can support biodiversity and associated ecosystem services, biodiversity colonization effects have rarely been studied [43]. In this paper, we introduce the

assessment of agro-environmental-climatic (AEC) measures established on arable land in the Czech Republic (CR), area intensively used for agriculture. Parameters assessed included overall diversity and structure of vegetation on arable land and bio-belts. The aim of the work was to evaluate the species composition of the vegetation of field crop stands and the vegetation of the bio-belts. The goal was to confirm the potential of the vegetation of AEC measures as a source of food for animals as well as to verify the risk of weeds spreading from the areas of AEC measures to arable land. The vegetation was assessed based on the representation of plant species significant for animals as a source of food and their capability of spreading in agricultural landscapes.

2. Materials and methods

The studied site is situated in the cadastral area of Morkovice-Slížany and in its close surroundings, in the Zlín Region, CR (49°14′53″ north latitude and 17°12′28″ east longitude). The area belongs to the Central Moravian Carpathians, and the geomorphological region falls in the sub-province of Outer Western Carpathians. Mean altitude of the area is 282 m a medium slope is 4°33′. The Central Moravian Carpathians belong in the Morava River basin. Geological bedrock is formed by prevailing Paleogene clay stones, sand stones and sporadically occurring conglomerates. The studied site exhibits a clear dominance of arable land which occupies about a half of the cadastral area, which is accustomed also by the high representation of moderately deep to deep fertile soils (brown soils, chernozems and luvisols). Prevailing soil types are heavy and moderately heavy soils. The long-term mean total annual precipitation is 564 mm, and the long-term mean temperature is 8.6 °C.

The Agrodružstvo Morkovice agricultural enterprise applies selected AE and climatic measures referred to as bio-belts. Bio-belts serve not only as hiding places for free living animals but can provide a rich food offer for them in the period from the main crop harvest to winter. Bio-belts contribute to the diversity of landscapes and may help to control soil erosion on sloping lands. Agro-environmental-climatic measures (previously only agro-environmental measures) were part of the Agricultural Policy of the Ministry of Agriculture of the Czech Republic, and it belonged to subsidies under the Rural Development Program. Among their goals was to support biodiversity in an intensively used agricultural landscape.

Bio-belts are strip fields located on the edge or inside soil blocks. The dimensions of the bio-belt are 6–24 m wide and at least 30 m long. The bio-belt had to be established by May 31st of the calendar year at the latest. Additionally, they had to be sown with a specified seed mixture the composition of which had to be in accordance with the regulation of the Ministry of Agriculture of the CR [44]. The mixture used for the sowing of the monitored bio-belts included: *Avena sativa* Bingo variety (49.7%), *Panicum miliaceum* Jagna variety (11.5%), *Brassica oleracea* var. *acephala* Boma variety (0.6%) and Astera variety (0.3%), *Fagopyrum esculentum* Pyra variety (11.5%), *Phacelia tanacetifolia* Větrovská variety (3.8%) and *Pisum arvense* Eso variety (22.9%). The residual biomass of the annual bio-belts was mulched in the spring of the following year, then a deep ploughing, and followed by a repeated sowing of the seed mixture. All preparations for plant protection, such as pesticides, are forbidden on the bio-belts.

There were 5 bio-belts on the cultivated arable land of the agricultural enterprise sized 104,39 ha, a total area of which was 3,63 ha. The width of the bio-belts was 24 m and was determined by the seeding machine. The area and dimensions of the bio-belts met the requirements of the Ministry of Agriculture of the CR. The selected bio-belts were established on the edge of the plot and are adjacent

to linear features (borders, tree lines). These bio-belts were chosen for the monitoring (Table 1). The vegetation composition was analyzed using phytocoenological relevés taken in two seasons of the year—in summer (July) and autumn (October) of 2018 and 2019.

Table 1. Characteristics of selected sites and bio-belts.

Site	Name	Land area (ha)	Bio-belt area (ha)
1	Kameňák Uhřice	53.9	0.71
2	Věžky	6.89	0.64
3	Malý gret	3.13	0.64
4	Dřínov	33.16	1.26
5	Telák dolní	7.31	0.38

The analysis of vegetation composition at the monitored sites in the crop stands and, in the bio-belts was made using phytocoenological relevés. Phytocoenological relevé is a form of record about the species composition of the vegetation and cover of plant species. One relevé was sized 3×3 meters (9 m^2). When the sites were delimited, the occurring plant species were recorded, and their cover determined using the Braun-Blanquet cover-abundance scale. Each site had 5 phytocoenological relevés recorded in the bio-belt and 5 phytocoenological relevés recorded in the stand of the crop grown on most land. Data obtained from the relevés were processed using multivariate analyses of ecological data. The analysis of main components - Detrended Correspondence Analysis (DCA) was used to calculate gradient length (Lengths of Gradient) and the redundancy analysis (RDA) followed [45]. Significance was evaluated using the Monte-Carlo test in which 999 permutations were calculated. The calculations were made by Canoco 5.0. computer programme [46].

Scientific names of individual plant species originate from the Pladias database of Czech flora and vegetation [47]. Based on the Pladias database, the plant species were divided into several groups according to selected two characteristics. The first one was the method of pollination to express a potential source of food for insects. The second one was the method of fruit and seed dispersal as an indirect expression of the potential of spreading within the agricultural landscape.

The method of pollination is ensured by abiotic vectors (anemophilia, hydrophilia), or biotic vectors such as for example insects (entomophilia), and there are also alternative methods of pollination (autogamy, cleistogamy, etc.). The information about pollination methods was taken from the BiolFlor database [48]. Plant species spread by various vectors and methods. The classification of species into dispersal categories was taken from Sádlo et al. [49]. The species were classified into the following categories: (i) Allium—primarily autochory, more rarely anemochory, endozoochory and epizoochory. This is the most common dispersal strategy. About a half of the included taxa are generalists without any clear adaptation to anemochory or zoochory; (ii) Bidens—primarily autochory and epizoochory, less frequently endozoochory. This strategy combines two basic methods of dispersal of which autochory is more significant one even despite the presence of morphological structures suggesting epizoochory; (iii) Cornus primarily autochory and endozoochory. The strategy is typical of herbs, shrubs, and lower trees with pulpy fruits. The category includes also taller trees with large, heavy, and nutrient-rich seeds; (iv) Epilobium—primarily anemochory and autochory, less frequently endozoochory and epizoochory. Plants with this strategy of dispersal are characteristic for mesic and dry sites; (v) Lycopodium—primarily anemochory, less frequently autochory, endozoochory, epizoochory and hydrochory. This dispersal strategy relies upon light and very small spores and seeds

that are dispersed and also omit various other vectors in addition to airborne distribution; (vi) Zea—taxa with this strategy are distributed by generative diaspores only exceptionally or not at all and do not form above-ground vegetative diaspores.

3. Results

There were 30 plant species identified on the selected five sites on which 4 crops were grown (*Brassica napus, Hordeum vulgare, Triticum aestivum* and *Zea mays*). In the bio-belts, 7 intentionally grown plant species were identified and 19 weed species. The numbers of plant species recorded on the respective sites are presented in Table 2.

Table 2. Numbers of plant species on the monitored sites.

Site	Site part	Main crop	Plants sown in bio-belts	Weeds
1	Bio-belt	1	7	15
	Arable land	1	1	3
2	Bio-belt	1	7	16
	Arable land	1	1	2
3	Bio-belt	1	5	15
	Arable land	1	0	2
4	Bio-belt	0	7	15
	Arable land	1	0	3
5	Bio-belt	0	7	16
	Arable land	1	0	2

The vegetation species composition in the bio-belts according to cover is shown in Figure 1. Species names of deliberately sown crop are marked in green. The names of weeds are marked in red. The highest proportions of the sown crops were *Phacelia tanacetifolia* and *Avena sativa*. Among weeds, *Chenopodium album*, *Setaria verticillata* and *Amaranthus retroflexus* had the highest proportion.

The representation of plants sown on the bio-belts and weeds on the respective sites is shown in Figure 2. The vegetation cover on arable land is made up of cultivated crops and there is little weed cover. The proportion of weeds is significantly higher in bio-belts, where the use of herbicides is prohibited.

The representation of plant species according to the method of pollination and dispersal mode is presented in Figure 3. On arable land, where there is a significant representation of the crop, the relevant method corresponding to the crop always prevails. Bio-belts have a more varied species composition and more varied methods of pollen dispersal. There is also a more pronounced representation of species with entomophilia.

Species representation according to the method of fruit and seed dispersal on the monitored sites is presented on Figure 4. The predominant way of dispersing fruits and seeds is the Allium strategy on all monitored areas. This type of fruit and seed dispersal is the most common strategy. The exception is plot No. 4, where Zea is the predominant propagation strategy on arable land.

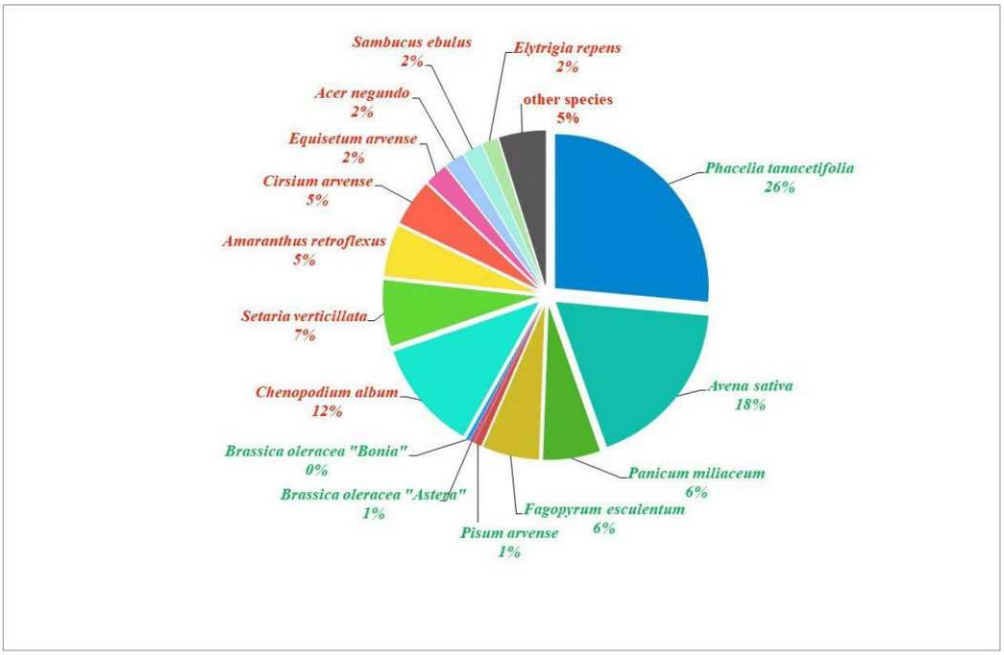


Figure 1. Species composition of vegetation from bio-belts (green—sown crops; red—weeds).

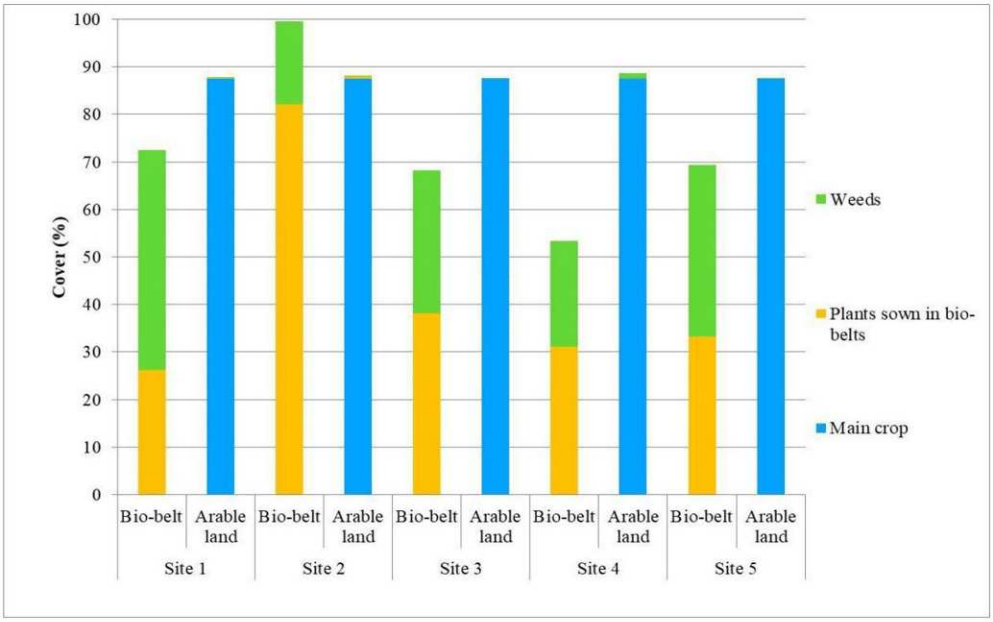


Figure 2. Representation of plant groups on the monitored sites.

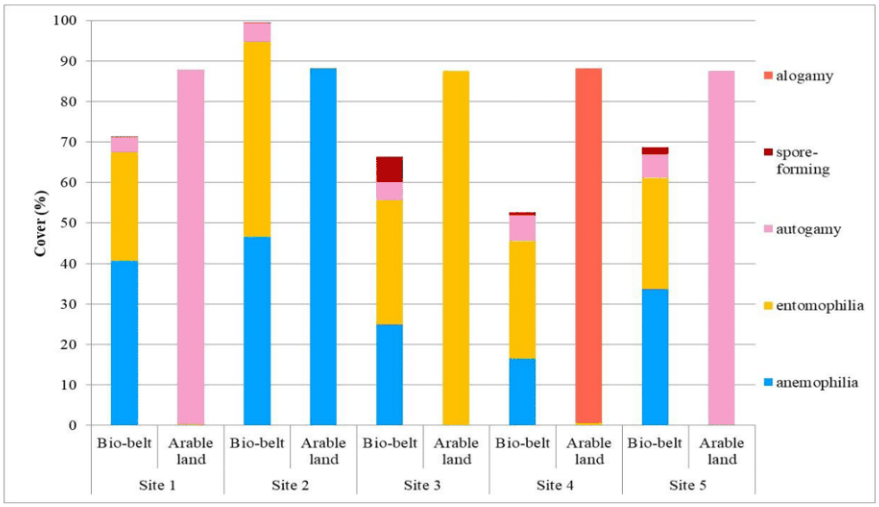


Figure 3. Species representation according to the method of pollination on the monitored sites.

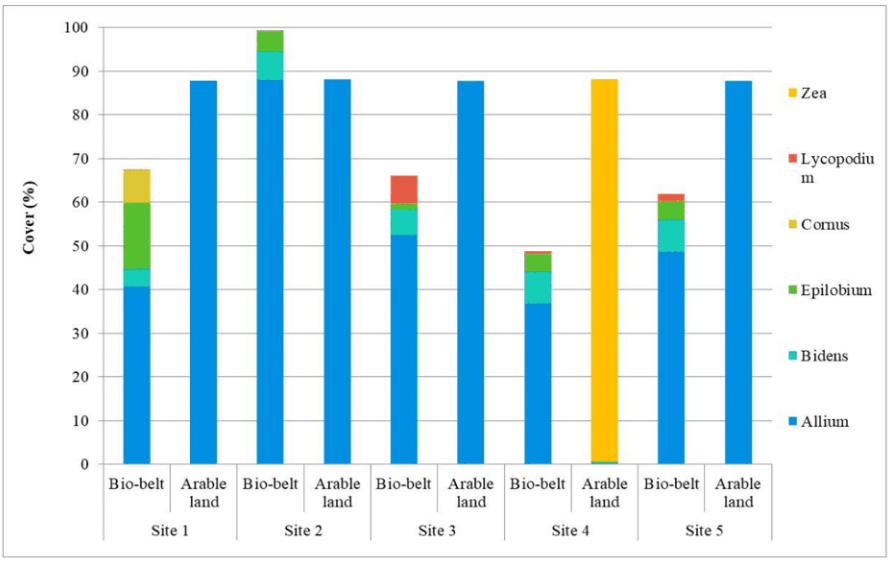


Figure 4. Species representation according to the method of fruit and seed dispersal on the monitored sites.

Results of RDA analysis which was used to assess the cover of plant taxa on the monitored sites were significant for all canonical axes at a significance level of $\alpha = 0.001$. The graphical illustration of RDA results is presented in Figure 5.

Based on the RDA analysis, the identified plant taxa can be divided into three groups. The division of taxa into groups according to the RDA analysis is shown in Table 3.

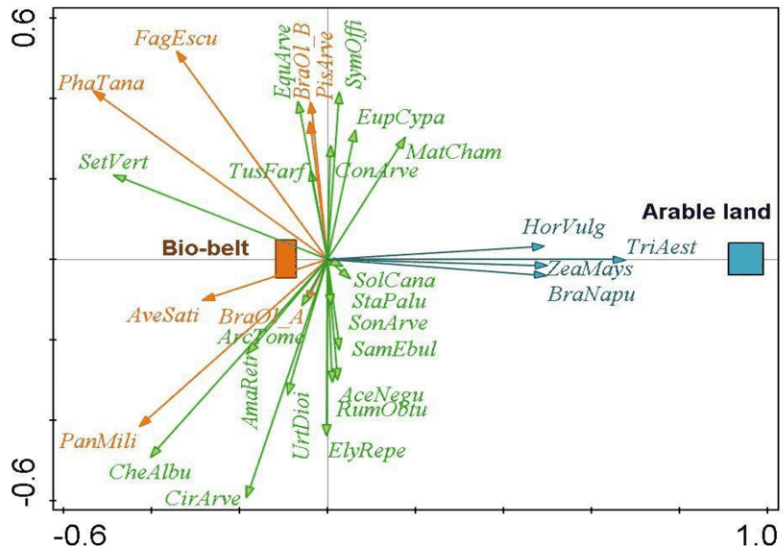


Figure 5. Occurrence of identified plant species on the sites of different use (result of RDA analysis; overall explained variability = 10.1%; F-ratio = 5.9; P-value = 0.001).

Table 3. Groups of plant species according to RDA analysis.

Group species		Species
Arable land (Group 1)	Crops	*Brassica napus (BraNapu), Hordeum vulgare (HorVulg), Triticum aestivum (TriAest), Zea mays (ZeaMays).*
Bio-belts (Group 2)	Bio-belt crops	*Brassica oleracea* convar. Bonia *(BraOl_B), Fagopyrum esculentum (FagEscu), Phacelia tanacetifolia (PhaTana), Pisum arvense (PisArve).*
	Weeds	*Convolvulus arvensis (ConArve), Equisetum arvense (EquArve), Euphorbia cyparissias (EupCypa), Matricaria chamomilla (MatCham), Rumex obtusifolius (RumObtu), Setaria verticillata (SetVert), Symphytum officinale (SymOffi), Tussilago farfara (TusFarf).*
Bio-belts (Group 3)	Bio-belt crops	*Avena sativa (AveSati), Panicum miliaceum (PanMili), Brassica oleracea* convar. Astera *(BraOl_A).*
	Weeds	*Acer negundo (AceNegu), Amaranthus retroflexus (AmaRetr), Arctium tomentosum (ArcTome), Cirsium arvense (CirArve), Elytrigia repens (ElyRepe), Chenopodium album (CheAlbu), Sambucus ebulus (SamEbul), Solidago canadensis (SolCana), Sonchus arvensis (SonArve), Stachys palustris (StaPalu), Urtica dioica (UrtDioi).*

4. Discussion

The results show that bio-belts represent plant communities markedly more diverse than the crop stands on arable land. Studies confirmed [50 53] that non-cropped elements such as semi-natural vegetation, grassland strips and hedgerows provide high-quality habitats for various taxa and their positive impact on biodiversity. The greater species diversity of vegetation creates a potential for a higher offer of food for animals [44,54,55]. The significant share of entomophilous plant species (Figure 3) is a food source for insects [56], which is spatially available and in terms of time longer available thanks to limited cultivation measures. On arable land, the source of food for pollinating insects is given by the grown crop, and in terms of time is limited to the period of its flowering. Crochard et al. [57] analysis provided evidence that pollinators are shared between flowering crops, as well as between flowering crops and associated weeds. Theirs results suggest that arable weeds (field edges weeds), flowering or not potential levers for enhancing pollination services in an agricultural landscape. This is in line with other studies highlighting arable weeds as important resources for wild pollinators [58–60].

The diversity of vegetation in bio-belts (Figures 1 and 2) is given by the sown mixture of plants but also by the higher share of weeds. The representation of weeds in the weed vegetation is varied and the monitored sites markedly differ from one another. While weeds clearly dominate on Sites 1 and 5, sown crops succeed in being a serious competition to weeds on Sites 2 and 4. Weeds spread between fields and adjacent lands in agricultural landscapes, and some weeds growing on boundaries may spread into the stands of main crops e.g, *Artemisia vulgaris, Cirsium arvense, Lactuca serriola* [4,61–63]. This is usually the reason omit landowners often perceive field edges as a source of weeds occurring in the main crops [64–66]. A type dominating in terms of spreading fruits and seeds in the vegetation of bio-belts is Allium (Figure 3). This type has a limited dispersal into the surroundings, and most seeds enrich the soil seed bank. When the site with the bio-belt returns to common cultivation of crops, the seeds of weeds can germinate and affect the growing crops. A elevated risk of subsequent weeding exists particularly in *Chenopodium album* and *Amaranthus retroflexus*. In bio-belts, plant species were found with a high potential of spreading to adjacent lands, representatives of *Asteraceae* family (*Cirsium arvense, Tussilago farfara*). Therefore, bio-belts should not be established on sites with the occurrence of these species.

It further follows from the ordination diagram (Figure 5, Table 3) that the occurrence of weeds on arable lands is successfully controlled mainly by herbicides and therefore sown crops have a dominant representation on them. However, the vegetation of bio-belts exhibits more complex competitive and synergic relationships, e.g. the synergic relationship of *Brassica oleracea* convar. Bonia, *Fagopyrum esculentum*, *Phacelia tanacetifolia*, and *Pisum arvense*. This group competes with the weed species of *Convolvulus arvensis, Equisetum arvense, Euphorbia cyparissias, Matricaria chamomilla, Rumex obtusifolius, Setaria verticillata, Symphytum officinale* and *Tussilago farfara* only with some difficulties.

The second group with synergic relationships is represented by *Avena sativa*, *Panicum miliaceum,* and *Brassica oleracea* convar. Astera. These plant species are difficult to compete with *Acer negundo, Amaranthus retroflexus, Arctium tomentosum, Cirsium arvense, Elytrigia repens, Chenopodium album, Sambucus ebulus, Solidago canadensis, Sonchus arvensis, Stachys palustris* and *Urtica dioica.* It follows that the composition of plant mixtures used in bio-belts is also particulary important for the suppression of weeds and reduction of their future development.

Human activities have been found to be responsible for enhancing biological invasion, in

particular by increasing pressure on propagule, and cropping areas [67]. Attention should also be given to the occurrence of invasive plant species such as *Acer negundo* and *Solidago canadensis*. Neither of them is a common field weed, and their occurrence and cover in the bio-belt is exceptionally low. Nevertheless, their occurrence should be regulated. It would be useful to extend the rules for AE-measures and to permit the application of herbicides in case that an invasive plant species occurs.

5. Conclusions

Bio-belts as agro-environmentally-climatic measures increase the species diversity of vegetation in agricultural landscapes. The vegetation of bio-belts has a potential to improve the food offer and to enhance spatial and time availability of food sources for animals. On the other hand, bio-belt also represent a certain risk of weeds enriching the soil seed bank, which can later show as increased weed infestation of crops when the bio-belt area is returned to common use. Additionally, the occurrence of species from the *Asteraceae* family with the Epilobium type of fruit and seed dispersal is problematic omit. Bio-belts may become sources of diaspores of those species and adjacent lands can become infested with weeds. The composition of seed mixture used for sowing the bio-belts appears no less important. Suitable combinations can ensure higher competition of crops and hence lower weed infestation. The conditions and parameters of bio-belts will be another area of research that will seek common solutions to support biodiversity and reduce risks for agricultural production. Vegetation of bio-belts is a welcome contribution to the maintenance and support of biodiversity in intensively used agricultural landscapes. Nevertheless, the risks connected with bio-belts for agricultural production must be financially compensated. The compensation is important to mitigate worries and unwillingness of farmers to adopt agro-environmentally-climatic measures.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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Příloha 13

LISTY CUKROVARNICKÉ a ŘEPAŘSKÉ

Vliv technologií zpracování půdy na aktuální zaplevelení cukrovky

EFFECT OF TILLAGE TECHNOLOGY ON CURRENT WEED INFESTATION OF SUGAR BEET

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Miliony pěstitelů, velkých i malých, využívají redukované technologie zpracování půdy ke svému užitku. V dnešní době se tyto technologie používají v celém světě na 111 mil. ha. Je to jeden z finančně nejefektivnějších způsobů, jak chránit a zlepšovat půdní vlastnosti. Tyto technologie zlepšují úrodnost půdy zvyšováním biologické aktivity, snižují potřebu hnojení a výskytu eroze a v neposlední řade snižují pracovní a potažmo finanční náklady hospodaření (1). Použití bezorebných technologií je spojeno se zvýšením obsahu půdní vody v období suchých měsíců a period s nerovnoměrným rozložením srážek (2).

Pěstování cukrovky naráží na řadu problémů především na erozně ohrožených půdách. Omezení eroze půdy je závislé také na struktuře povrchové vrstvy půdy, infiltraci vody do půdy a vodostálosti půdních agregátů, které jsou zpravidla lepší při redukovaném zpracování půdy (3, 4).

Z výsledků uváděných Badalíkovou a Červinkou (5) je patrné, že i přes rozlišné výnosy v rozdílných pokusných lokalitách, dosahovaly varianty pěstování cukrovky bez použití orby srovnatelných výsledků s klasickým zpracováním půdy (s orbou). Klasické zpracování půdy k cukrovce ne vždy přináší její nejvyšší výnosy (6). Také Awad et al. (7) zjistili, že lepších výnosů cukrovky a zachování půdní vláhy bylo dosaženo při kypření půdy namísto orby. Redukované zpracování půdy lze využít formou bezorebného zpracování půdy, mělkého zpracování půdy nebo setí do vymrzajících meziplodin jako ochrana proti větrné i vodní erozi (8, 9).

Vliv zpracování půdy na plevele byl a je studován řadou autorů (10, 11, 12). Většina z nich ovšem svou pozornost zaměřuje na porosty úzkořádkových obilnin (pšenice, ječmen). Cukrová řepa je z tohoto pohledu opomíjena. To patrně souvisí s používáním herbicidů, které značně limitují výskyt a škodlivost plevelů. I přesto se výskyt a druhové spektrum plevelů v cukrovce mění i v závislosti na technologii zpracování půdy (obr. 1.).

Materiál a metody

Polní pokus se nachází na pokusné stanici Mendelovy univerzity v Žabčicích. Lokalita patří do kukuřičné výrobní oblasti (KVO) ječného subtypu, a to v nadmořské výšce 184 m n. m. v rovinatém terénu. Žabčice spadají do velmi teplého a suchého klimatického regionu. Dle sledování klimatu za posledních třicet let je průměrná roční teplota 9,2 °C, dle úhrnu srážek náleží lokalita k sušším oblastem. V třicetiletém průměru byl roční úhrn srážek 481 mm. Údaje o srážkách a teplotách byly naměřeny na meteorologické stanici v Žabčicích. Dlouhodobé průměry srážek a teplot za jednotlivé měsíce jsou uvedeny v tab. I. Na katastrálním území Žabčic převládají severozápadní větry, které způsobují na stanovišti vodní deficit. Tyto rozdíly způsobené převahou výparu nad srážkami jsou znatelné zejména v jarním období, přibližně od března do června. Proto jsou porosty po velkou část vegetačního období odkázány na půdní zásobu vláhy.

Obr. 1. Výskyt plevelů v porostech řepy ovlivňuje kromě herbicidů i zpracování půdy



Tab. I. Dlouhodobé průměry teplot a úhrnů srážek (1961 až 1990)

Měsíc	Srážky (mm)	Teploty (°C)
leden	25	–2,0
únor	25	0,2
březen	24	4,3
duben	33	9,6
květen	63	14,6
červen	69	17,7
červenec	57	19,3
srpen	54	18,6
září	36	14,7
říjen	32	9,5
listopad	37	4,1
prosinec	26	0,0

Lokalita je situována v nivní oblasti řeky Svratky. Půdní profil je pod stálým vlivem spodní vody, což má za následek intenzivní glejový proces do hloubky silně narůstající. V suchém období půda vysychá a vznikají velké trhliny. Ornice je hlinitá až jílovitohlinitá, mocná 35 cm, přechodný horizont sahá do hloubky 45 cm, je však zrnitostně těžší, šedohnědý. Glejový horizont dosahuje do hloubky 90 cm, je šedohnědý a jílovitý. V orničním horizontu půdy je střední obsah humusu 2,28 %. Půdní reakce je neutrální a pH je 6,9. Půdy řešeného území mají dobré sorpční vlastnosti, sorpční komplex je nasycený (V = 99,0–99,8) a zásoba snadno přístupných živin je většinou dobrá.

Polní pokus byl založen na podzim v roce 2003 a představuje plochu 2,3 ha (100 m × 225 m). Jednotlivé parcely mají velikost 1 000 m² (100 × 10 m). V polním pokusu byl použit sedmihonný osevní postup: vojtěška setá – první užitkový rok, vojtěška setá – druhý užitkový rok, ozimá pšenice, kukuřice na siláž, ozimá pšenice, **cukrová řepa** a jarní ječmen.

V rámci sedmihonného osevního postupu jsou ke každé plodině soustavně používány tři varianty zpracování půdy:

– **Klasické zpracování půdy (CT):** Po sklizni předplodiny je provedená podmítka dlátovým podmítačem Kverneland do hloubky cca 0,1 m. Uválení je vhodné za suchého léta. V případě, že nenaroste výdrol, je vhodné znovu provést podmítku, aby došlo k lepšímu zapravení následující orbou. Středně hluboká orba do hloubky 0,2–0,24 m je následnou operací. Je provedena otočným oboustranným pluhem Lemken. Výsev je zajištěn secí kombinací Accord.
– **Minimalizační zpracování půdy (MT):** Podmítka je provedena po sklizni do hloubky 0,1 m dlátovým podmítačem Kverneland, který zajistí mělké zpracování. Výsev je proveden secí kombinací Accord.
– **Bez orby (přímé setí, NT):** Povrch půdy se po sklizni předplodiny nechá nezpracován. Přímé setí zajistí secí kombinace Accord. Předseťové zpracování půdy na hloubku setí je použito u kukuřice a cukrovky.

Zaplevelení bylo vyhodnocováno v porostech cukrovky v termínu 9. 4. 2013 a 1. 4. 2014. Počty jedinců jednotlivých druhů plevelů byly zjišťovány na ploše 1 m², a to ve 24 opakováních. Dále uváděné české a latinské názvy jednotlivých druhů plevelů byly použity podle KUBÁTA (13).

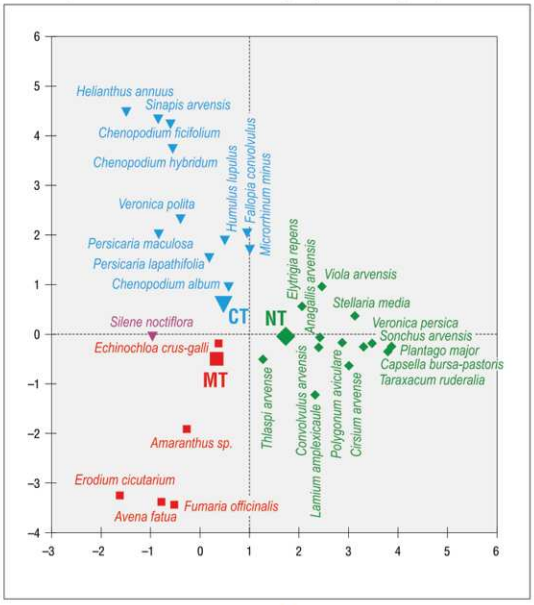
Aplikace herbicidů byla v roce 2013 provedena 9. 5. 2013 (herbicidy: Betanal Max PRO, Goltix TOP), 21. 5. 2013 (herbicidy: Betanal Max PRO, Goltix TOP) a 28. 5. 2013 (herbicid Targa Super). V roce 2014 byla aplikace herbicidů provedena 23. 4. 2014 (herbicidy: Betanal Max PRO, Goltix TOP), 5. 5. 2014 (herbicidy: Betanal Expert, Pyramin Turbo, Lontrel 300), 20. 5. 2014 (herbicid Fusilade Forte 150 EC) a 22. 5. 2014 (herbicidy: Betanal Max PRO, Pyramin Turbo, Lontrel 300).

Tab. II. Průměrný počet plevelů v cukrovce na jednotlivých variantách technologií zpracování půdy a v jednotlivých letech

Druhy plevelů	Technologie zpracování půdy			Rok sledování	
	CT	MT	NT	2013	2014
	Průměrný počet plevelů (ks.m^{-2})				
Amaranthus sp.	0,79	4,00	0,56	1,33	0,38
Anagallis arvensis	0,06	0,02	0,19		0,10
Avena fatua		0,50			0,06
Capsella bursa-pastoris	0,04		1,56	0,33	0,01
Cirsium arvense	0,02	0,17	1,08	0,17	0,25
Convolvulus arvensis	0,27	0,50	3,63		1,83
Echinochloa crus-galli	5,46	7,71	6,38	6,67	7,28
Elytrigia repens	0,04	0,04	0,90		0,65
Erodium cicutarium		0,02			0,01
Fallopia convolvulus	2,29	0,50	1,35	4,33	1,43
Fumaria officinalis		0,04			
Helianthus annuus	0,06				0,04
Humulus lupulus	0,02		0,02		0,03
Chenopodium album	2,67	1,40	2,52	3,83	2,75
Chenopodium ficifolium	0,04				0,01
Chenopodium hybridum	0,27	0,02			0,04
Lamium amplexicaule		0,15	0,33		0,04
Microrrhinum minus	0,19	0,02	0,21		0,18
Persicaria lapathifolia	0,50	0,21	0,19		0,17
Persicaria maculosa	0,15	0,06			0,06
Plantago major	0,02	0,00	0,85		0,19
Polygonum aviculare	0,15	0,13	1,71	0,50	1,08
Silene noctiflora	0,13	0,17		0,17	0,07
Sinapis arvensis	0,04				0,01
Sonchus arvensis			0,10		0,07
Stellaria media	0,06		0,35		0,04
Taraxacum sect. *Ruderalia*	0,00		0,35		0,06
Thlaspi arvense	0,04	0,08	0,15		0,13
Veronica persica	0,10	0,10	1,65	0,50	0,24
Veronica polita	0,10	0,02	0,04		0,11
Viola arvensis	0,10		0,27	0,33	0,10
Počet druhů	4,38	3,92	6,46	4,50	4,72
Počet jedinců plevelů	13,63	15,85	24,40	18,17	17,42

Mnohorozměrné analýzy ekologických dat byly využity pro zjištění vlivu technologie zpracování půdy na výskyt jednotlivých druhů plevelů. Délkou gradientu (*Lengths of Gradient*), zjištěného segmentovou analýzou DCA (*Detrended Correspondence Analysis*) se řídil výběr optimální analýzy. Následně byla použita kanonická korespondenční analýza CCA (*Canonical Correspondence Analysis*). Průkaznost byla testována pomocí

Obr. 2. Ordinační diagram zobrazující vztahy nalezených druhů plevelů a variant technologií zpracování půdy



Varianty technologií zpracování půdy: ▼ CT – klasické zpracování půdy; ■ MT – minimalizační zpracování půdy; ◆ NT – bez orby (přímé setí)

testu Monte-Carlo a bylo propočítáno 499 permutací. Data byla zpracována počítačovým programem Canoco 4.0. (14).

Výsledky a diskuse

Ve sledovaných letech 2013 a 2014 bylo v porostech cukrovky celkem nalezeno 31 druhů plevelů. Průměrné počty jednotlivých druhů plevelů jsou uvedeny v tab. II. Nejvyšší zaplevelení bylo zjištěno na variantě bez orby (NT), a to 24,40 ks.m^{-2}, ostatní varianty byly výrazně méně zapleveleny. Při využití minimalizačních technologií (MT) byly pozemky zapleveleny 15,85 ks.m^{-2} a na variantě klasického zpracování půdy bylo zaplevelení 13,63 ks.m^{-2}.

Výsledky zaplevelení cukrovky ze tří variant zpracování půdy byly vyhodnoceny analýzou DCA. Délka gradientu byla 3,838 u získaných dat a z tohoto důvodu byla vybrána pro následující zpracování dat kanonická korespondenční analýza (CCA).

Analýza CCA vymezuje prostorové uspořádání jednotlivých druhů plevelů a variant technologií zpracování půdy. Prostorové uspořádání je určeno vztahem výskytu plevelných druhů a variant zpracování půdy. Toto uspořádání bylo graficky zobrazeno pomocí ordinačního diagramu. Druhy plevelů jsou zde zobrazeny pomocí bodů (symboly), které mají odlišnou barvu a tvar. Jednotlivé varianty technologie zpracování půdy jsou zobrazeny jako body různého tvaru a barvy. V případě, že se bod příslušného druhu nachází v blízkosti bodu varianty technologie zpracování půdy, je jeho výskyt častější na této variantě.

Výsledky zaplevelení na rozdílných variantách technologií zpracování půdy pomocí analýzy CCA jsou signifikantní na hladině významnosti α = 0,002 pro všechny kanonické osy a vysvětlují 32,4 % celkové variability v datech. Výsledky jsou tedy statisticky vysoce průkazné.

Podle ordinačního diagramu (obr. 2.) můžeme druhy rostlin rozdělit do čtyři skupin. První skupina druhů plevelů se častěji vyskytovala v porostu cukrovky s použitím klasického zpracování půdy (CT, orba): *Fallopia convolvulus, Helianthus annuus, Humulus lupulus, Chenopodium album, Chenopodium ficifolium, Chenopodium hybridum, Microrrhinum minus, Persicaria lapathifolia, Persicaria maculosa, Sinapis arvensis* a *Veronica polita*.

Druhá skupina je reprezentovaná jedním druhem, a to *Silene noctiflora*. Tento druh se vyskytoval především na variantě s klasickým zpracováním půdy a také na variantě s minimalizačním zpracováním.

Třetí skupinu tvoří druhy, které se více vyskytovaly na variantě s minimalizační technologií (MT): *Amaranthus* sp., *Avena fatua, Echinochloa crus-galli, Erodium cicutarium* a *Fumaria officinalis*.

Obr. 3. Plevelné druhy vyskytující se v porostech cukrové řepy více při konvenčním (1, 2, 3) a bezorebném (4, 5, 6) zpracování půdy



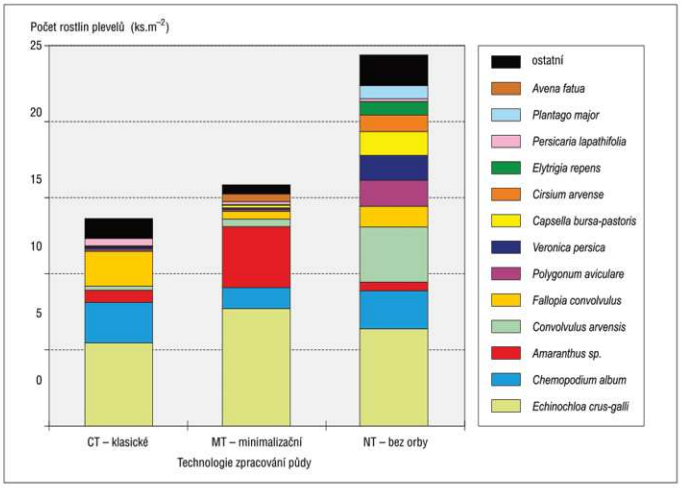
1 – mladá rostlinka cukrovky a klíční rostlina merlíku zvrhlého (Chenopodium hybridum), 2 – klíční rostlinka rdesna červivce (Persicaria maculosa), 3 – klíční rostlina opletky obecné (Fallopia convolvulus) a mladá rostlina cukrovky, 4 – jitrocel větší (Plantago major) na bezorebné variantě, 5 – lodyha svlačce rolního (Convolvulus arvensis) a rostlina cukrovky, 6 – pampeliška lékařská (Taraxacum sect. Ruderalia) na bezorebné variantě

A do čtvrté skupiny můžeme zařadit druhy plevelů, které byly četnější na bezorebné variantě technologie zpracování půdy (NT, přímé setí): *Anagallis arvensis, Capsella bursa-pastoris, Cirsium arvense, Convolvulus arvensis, Elytrigia repens, Lamium amplexicaule, Plantago major, Polygonum aviculare, Sonchus arvensis, Stellaria media, Taraxacum* sect. *Ruderalia, Thlaspi arvense, Veronica persica* a *Viola arvensis*.

Z výsledků je patrné, že v porostech cukrovky při odlišném zpracování půdy dochází k výrazným změnám v druhovém spektru plevelů (obr. 3.). Dle statistického zpracování existují výrazné změny mezi klasickým zpracováním půdy, minimalizační zpracování půdy a technologií bez orby. Na variantě s minimalizační technologií bylo zaznamenáno vyšší zastoupení jednoletých trav především druhu *Echinochloa crus-galli* a také *Avena fatua*. Dalším jednoletým druhem, který se na této variantě častěji vyskytoval, byl rod *Amaranthus* sp. Tyto druhy jsou poměrně častými plevely vyskytující se v porostech cukrovky. Pokud bude využita při pěstování cukrovky minimalizační technologie zpracování půdy, je nutné počítat s vyšším zaplevelením jednoletými druhy plevelů, a to především trávami a rodem *Amaranthus*.

Nejvyšší zaplevelení (obr. 4.) bylo zaznamenáno na variantě bez orby (s přímým setím). Na této variantě výrazně stouplo

Obr. 4. Zastoupení jednotlivých druhů plevelů na variantách zpracování půdy



zastoupení vytrvalých druhů plevelů. Jedná se především o druhy *Cirsium arvense, Convolvulus arvensis, Elytrigia repens, Plantago major, Sonchus arvensis* a *Taraxacum* sect. *Ruderalia*. Dále se zde více vyskytovaly druhy z čeledi brukvovitých (*Capsella bursa-pastoris, Thlaspi arvense*) a druhy chemicky obtížněji hubitelné (*Polygonum aviculare, Thlaspi arvense*). Bude-li porost cukrovky zakládán bezorebnou technologií, je nutné počítat s nárůstem výskytu vytrvalých druhů a druhů chemicky špatně regulovatelných.

Technologie zpracování půdy působí na distribuci semen plevelů v půdním profilu a ovlivňuje regulaci některých druhů plevelů. Při využití redukovaného zpracování půdy dochází ke změnám v distribuci semen v půdě a v mechanické regulaci plevelů. To má za následek změny v druhovém spektru plevelů, na které pěstitel musí reagovat změnou při jejich chemické regulaci.

Závěr

Zpracování půdy výrazně zasahuje do druhového spektra plevelů i do intenzity zaplevelení. Z výsledků pokusu je zřejmé, že při redukovaném zpracování půdy jsou porosty cukrovky více zapleveleny. Na variantě s klasickým zpracováním půdy se výrazně prosadily především druhy *Chenopodium album, Fallopia convolvulus* a *Persicaria lapathifolia*. Na variantě s minimalizačním zpracováním půdy to byly především druhy *Echinochloa crus-galli* a *Amaranthus* sp. Varianta bez orby byla výrazněji zaplevelena vytrvalými (*Cirsium arvense, Convolvulus arvensis, Elytrigia repens, Plantago major, Taraxacum* sect. *Ruderalia*) a některými jednoletými druhy (*Capsella bursa-pastoris, Polygonum aviculare, Veronica persica*).

Redukované způsoby zpracování půdy při zakládání porostů cukrovky jsou příčinou vyššího zaplevelení, což se může projevit ve vyšších nákladech na chemickou regulaci plevelů nebo snížením výnosů cukrovky způsobené konkurencí plevelů. Redukované zpracování půdy dále vyvolá změnu v druhovém spektru plevelů a může umožnit vysoké zaplevelení dříve nevýznamnými druhy plevelů. To klade vyšší nároky na kontrolu zaplevelení porostů cukrovky a na správnou volbu herbicidu.

Zpracování půdy může působit jako selekční faktor na plevele a upřednostňovat jedince s vlastnostmi, díky kterým přežívají. To je základem procesu nazývaného mikroevoluce na orné půdě (15).

Poděkování: Práce vznikla jako výstup projektu Interní grantové agentury AF MENDELU číslo: TP 10/2013 „Studium vybraných faktorů ovlivňující realizaci biologického potenciálu zemědělských kultur". Příspěvek vznikl za finanční podpory projektu QJ1210008, s názvem: „Inovace systémů pěstování obilnin v různých agroekologických podmínkách ČR".

Souhrn

Výskyt a druhové spektrum plevelů v cukrovce se mění také v závislosti na technologii zpracování půdy. Polní pokus se nachází na pokusné stanici Žabčice (MENDELU). Lokalita patří do kukuřičné výrobní oblasti (KVO). V polním pokusu byl použit sedmihonný osevní postup: vojtěška setá (*Medicago sativa*) – první užitkový rok, vojtěška setá – druhý užitkový rok, ozimá pšenice (*Triticum aestivum*), kukuřice na siláž (*Zea mays*), ozimá pšenice, cukrovka (*Beta vulgaris*), jarní ječmen (*Hordeum vulgare*). V rámci sedmihonného osevního postupu jsou ke každé plodině soustavně používány tři varianty zpracování půdy. Variantami technologií zpracování půdy bylo klasické zpracování půdy (CT), minimalizační zpracování půdy (MT) a bezorebné (přímé setí, NT). Ke statistickému zpracování dat byla použita analýza CCA (*Canonical Correspondence Analysis*). Ve sledovaných letech 2013 a 2014 bylo v porostech cukrovky celkem nalezeno 31 druhů plevelů. Na variantě s klasickým zpracováním půdy se výrazně prosadily především druhy *Chenopodium album, Fallopia convolvulus* a *Persicaria lapathifolia*. Na variantě s minimalizačním zpracováním půdy se jednalo především o druhy *Echinochloa crus-galli* a *Amaranthus* sp. Varianta bez orby byla převážně zaplevelena druhy vytrvalými (*Cirsium arvense, Convolvulus arvensis*) a některými jednoletými (*Capsella bursa-pastoris, Polygonum aviculare*). Redukované způsoby zpracování půdy při zakládání porostů cukrovky jsou příčinou vyššího zaplevelení.

Klíčová slova: plevele, cukrovka, zpracování půdy, minimalizace zpracování půdy.

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Winkler J., Chovancová S., Neudert L.: Effect of Tillage Technology on Current Weed Infestation of Sugar Beet

The incidence and species spectrum of weeds in sugar beet change depending on used tillage. Field trial is situated at expertimental station Žabčice (MENDELU). The locality belongs to corn production area (CPA). Seven-step crop rotation was used in this research: gourd alfalfa (*Medicago sativa*) – the first year, alfalfa wheat – the second year, winter wheat (*Triticum aestivum*), maize for grain (*Zea mays*), winter wheat, sugar beet (*Beta vulgaris*), spring barley (*Hordeum vulgare*). Three variants of tillage are consistently applied to each crop within the seven-step crop rotation. Conventional tillage (CT), minimum tillage (MT) and no-tillage (direct sowing, NT) are used. CCA analysis (Canonical Correspondence Analysis) was used for statistical evaluation of data. Thirty one weed species were observed in growths of sugar beet in monitored years 2013 and 2014. *Chenopodium album*, *Fallopia convolvulus* and *Persicaria lapathifolia* were the most common species on the variant of conventional tillage. *Echinochloa crus-galli* and *Amaranthus* sp. occurred mainly on the minimum tillage variant. No-tillage variant was weedy predominantly by perennial species (*Cirsium arvense*, *Convolvulus arvensis*) and some annual species (*Capsella bursa-pastoris*, *Polygonum aviculare*). Reduced tillage used during establishing of sugar beet growths leads to higher weed infestation.

Key words: weeds, sugar beet, tillage, minimum tillage.

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Effect of Tillage Technology Systems for Seed Germination Rate in a Laboratory Tests

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Abstract: Reduced and soil-protective tillage technologies may represent certain negatives for cultivated crops associated with the biomass of mulch from intermediate crops and post-harvest residues. Sown crops, as well as field weeds, are exposed to impaired soil conditions. Soil conditions were assessed using biological tests. Eight plant species were chosen for the tests. Germination of tested plant species took place in controlled conditions in climaboxes. Seeds on Petri dishes were watered with soil leachates from three variants of tillage (Conventional, Minimum tillage, Direct sowing). Soil samples were collected from a 15-year field experiment. The soil leachates inhibited the germination rate of the chosen plant species. In the first term, all species exhibited a lower germination capacity in variants watered with the soil leachate. The reduced tillage technologies can apparently significantly slow down the germination rate in field crops and vegetables. Simple biological tests have the potential to assess the condition of arable soils.

Keywords: soil condition; biological tests; tillage

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1. Introduction

Plants growing together on a site can support one another in their growth, but they can also compete or affect one another through allelopathy. The action of allelopathic substances may show even in the subsequently grown crops [1]. Allelopathy is defined as the acting of one plant on another by means of chemical compounds released into the surroundings [2–4]. Thus, allelopathy plays an important role in agriculture for selecting preceding crop, method of tillage and stand establishment [5]. Moreover, crop development is affected by allelopathy from certain weed species [6]. Alsaadawi et al. [7] inform us that incorporating post-harvest residues of sunflower into the soil and subsequent growing of beans led to the efficient suppression of weeds, thus allowing a significant reduction of herbicides. According to TeKrony et al. [8], due attention must be given to the effects of allelopathy particularly at establishing maize stands. Allelopathy shows in the impaired germination capacity of maize [9], which results in stand gaps and hence in the reduced yield [10,11]; this also applies to yields of other crops [12].

Tillage technologies referred to as reduced or soil-protecting leave the post-harvest residues of crops on the ground surface or are incorporated only to a shallow depth under the soil surface. Decaying plant residues can influence following crops or the growth of weeds; this is a certain risk which is considerably higher in these technologies [13,14].

Tisdall [15] claims that if straw and post-harvest residues are left on the soil surface or are accumulated in clumps, fungi and fungal organisms develop [16,17]. At the same time, the decomposition of organic substances changes soil chemical properties, particularly contents of nitrogen, carbon, and soil pH [15,18–20]. According to Marendiak et al. [21], nitrogen is mobilized by microorganisms during the decomposition of straw, which negatively affects the growth of sown crops. Ocio et al. [22], Hao et al. [23], Ning et al. [24] and Liu et al. [25] found out that straw incorporation into the soil by ploughing leads to the increased biomass of microorganisms. Marendiak et al. [21] arrived at similar conclusions and pointed out that the straw incorporation into the soil is beneficial, namely for the development of cellulolytic microflora. Some authors suggest that negative yield responses due to mulching with plant residues are due to nitrogen immobilization [26]. According to Baeumer and Bakermans [27], the use of no-tillage technologies results in the increased concentrations of phosphorus, potassium, and nitrogen in the upper soil layer. Moreover, no-till leads to a significant increase in acid phosphatase activity, promotes the formation of soil aggregates and improves their stability due to the presence of high crop residue and increased soil organic matter in the topsoil [28].

The reduced and soil-protecting technologies may show certain negatives associated with the biomass of mulch from intermediate crops and post-harvest residues. The sown plants are exposed to effects of allelopathy, to changes in the content of soil moisture, in the content of nutrients, decreased heat flux and development of microorganisms [5,26].

Soil environment is a dynamic complex of living and inanimate nature and processes occurring among the individual components. This complex is considerably affected by tillage systems which alter the conditions for the germination of crops, but also weeds, too. Therefore, the following hypothesis was set up: reduced tillage technologies alter the soil environment and create unfavourable phytotoxic conditions for the germination of plant seeds. Partial goals set up to confirm or refute the hypothesis were as follows: (i) to determine the effect of soil leachate on the germination capacity of the selected plant species, (ii) to determine the effect of soil leachate on the dynamics of plants species germination capacity, and (iii) to define seed germination trends in the selected groups of crops under the effect of soil leachates.

2. Materials and Methods

2.1. Characteristics of Locality and Field Experiment

The long-term field experiment was established in the autumn of 2003 at the field experimental station in Žabčice (Mendel University in Brno). The locality is situated between the villages of Žabčice and Židlochovice (South Moravian Region, Czech Republic (CR); 49.0237689 N, 16.6143786 E). The plot is in a flat terrain at an altitude of 179 m a.s.l. The long-term mean annual temperature is 9.2 °C and the long-term total annual precipitation amount is 481 mm. The soil type in the locality is Gleyic Fluvisol, which developed on the adjacent Svratka River alluvial sediments. In terms of structure, it is a clay-loam soil (heavy to very heavy). The acidity of soils is neutral (pH 6.9) with a medium content of humus of 2.28%. Nutrients available to the grown crops are at a sufficient level, and the base-exchange complex is well saturated too.

In the field experiment, three variants of tillage technologies were applied within a seven-plot crop rotation. The size of individual plots was 100 m × 10 m (1000 m^2); the plots were organized into long blocks. In the technologies of growing the crops, common industrial fertilizers and pesticides were used, registered for the conditions of conventional agriculture in the CR. The rotation of crops was organized as follows: alfalfa—1st utility year, alfalfa—2nd utility year, winter wheat, maize (for silage), winter wheat, sugar beet, spring barley. Continuous variants of tillage technologies used for the grown crops were as follows:

(i) Conventional tillage with ploughing (CT)—after the harvest of the preceding crop, ploughing to a depth of 0.20–0.24 m followed (medium deep) by the swivelling reversible Lemken plough. In the spring period, a sowing followed using the Accord seeding combination.
(ii) Minimum tillage (MT)—the harvest of preceding crop was followed by the shallow tillage using a chisel-type soil loosener Kverneland to a depth of 0.10 m, after which a sowing followed in spring using the Accord seeding combination.
(iii) Direct sowing (NT)—the soil surface was not treated after the harvest of the preceding crop and am Accord seeding combination was used for sowing. Pre-sowing soil preparation for seeding depth was made only in maize and sugar beet.

2.2. Methodology of Soil Sampling and Preparation of Soil Leachates

Soil samples from three tillage variants in the field experiment, i.e., after 15 years of the action of technologies, were sampled in 2018 after the harvest of spring barley. In each variant, 8 sampling points were marked, at which 5 partial samples were collected from a depth of 0.15 m using the soil probing rod. The collected partial soil samples were mixed, homogenized, and a mixed sample was created. Mixed soil samples were spread in a thin layer. The drying was performed for 7 days at room temperature. Then, the samples were stored.

Prior to starting the laboratory experiment, 20 g of soil was weighed from each mixed sample from each tillage variant in 8 repetitions. The weighed amount of soil was mixed with 50 mL of distilled water in plastic bottles and left in the shaker for 2 h. After a thorough shaking, the content of bottles was filtered on the filter paper. The obtained leachate was then used to water the seeds of selected plant species.

2.3. Methodology of Laboratory Experiments with Germination

There were eight plant species used in the laboratory experiment. The tested species included representatives of field crops (*Triticum aestivum* L., *Hordeum vulgare* L.), intermediate crops (*Sinapis alba* L., *Phacelia tanacetifolia* Benth.), vegetables (*Allium cepa* L., *Lactuca sativa* L.) and field weeds (*Tripleurospermum inodorum*/L./Sch.Bip., *Galium aparine* L.).

The experiment with the seed germination rate of selected plant species took place in climaboxes with a light regime of 12 h dark/12 h light at an air temperature of 15 °C. The seeds germinated in Petri dishes; each dish contained 8 seeds on 3 layers of filter paper. Seeds on the Petri dishes were watered with soil leachates from the three variants of tillage (CT, MT, NT) and with tap water (Control). Each variant of tillage and plant species had 8 repetitions, and each repetition had a separate Petri dish. The germination of seeds was assessed in 4 terms. The first term (I) was Day 3 from the establishment of the experiment; the second term (II) was Day 7, the third term (III) was Day 14, and the fourth term (IV) was Day 21 from the establishment of the experiment. During the experiment, the Petri dishes were evenly watered.

Germination was assessed for each plant species separately. All data were subjected to tests of homogenity and normality. The results were statistically evaluated by the multifactor ANOVA and by the Fischer LSD test. The data were not transformed prior to the statistical analysis.

3. Results

The germination capacity of caryopses of field crops *Triticum aestivum* and *Hordeum vulgare* was the lowest in the variant watered with the NT systems leachate in the first term of assessment (Day 3 from the establishment of the experiment). In the other terms, the germination capacity was gradually becoming equal, and in the third and fourth term, differences were no more statistically significant (Figures 1 and 2).

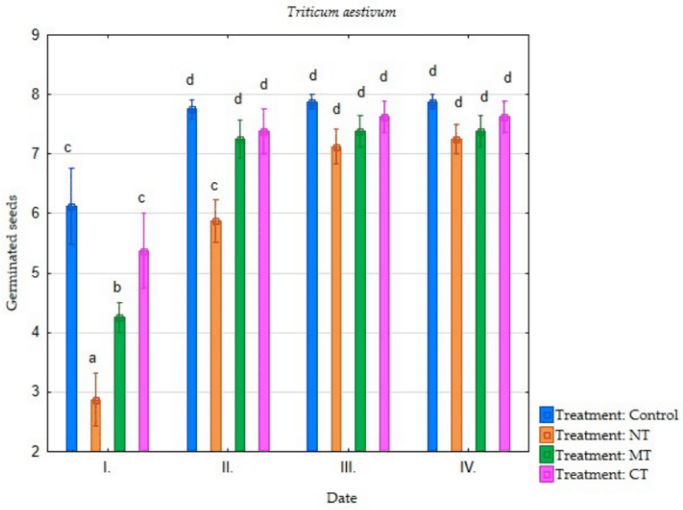


Figure 1. Development of the germination of *Triticum aestivum* caryopses watered with soil leachates from different soil tillage. The results represent the mean of 8 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, the whiskers representing the standard error, values with different letter (a, b, c, d) differ significantly. Variants of tillage technologies: CT—Conventional tillage with ploughing; MT—Minimum tillagethe; NT—Direct sowing.

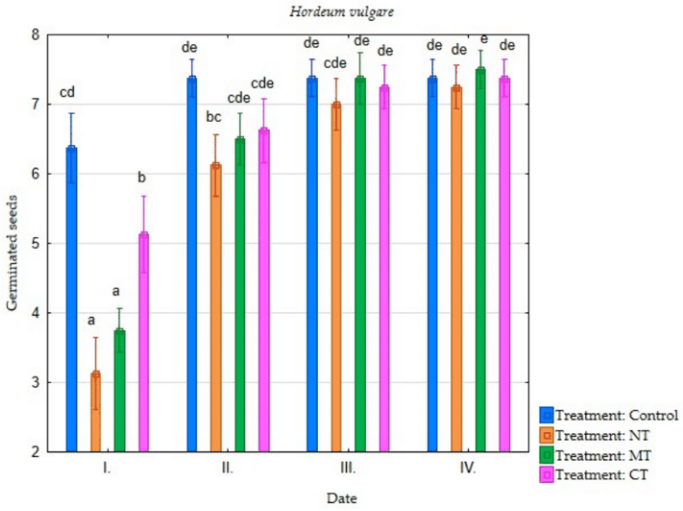


Figure 2. Development of the germination of *Hordeum vulgare* caryopses watered with soil leachates from different soil tillage. The results represent the mean of 8 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, the whiskers representing the standard error, values with different letter (a, b, c, d, e) differ significantly. Variants of tillage technologies: CT—Conventional tillage with ploughing; MT—Minimum tillagethe; NT—Direct sowing.

The germination response of crops used as intermediate crops (*Sinapis alba*, *Phacelia tanacetifolia*) was similar. The lowest one was recorded in the variant watered with NT and MT leachates in the first term of assessment (Day 3 from the establishment of the experiment). In the following terms (II, III, IV), the germination capacity reached similar values with differences not being statistically significant (Figures 3 and 4).

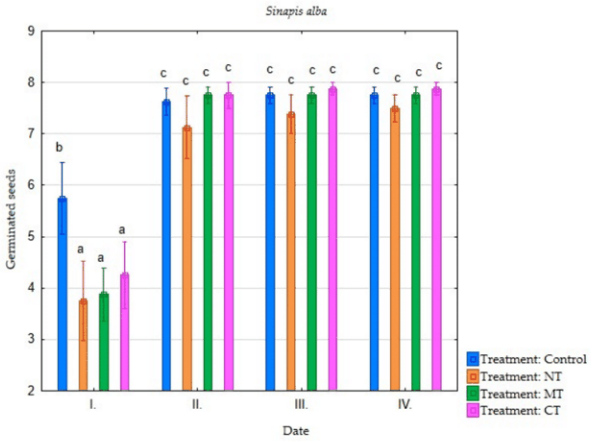


Figure 3. Development of the germination of *Sinapis alba* caryopses watered with soil leachates from different soil tillage. The results represent the mean of 8 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, the whiskers representing the standard error, values with different letter (a, b, c) differ significantly. Variants of tillage technologies: CT—Conventional tillage with ploughing; MT—Minimum tillagethe; NT—Direct sowing.

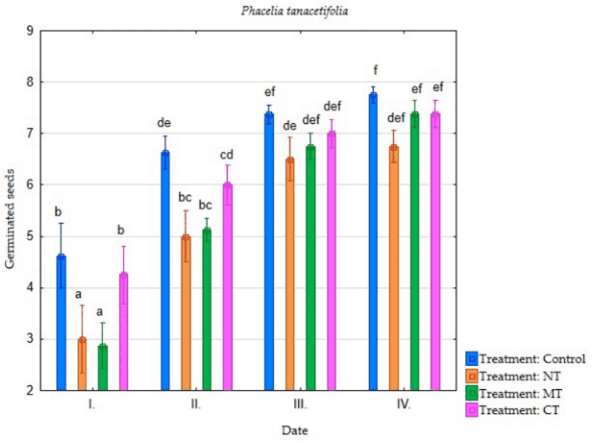


Figure 4. Development of the germination of *Phacelia tanacetifolia* caryopses watered with soil leachates from different soil tillage. The results represent the mean of 8 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, the whiskers representing the standard error, values with different letter (a, b, c, d, e, f) differ significantly. Variants of tillage technologies: CT—Conventional tillage with ploughing; MT—Minimum tillagethe; NT—Direct sowing.

The most pronounced reaction was recorded in the germination capacity of seeds vegetables (*Allium cepa*, *Lactuca sativa*). Soil leachates from the variants of reduced tillage (NT and MT) exhibited a lower germination capacity in the first term of assessment. In the last term of assessment, this difference was no more statistically significant. The soil leachates obviously inhibit the process of germination (Figures 5 and 6).

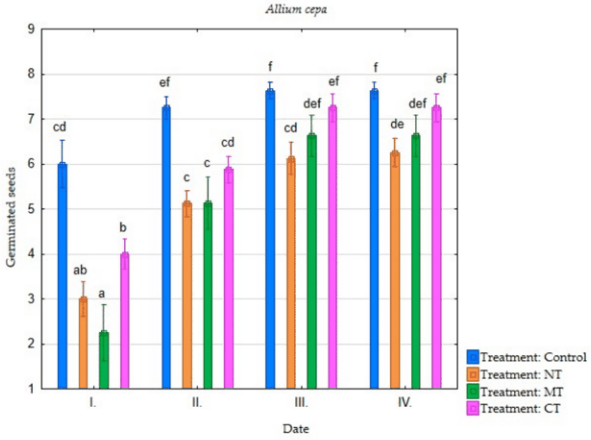


Figure 5. Development of the germination of *Allium cepa* caryopses watered with soil leachates from different soil tillage. The results represent the mean of 8 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, the whiskers representing the standard error, values with different letter (a, b, c, d, e, f) differ significantly. Variants of tillage technologies: CT—Conventional tillage with ploughing; MT—Minimum tillagethe; NT—Direct sowing.

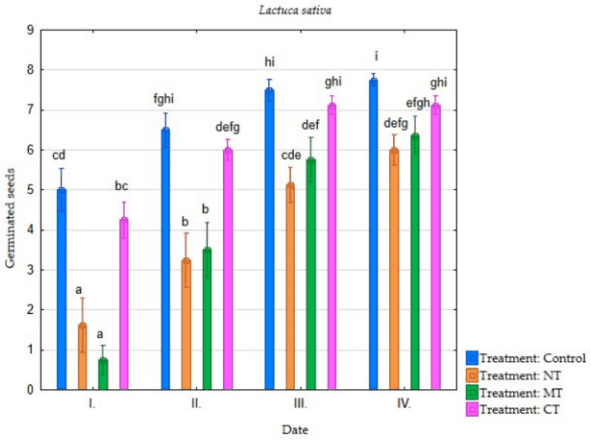


Figure 6. Development of the germination of *Lactuca sativa* caryopses watered with soil leachates from different soil tillage. The results represent the mean of 8 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, the whiskers representing the standard error, values with different letter (a, b, c, d, e, f, g, h, i) differ significantly. Variants of tillage technologies: CT—Conventional tillage with ploughing; MT—Minimum tillagethe; NT—Direct sowing.

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Compared with the cultural plant species, the germination of two weeds (*Tripleurospermum inodorum*, *Galium aparine*) was markedly differed. Significant differences in seed germination rate were between the terms of assessment. Germination was clearly lower in the first term of assessment. Higher germination was recorded in the variants with soil leachates from reduced variants of tillage (NT and MT); lower germination was observed in the leachate from the variant with the CT. The differences in germination observed for the variants with leachate were not statistically significant (Figures 7 and 8).

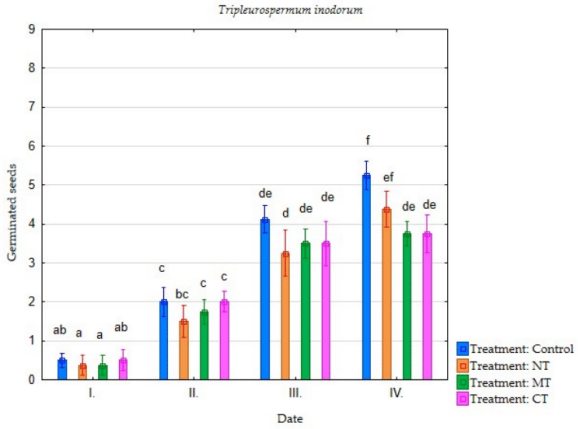


Figure 7. Development of the germination of *Tripleurospermum inodorum* caryopses watered with soil leachates from different soil tillage. The results represent the mean of 8 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, the whiskers representing the standard error, values with different letter (a, b, c, d, e, f) differ significantly. Variants of tillage technologies: CT—Conventional tillage with ploughing; MT—Minimum tillagethe; NT—Direct sowing.

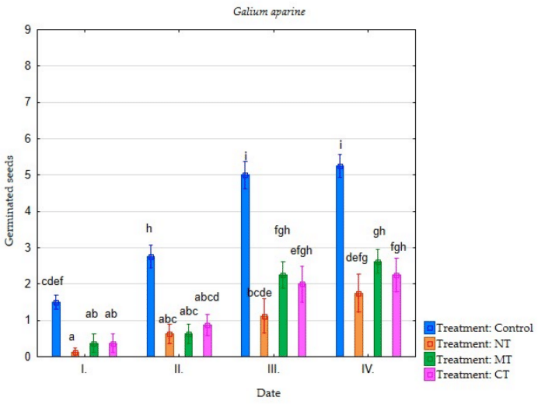


Figure 8. Development of the germination of *Galium aparine* caryopses watered with soil leachates from different soil tillage. The results represent the mean of 8 biological replicates ± SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level $p = 0.05$ (Fisher LSD test). The plot shows the mean, the whiskers representing the standard error, values with different letter (a, b, c, d, e, f, g, h, i) differ significantly. Variants of tillage technologies: CT—Conventional tillage with ploughing; MT—Minimum tillagethe; NT—Direct sowing.

Germination of seeds results of individual selected plant species are presented in Table 1. It follows from them that the germination response is different in them. The highest germination capacity was exhibited by the control variant in which only water was used for irrigation. The other experimental variants with the soil leachates showed different effects on the germination capacity of selected plant species.

Table 1. Average germination of studied plant species.

Irrigation with Soil Leachate	Terms of Evaluation (Date)	Average Germination of Selected Plant Species (Number of Germinated Seeds)							
		Triticum aestivum	*Hordeum vulgare*	*Sinapis alba*	*Phacelia tanacetifolia*	*Allium cepa*	*Lactuca sativa*	*Tripleurospermum inodorum*	*Galium aparine*
Minimum tillage (MT)	I.	4.25	3.75	3.88	2.88	2.25	0.75	0.38	0.38
	II.	7.25	6.50	7.75	5.13	5.13	3.50	1.75	0.63
	III.	7.38	7.38	7.75	6.75	6.63	5.75	3.50	2.25
	IV.	7.38	7.50	7.75	7.38	6.63	6.38	3.75	2.63
Direct sowing (NT)	I.	2.88	3.13	3.75	3.00	3.00	1.63	0.38	0.13
	II.	5.88	6.13	7.13	5.00	5.13	3.25	1.50	0.63
	III.	7.13	7.00	7.38	6.50	6.13	5.13	3.25	1.13
	IV.	7.25	7.25	7.50	6.75	6.25	6.00	4.38	1.75
Conventional tillage CT)	I.	5.38	5.13	4.25	4.25	4.00	4.25	0.50	0.38
	II.	7.38	6.63	7.75	6.00	5.88	6.00	2.00	0.88
	III.	7.63	7.25	7.88	7.00	7.25	7.13	3.50	2.00
	IV.	7.63	7.38	7.88	7.38	7.25	7.13	3.75	2.25
Water (Control)	I.	6.13	6.38	5.75	4.63	6.00	5.00	0.50	1.50
	II.	7.75	7.38	7.63	6.63	7.25	6.50	2.00	2.75
	III.	7.88	7.38	7.75	7.38	7.63	7.50	4.13	5.00
	IV.	7.88	7.38	7.75	7.75	7.63	7.75	5.25	5.25

From the summary of the analysis of variance (Table 2), it is obvious that the effect of evaluation time (I–IV) on seed germination was strongest for all tested species. Overall effect of different soil leachate (treatment) on seed germination was statistically significant in all species except *Sinapis alba* and *Tripleurospermum inodorum*.

Table 2. Summary of analysis of variance for germination of selected species according to treatment and time of assessment.

Source of Variance	*Triticum aestivum*	*Hordeum vulgare*	*Sinapis alba*	*Phacelia tanacetifolia*	*Allium cepa*	*Lactuca sativa*	*Tripleurospermum inodorum*	*Galium aparine*
Treatment	***	***	NS	***	***	***	NS	***
Time of evaluation	***	***	***	***	***	***	***	***
Treatment × time of evaluation	*	*	NS	NS	NS	NS	NS	*

Differences in germination depending on treatment and time of evaluation and its interaction by ANOVA; non-significant (NS) or significant at $p \leq 0.05$ (*) or $p \leq 0.001$ (***), respectively.

4. Discussion

Results of germination tests indicate that soil leachates inhibit the germination of most tested plant species as compared with the water. Thus, it can be assumed there are substances in the arable soils, which slow down the seed germination rate of field crops and vegetables, and even may induce dormancy in weeds. A precise identification and determination of inhibiting substances is very difficult. However, a degree of inhibition can be determined by simple biological tests of germination. Higher plants currently most used to evaluate the environment contamination are *Allium cepa*, *Vicia faba*, *Zea mays*, *Tradescantia*, *Nicotiana tabacum*, *Crepis capillaris* and *Hordeum vulgare* [29]. Very sensitive vegetable species are *Allium cepa* and *Lactuca sativa* [29,30]. The reaction of vegetable species was expressive and statistically significant especially in *Lactuca sativa*, which was in line with the findings of Mañas et al. [30]. Moreover, some studies recommended *Lactuca sativa* as a bioindicator to determine the toxicity of soil and water samples [31].

The results also indicate that the reduced technologies of tillage (NT and MT) slow down the germination of the seeds of studied species. This is obvious particularly in the first term of assessment. We can assume that in field conditions, the inhibition of germination rate can show as uneven and slowed-down emergence or in the development of some soil pathogens. According to Chovancová et al. [32], Małecka-Jankowiak et al. [33] and Mancinelli et al. [34], the system of tillage changes soil properties and thus affects the growth and development of plants. According to Wang et al. [35], despite the high potential of mulch, its effect for increasing yield would depend on the amount of precipitation during the crop growing season. As the composition of soil organisms changes due to the decomposition of post-harvest residues, applied pesticides and industrial fertilizers, the soil processes change too [36–39]. This may result in the development of inhibiting substances slowing down the process of germination, which is particularly obvious in the reduced technologies of tillage. The trend is evident namely in cereals (*Triticum aestivum*, *Hordeum vulgare*), i.e., in crops that are grown on the experimental plot. On the other hand, it is not so apparent in *Sinapis alba* and *Phacelia tanacetifolia*, which are not represented in the crop rotation. This shows that post-harvest residues of a certain crop in the soil inhibit (slow down) the germination of seeds of identical plant species.

A number of authors claim that the addition of extracts from different crops results in a slowed-down germination rate in maize [9,10,26,40] and spring barley [41]. A cause in the decreased germination rate can be a change in the production of H_2O_2 due to the disturbed balance between phytohormones (abscisic acid and ethylene) in the seeds [42] by oxidation stress induced by phytotoxins from extracts, which cause damage to cells [43] and change in the mobilization of reserves as well as in the generation of energy during germination [44]. It follows out from the results that consequences of the action of biomass decay show also in the soil leachate.

The response of weed species (*Tripleurospermum inodorum*, *Galium aparine*) was different than that of cultural plants. Compared with the control variant, which was irrigated with water, soil leachates slowed down the germination of their seeds too. However, differences between the leachates from the variants of tillage technologies were no more statistically significant. Therefore, the germination of weed species is not affected by inhibitory substances in the soil environment. Although many authors point out the influence of technologies on the change in the infestation of field crops by weeds [45–47], our research results suggest that inhibitory substances in the soil environment should not be held responsible for that.

Thus, technologies of tillage change the soil environment; in reduced technologies, the action of inhibitory substances may show in the germination rate. Slowed-down germination can affect the quality of field crop and vegetable stands. Conventional tillage technology mitigates these negative consequences.

5. Conclusions

The research confirmed that the tillage systems change the soil environment. Soil leachates showed an inhibitory influence on the seed germination rate of selected plant species. In the first term of assessment, all plant species in variants watered with the soil leachate exhibited lower germination. The total number of germinated seeds did not differ, though. The soil environment has a potential to slow down germination, which can be a reason for uneven emergence in field crops. It is also obvious that reduced technologies of tillage can considerably slow down the germination rate in field crops. The phenomenon is more conspicuous in crops grown one after the other and with the use of reduced technologies. Results of our laboratory test show a great potential of biological methods. The complex of soil environment factors affecting the germination of seeds can be assessed comprehensively thanks to simple biological tests. The assessment of the combined effect of agrochemicals by means of biological tests appears very promising. The tests represent a low-cost, complex, and more applicable variant for evaluating the condition of agricultural soils.

Results suggest that alternative methods of management, which reduce the amounts of agrochemicals on arable land and in substrates that are increasingly used for intensive production, should be given more attention. In this context, an issue comes to the fore of hydroponic growing of vegetables, where a rockwool growing medium is used as a substrate.

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Příloha 15

LISTY CUKROVARNICKÉ a ŘEPAŘSKÉ

Vliv hnojení cukrovky chlévským hnojem na zaplevelení

Influence of Manure on Weed Infestation of Sugar Beet

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Pěstování rostlin podle zásad udržitelného rozvoje je spojeno se zachováním určitého podílu organické hmoty v půdě (1). Správné pěstitelské postupy se snaží zvýšit podíl organické hmoty v půdě, a tím se zvyšuje zastoupení půdního organického uhlíku (2). V současné době nabírá zvyšování půdního uhlíku nový rozměr v souvislosti s úsilím o omezení množství skleníkových plynů. Podle některých autorů (3) snižuje uhlík hromaděný v půdě obsah atmosférického CO_2. Organická hmota a vyšší kumulace uhlíku chrání půdní agregáty a také humus před destruktivní činností půdních mikroorganismů (4).

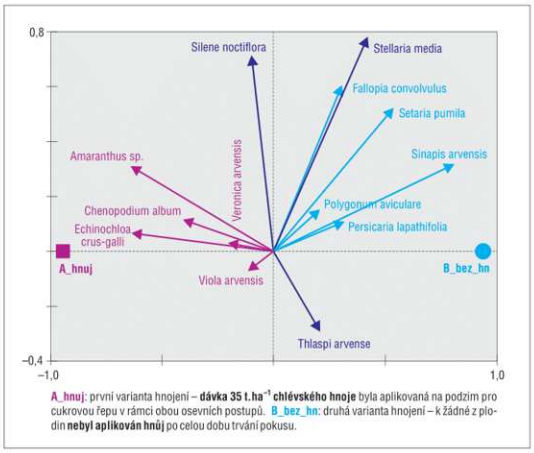
Organický uhlík je do půdy dodáván prostřednictvím organických hnojiv a ve formě posklizňových zbytků. Aplikace organických hnojiv, především chlévského hnoje, podporuje stabilitu půdních agregátů, pozitivně působí na humusové látky v půdě a také dodává příznivě působící mikroorganismy (5, 6, 7). Kromě těchto pozitivních schopností je nežádoucí součástí chlévského hnoje také velké množství plodů a semen plevelů (8).

Půdní semenná banka představuje hlavní zdroj plevelů na orné půdě a zajišťuje jejich přežití do budoucna (9). Vlastní úroveň zaplevelení, tj. množství plodů a semen plevelů v půdě a počet rostlin plevelů v porostech polních plodin, je výsledkem a do značné míry odráží historii všech uplatňovaných pěstitelských opatření na daném pozemku (10, 11). Z uplatňovaných opatření se jedná především o technologii zpracování půdy (12) a také o střídání plodin (13, 14). Střídání plodin na pozemku je důležitým opatřením, které ovlivňuje druhovou pestrost společenstev plevelů (15). Osevní postup vytváří podmínky pro větší rozmanitost v druhovém spektru plevelů než v monokulturách plodin (16), kde monotónní regulace plevelů vykazuje stejný selekční tlak na plevele. Tím jsou upřednostňovány druhy s fenotypem a fenologií podobnou pěstovaným plodinám (17).

Význam půdní semenné banky se zvyšuje především v systémech s omezeným používáním herbicidů, kde je důležité omezit počet semen plevelů v půdě a tím usnadnit regulaci plevelů (18). Integrované systémy regulace plevelů mají potenciál k omezení využívání herbicidů a udržení úspěšné regulace plevelů v dlouhodobém horizontu (19). Je však nutné upozornit, že procentické zastoupení semen určitého druhu plevele v půdní zásobě nebývá v korelaci se zastoupením toho stejného druhu v aktuálním zaplevelení (20).

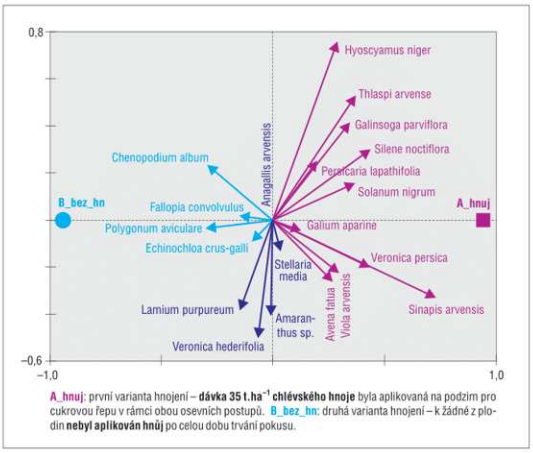
Chlévský hnůj je důležitý ve výživě pěstovaných plodin, řada z nich na jeho aplikaci reaguje zvýšením výnosu. Jsou to především okopaniny, jako je cukrovka, případně brambory, a dále také zelenina, kukuřice, některé olejniny (např. slunečnice a mák), ale také na chudých půdách pěstované žito. Vliv hnojení chlévským hnojem a střídání plodin na zaplevelení je tématem tohoto článku.

Obr. 1. Ordinační diagram zobrazující vztahy mezi plody a semeny druhů v půdní semenné bance a hnojení chlévským hnojem



A_hnuj: první varianta hnojení – **dávka 35 t.ha^{-1} chlévského hnoje** byla aplikovaná na podzim pro cukrovou řepu v rámci obou osevních postupů. **B_bez_hn**: druhá varianta hnojení – k žádné z plodin **nebyl aplikován hnůj** po celou dobu trvání pokusu.

Obr. 2. Ordinační diagram zobrazující vztahy mezi zaplevelením druhů v následných plodinách a hnojení chlévským hnojem



A_hnuj: první varianta hnojení – **dávka 35 t.ha^{-1} chlévského hnoje** byla aplikovaná na podzim pro cukrovou řepu v rámci obou osevních postupů. **B_bez_hn**: druhá varianta hnojení – k žádné z plodin **nebyl aplikován hnůj** po celou dobu trvání pokusu.

Materiál a metody

Pokusná stanice se nachází v kukuřičné výrobní oblasti, asi 20 km jižně od Brna, v klimatickém regionu velmi teplém, suchém. Průměrná roční teplota za posledních třicet let je 9,2 °C a v třicetiletém průměru byl roční úhrn srážek 481 mm.

Vyhodnocení zaplevelení a odběr půdních vzorků probíhaly v letech 1994 a 1995. Vlastní polní pokusy byly založeny již v roce 1970 a jedná se tedy o pokus s dlouhodobým působením určitých pěstitelských postupů.

Polní pokusy byly prováděny na polní pokusné stanici Mendelovy univerzity v Žabčicích. Cílem těchto pokusů bylo sledovat vliv různých pěstitelských postupů se zaměřením především na pěstování cukrové řepy a jarního ječmene.

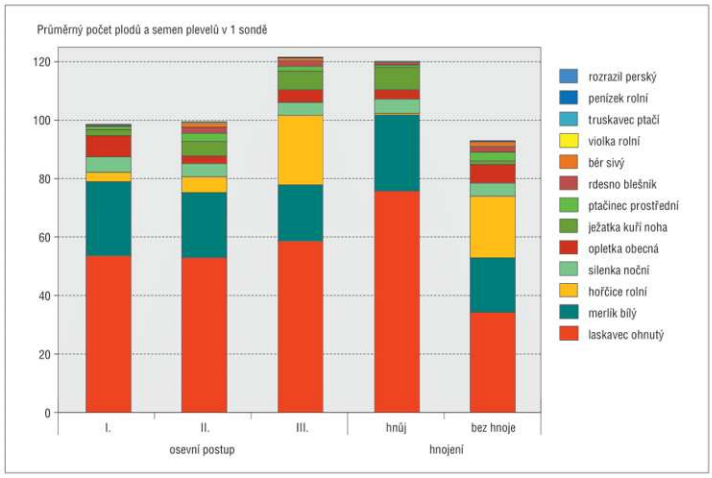
Z pěstitelských postupů byla pozornost soustředěna na vliv **střídání plodin**. Sledování probíhalo ve třech variantách střídání plodin s odlišnou koncentrací jarního ječmene a cukrovky:

I. první varianta střídání plodin: **jarní ječmen** (**25 %**), jetelovina (25 %), ozimá pšenice (25 %), **cukrovka** (**25 %**); jednalo se o osevní postup Norfolkského typu,

II. druhá varianta střídání plodin: **jarní ječmen** (**37,5 %**), jetelovina (12,5 %), ozimá pšenice (25 %), **cukrová řepa** (**25 %**),

III. třetí varianta střídání plodin: **jarní ječmen** (**62,5 %**), **cukrová řepa** (**37,5 %**).

Obr. 3. Půdní semenná banka na variantách s odlišným střídáním plodin a hnojení



Tab. I. Průměrný počet semen plevelů (potenciální zaplevelení) ze sledovaných variant osevních postupů a hnojení

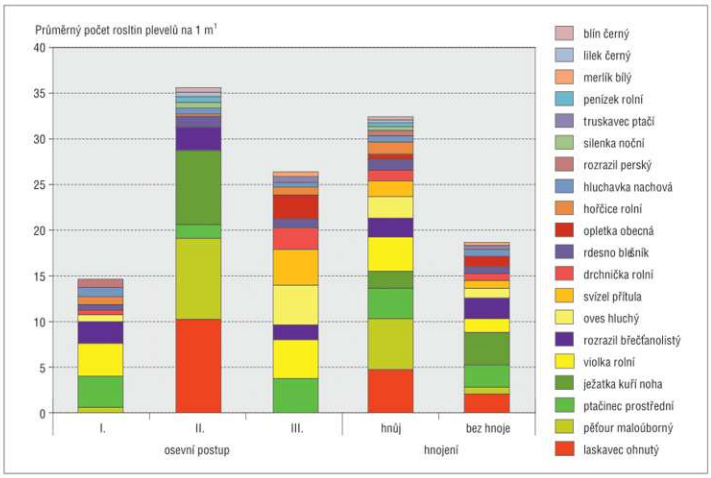
Druhy rostlin		Osevní postupy a hnojení					
		I. j. ječmen (25 %), cukrovka (25 %)		II. j. ječmen (37,5 %), cukrovka (25 %)		III. j. ječmen (62,5 %), cukrovka (25 %)	
český název	vědecký název	A – hnůj 35 t.ha^{-1}	B – bez hnoje	A – hnůj 35 t.ha^{-1}	B – bez hnoje	A – hnůj 35 t.ha^{-1}	B – bez hnoje
		Průměrný počet semen na sondu (ks)					
Laskavec ohnutý	*Amaranthus* sp.	76,50	30,75	60,50	45,50	90,50	26,75
Merlík bílý	*Chenopodium album*	34,25	16,50	22,25	22,25	21,50	17,00
Hořčice rolní	*Sinapis arvensis*	1,75	4,75		11,00		47,75
Silenka noční	*Silene noctiflora*	8,50	2,00	3,00	6,00	3,25	5,50
Opletka obecná	*Fallopia convolvulus*	6,50	8,00	0,25	4,75	2,75	6,00
Ježatka kuří noha	*Echinochloa crus-galli*	4,00	0,25	8,00	2,00	11,25	1,50
Ptačinec prostřední	*Stellaria media*	2,00			5,75		3,25
Rdesno blešník	*Persicaria lapathifolia*	0,25	0,25	2,00	2,00		3,75
Bér sivý	*Setaria pumila*				2,50		1,75
Violka rolní	*Viola arvensis*	0,75			1,00	0,50	
Truskavec ptačí	*Polygonum aviculare*						0,25
Penízek rolní	*Thlaspi arvense*				0,25		
Rozrazil perský	*Veronica persica*	0,25					
Průměrný počet jedinců plevelů		134,75	62,50	96,00	103,00	129,75	113,50

Dalším sledovaným pěstitelským opatřením bylo hnojení chlévským hnojem. Všechny varianty střídání plodin měly dvě dlouhodobé varianty hnojení hnojem, které byly uplatňovány od založení polního pokusu:

A) První varianta hnojení: **dávka 35 t.ha^{-1} chlévského hnoje** byla aplikovaná na podzim pro **cukrovou řepu** v rámci obou osevních postupů.

B) Druhá varianta hnojení: k žádné z plodin **nebyl aplikován hnůj** po celou dobu trvání pokusu.

Obr. 4. Aktuální zaplevelení následných plodin pěstovaných po cukrovce



Stanovení zaplevelení

Potenciální zaplevelení bylo stanoveno ze směsných půdních vzorků. Dílčí odběry půdy byly odebrány půdní sondou do hloubky 30 cm, ze 4 míst a následně byl jejich smícháním vytvořen směsný vzorek. Odběr vzorků proběhl na jaře roku 1995. Následně byly půdní vzorky zhomogenizovány a vysušeny, následovalo jejich rozplavení, kdy byla odstraněna část minerálního podílu. Rozplavené vzorky byly ručně separovány, přičemž byly odděleny plody a semena plevelů od zbývajícího minerálního podílu a zbytků rostlin. Následně proběhlo určení jednotlivých rostlinných druhů plodů a semen a ty byly spočítány.

Aktuální zaplevelení bylo stanoveno pomocí početní metody. Hodnocení probíhalo na jaře 1994 a 1995 v termínu před aplikací herbicidů v porostech následně pěstovaných plodin. Počty plevelů byly stanoveny na ploše 0,25 m^2 ve 4 opakováních pro každou variantu. České a latinské názvy jednotlivých druhů plevelů byly použity podle KUBÁTA (21).

Získané údaje byly zpracovány mnohorozměrnou analýzou ekologických dat. Výběr optimální analýzy se řídil délkou gradientu (*Lengths of Gradient*), zjištěného segmentovou analýzou DCA (*Detrended Correspondence Analysis*). Pro další zpracování byla použita redundanční analýza (redundancy analysis, RDA), která je

Tab. II. Průměrný počet rostlin plevelů (aktuální zaplevelení) ze sledovaných variant osevních postupů a hnojení

Druhy rostlin		Osevní postupy a hnojení					
		I. j. ječmen (25 %), cukrovka (25 %)		II. j. ječmen (37,5 %), cukrovka (25 %)		III. j. ječmen (62,5 %), cukrovka (25 %)	
český název	vědecký název	A – hnůj 35 t.ha^{-1}	B – bez hnoje	A – hnůj 35 t.ha^{-1}	B – bez hnoje	A – hnůj 35 t.ha^{-1}	B – bez hnoje
		Průměrný počet rostlin plevelů (ks.m^{-2})					
Laskavec ohnutý	*Amaranthus* sp.			14,25	6,25		
Pěťour maloúborný	*Galinsoga parviflora*	1,25		15,50	2,25		
Ptačinec prostřední	*Stellaria media*	3,50	3,25	1,00	2,00	5,50	2,00
Ježatka kuří noha	*Echinochloa crus-galli*			5,50	10,75		
Violka rolní	*Viola arvensis*	5,00	2,25			6,25	2,25
Rozrazil břečťanolistý	*Veronica hederifolia*	2,75	2,00	1,25	3,75	2,25	1,00
Oves hluchý	*Avena fatua*	1,50				5,50	3,25
Svízel přítula	*Galium aparine*					5,25	2,50
Drchnička rolní	*Anagallis arvensis*		1,00			3,50	1,25
Rdesno blešník	*Persicaria lapathifolia*		1,25	1,50	1,00	2,00	
Opletka obecná	*Fallopia convolvulus*					1,75	3,50
Hořčice rolní	*Sinapis arvensis*	1,75		0,50		1,75	
Hluchavka nachová	*Lamium purpureum*	2,00			1,25		1,00
Rozrazil perský	*Veronica persica*	1,75					
Silenka noční	*Silene noctiflora*			1,25			
Truskavec ptačí	*Polygonum aviculare*						1,25
Penízek rolní	*Thlaspi arvense*			1,25			
Merlík bílý	*Chenopodium album*						1,00
Lilek černý	*Solanum nigrum*			1,00			
Blín černý	*Hyoscyomus niger*			1,00			
Průměrný počet jedinců plevelů		19,50	9,75	44,00	27,25	33,75	19,00

založena na modelu lineární odpovědi (*Linear Response*). Při testování průkaznosti pomocí testu Monte-Carlo bylo propočítáno 999 permutací. Data byla zpracována pomocí počítačového programu Canoco 4.0. (22). Opakování a varianty osevních postupů byly do analýz zadány jako covariata, což umožňuje eliminovat jejich vliv. Lépe se také projeví vliv hnojení hnojem na potenciální i aktuální zaplevelení.

Výsledky a diskuse

Půdní semenná banka (potenciální zaplevelení) je reprezentováno plody a semeny plevelů. Po analýze půdních vzorků byla identifikována semena 13 druhů rostlin. Průměrný počet semen jednotlivých druhů je uveden v tab. I.

Zaplevelení porostů (aktuální zaplevelení) je reprezentováno rostlinami plevelů. Po vyhodnocení porostů plodin pěstovaných po cukrovce bylo nalezeno 20 druhů rostlin. Průměrný počet rostlin jednotlivých druhů je uveden v tab. II.

Na základě analýzy DCA byla vypočtena délka gradientu pro data o potenciálním zaplevelení (půdní semenná banka), který činila 1,432. Pro následné zpracování byla proto vybrána redundanční analýza (RDA). Na základě frekvence výskytu a početnosti plodů a semen v analyzovaných půdních vzorcích bylo analýzou RDA vytvořeno grafické a prostorové uspořádání druhů plevelů a variant hnojení hnojem (obr. 1.). Druhy plevelů jsou zde zobrazeny pomocí vektorů (šipek), které mají odlišnou barvu a směr. Varianty hnojení hnojem jsou zobrazeny jako body různého tvaru a barvy. V případě, že vektor příslušného druhu plevele směřuje k bodu varianty hnojení, byl jeho výskyt častěji zaznamenán právě na této variantě.

Vliv hnojení hnojem na semena v půdě je signifikantní na hladině významnosti $\alpha = 0{,}001$ pro všechny kanonické osy a vysvětluje 32,9 % celkové variability v datech. Výsledky jsou tedy statisticky vysoce průkazné. Podle ordinačního diagramu (obr. 1.) můžeme druhy rostlin rozdělit do tří skupin. První skupina je tvořena druhy, jejichž semena se více vyskytovala na hnojené variantě, a byly to druhy: laskavec ohnutý, merlík bílý, ježatka kuří noha, violka rolní a rozrazil perský. Druhou skupinu tvoří druhy, jejichž semena byla častěji na nehnojené variantě: hořčice rolní, opletka obecná, ptačinec prostřední, rdesno blešník, bér sivý a truskavec ptačí. Třetí skupina je tvořena druhy, u kterých množství semen bylo ovlivněno jinými faktory: silenka noční a penízek rolní.

Obr. 5. Půdní vzorek pro stanovení potenciálního zaplevelení po rozplavení a vysušení určený k ruční separaci semen (část minerálního podílu a semena plevelů)



Obr. 6. Ručně vybrané plody a semena plevelů z jednoho vzorku



Podobně byly zpracovány i výsledky aktuálního zaplevelení. DCA vypočetla délku gradientu pro data o aktuálním zaplevelení, a ta činila 3,383. Na základě frekvence výskytu a početnosti jedinců plevelů v porostech následných plodin bylo analýzou RDA vytvořeno grafické a prostorové uspořádání druhů plevelů a variant hnojení hnojem.

Vliv hnojení hnojem na aktuální zaplevelení je signifikantní na hladině významnosti $\alpha = 0{,}001$ pro všechny kanonické osy a vysvětluje 17,3 % celkové variability v datech. Výsledky jsou tedy statisticky vysoce průkazné. Podle ordinačního diagramu (obr. 2.) můžeme druhy rostlin rozdělit do tří skupin. První skupina je tvořena druhy s vyšším výskytem na hnojených variantách, to byly druhy: blín černý, hořčice rolní, lilek černý, oves hluchý, pěťour maloúborný, penízek rolní, rdesno blešník, rozrazil perský, silenka noční, svízel přítula a violka rolní. Druhou skupinu tvoří druhy s vyšším výskytem na nehnojené variantě: ježatka kuří noha, merlík bílý, truskavec ptačí a opletka obecná. Třetí skupina je tvořena druhy, u kterých množství semen bylo ovlivněno jinými faktory: drchnička rolní, hluchavka nachová, laskavec ohnutý, ptačinec prostřední a rozrazil břečťanolistý.

V půdní semenné bance mají dominantní postavení především pozdně jarní druhy plevelů (obr. 3.). Dlouhodobé hnojení hnojem zvyšuje počet semen především u druhů laskavec (obr. 7.), merlík bílý a ježatka kuří noha. Naopak dlouhodobé nehnojení chlévským hnojem zvyšuje zastoupení semen pouze u hořčice rolní. Je tedy zřejmé, že aplikace chlévského hnoje je velmi významným zdrojem nových semen v půdě a posiluje tak půdní semennou banku.

Vlastní zaplevelení následných plodin je kromě hnojení hnojem významně ovlivněno střídáním plodin (obr. 4.). Nejnižší zaplevelení je na norfolkském osevním postupu, u ostatních variant je pak zaplevelení porostů vyšší. Vyšší zaplevelení je také vždy na hnojených variantách. Ovšem reakce druhů plevelů byla odlišná. Výskyt laskavce byl značně ovlivněn střídáním plodin, i když i zde měl laskavec vyšší počet jedinců na hnojených variantách a díky jeho vysokému podílu v semenné bance se dá předpokládat vysoké zaplevelení i v následných letech.

Dalším druhem silně ovlivněným střídáním plodin je ježatka kuří noha, ta se ovšem vyskytovala především na nehnojené variantě. Jedná se o pozdně jarní druh s podobnými nároky jako laskavec. Je tedy možné, že mezi nimi probíhá konkurenční boj, kdy se na nehnojených variantách ježatka patrně lépe prosazuje.

Hnůj je zdrojem celé řady živin, především dusíku, což může být důvod vyššího vzcházení některých plevelů ze skupiny přezimujících nebo časně jarních, jako jsou hořčice rolní, oves hluchý, svízel přítula a violka rolní.

U části druhů, které nebyly nalezeny v půdní semenné bance, můžeme předpokládat, že byla na pozemek zavlečena právě aplikací hnoje. Jedná se o druhy: blín černý, lilek černý a pěťour maloúborný. Patrně se na hnojiště dostaly jako součást organického odpadu ze zahrad a polí.

Obr. 7. Klíční rostliny rodu laskavec (Amaranthus sp.)



Z tohoto důvodu je důležité dbát na kvalitní zrání chlévského hnoje nebo jeho kompostování. Kompostování hnoje má několik výhod ve srovnání s čerstvým hnojem, a to především v nižším počtu životaschopných semen plevelů, ale také ve zmenšení objemu hnoje a s tím související levnější dopravou i menší velikostí částic, která usnadňuje jeho rozmetání (23, 24, 25).

Hnojení hnojem také zlepšuje půdní strukturu i obsah živin včetně mikroprvků, a tím podporuje konkurenční schopnosti pěstovaných plodin. Ty mohou díky vyšší konkurenceschopnosti lépe potlačovat plevele, to je velmi důležité v rámci regulace plevelů (26).

Závěr

Dlouhodobé hnojení chlévským hnojem zvyšuje potenciální i aktuální zaplevelení. V půdní semenné bance se zvyšuje především podíl pozdně jarních druhů, jako jsou laskavec, merlík bílý a ježatka kuří noha. Reakce aktuálního zaplevelení na hnojení hnojem je odlišná podle druhů. Přibývá zaplevelení laskavcem, ovšem jeho výskyt je významně ovlivněn střídáním plodin. Dále narůstá výskyt druhů: hořčice rolní, oves hluchý, svízel přítula a violka rolní. A také se objevují druhy zavlečené hnojem na pozemek (blín černý, lilek černý a pěťour maloúborný). Z tohoto důvodu je důležité mít pod kontrolou odpadní materiál, který je vyvážen na hnojiště a dbát na kvalitní kompostování hnoje.

Hnojení hnojem má nezastupitelnou roli při pěstování některých plodin, jako je cukrová řepa. Pozitivní reakce na jeho aplikaci se projeví nejen na výnosu plodiny, ale také na stavu půdy. Přináší to ovšem určité riziko zvýšeného zaplevelení, proto je potřeba na hnojených pozemcích uzpůsobit mechanickou a chemickou regulaci plevelů.

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Souhrn

Hnojení chlévským hnojem podporuje stabilitu půdních agregátů, pozitivně působí na humusové látky v půdě a dodává příznivě působící mikroorganismy. Kromě těchto pozitivních schopností je součástí chlévského hnoje také velké množství plodů a semen plevelů. Polní pokusy byly vedeny na polní pokusné stanici v Žabčicích (Mendelova univerzita, Jihomoravský kraj, ČR). Pokusy byly zaměřeny na střídání plodin a to ve třech variantách: I. – jarní ječmen (25 %), jetelovina (25 %), ozimá pšenice (25 %), cukrovka (25 %); II. – jarní ječmen (37,5 %), jetelovina (12,5 %), ozimá pšenice (25 %), cukrovka (25 %); III. – jarní ječmen (62,5 %), cukrovka (37,5 %). Dalším sledovaným pěstitelským opatřením bylo hnojení chlévským hnojem. Všechny varianty střídání plodin měly dvě dlouhodobé varianty hnojení hnojem: A – hnojení chlévským hnojem v dávce 35 $t.ha^{-1}$, která byla aplikovaná na podzim pro cukrovku; B – k žádné z plodin nebyl aplikován hnůj po celou dobu trvání pokusu. Potenciální zaplevelení bylo stanoveno ze směsných půdních vzorků. Vzorky byly odebrány z hloubky 30 cm, aktuální zaplevelení bylo stanoveno pomocí početní metody. Získané údaje byly zpracovány mnohorozměrnými analýzami ekologických dat segmentovou analýzou DCA a redundanční analýzou (RDA). Z výsledků bylo zjištěno, že půdní semenná banka je reprezentována plody a semeny plevelů 13 druhů rostlin. Zaplevelení porostů (aktuální zaplevelení) je reprezentováno rostlinami plevelů 20 druhů. Dlouhodobé hnojení chlévským hnojem zvyšuje potenciální i aktuální zaplevelení.

LCaŘ 133, č. 4, duben 2017

V půdní semenné bance se zvyšuje především podíl pozdně jarních druhů (*Amaranthus* sp., *Chenopodium album, Echinochloa crus-galli*). Reakce aktuálního zaplevelení na hnojení hnojem je odlišná podle druhů. Přibývá zaplevelení *Amaranthus* sp., ovšem jeho výskyt je významně ovlivněn střídáním plodin, a narůstá také výskyt druhů *Sinapis arvensis, Avena fatua, Galium aparine* a *Viola arvensis*. Objevují se také druhy zavlečené na pozemek hnojem (*Hyoscyomus niger, Solanum nigrum, Galinsoga parviflora*). Hnojení hnojem má nezastupitelnou roli při pěstování některých plodin, jako je cukrová řepa. Přináší však určité riziko zvýšeného zaplevelení, proto je třeba na hnojených pozemcích uzpůsobit mechanickou a chemickou regulaci plevelů.

Klíčová slova: chlévský hnůj, hnojení, plevele, půdní semenná banka, střídání plodin, cukrovka.

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Winkler, J., Rypová, I., Dvořák J.: Influence of Manure on Weed Infestation of Sugar Beet

Fertilization with manure has a positive effect on soil stability, humus in soil and provides it with beneficial microorganisms. Apart from these positives, farmyard manure also contains a lot of fruit and weed seeds. Field experiments took place at the field experiment station in Žabčice (Mendel University, South Moravia, Czech Republic). The experiments focused on crop rotation in three variants: I. – spring barley (25%), clover (25%), winter wheat (25%), sugar beet (25%); II. – spring barley (37.5%), clover (12.5%), winter wheat (25%), sugar beet (25%); III. – spring barley (62.5%), sugar beet (37.5%). Another monitored cultivation measure was fertilization with manure. All variants in the crop rotation had two types of long-term fertilization: A – fertilization with manure in the dose of 35 t ha^{-1}, which was applied on sugar beet in fall; B – no manure was applied for the entire duration of the experiment. The potential weed infestation was determined from soil samples from the depth of 30 cm; the actual weed infestation was assessed by an arithmetic method. The obtained data were processed by multivariate analyses of ecological data (Detrended Correspondence Analysis, redundancy analysis). The results showed that the soil seed bank is represented by fruits and seeds of 13 weed species. Weed infestation (the actual weed infestation) is represented by 20 weed species. Long-term fertilization with manure increases the potential as well as the actual weed infestation. The share of late spring species increases in the soil seed bank (*Amaranthus* sp., *Chenopodium album, Echinochloa crus-galli*). The response of actual weed infestation to manure fertilization varies depending on the species. The representation of *Amaranthus* sp. increases but its incidence is significantly affected by crop rotation. The incidence of *Sinapis arvensis, Avena fatua, Galium aparine* and *Viola arvensis* species increases as well. There are also species imported by manure in the soil (*Hyoscyomus niger, Solanum nigrum, Galinsoga parviflora*). Fertilization with manure carries a risk of increased weed infestation, it is thus necessary to modify the mechanical and chemical weed control.

Key words: manure, fertilization, weeds, soil seed bank, crop rotation, sugar beet.

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Solar Park: Opportunity or Threat for Vegetation and Ecosystem

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ABSTRACT

Solar parks are currently considered a new source of energy generation and one of the methods for reducing the usage of fossil fuels. The studies related to the influence of solar parks on vegetation structure are not yet sufficient. The aim of this paper was to evaluate the structure of vegetation biodiversity within a solar park. The vegetation assessment took place in the solar park, located in the cadastral territory of Tišnov (Czech Republic). A total of 85 taxa of vascular plants were found. The vegetation of the solar park is species-rich and significantly fragmented. Perennial grasses and perennial dicots dominate between the panels, whereas annual grasses and annual dicots have more coverage under the photovoltaic (PV) panels. The influence of the solar park microclimate is seen in a higher representation of species with the indication of characteristics mid-continental, and species with the indication of characteristics mid-ocean are more represented among within the PV panels. The vegetation of the solar park is noteworthy from the perspective of biological importance in the agricultural landscape and has a substantial potential to perform ecosystem functions.

Keywords: solar parks, photovoltaic panels, synanthropic flora, technosphere.

INTRODUCTION

Photovoltaic (PV) panels are currently seen as one of the tools to limit the use of fossil fuels for energy production and are also seen as one of the tools to reduce emissions, including CO_2 (Brodziński et al., 2021; De Sousa, 2013; Dovì a Battaglini, 2015). The development and expansion of electricity production from renewable sources, including solar energy, have been facilitated by the decline in the cost of PV modules and the simultaneous rise in the cost of energy produced by burning fossil fuels (Alsagri, 2020; Shahsavari et al., 2019; Millstein et al., 2017; Blazy et al. 2021). This has made renewable energy sources, such as wind and solar energy, viable options (MacDonald et al., 2016). The development of large-scale solar parks can be seen in some countries, especially in China and also in Europe, where it is Germany or the Czech Republic (Roos, 2021). In Europe, solar parks are most often located on arable land and pasture; which represents a significant change in land use (MacKay, 2013). Agricultural land, rural and urban settlements that surround solar projects represent a permanent threat to the existence of native flora and fauna as well as continuous anthropogenic disturbance. The area within the solar park can become a refuge for local species. The flora and fauna in solar parks escape disturbances or predation to which they would be exposed in surrounding areas (Sinha, et al., 2018).

The anthropogenic nature of disturbances affects the composition of species biodiversity and greatly influences biotic homogenization (Wang et al., 2021; Winkler et al., 2021). The plant species with specific characteristics that tolerate or require anthropogenic disturbance and various meteorological and soil conditions may be preferred over natural ecosystems (Kowalik et al. 2014; Williams et al., 2015). Habitat fragmentation caused by urbanization or agriculture leads to the loss of native species and has a negative impact on biodiversity (Nichol et al., 2010; Syphard et al., 2011; Dylewski et al., 2020). Therefore, the areas with natural and semi-natural vegetation are

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increasingly considered a haven for biodiversity (Byrne et al., 2015; Boulton et al., 2020).

However, the studies considering the influence of PV panels on vegetation characteristics are limited (Zisis et al., 2019; Jahanfar et al., 2019; Turney, Fthenakis, 2011). The lack of knowledge about the vegetation-solar park relationships limits the prediction of climate impacts of solar parks (Wang, Eltahir, 2000a; Wang, Eltahir, 2000b), as vegetation dynamics in solar parks play a key role in soil-climate interactions (Zeng, Yoon, 2009). Solar park vegetation can have implications for microclimate, biodiversity, soil erosion, air quality, and ecosystem energy balance (Armstrong et al., 2014, Hernandez et al., 2014). The physical presence of solar parks will affect the fluxes of solar radiation and thus the temperature, speed, wind turbulence, and distribution of precipitation in the solar park (Armstrong et al., 2014). These factors affect the vegetation, which can change the species composition and the intensity of occurrence of some plant species. The aim of the paper was (i) to evaluate the biodiversity structure of the vegetation of the solar park, (ii) to assess the representation of plant species indicating the specific conditions of the ecosystem (iii) to determine the influence of PV panels on the structure of the vegetation in the solar park.

MATERIAL AND METHODS

Territorial characteristics

The solar park (Figure 1) is located in the cadastral territory of the municipality of Tišnov (South Moravian Region, Czech Republic; 49.3358417N, 16.4452700E; Figure 1). The land is located 265 meters above sea level. The long-term average annual temperature is 6–7 °C, and the long-term annual precipitation is 650–750 mm. Geographically, the area of interest falls into the Boskovická brázda. The object of the solar power plant is on a plot of land with a total area of 17,224 m^2. The land had been used as a waste dump until 2008. Construction and inert waste were mainly dumped here. In 2009, the landfill was reclaimed, the soil was transported to the land, and the surface of the land was leveled. In 2010, PV panels were installed, and the solar power plant operation began. Extensive grazing provided by sheep regulates the vegetation in the solar park, and unsaved vegetation is occasionally mulched.

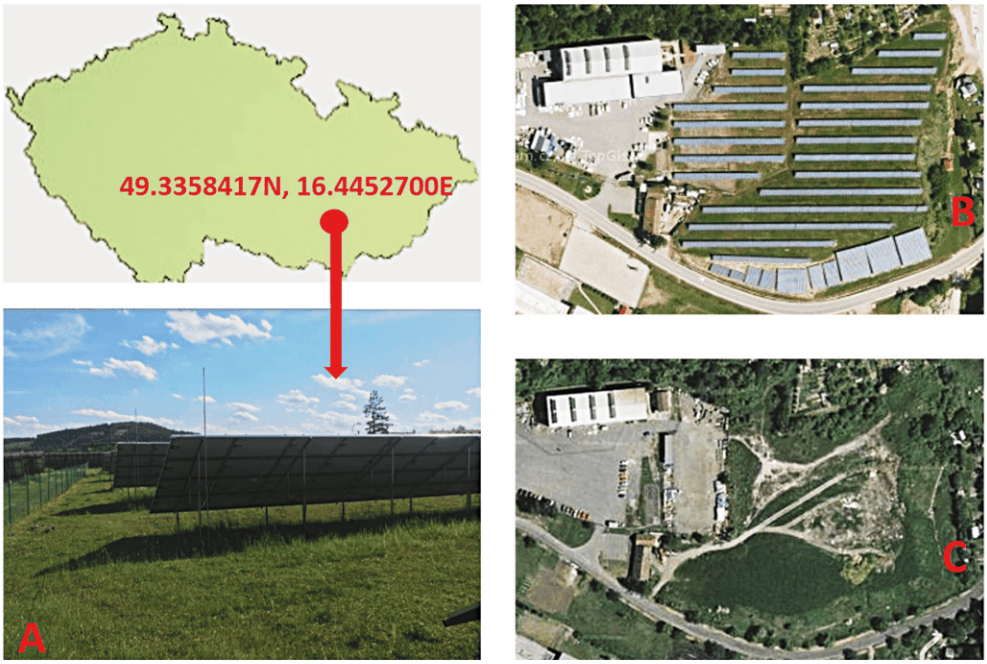


Figure 1. Site with the solar park (A - PV panels; B – current state of the land; C – land before reclamation)

Methodology for assessing vegetation

Vegetation was assessed using the method of phytocenological images. The size of the images was 20 m^2 (2 × 10 m). Within the solar park, images were recorded at two different locations, between the PV panels and below the PV panels. Five permanent areas were marked at each site, on which images were recorded. Vegetation was evaluated according to a standard procedure. First, all taxa of plants appearing on the image were identified, and then the above-ground biomass coverage of individual taxa was estimated. The images were recorded in the same areas in 2016, 2017, and 2018, always in spring and summer. The scientific names of the plant species were taken from the Pladias flora and vegetation database (Chytrý et al., 2021).

On the basi of the information from the database of Tyler et al. (2021), plant species were divided into several groups according to 3 criteria. The first criterion was the significance for biological relevance (Biodiversity relevance). The importance of biodiversity relevance is defined for each species as the number of other organisms that depend on this species or use it as a food source, substrate, shelter, or condition for survival and reproduction. The importance of the relevance of the biodiversity of plant species is given on an eight-point logarithmic scale:

- BR1 <6 associated species
- BR2 6 12
- BR3 = 13–24
- BR4 = 25–50
- BR5 = 51–100
- BR6 = 101–200
- BR7 = 201–400
- BR8 = >400

The second criterion was the continentality. In addition to temperature extremes and temperature sums, the distribution of temperatures and precipitation over time is important for the occurrence of plant species, which is commonly summarized as continentality. A nine-point scale was used to express the continentality:

- Co1 = hyperoceanic (limited to the Atlantic coast)
- Co2 = strongly oceanic (absent in most continental areas)
- Co3 = mid-oceanic (dominant occurrence in the oceanic region, but with some occurrences in continental areas)
- Co4 = weakly oceanic (dominant occurrence in oceanic conditions but showing no climatic constraints)
- Co5 = indifferent (shows end of oceanic influence)
- Co6 = continental (showing no climatic limitations)
- Co7 mid-continental (predominance of occurrence in areas with continental conditions)
- Co8 = strongly continental (absent in most oceanic regions)
- Co9 = hyper continental (limited to the most continental part)

Light was the third parameter expressing the optimal light/shade conditions for the given species. This criterion is expressed on a seven-point scale:

- Li1 = strong shade
- Li2 = medium-deep shade
- Li3 = partial shade to shade
- Li4 = half-shadow
- Li5 = sun to partial shade
- Li6 = sun, but also permanent moderate shading
- Li7 = constant full sun

The coverage values of the plant taxa found at the monitored sites were processed using a multivariate analysis of ecological data. The selection of the optimal analysis was guided by the gradient lengths determined by segmental Detrended Correspondence Analysis (DCA). Canonical Correspondence Analysis (CCA) was also used. Statistical significance was determined using a Monte-Carlo test in which 999 permutations were calculated. The computer program Canoco 4.0 was used to process the data (Ter Braak a Šmilauer, 2012).

RESULTS

On the basis of the vegetation evaluation, 85 taxa of vascular plants were found. The average coverage of groups of plant species is shown in Figure 3. The representation differs significantly between the observed habitats. Perennial grasses and perennial dicot species dominate between the panels. The average vegetation cover is significantly lower on the site under the panels. The lower coverage is especially noticeable in perennial grasses. On the contrary, annual grasses and annual dicot species have a higher coverage

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under the panels. The relationship between the species found and the monitored habitats were assessed using CCA analysis. The graphical result of the analysis is presented in Figure 2. The division of species into groups according to the analysis is shown in Table 1. The first group of species (Between) had a predominant occurrence and higher coverage in the habitat between the PV panels. These are mainly perennial grass species and perennial dicotyledons. The second group (indifferent) consists of species without a significant preference for a specific location recorded at both habitats. The third group of species (Under) was more often found in the habitats under PV panels. The fourth group of species (Under – nitrophilic) was also more often recorded in the habitat under the panels, but they formed a separate group.

Plant species were divided into groups according to biological relevance (Biodiversity relevance). The share of coverage of individual groups is shown in Figure 4. The habitats between the panels were mainly represented by species that create mutual relationships with 51–200 other species (BR5, BR6). The species linked to 6–24 other species of living organisms (BR2, BR3) had a higher representation in the habitat under the PV panels.

Representation of continentality using plant species is shown in Figure 5. Both habitats are dominated by indifferent species (Co5). In the habitat between the PV-panels, mid-oceanic species (Co3) have a higher share of the coverage. Under the PV panels habitat, there is a higher share of mid-continental species (Co7). Another evaluation criterion corresponded to the lighting conditions. The share of the coverage of the individual groups is shown in Figure 6. The sites between the panels were mainly represented by groups with a value of Li5 (sun – partial shade) and Li6 (sun, but also permanent moderate shading). On the site under the PV panels, species Li7 (constant full sun) had a higher representation, and species Li3 (partial shade to shade) and Li4 (half-shadow) had only slightly higher coverage.

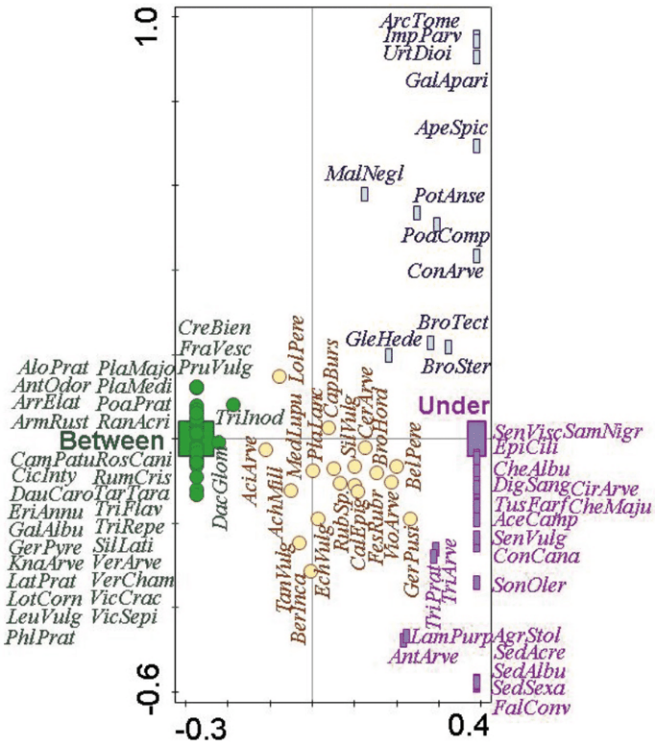


Figure 2. Ordinal diagram expressing the relationship between the occurrence of plant species and the location in the solar park (A - PV panels, B – current state of the land, C – land before reclamation)

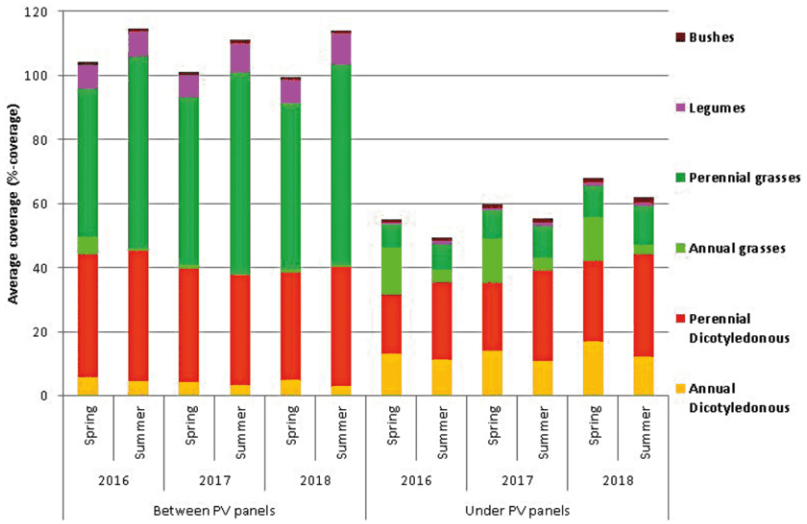


Figure 3. Average coverage of plant species groups in the solar park

Tabel 1. Distribution of the found species into groups according to their relationship to habitats in the solar park based on CCA analysis

Groups	Species plants (Abbreviations)
The first group of species with the occurrence of between	*Alopecurus pratensis (AloPrat), Anthoxanthum odoratum (AntOdor), Armoracia rusticana (ArmRust), Arrhenatherum elatius (ArrElat), Campanula patula (CamPatu), Cichorium intybus (CicInty), Crepis biennis (CreBien), Dactylis glomerata (DacGlom), Daucus carota (DauCaro), Erigeron annuus (EriAnnu), Fragaria vesca (FraVesc), Galium album (GalAlbu), Geranium pyrenaicum (GerPyre), Knautia arvensis (KnaArve), Lathyrus pratensis (LatPrat), Leucanthemum vulgare (LeuVulg), Lotus corniculatus (LotCorn), Phleum pratense (PhlPrat), Plantago major (PlaMajo), Plantago media (PlaMedi), Poa pratensis (PoaPrat), Prunella vulgaris (PruVulg), Ranunculus acris (RanAcri), Rosa canina (RosCani), Rumex crispus (RumCris), Silene latifolia (SilLati), Taraxacum* sect. *Taraxacum (TarTara), Trisetum flavescens (TriFlav), Tripleurospermum inodorum (TriInod), Trifolium repens (TriRepe), Veronica arvensis (VerArve), Veronica chamaedrys (VerCham), Vicia cracca (VicCrac), Vicia sepium (VicSepi)*
The second group of indifferent species	*Acinos arvensis (AciArve), Achillea millefolium (AchMill), Bellis perennis (BelPere), Berteroa incana (BerInca), Bromus hordeaceus (BroHord), Calamagrostis epigejos (CalEpig), Capsella bursa-pastoris (CapBurs), Cerastium arvense (CerArve), Echium vulgare (EchVulg), Festuca rubra (FesRubr), Geranium pusillum (GerPusi), Lolium perenne (LolPere), Medicago lupulina (MedLupu), Plantago lanceolata (PlaLanc), Rubus* sp. *(RubSp.), Silene vulgaris (SilVulg), Tanacetum vulgare (TanVulg), Viola arvensis (VioArve)*
The third group of species occurring under the panels (Under)	*Acer campestre (AceCamp), Agrostis stolonifera (AgrStol), Anthemis arvensis (AntArve), Cirsium arvense (CirArve), Conyza canadensis (ConCana), Digitaria sanguinalis (DigSang), Epilobium ciliatum (EpiCili), Fallopia convolvulus (FalConv), Chelidonium majus (CheMaju), Chenopodium album (CheAlbu), Lamium purpureum (LamPurp), Sambucus nigra (SamNigr), Sedum acre (SedAcre), Sedum album (SedAlbu), Sedum sexangulare (SedSexa), Senecio viscosus (SenVisc), Senecio vulgaris (SenVulg), Sonchus oleraceus (SonOler), Trifolium arvense (TriArve), Trifolium pratense (TriPrat), Tussilago farfara (TusFarf)*
The fourth group of species with the occurrence of Under - nitrophilic	*Apera spica-venti (ApeSpic), Arctium tomentosum (ArcTome), Bromus sterilis (BroSter), Bromus tectorum (BroTect), Convolvulus arvensis (ConArve), Galium aparine (GalApari), Glechoma hederacea (GleHede), Impatiens parviflora (ImpParv), Malva neglecta (MalNegl), Poa compressa (PoaComp), Potentilla anserina (PotAnse), Urtica dioica (UrtDioi)*

DISCUSSION

The vegetation of solar parks has its own distinct dynamics; the type and characteristics of the vegetation do not respond to the changing microclimate caused by solar parks (Wang, Eltahir, 2000a; Wang, Eltahir, 2000b). The obtained results show that solar park vegetation is relatively stable over the growing season and time, but there are large differences between solar park habitats. The vegetation under the PV panels is significantly different, there are fewer perennial grass

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Figure 4. Share of the coverage of species groups according to indicator values for biological relevance

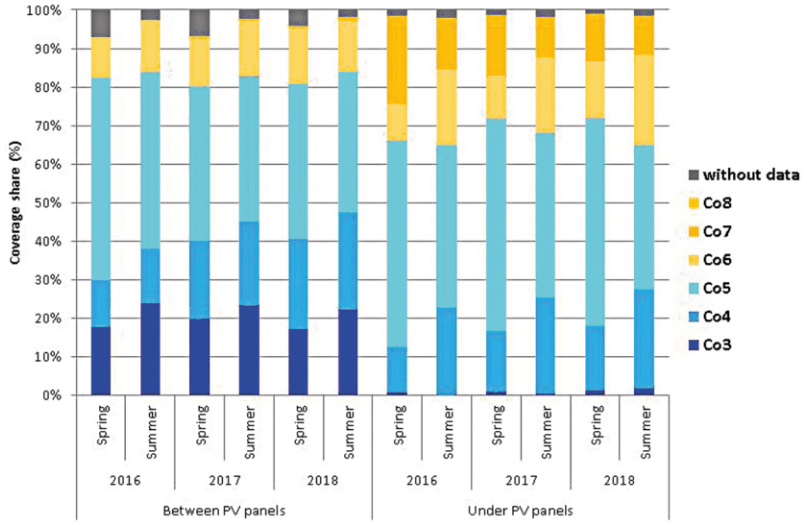


Figure 5. Share of the coverage of species groups according to indicative values for continentality

species, and the share of annual plant species is increasing. The marked fragmentation of habitats and the strip arrangement of PV panels are very typical for solar parks. The nature of the layout of the ecosystem of solar parks is similar to vineyards in the Czech Republic (Ragasová et al., 2021).

Solar projects can help preserve and promote biodiversity by providing a haven for plants. Botanical biodiversity can lead to a greater abundance of invertebrates and higher diversity of bird species (Montag et al., 2016; Gazdag a Parker 2019). However, even here, there are significant differences in the habitats within the solar park. The vegetation under panels is less attractive for establishing ecosystem relationships and providing ecosystem functions. The inter-row vegetation will compensate this deficiency, which has high biological relevance. The vegetation of solar parks has a number of ecosystem functions; it can serve as a source of food for animals, contributes to the

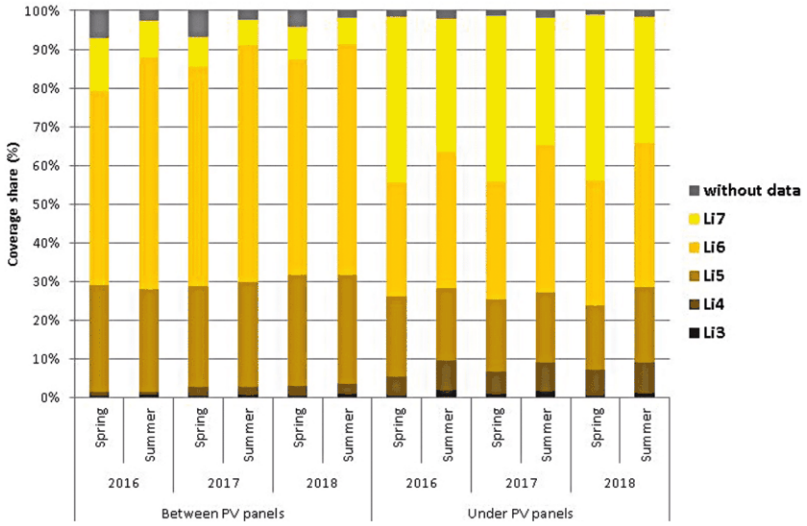


Figure 6. Share of the coverage of groups of species according to indicative values for light conditions

support of biodiversity, and protects against water and wind erosion (Uldrijan et al., 2016; Uldrijan et al., 2021; Schindler et al., 2018; Blaydes et al., 2021; Tang et al., 2018). Vegetation is a source of nectar and pollen for pollinators (Blaydes et al., 2021, Walston et al., 2021), provides shelter for fauna, and contributes to nutrient cycling (Ren et al. 2020). The consequence of solar panels is also a specific microclimate, mainly the change in wind speed, lighting conditions, and the deflection of rainfall (Hassanpour et al. 2018; Guoqing et al. 2021). In the monitored conditions of the solar park, the habitat between the panels is more suitable for the occurrence of the species indicating oceanic climatic conditions. On the contrary, the places under panels are more suitable for the species indicating a continental climate. This may be a consequence of the different rainfall distribution. Under the PV panels, the vegetation is protected from rain, and the water enters here by running off from the inter rows or by soil capillarity. These microclimatic conditions are probably more similar to the course of the continental climate. Owing to this, the PV panels create living space for species that the surrounding vegetation would otherwise displace.

Light conditions are also part of the specific microclimate of solar parks (Montag et al., 2016). In shaded conditions under the panels, light-demanding plant species have a higher share of coverage. This paradox may be a result of limited vegetation competition (lower average cover) under the panels. The limited solar radiation is probably better compensated by a sufficient amount of other life factors and less competition from other species. Sunstroke plant species seem to better compensate for the lack of direct sunlight and give way to the competition of other species in the intermediate row. The response of vegetation in solar parks can also affect the climate change (Kucharski et al., 2012; Zeng, Yoon, 2009). Here, the carbon cycle and the carbon storage in the plant biomass of the solar park will be crucial (Heimann, Reichstein, 2008). The microclimatic conditions of solar parks can change the species composition of vegetation, biotic interactions, and, consequently, ecosystem functions such as soil carbon storage (Melguizo-Ruiz et al., 2020). The vegetation of solar parks can also represent the surrounding agricultural land as a source of weed spread and the introduction of pests. Some species are already able to spread during the construction of solar parks, using the technology and equipment used to build these parks. Therefore, weed control is essential (Guerin, 2017). Since solar farms are built on land with optimal solar radiation, this vegetation also increases the risk of hazards such as fires (Dias et al., 2021; Chiabrando et al., 2009).

The massive occurrence of various human artifacts in ecosystems and geological layers that are products of human technological creativity leads to the use of the term “technosphere” (Haff,

2012; Herrmann-Pillath, 2013; Herrmann-Pillath, 2018). The ecosystem of a solar park is a connection between biological and technical components; therefore, solar parks can be described as an example of the technosphere.

CONCLUSIONS

The solar park creates very diverse habitats for vegetation. This makes the vegetation of the solar park very diverse. Between the PV panels, there are species dominated by perennial grasses and perennial dicotyledons, and under the PV panels, there is a higher coverage of annual grasses and annual dicotyledons. The presence of PV panels changes the conditions for the plants and thus enriches the landscape of the place. The influence of the microclimate is shown in a higher representation of species with the indication of mid-continental, and species with the indication of mid-ocean traits/characteristics are more represented within the PV panels. Plant species also respond to different light conditions. The species requiring constant full sun had a higher representation under PV panels. The species that require full sun, but also tolerate permanent moderate shading are mainly represented between panels.

The vegetation of the solar park has a significant potential to fulfill ecosystem services and is important from the perspective of biological relevance in the agricultural landscape. The habitats between the panels were mainly represented by species that create mutual relationships with 51–200 other species. The habitat under the PV-panels had a higher representation of species with lower values of biological relevance (6–24 species). The human civilization changes and transforms ecosystems but also geological layers. The results of human technological creativity are referred to as the technosphere. Its example also includes solar parks, showing the connection and mutual influence of human civilization and the biosphere.

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Příloha 17

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THE EFFECT OF THREE TILLAGE TREATMENTS ON WEED INFESTATION IN MAIZE MONOCULTURE

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Abstract

This study assessed the impact of using soil tillage on the weed infestation intensity and weed species composition in maize monoculture. Maize has been grown in monoculture consecutively in our research since 2001 and three treatments of soil tillage were applied: conventional tillage (CT), minimum tillage (MT) and no-tillage (NT). Maize monoculture occurs across large plots of land and due to the growth conditions of maize and emerging conservational tillage technologies a broad variety of weed species is introduced and widespread in such plots. The weed infestation in our research had been observed for four years between 2012 and 2015. An arithmetic method and the multivariate analyses of ecological data were used to determine the effect of tillage on weed infestation. The highest weed infestation mainly formed by perennial species was recorded in NT, whereas rich spectrum of annual weed species were more frequently observed in MT. Based on our results can be stated that the specific soil treatments have created different conditions not only for weed emergence, but also for soil properties. Thus, studying the effect of soil tillage treatments on weed infestation may enable further development of weed infestation prediction followed by a targeted application of herbicides leading to the farmers' cost cutting and less stress for environment.

Key words: Conventional tillage, Minimum tillage, No-tillage, CCA analysis

Introduction

Maize is the third most produced commodity on the planet today; however, there are large differences in yields following the particular conditions of a region (Faostat, 2013; Ranum *et al.*, 2014). Maize is well recognized as a wide-row crop with gradual growth at the beginning stage as well as greatly sensitive to soil erosion (Whalen & Sampedro, 2010). Additionally maize is highly responsive and suppressed by the early competitive weed species (Cerrudo *et al.*, 2012) therefore it is necessary to control the weed occurrence (Page *et al.*, 2012). Concurrently, competing with weeds for the essential resources may significantly reduce the maize crop growth (Liebman *et al.*, 2004). Insufficient weed control decreases water and nitrogen efficiency use that is the fundamental element for achieving high yields (Thomson *et al.*, 2000). Weeds and weed control practices are major worldwide agricultural concerns and many farmers heavily rely on high input cultivation management and herbicide dependent strategy (Meissle *et al.*, 2010; Vasileiadis *et al.*, 2011). Following that, the increasing ability of weed species to develop herbicide resistance is another critical challenge (Holt, 1994; Buhler *et al.*, 2000). Nevertheless, a long-term intensification of agricultural systems followed by adjusted tillage treatments in Europe (Le Féon *et al.*, 2010) have also triggered some negative impacts (soil erosion, a decrease of soil fertility and biodiversity, etc.; Matson *et al.*, 1997). However, the energy efficiency of conservational tillage (Moitzi *et al.*, 2019), urge for sustainable agriculture and the general economic pressure on cost cutting have led farmers to change their tillage management, to diminish a number of crops and optionally even to cultivate crops in a monoculture (Briggs and Walters, 2001). Additionally, according to the observation by Neugschwandtner *et al.*, (2014, 2015), tillage treatments affect both soil chemical properties and potential crop yields. Regarding to their results, NT compared to CT had resulted in improved crop yield in drier conditions, due to enhanced water availability (Neugschwandtner *et al.*, 2015). Thus, tillage treatment may also act as a selective factor for weed occurrence and prioritize the growth of some species. This is the origin of the process, which is called by Briggs and Walters (2001) the microevolution on arable lands. Therefore, the weed control strategies should be understood as an integrated science encompassing various methods (Liebman *et al.*, 2004). Accordingly, a repetitive cultivation of maize monoculture together with a soil tillage management have created a new framework not only for the cultivation of maize, but growth of weeds as well. A study of the relationship between soil tillage treatments and a level of weed infestation requires long-term monitoring which is time- and labour-demanding. However, it may serve as an effective tool for weed infestation prediction followed by a targeted application of herbicides.

Materials and Methods

Experimental site: The long-term field research is situated at the Agroservis 1. zemedelska, agriculture enterprise in Visnove (GPS 48.986816, 16.157876, Czech Republic). The experimental fields belong to the corn production area with rather flat terrain at an altitude of 230 m asl. The long-term average annual temperature is 8.5°C and annual total precipitation reaches 470 mm (data of long-term monitoring between 1961 and 1990 from the meteorological station nearest to the experimental site). The topsoil layer is a medium-heavy soil, recognized as chernozem, with the thickness of topsoil profile exceeding a depth of 0.6 m. The mean value of organic matter is 1.47 % and pH neutral (6.61).

Design and soil management: The field trail with a total area of 21.83 ha has been designed as a long-term experiment where maize has been grown consecutively on the same land since 2001. The size of each evaluated plot was 150 × 100 m for each tillage treatment applied as follows throughout the whole duration of the experiment: conventional tillage (CT) – ploughing was carried out by reversible plow with rotatable to a depth of 0.22 m. Sowing with fertilizer application was performed by sowing combinations followed by rolling in spring. Minimum tillage (MT) – shallow tillage was carried out by disc cultivator to a depth 0.10 – 0.12 m followed by sowing with fertilizer application. No-tillage (NT) – the soil surface was not being cultivated after harvesting and a direct sowing with ferilizer application was then carried out by a sowing combinations followed by rolling. It should be noted, that same industrial fertilizers were used in all tillage treatments and also the same pre-emergent and post-emergent herbicides were applied.

Methods of weed infestation assessment: The weed infestation was evaluated by numerical method where the number of individual weeds was counted in each tillage treatment of monitored plots on 1 m^2 in 30 repetitions randomly selected within the typical vegetation growth. Evaluation was conducted every year (from 2012 to 2015) in August. Overall weed control was conducted when maize was according to BBCH-scale at growth stage from 00 to 14, therefore the evaluation of weed infestation had been carried out in August (maize at growth stage 69-75), when the effects of applied herbicide were not yet significant. Following herbicide applications were not possible due to the height of crops and thus the effect of soil tillage treatments could have been evaluated. The species nomenclature follows the Key to the flora of the Czech Republic (Kubát *et al.*, 2002).

The obtained data were processed by multivariate analyses of ecological data to reveal the effect of the applied tillage treatment on the varying weed species spectrum in maize. The objective of this method is to identify the structure and relationships in a complex data set encompassing many sampling units and variables. Groupings are perceived regarding the data, similarities and differences displaying into the ordination diagrams. In our case, one grouping refers to weeds on individual plots (species composition, number of individuals) and the other grouping covers the soil tillage treatments in terms of long-term maize monoculture. Before selecting the optimal analysis characterizing the correlation between groups, the *Length of Gradient* was identified by indirect gradient analysis (DCA). Based on the revealed length of the gradient (4.007), the Canonical Correspondence Analysis (CCA) was selected for further processing. This analysis defines the spatial arrangement of particular weed species in relation to the soil tillage treatments. A total number of 499 permutations were calculated in a Monte Carlo test (Ter Braak & Smilauer, 1998).

Results

Thirty-three various species of weeds had been found on evaluated plots within the monitoring period. The average numbers of occurring weeds across treatments and years are shown in Table 1. The most abundant weed infestation had been identified in NT with average number of individuals 11.09 pcs.m^{-2} and weed species *Convolvulus arvensis* L. occurred here most often. Plots that had been influenced least by weed occurrence were those where CT was applied. An average number of individuals found in this treatment was 6.15 pcs.m^{-2} and species *Echinochloa crus-galli* (L.) P.B. was the most abundant.

The results of CCA analysis are significant at the significance level $\alpha = 0{,}002$ for both canonical axes and are shown in Fig. 1. Weed species and tillage treatments are displayed as points of different form and color. Following these results identified weed species were divided into 5 groups. The first group of weeds occurred mainly in CT, represented by species as follow: *Anagallis arvensis* L., *Atriplex patula* L., *Atriplex sagittata* BORKH., *Bromus sterilis* L., *Echinochloa crus-galli* L., *Euphorbia helioscopia* L., *Fallopia convolvulus* (L.) Á. LÖVE, *Polygonum aviculare* L., *Rubus* spp., and *Taraxacum* sect. *Ruderalia*. The second group of weed species was identified mostly in CT and MT, very few or none in NT: *Chenopodium hybridum* L., *Thlaspi arvense* L., and *Viola arvensis* MURRAY. The third group occurred especially in MT, represented by species as follows: *Datura stramonium* L., *Elytrigia repens* (L.) NEVSKI, and *Persicaria lapathifolia* (L.) DELARBRE. The weed species *Convolvulus arvensis*, *Stellaria media* (L.) VILL., and *Urtica dioica* L. represent a fourth group of weeds, which were found in MT and NT. The fifth group, recorded predominantly in NT is represented by species as follows: *Amaranthus* sp., *Cirsium arvense* (L.) SCOP., *Conyza canadensis* (L.) CRONQUIST, *Equisetum arvense* L., *Euphorbia cyparissias* L., *Lathyrus tuberosus* L., *Linaria vulgaris* MILL., *Sambucus nigra* L., *Setaria pumila* (POIRET) R. et SCH., *Sonchus oleraceus* L., and *Veronica polita* FRIES. It can be stated that the influence of weather conditions in each year may have influenced the intensity of weed infestation, which had been the highest during the first year of observation, yet the species spectrum diversity had been the lowest. Weed infestation of the first year had been formed mainly by species *Echinochloa crus-galli*, which occurrence had declined in following years. Additionally, the results showed that the combination of the monoculture conditions and particular soil treatment have created certain environment affecting differently the intensity (number of weeds) of weed infestation during the monitored period. Therefore, we can assume that those factors have been changing soil properties and they have been also creating different conditions for weed emergence depending on the weather. These circumstances influence not only the intensity of weed infestation but at the same time the occurrence of individual weed species.

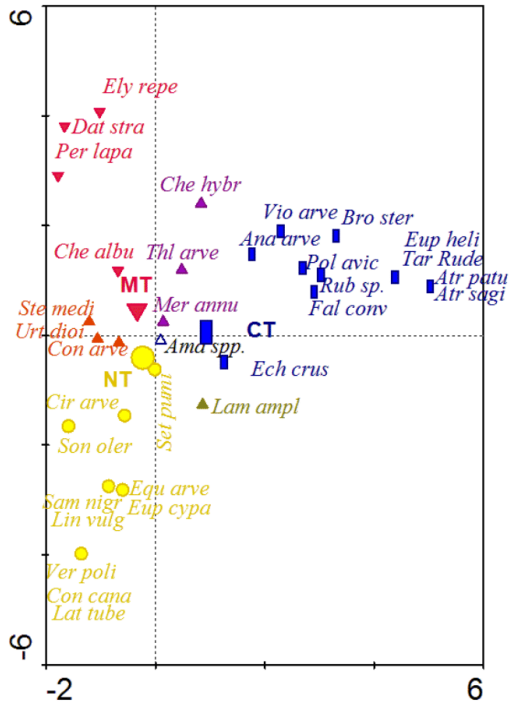


Fig. 1. CCA ordination diagram showing relations between tillage treatments and weed species in maize monoculture growths (Trace = 0.361, F-ratio = 5.905, P-value = 0.002).

Note: CT: conventional tillage, MT: minimum tillage, NT: no tillage

Legend: Ama sp. *– Amaranthus* spp., *Ana arve – Anagallis arvensis, Atr patu – Atriplex patula , Atr sagi – Atriplex sagittata, Bro Ster – Bromus sterilis, Cir arve – Cirsium arvense, Con arve – Convolvulus arvensis, Con cana – Conyza canadensis, Dat stra – Datura stramonium, Ech crus – Echinochloa crus-galli, Ely repe – Elytrigia repens, Equ arve – Equisetum arvense, Eup cypa – Euphorbia cyparissias, Eup heli – Euphorbia helioscopia, Fal conv – Fallopia convolvulus, Che albu – Chenopodium album, Che hybr – Chenopodium hybridum, Lam ampl – Lamium amplexicaule, Lat tube – Lathyrus tuberosus, Lin vulg – Linaria vulgaris, Mer annu – Mercurialis annua, Per lapa – Persicaria lapathifolia, Pol avic – Polygonum aviculare, Rub sp. – Rubus* spp., *Sam nigr – Sambucus nigra, Set pumi – Setaria pumila, Son oler – Sonchus oleraceus, Ste medi – Stellaria media, Tar Rude – Taraxacum* sect. *Ruderalia, Thl arve – Thlaspi arvense, Urt dioi – Urtica dioica, Ver poli – Veronica polita, Vio arve – Viola arvensis.*

Discussion

The significant differences are apparent between the weed species spectrum in maize monoculture under different tillage treatments. The major differences had been observed between the conventional tillage (CT) and remaining treatments of soil conservational tillage (MT, NT). CT greatly supported the occurrence of early spring species (*Anagallis arvensis*, *Fallopia convolvulus*, *Polygonum vulgare*) and late spring species (*Atriplex patula*, *Echinochloa crus-galli*, *Euphorbia helioscopia*). Overwintering weed species (*Sonchus oleraceus*, *Stellaria media*) and perennial species (*Cirsium arvense*, *Convolvulus arvensis*, *Lathyrus tuberosus*, *Linaria vulgaris*) had been observed mainly in MT and NT. Therefore, we can assume the increasing occurrence of persistent weed species with the increased popularity of soil conservation tillage (MT, NT). Species *Convolvulus arvensis* was the most frequently represented weed species overall. Its occurrence was very prevalent, particularly in NT. This perennial weed is characterized by pulpy root system easily broken, but capable to quickly regenerate (Crabtree & Westwood, 1976). According to the research of Jurado-Expósito *et al*., (2004) the crop rotation had greatly influenced the density of species *Convolvulus arvensis* and had become an increasingly prevalent problematic species in NT management. Moreover, Burns *et al*., (2013) considered another perennial species *Cirsium arvense* also as a problematic invasive weed, particularly of the northern hemisphere, which requires targeted management using integrating control approaches, in order to achieve a suppression of this species. Graglia *et al*., (2006) also suggested intensive soil operations including hoeing and mowing to decrease the occurrence of above-mentioned species and to achieve a satisfactory yield as well. Other authors (Mayor & Maillard, 1995) also described the increase of perennial weeds due to the reduction of the depth of tillage. Additionally, perennial weed species can unfavorably influence the crop productivity in organic cropping (Turner *et al.*, 2007). Concurrently, the quality of the production, crop yield or cultivation operations may be aggravated by vigorous growth of perennials and their abundant occurrence (Graglia *et al.*, 2006). The most occurred species in MT was *Chenopodium album*, which is classified as a late spring species, rather thermophilous species broadly considered as typical weed species in wide-row crops (Liebman *et al.*, 2004). Based on some results (Buhler, 1992; Barberi *et al.*, 1998) can be also stated, that the cultivation management in terms of conservational tillage support the incidence of *Chenopodium album*, particularly when MT is applied. Another late spring weed species, *Echinochloa crus-galli,* had been abundantly identified in all tillage treatments. Nevertheless, its presence was dominant in CT and NT. Its great germination rate out of seeds lying on the soil surface was also well recognized by research of Chauhan and Johnson (2011). Our results are most likely the combination of both, seeds from the soil surface and large seed stock in the soil seed bank. Species *Echinochloa crus-galli* is perceived as the world's most harmful grass weed species (Rao *et al.*, 2007) with a major share in weed infestation in various crops, maize included (Holm *et al.*, 1991). Chauhan & Johnson (2011) stated that species *Echinochloa crus-galli* and others with similar germination requirements have a great potential to be very problematic in NT treatments. Moreover, when seeds can remain dormant for several years. However, the seed bank may be greatly reduced by using conventional tillage (Chin, 2001). This statement can be underpinned also by our results when the lowest average weed infestation had been observed in CT. An increasing uniformity of the flora on fields was, according to Baessler & Klotz (2006) attributed to the large extent of the agricultural

intensification (e.g. the application of mineral fertilizer, crop rotation). The former typical weed species of arable lands were not able to survive the rapid intensification of the last century, so whether they have generally decreased their occurrence or had disappeared entirely. However, the average number of weed species has not changed significantly since 1990 (Baessler & Klotz, 2006).

Some other weed species not considered as typical species of arable lands in the Czech Republic (e.g. *Urtica dioica, Mercurialis annua*) had been identified on our experimental plots. Their occurrence had been observed particularly in areas of conservational tillage treatments, most likely due to the specific conditions created by maize monoculture and minimum tillage.

Conclusion

The specificity of maize monoculture and maize growth structure in general open an opportunity for forming specific weed spectrum, which has been not recognized as typical before. Identifying the importance and the effect of tillage treatments can create the new approaches and measures useful for weed management. And based on our results we have been already looking at the increasing occurrence of persistent weed species, its growing intensity depending on tillage treatment, etc. Thus, such a trend will lead to a change of the growth patterns of weeds, followed by new challenges in weed control, including the development of new active substances, herbicide application, etc.

Table 1. The average number of weed individuals and species identified in maize (pcs.m^{-2}).

Weed species	Soil tillage			Monitored year			
	CT	MT	NT	2012	2013	2014	2015
Amaranthus sp.	0.16	0.20	0.31	0.08	0.36	0.12	0.33
Anagallis arvensis L.	0.03	0.02		0.02	0.03		
Atriplex patula L.	0.05						0.07
Atriplex sagittata BORKH.	0.06						0.08
Bromus sterilis L.	0.04	0.02					0.08
Cirsium arvense (L.) SCOP.	0.40	0.71	2.78	0.81	1.66	0.48	2.23
Convolvulus arvensis L.	0.43	1.94	3.03	0.31	1.53	1.50	3.84
Conyza canadensis (L.) CRONQUIST			0.01	0.01			
Datura stramonium L.		0.43			0.41		0.17
Echinochloa crus-galli (L.) P.B.	2.48	0.98	1.86	3.68	1.77	0.87	0.79
Elytrigia repens (L.) NEVSKI		0.03					0.04
Equisetum arvense L.			0.02				0.02
Euphorbia cyparissias L.			0.16				0.21
Euphorbia helioscopia L.	0.05					0.07	
Fallopia convolvulus(L.) Á. LÖVE	0.42	0.11	0.04	0.32		0.27	0.17
Chenopodium album L.	0.79	3.13	1.08	5.27	0.11	1.00	0.29
Chenopodium hybridum L.	0.08	0.11	0.02			0.26	0.02
Lamium amplexicaule L.	0.03		0.04			0.09	
Lathyrus tuberosus L.			0.01	0.01			
Linaria vulgaris MILL.			0.02				0.02
Mercurialis annua L.	0.23	0.28	0.35		0.58	0.27	0.29
Persicaria lapathifolia (L.) DELARBRE		0.02		0.02			
Polygonum aviculare L.	0.32	0.12	0.02	0.09	0.30		0.21
Rubus sp.	0.15	0.03			0.24		
Sambucus nigra L.			0.04			0.02	0.03
Setaria pumila (POIRET) R. et SCH.	0.15	0.14	0.38		0.33	0.33	0.23
Sonchus oleraceus L.		0.02	0.06		0.10		
Stellaria media (L.) VILL.		0.08	0.10			0.16	0.08
Taraxacum sect. Ruderalia	0.02					0.02	
Thlaspi arvense L.	0.07	0.08	0.05		0.07	0.19	
Urtica dioica L.	0.12	0.53	0.73	0.06	1.20	0.46	0.12
Veronica polita FRIES			0.01	0.01			
Viola arvensis MURRAY	0.10	0.05		0.01	0.06	0.13	
Number of individuals	**6.15**	**9.01**	**11.09**	**10.70**	**8.74**	**6.22**	**9.33**

CT: Conventional tillage, MT: Minimum tillage, NT: No tillage

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Promoting Biodiversity: Vegetation in a Model Small Park Located in the Research and Educational Centre

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ABSTRACT

University campuses, as important elements of urban greenery, are related with a positive impact on student health and well-being. They provide unique possibilities for estimating biodiversity change. This study focused on the biodiversity in the Campus. The study aimed at: assessing the plant biodiversity occurring in the park; assessing the representation of native species and determining the frequency at which invasive species occur; as well as recommending an adaptation of the park management. The Park was sub-divided into biotopes and a phytocoenological relevé was recorded. Park projects create biodiversity islands that may contribute to improve urban space. A species composition that is close to natural vegetation creates a space for native species, which thus better adapt to living in urban conditions. Localities created by humans, which imitate natural ecosystems, increase the biodiversity and are valuable natural islands in cities. The semi-natural phytocoenoses however, do not resist the occurrence of invasive plant species. Regarding the small size of the studied park, manual elimination or cutting of invasive plant species is sufficient.

Keywords: urban greenery, localities created by humans, diversity of plant species, invasive plant species

INTRODUCTION

The growing number of city inhabitants results in increased interest in urban greenery all around the world (Abass et al., 2019; Maurer et al., 2021; Yang et al., 2021) from both residents and scientists. It is obvious that urban greenery is a significant part of human civilization and its role is unreplaceable. Urban green areas contribute to numerous benefits to the urban environment and the society, such as maintaining ecological processes, generating ecosystem services (Bertram and Rehdanz, 2015; Andersson-Sköld et al., 2018), providing the space for recreation and physical activities (Schipperijn et al., 2013; Yang et al., 2021) as well as exerting direct and indirect impact on human well-being and health (Zhang et al., 2021; Zhou et al., 2021). Green areas are increasingly considered as tools for mitigation of climate change (including urban-heat islands, floods) and as biodiversity refuges (Byrne et al., 2015; Boulton et al., 2020). Habitat fragmentation caused by urbanization or obliteration of natural vegetation leads to the loss of native species and has a negative impact on

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the biodiversity (Nichol et al., 2010; Syphard et al., 2011; Dylewski et al., 2020). Additionally, urbanization causes the development of new habitats such as roadsides, pavings, parks, gardens, playgrounds and educational centres (Li et al., 2019). In order to compensate nature loss in the mass urbanization era, urban green areas provide the opportunity of supporting and protecting the diverse ecosystems of our planet (Hwang et al., 2021). This greenery mainly includes city parks, which, however, are very often established in the places strongly influenced and created by humans. Various Park projects, which imitate natural ecosystems, have been developed. However, their anthropogenic character influences the models of species biodiversity and has great impact on biotic homogenization (Wang et al., 2021). Introduction of new species based on human preferences supresses the natural barriers of species distribution (Capinha et al., 2015). Moreover, relatively similar urban environments with intense anthropogenic disturbance, and different climatic and soil conditions, compared to natural ecosystems may favour species with particular properties (Koda et al., 2013; Kowalik et al. 2014; Williams et al., 2015). The question whether the areas imitating natural ecosystems may cope with the diverse requirements is of key significance (Vaverková et al., 2019).

According to Holt et al. (2019), university campuses, as important elements of urban greenery, are strictly related with a positive impact on human health and well-being. Campuses and academic premises also provide unique possibilities for estimating biodiversity change and effects of biotic homogenization (Wang et al., 2021). However, little attention is drawn to the greenery in campuses. Therefore, this study focused on the biodiversity of an educational park located in the premises of the Warsaw University of Life Sciences (SGGW). The analysed object is the Research and Educational Centre of the Faculty of Civil and Environmental Engineering – the SGGW Water Centre, comprising an area with a system of water reservoirs. The study aimed at (i) assessing the plant biodiversity occurring in the park; (ii) assessing the representation of native species and determining the frequency at which invasive species occur; and (iii) recommending an adaptation of the park management to the existing vegetation in the park.

MATERIAL AND METHODS

University campus description

The SGGW is a modern natural science university, with its roots its founding in 1816. The university conducts the research in agricultural sciences, but also in science, life sciences, social sciences, or in engineering and technology. The mission of SGGW is to serve the intellectual, social and economic development of Polish society and international community with particular emphasis on sustainable development of rural areas, food economy and widely understood natural environment. Nowadays, SGGW has more than 70 hectares of land which includes more than 49 buildings; the students are educated in 14 faculties (Figure 1). The university buildings also might include: student hostels, library, Equine Clinic and Small Animal Clinic, Production Greenhouses, Water Treatment Station, swimming and other sports pools and a modern research site of Water Centre with Water Park.

The SGGW university campus is located in the southern part of Warsaw at the district of Ursynów. This campus can be historically divided into two parts separated by Nowoursynowska street (Figure 1). In the north-eastern part of the campus, there are the most important historical buildings, including Krasinski Palace (originally also called Rozkosz Palace). The beginnings of the palace and park complex are estimated in 1776, when Duchess Izabela Lubomirska of the Czartoryski family built a small palace for her daughter, Aleksandra Potocka (Figure 2a). In this part of the campus, apart from the didactic buildings, there are also the Rector's office and the university administration, as well as the green Perennial Plant of SGGW and nature reserve "Skarpa Ursynowska". On the opposite side of the Nowoursynowska street, the academic campus of SGGW is called the "new part", which includes modern completed academic buildings, laboratories, dormitories, and green open space for students (Figure 2b).

Greenery and sustainable development aspects are an important element of SGGW University Authorities management policy. Those elements are visible both in spatial and architectural organization of the entire campus, as well as in the field of scientific research. One of the most important laboratory facilities is the building of the Water Centre SGGW, where with the

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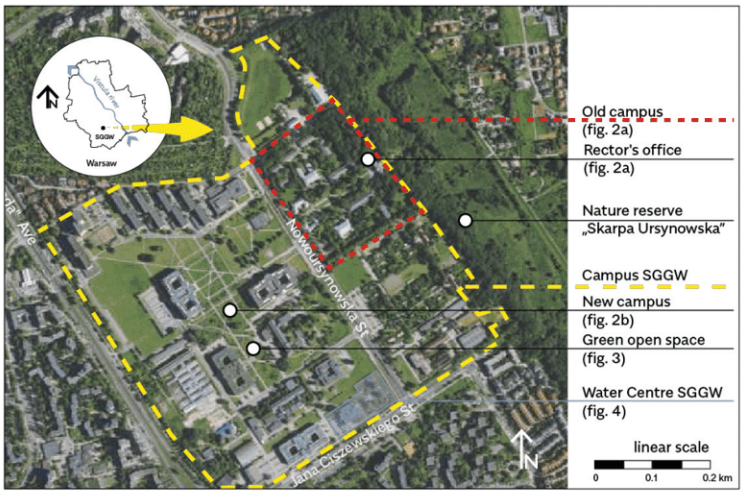


Figure 1. Location of the Warsaw University of Life Sciences.



Figure 2. View of the SGGW campus: on the left the historical Krasiński Palace building, which is currently the university's rector's office; on the right a view of the new campus buildings.

use of the newest laboratory equipment scientific research is conducted, e.g. in the aspect of environmental protection. Research and observation of habitats carried out in the Water Park are used in the management of greenery with the circulation of water and biomass throughout the campus. The presented habitat biodiversity assessment is focused on the implementation of the Green Campus elements (Figure 3). The observations carried out in the Water Park are also used to maintain green areas in the historic part of the campus and to limit the impact on the nearby nature reserve.

The Research and Educational Centre – Water Centre of the SGGW is located at the main university campus in Warsaw, in the eastern part of the Ursynów district (Figure 1). The total area of the project is around 14,600 m^2. The Water Centre comprises an educational and research facility with the development area of ca. 2,000 m^2 and the total area of ca. 5,600 m^2. The Water Centre consists of three parts: the Main Laboratory Building, the Water Park and the Meteorological Station (Figure 4).

The general aim of the Research Centre – Water Centre is to improve the quality of education in the Faculty of Civil and Environmental Engineering, as well as permanent development of the academic staff, improvement of the research methods and techniques, implementation of experience into practical applications, which should support the University in its educational and research activity, as well as in influencing the economy through the knowledge-to-business transfer. There are 20 laboratories in the building, furnished with advanced scientific and research equipment, as well as an exhibition hall, which presents and popularises the research fields of the Faculty of Civil and Environmental Engineering (Szymański and Borecki, 2010).

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Figure 3. View of the green open space between the buildings in the "new" part of the SGGW campus.

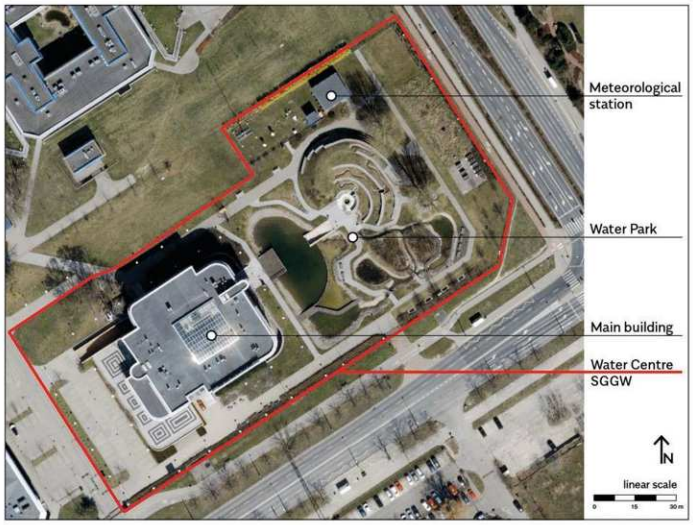


Figure 4. Location of the SGGW Water Centre

An educational establishment known as the Water Park is situated in the area around the Main Building of the Centre. It comprises a model of a watercourse connected with trophic reservoirs, with its outlet in the ultimate water reservoir. The whole water system represents water circulation in the environment. The system is subdivided into a part that represents a mountain catchment basin and a part that corresponds to a lowland river catchment basin. The water system is supplemented with models of hydrotechnical facilities, situated along the river course and on the reservoirs (trap, tower spillway, weirs). The models present sample construction solutions of hydrotechnical facilities and allow the students to become acquainted with modelling systems of hydraulic and hydrobiological conditions. In the reservoir, there is a dock ending with a glass wall and lighting, which allows descending into the water reservoir and observe the development of a coastal area. Water in the Water Park system flows in a closed circuit using a system of pumps feeding water from the ultimate reservoir to the initial station, which is a ground object built in a gabion and landmass construction. Water quality is maintained mainly through a natural reed bed treatment plant which is part of the water system. A model of the watercourse is related to trophic

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reservoirs, with its outlet in the ultimate water reservoir. The structure is unique for Poland. It is used in the educational process, scientific activities, and popularisation of general knowledge to illustrate the water circulation in nature and to teach about the principles of designing and executing hydrotechnical activities. Two habitats with vegetation representative for a wet habitat on a sandy subsoil and on an organic soil – peat are also located in the Water Park. A large area of the Water Park is covered by lawns. Depending on the location, the lawns are equipped with irrigation and drainage systems. This allows for analysing vegetation growth and behaviour during dry and wet periods.

The Water Park as an external laboratory and the laboratories located in the Water Centre building are a common research base and complementary to each other. A meteorological station situated in the surroundings of the Main Building of the Centre monitors the quality of atmospheric air and selected meteorological parameters, as well as air pollution measured on multiple levels. The results of meteorological measurements are used in many aspects related to the research carried out in other laboratories, pertaining to environmental elements and climate change.

Biotope characteristics and monitoring of the existing vegetation

Several different habitats were created in the park: (i) Hill with grasslands: the biotope imitates a meadow community. Mowing takes place several times during the growth season and the cut biomass is removed (Figure 5a). (ii) Pond: the biotope is a smaller water reservoir with unclosed coastal vegetation maintained only extensively. Dry and dead vegetation parts are removed continuously (Figure 5b). (iii) Oligotrophic reservoir: the biotope includes a shallow water reservoir and adjacent coastal areas. A substrate with a low nutrient content was used for its establishment. Dead vegetation residues are removed and nutrients are not replenished (Figure 5c). (iv) Mesotrophic reservoir: the biotope includes a shallow water reservoir and adjacent coastal areas. A substrate with the moderate content of nutrients was used for its establishment. Dead vegetation residues are removed sporadically and nutrients are not replenished (Figure 5d). (v) Eutrophic reservoir: the biotope includes a shallow water reservoir and adjacent coastal areas. A substrate with a high content of nutrients was used for its establishment. Dead vegetation residues are not removed (Figure 5e).

The vegetation was assessed using the method of phytocoenological relevés, 30 m^2 in size. The Park was sub-divided into 5 biotopes and a phytocoenological relevé was recorded in each of them. The assessment took place twice: in July 2020 and July 2021. First, all taxa of vascular plants occurring in the phytocoenological relevé were identified. Then, the above-ground biomass coverage of individual taxa was estimated. The scientific names of the recognised plant species were taken from the flora and vegetation database (Pladias, 2020). On the basis of the information from the Pladias database, the plant species were classified into groups according to their invasive status. Spatial and graphical expression of the relationships between the monitored habitats and the occurrence of plant species was processed using canonical correspondence analysis (CCA). The data were processed using the Canoco 4.0 computer program (Ter Braak and Šmilauer, 2012).

The invasive status is a classification of alien taxa into three categories reflecting their position in the invasion process. The alien taxa which only occasionally reproduce in the wild in Central Europe, do not form self-replacing populations, and rely on repeated introductions for their persistence, are referred to as casual. Naturalized taxa are alien plants which reproduce in the wild and sustain populations over many life cycles without the direct human intervention (or despite human intervention). Invasive plants are naturalized plants (Pauková, 2019) which produce reproductive offspring, often in large numbers, at considerable distances from the parent plants, and thus have a potential to spread over wide areas (Richardson et al., 2000, 2011; Bielecka and Królak, 2019; Fos et al., 2021). This classification does not apply to native taxa which are reported as separate categories. The data were taken from the second edition of the Catalogue of alien plants of the Czech Republic (Pyšek et al., 2012 and references related to individual taxa therein).

RESULTS AND DISCUSSION

Vegetation assessment identified 79 taxa of vascular plants. The number of species classified according to their invasive status is presented in Table 1. Contributions of individual groups on

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Figure 5. Biotopes in the Water Park: a) Hill with grasslands; b) Pond; c) Oligotrophic reservoir; d) Mesotrophic reservoir; e) Eutrophic reservoir.

the coverage in the phytocoenological relevés are presented in Figure 6.

Urban greenery and its biodiversity represent an important connection between humans and nature in the Anthropocene (Aronson et al., 2017; Wang et al., 2021). Moreover, it has a great potential with regard to environmental protection among the habitats present in cities all over the world; however, it is still not sufficiently used (Chollet et al., 2018). These habitats cover large areas and may represent perfect opportunities to increase biodiversity in cities. This is particularly important in the context of diminishing extensively managed urban green areas, as observed in Western Europe (Peyraud et al., 2012).

The number of plant taxa found in the first biotope Hill with grasslands was 41. Native plant species included: *Achillea millefolium, Calamagrostis epigejos, Cerastium holosteoides, Crepis mollis, Elymus repens, Epilobium hirsutum, Equisetum arvense, Festuca arundinacea, Festuca rubra, Fraxinus excelsior, Hypericum perforatum, Lolium perenne, Lycopus europaeus, Medicago lupulina, Pilosella officinarum, Plantago lanceolata, Poa pratensis, Populus alba, Salix caprea, Taraxacum* sect. *Taraxacum,*

Table 1. Number of plant species from the monitored biotopes classified in groups according to their invasive status

Groups according to invasive status	Biotopes				
	Hill	Pond	Oligotrophic reservoir	Mesotrophic reservoir	Eutrophic reservoir
Native	23	10	13	24	32
Naturalized	12	1	1	1	3
Casual	1	0	0	0	1
Invasive	5	1	1	4	4

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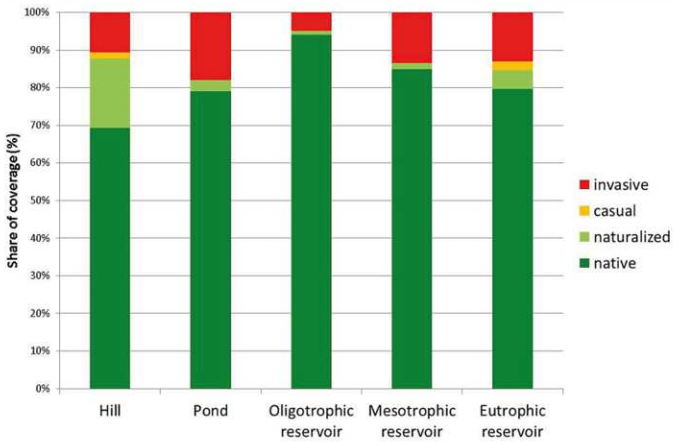


Figure 6. Contribution of plant species groups on the coverage in the phytocoenological relevés.

Tragopogon orientalis, Trifolium pratense, Trifolium repens, Urtica dioica, and *Vicia tetrasperma.* The native plant species living in cities are part of the regional pool of species. According to Werner (2011), urban areas contribute to changes but also to conservation and protection of this regional pool of species. Therefore, it is extremally important to protect and plan the conservation of these native species.

Naturalized plant species were *Bromus hordeaceus, Cichorium intybus, Lactuca serriola, Lathyrus tuberosus, Linaria vulgaris, Oenothera biennis, Parthenocissus quinquefolia, Senecio vulgaris, Setaria pumila, Sonchus arvensis,* and *Sonchus oleraceus*. The plant species with casual status included *Berberis thunbergii* and the plant species with invasive status in this biotope were *Cirsium arvense, Conyza canadensis, Galinsoga parviflora,* and *Solidago canadensis.* Invasive plants may result in biodiversity decrease, diminish the ecosystem resistance to perturbations and cause ecosystem degradation (Jang et al., 2020). Additionally, Jang et al. (2020) confirmed that private housing areas are the main sources of invasive plant spread. What is more, the proportion of invasive species are an indicator for the intensity of human disturbances (Gregor et al., 2012). However, this is not standard for all cities. For example, Frankfurt/Main (Germany) differs somewhat in the share of invasive species from the average of Central European cities. According to the study conducted by Gregor et al. (2012) the low proportion of invasive species in Frankfurt, probably, reflects large areas of forests and low productive grasslands in today's city's limits.

Water environments, such as rivers, ponds and ditches, are particularly affected by the invasion of exotic water plants. Moreover, pond sediments act as seed banks of many species, and water level oscillations cause recruitment of seeds from these banks (Hayasaka et al., 2018). The number of plant taxa found in the second biotope Lake was 12. Native species included *Epilobium hirsutum, Equisetum palustre, Iris pseudacorus, Juncus articulatus, Juncus effusus, Mentha aquatica, Nymphaea alba, Phragmites australis, Populus alba,* and *Salix caprea.* Naturalized species were represented by *Epilobium adenocaulon* and the plant species with invasive status identified in this biotope included *Solidago canadensis*.

The number of plant taxa found in the third biotope „Oligotrophic reservoir" was 15. Native species included *Alisma lanceolatum, Epilobium hirsutum, Equisetum palustre, Iris pseudacorus, Juncus articulatus, Juncus effusus, Lycopus europaeus, Nymphaea alba, Phragmites australis, Populus alba, Ranunculus repens, Typha angustifolia,* and *Typha latifolia.* Naturalized species were represented by *Epilobium adenocaulon* and the plant species with invasive status in this biotope included *Solidago canadensis*.

The number of plant taxa found in the fourth biotope Mesotrophic reservoir was 29. Native species included *Achillea millefolium, Alnus glutinosa, Calamagrostis epigejos, Epilobium hirsutum, Equisetum hyemale, Equisetum palustre, Juncus articulatus, Juncus effusus, Lycopus europaeus, Lysimachia vulgaris, Mentha aquatica, Phragmites australis, Plantago lanceolata, Ranunculus repens, Salix ×rubra, Salix alba, Salix*

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euxina, Salix viminalis, Sambucus nigra, Trifolium fragiferum, Trifolium pratense, Trifolium pratense, Typha angustifolia, Typha latifolia, Ulmus laevis, and *Urtica dioica.* Naturalized plant species were represented by *Setaria pumila* and the plant species with invasive status identified in this biotope were *Conyza canadensis, Erigeron annuus,* and *Solidago canadensis.*

The number of plant taxa found in the fifth biotope Eutrophic reservoir was 40. Native plant species included *Alisma lanceolatum, Betula pendula, Bidens tripartita, Calamagrostis epigejos, Carex pseudocyperus, Epilobium hirsutum, Equisetum palustre, Eupatorium cannabinum, Festuca arundinacea, Filipendula ulmaria, Juncus articulatus, Juncus effusus, Lycopus europaeus, Lythrum salicaria, Mentha aquatica, Nymphaea alba, Persicaria amphibia, Phragmites australis, Plantago lanceolata, Populus alba, Quercus cerris, Ranunculus repens, Rumex aquaticus, Salix euxina, Salix viminalis, Symphytum officinale,Tussilago farfara, Typha angustifolia, Typha latifolia, Typha laxmannii, Urtica dioica,* and *Veronica maritima.* Naturalized plant species were *Lactuca serriola, Linaria vulgaris* and *Parthenocissus quinquefolia.* Plant species with casual status included *Viburnum rhytidophyllum* and the plant species with invasive status found in this biotope were *Conyza canadensis, Erigeron annuus, Reynoutria japonica,* and *Solidago canadensis.*

The species spectrum of vegetation differs significantly between habitats, as can be seen in Figure 7. The Hill habitat creates conditions for meadow species. Other habitats create conditions for more water-intensive species. The nutrient- and water-rich habitat (Mesotrophic reservoir; Eutrophic reservoir) is also the most diverse species. The species located in the middle of the ordination diagram (Figure 7) are the species whose occurrence intersects between habitats. This may be due to the proximity of habitats, or their introduction through human activity, or their natural ability to spread.

Many of the identified plant species were not typical representatives of coastal or aquatic vegetation. The conditions were created artificially; some local plant species succeeded in coping with these new and untypical conditions and survived. Plant species may spread from adjacent areas and colonize sites in artificially created biotopes where the competition from other plants is lower. Although the ecosystems were created artificially, native plant species significantly predominated in them. The authors of this paper found that the research area contributed to the species richness, irrespective of the presence of native and non-native species. This provides the preconditions for the development of a stable phytocoenosis that will be able to resist invasion of non-native species. The importance of campus areas is supported by previous studies in China and Turkey (Liu et al., 2017; Güler, 2019); other urban green areas, such as urban parks and botanical gardens have also been considered (Golding et al., 2010; Nielsen et al., 2014).

Highly invasive non-native plant species, such as *Conyza canadensis, Erigeron annuus, Galinsoga parviflora, Reynoutria japonica* and particularly *Solidago canadensis*, were recorded there as well. The future management of the Water Park needs to be focused on the elimination of these species in order to prevent their overpopulation and possible spreading to other neighbouring localities. On the basis of the studies of invasive species, Hayasaka et al. (2018) suggest management of such areas through successful control and/or elimination of invasive species (Fos et al., 2021) in order to maintain biodiversity of the native vegetation and achievement of the prevalence in the restriction of its development. Furthermore, the most effective method of controlling invasive species is maintaining and clipping rhizomes and stalk segments underwater.

It is also necessary to give attention to the control of plant species with airborne fruits and seeds, such as *Calamagrostis epigejos, Cirsium arvense, Epilobium adenocaulon, Lactuca serriola, Oenothera biennis, Senecio vulgaris, Sonchus arvensis, Sonchus oleraceus,* and *Tussilago farfara.* Seed dissemination is of key importance for a wide range of ecological processes (Trakhenbrot et al., 2014). Although these species do not belong to typical representatives of coastal vegetation, they are often distributed by wind from the nearby surroundings and colonize sites with scarce vegetation.

Undesirable plant species, whose occurrence has to be controlled and greatly limited, are ruderal species which colonize sites rich in nutrients; they belong to widespread species such as *Sambucus nigra, Setaria pumila* and *Urtica dioica.* The occurrence of these species is often connected with unkempt and neglected localities. Seeds and propagules of ruderal species may be transported to other biotopes (Vaverková et al.,

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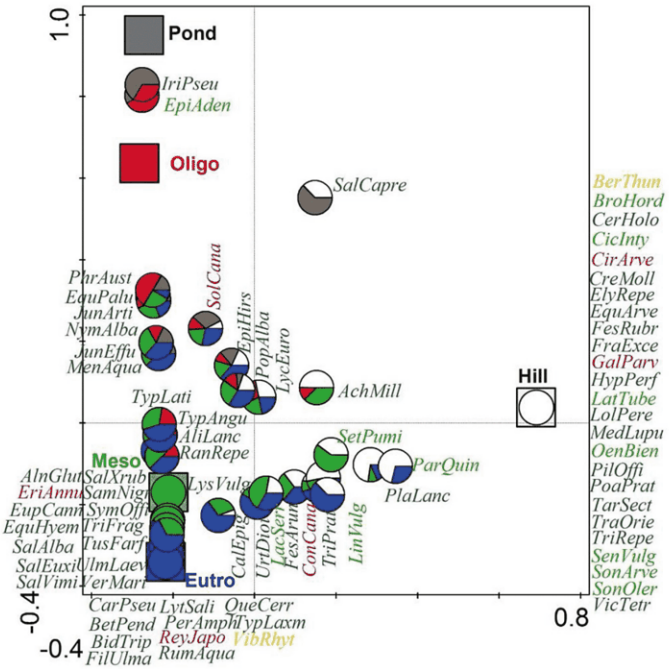


Figure 7. Graphical expression of relationships between habitats and found plant species.

Explanations: Habitats: Hill – Hill; Pond – Pond; Oligo – Oligotrophic reservoir; Meso – Mesotrophic reservoir; Eutro – Eutrophic reservoir.

Species: *AchMill – Achillea millefolium, AliLanc – Alisma lanceolatum, AlnGlut – Alnus glutinosa, BerThun – Berberis thunbergii, BetPend – Betula pendula, BidTrip – Bidens tripartita, BroHord – Bromus hordeaceus, CalEpig – Calamagrostis epigejos, CarPseu – Carex pseudocyperus, CerHolo – Cerastium holosteoides, CicInty – Cichorium intybus, CirArve – Cirsium arvense, ConCana – Conyza canadensis, CreMoll – Crepis mollis, ElyRepe – Elymus repens, EpiAden – Epilobium adenocaulon, EpiHirs – Epilobium hirsutum, EquArve – Equisetum arvense, EquHyem – Equisetum hyemale, EquPalu – Equisetum palustre, EriAnnu – Erigeron annuus, EupCann – Eupatorium cannabinum, FesArun – Festuca arundinacea, FesRubr – Festuca rubra, FilUlma – Filipendula ulmaria, FraExce – Fraxinus excelsior, GalParv – Galinsoga parviflora, HypPerf – Hypericum perforatum, IriPseu – Iris pseudacorus, JunArti – Juncus articulatus, JunEffu – Juncus effusus, LacSerr – Lactuca serriola, LatTube – Lathyrus tuberosus, LinVulg – Linaria vulgaris, LolPere – Lolium perenne, LycEuro – Lycopus europaeus, LysVulg – Lysimachia vulgaris, LytSali – Lythrum salicaria, MedLupu – Medicago lupulina, MenAqua – Mentha aquatica, NymAlba – Nymphaea alba, OenBien – Oenothera biennis, ParQuin – Parthenocissus quinquefolia, PerAmph – Persicaria amphibia, PhrAust – Phragmites australis, PilOffi – Pilosella officinarum, PlaLanc – Plantago lanceolata, PoaPrat – Poa pratensis, PopAlba – Populus alba, QueCerr – Quercus cerris, RanRepe – Ranunculus repens, ReyJapo – Reynoutria japonica, RumAqua – Rumex aquaticus, SalAlba – Salix alba, SalCapre – Salix caprea, SalEuxi – Salix euxina, SalVimi – Salix viminalis, SalXrub – Salix ×rubra, SamNigr – Sambucus nigra, SenVulg – Senecio vulgaris, SetPumi – Setaria pumila, SolCana – Solidago canadensis, SonArve – Sonchus arvensis, SonOler – Sonchus oleraceus, SymOffi – Symphytum officinale, TarSect – Taraxacum* sect. *Taraxacum, TraOrie – Tragopogon orientalis, TriFrag – Trifolium fragiferum, TriPrat – Trifolium pratense, TriRepe – Trifolium repens, TusFarf – Tussilago farfara, TypAngu – Typha angustifolia, TypLati – Typha latifolia, TypLaxm – Typha laxmannii, UlmLaev – Ulmus laevis, UrtDioi – Urtica dioica, VerMari – Veronica maritima, VibRhyt – Viburnum rhytidophyllum, VicTetr – Vicia tetrasperma.*

2012; Vaverková and Adamcová, 2014; El-Bana, 2015). Moreover, according to Fortuna-Antoszewicz et al., (2018) excessive expansion of invasive species may disturb the ecological balance of an ecosystem in a given area, replacing less expensive and less competitive species.

The results of studies by Nordh et al. (2009) indicate that the quality of small urban parks does

not only depend on their size. Nevertheless, small-scale landscaping works often go hand in hand with a radical transformation of geological and paedological conditions, as well as water regime changes that result from human activity. Due to this, an ecosystem imitating natural ecosystems comes to existence, which would not originate without human intervention. Managers should reduce extensive planting of non-native species and replace them with native species suitable for specific local conditions (Wang et al., 2021).

According to El-Bana (2015), perturbations of native species results in breaks in their spatial distribution, favouring the colonization by less competitive ruderal and invasive species. Correct Park management may potentially have impact on the sustainable development of the campus and the city. The adaptation level of each park should differ depending on the local neighbourhood and context (Ibrahim et al., 2020). These research results demonstrate that humans not only affect landscapes, but they directly create also new ecosystems (Winkler et al., 2021).

CONCLUSIONS

Ecological building design, including sustainable development and a circular economy, will definitely be one of the foundations of construction industry in the future. Some companies, national and academic institutes are already being modernized to face these challenges in the near future. The discussed case of the Warsaw University of Life Sciences is an interesting example of implementation of the green building strategy of the future, taking into account historical (Old part campus) and environmental aspects (location next to nature reserve). The implemented strategy of the Warsaw University of Life Sciences development considers not only the reduction of CO_2 emissions, but also the development of a circular economy, waste recycling, production of green energy, and use of rainwater. The innovative building of the Water Centre the Warsaw University of Life Sciences is also a proof of the above. It constitutes a modern laboratory adapted to the research on the improvement of the natural environment. These activities deserve to be distinguished on the scale of academic campuses in Poland and Europe.

Small Park projects increase the diversity of plant species, due to which they create biodiversity islands that may contribute to improve sustainable urban space. The interconnection of city and nature finds applications exactly in such projects. A species composition that is close to natural vegetation creates a space for native animal species, which thus better adapt to living in urban conditions.

Studies of the vegetation composition show that most plant species are native. However, the occurrence of invasive plant species was recorded as well. Therefore, it is necessary to focus on vegetation control and removal in order to prevent the development of new diaspores. Regarding the small size of the studied park, manual elimination or cutting of invasive plant species is sufficient. Nevertheless, correct identification of plants and educating the park managers are necessary. If these invasive plant species are not subject of targeted control, even small plots may become sources of diaspores and cause their further undesirable spreading. By competition, the invasive plant species suppress the native species, thus changing the food supply of the habitat and inducing changes in the faunal composition. In addition, they can also affect humans either in the form of pollen allergies or impair the aesthetic impression provided by the vegetation. The localities created by humans, which imitate natural ecosystems, increase the biodiversity and are valuable natural islands in cities. The semi-natural phytocoenoses of these localities, however, cannot resist the occurrence of invasive plant species.

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Municipal solid waste landfill: Evidence of the effect of applied landfill management on vegetation composition

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Abstract

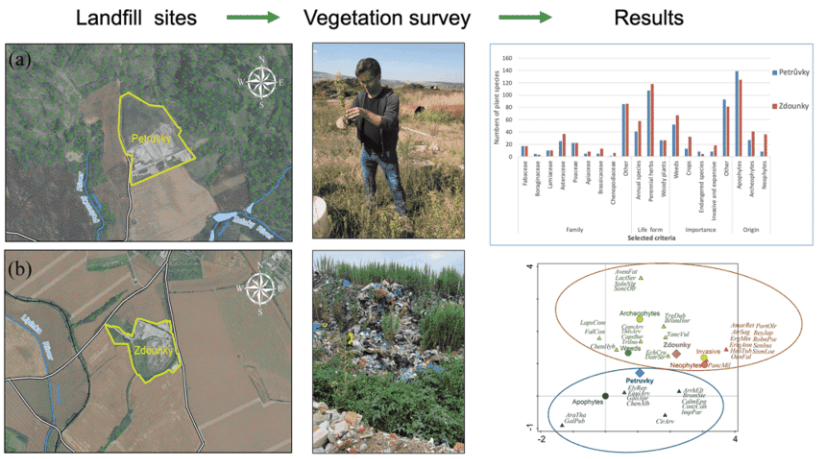
Proper management of municipal solid waste (MSW) is crucial to avoid pollution, environmental impacts and threat to public health. The problem of MSW is mainly arising from inadequate landfill site management. The objective of this study was to evaluate the impact of management practices and environmental risks at two landfill sites. The landfills were subject to long-term (10 years) vegetation monitoring. The vegetation was assessed using a floristic survey of identified plant species. The vegetation analysis showed that significant differences existed between the two landfill locations, with neophytes, invasive and expansive species dominating on one of the landfill sites, which may be attributed to climatic and geomorphological differences between the two sites, but also to variations in landfill management. These environmentally problematic species can potentially spread from the landfill into adjacent ecosystems, displace native plants and degrade adjacent farmland areas. The study of vegetation monitoring data suggests that, in addition to other types of monitoring, landfills should be subjected to regular vegetation biomonitoring, too. Landfill management practices should target the regulation of unwanted species, create conditions that are favourable to native plant species and provide as early as possible the restoration of filled cells.

Keywords

Waste, landfill management, environmental impacts, vegetation survey, landfill surroundings

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Graphical Abstract



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Introduction

Despite being the least preferred option for waste disposal, landfilling is still widespread worldwide (Abiriga et al., 2020; Pandey and Shukla, 2019; Rezaeisabzevar et al., 2020; Sauve and Van Acker, 2020; Vaverková et al., 2020). A landfill site is used for the burial of waste materials, by reason of its low cost, tolerable hygiene and beneficial management (Krzykawska, 2018; Li et al., 2021). Sanitary landfills are specially designed and constructed to protect human and environmental health. These are sites with working control systems for the collection and treatment of landfill leachate and gas that prevent and monitor potential groundwater, land and air pollution (Paleologos et al., 2018; Youcai and Ziyang, 2017). Moreover, the design and construction of the liner as well as the siting itself are crucial factors for a sanitary landfill. Improper landfill management, leaks or accidents can cause deterioration of environmental qualities (Abiriga et al., 2020; Cuartas et al., 2018; Koda et al., 2017), can create public health risks and adversely affect the environment by pollution to water systems and to vegetation, odours, fires and generation of air pollutants that contribute to global warming (Carriero et al., 2018; Xin et al., 2016). Controlled management of municipal solid waste (MSW) is one of the major environmental problems in many countries. According to Paoli et al. (2012), each process of assessing the environmental impacts of waste management should include informative and regular monitoring of the environment with obtained data used for the evaluation of environmental impacts of specific activities and for environmental control. In recent years, the interest of the scientific community in issues related to the responses of living organisms to the emitted pollutants, the so-called biomonitoring is growing (Currier et al., 2020; Paoli et al., 2012; Sujetovienė et al., 2019; Uldrijan et al., 2021; Vaverková et al., 2019). The bioindicative properties of plants were indicated by Ellenberg et al. (1991). According to Vaverková et al. (2019) the method is simple, fast and cost-effective. Moreover, Koda et al. (2022) proved the possibility of using plants to assess the severity of anthropopressure and environmental pollution.

At the same time, restoration (e.g. re-vegetation) of landfills is necessary to compensate for the disturbance of ecosystems, to minimise unfavourable effects on the environment, to protect public health and to return affected lands to beneficial uses (Chen et al., 2016, 2017; Lavagnolo et al., 2018; Trach, 2020). It should be stressed, however, that no strict regulations exist with respect to the vegetation management (biomonitoring) of landfills. Many weed/invasive plant species have proven to be able to 'escape' even from a small area (e.g. landfills) (Vaverková et al., 2020). Therefore, the threat of neophytes and invasive plants to the native species and biodiversity has become a major focus of ecological research. Neophytes and invasive species decrease the species richness and are responsible for the loss of biological diversity. It is not only an ecological concern but it relates to global environmental and economic concerns, which makes the research of these plants an important issue (Bzdęga et al., 2021; Lodge, 1993; Song et al., 2018). According to Mehta et al. (2007), the management of neophytes and invasive species begins with an optimal detection strategy followed by control methods. Thus far, few data are focused on the potential role of landfills in plant invasion processes. An improved understanding of the relationship between the landfills and neophytes and invasive plant species will be helpful for the management of landfill sites. Generally, landfills create very specific conditions, which subsequently reflect into the vegetation species composition (Abichou et al., 2015; Vaverková et al., 2013; Weng et al., 2015; Yun et al., 2018). A contribution of this study is to present evidence that landfills can become significant sources of plant invasion if landfill management pays inadequate attention to the issue. This was accomplished by using the results of a 10-year vegetation monitoring study to assess the influence of different landfill management practices on the surrounding environment. It was hypothesised that the management practices applied on the landfill site create favourable conditions for neophytes and invasive species. The aims of the presented study were to evaluate whether (1) the vegetation on landfill sites depends on management practices; (2) the vegetation reflects the management practices applied; and (3) the landfill site vegetation can serve as an indicator of environmental risks. The long-term research conducted at the two landfills resulted in the lists of plant species identified on the surveyed sites, which were analysed.

Materials and methods

Study sites

The research objects were two landfill sites of the same category of technical security, situated in the Czech Republic (CR) (Figure 1), where waste is isolated from the environment.

The first one is Petrůvky landfill (Figure 1(a)), which was put into operation in 1994. This landfill is classified in Category S-OO1 and S-OO3 as a landfill receiving 'other waste', that is, waste with an essential content of biologically decomposable materials, mainly communal wastes from adjacent towns and villages. Its capacity was designed for a collection area serving about 118,000 inhabitants. The landfill has gas capture and monitoring, but without the conversion of landfill gas to energy. The Petrůvky landfill area is 72,130 m^2 and its total volume is 600,000 m^3. On its SW end, the landfill neighbours a meadow which is separated from the landfill by an unpaved road, while on the NE end, the landfill borders a forest. Phases 1 and 2 (closed sector) of the landfill were restored in 2004 and 2006, respectively (Figure 2). It consists of eight cells (sections) and is situated at a distance of 8 km from the town of Třebíč.

Detailed characteristics of the two landfills are presented in Table 1.

The second one is Zdounky landfill (Figure 1(b)) which is situated in the cadastral area of Nětčice, a part of the municipality of Zdounky in the Kroměříž district in the Zlín Region. As to technical security, the Zdounky landfill falls under the S-OO3

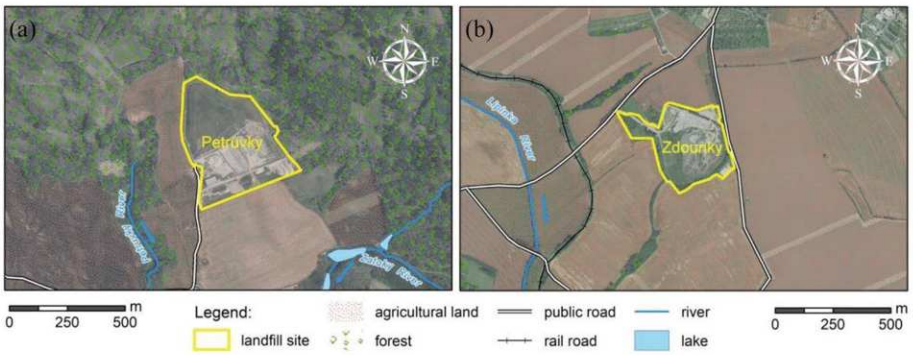


Figure 1. Location of landfills in the landscape: (a) Petrůvky landfill and (b) Zdounky landfill.

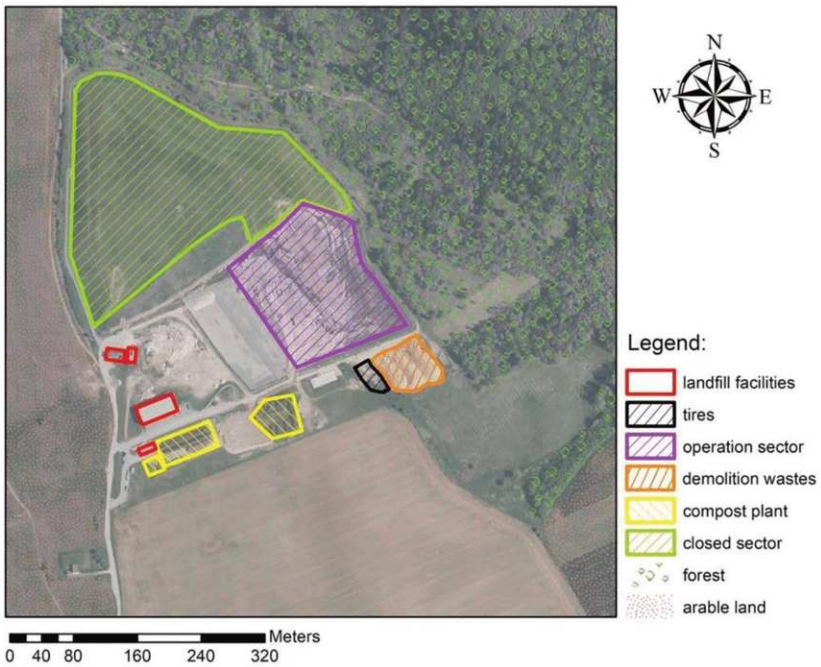


Figure 2. Development plan of the Petrůvky landfill's waste compartments.

Table 1. General characteristics of Zdounky and Petrůvky landfills.

Object	Petrůvky	Zdounky
Landfill	Sanitary MSW	Sanitary MSW
Origin	1994	1998
Category	SOO-3	SOO-3
Landfill area (m^2)	72,130	70,700
Altitude (m a.s.l.)	405	251–280
Mean annual rainfall (mm)	405	409
Mean annual temperature (°C)	9.2	10
World location coordinates	49°10′03.4″N 15°54′04.8″E	49°14′30.5″N 17°18′29.9″E
Total amount of waste (10^3 kg $year^{-1}$)	31,000	35,000

MSW: municipal solid waste. S-OO3: landfill intended for storage of waste in the category of other waste, including waste containing organic biodegradable substances.

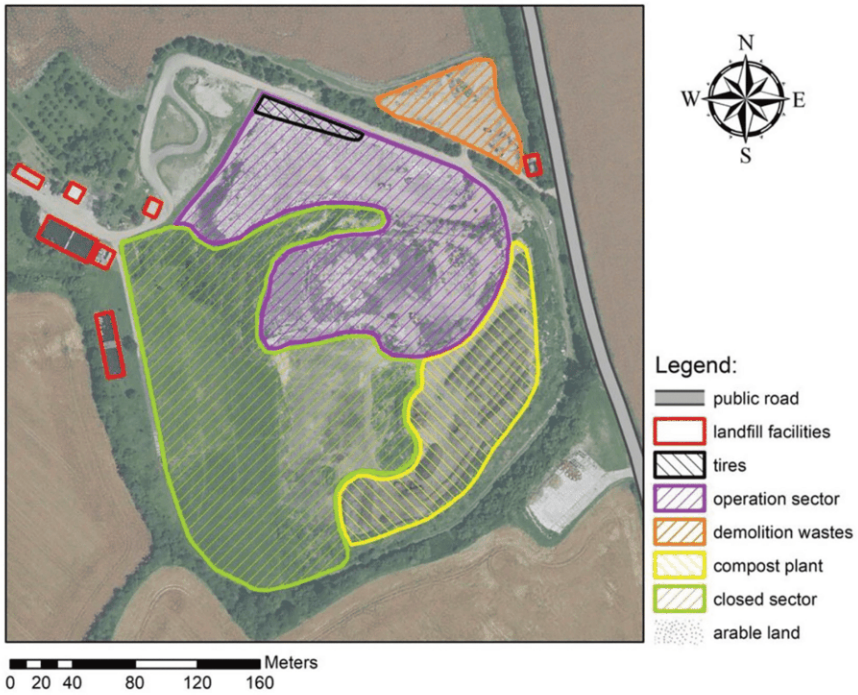


Figure 3. Development plan of the Zdounky landfill's waste compartments.

classification group in the CR, with gas capture and energy production. The waste stored in this landfill is classified as 'other waste' and includes waste with an essential content of biologically decomposable materials, mainly MSW from adjacent towns and villages. The facility is situated at an altitude ranging from 251 to 280 m above sea level (a.s.l.) and is located in a terrain depression, accessed by roads on its eastern and western sides. The site where the landfill was constructed was previously agricultural land sized 99,631 m^2, of which the landfill covers 70,700 m^2 now. The landfill was designed in five cells (sections), with a target total volume of 907,000 m^3 to serve an area with 75,000 inhabitants (Figure 3). The total annual amount of deposited waste is ca. $35{,}000 \times 10^3$ kg.

The Petrůvky landfill has already been restored by 50%; the active body and the new cells each form 25% of the total area. This landfill is surrounded by forests at two-thirds of its perimeter, the rest being agricultural lands. The Zdounky landfill has been restored by about 30%; the active body of the landfill constitutes 55% of the total area, while 15% of the landfill surface is currently used as a composting facility (Vaverková et al., 2020). The landfill is surrounded by farmland, that is by an agrocoenosis (Figure 1(b)). The method of both landfills restoration was to cover the area with high-density polyethylene (HDPE) geomembrane and the topsoil on which the vegetation was planted (grass mixture). The target for restoration was, as in many others sanitary landfills (Camerini and Groppali, 2014), the development of vegetation through the manipulation of both soil and vegetation conditions to create a meadow.

Vegetation survey

The two landfills were subject to the long-term vegetation monitoring in the period from 2008 to 2018, during the growing seasons (May–October). The monitoring period was chosen based on the length of the vegetation period, which is the growing season when conditions are favourable for plants to grow. The vegetation was assessed using a floristic survey of the identified plant species. Vegetation monitoring took place in the monitored period on the entire landfill area. Research plots were delineated within the landfill areas and plant species were identified and recorded within the research plots. Vegetation regulation in the restored parts of the landfill consisted of mowing twice a year. There was no targeted regulation in other parts of the landfill. No herbicides were used during monitoring. Characteristics of detected plants were obtained from available literature sources (Kubát et al., 2002; Pladias, 2021). Criteria determined for each identified species were as follows: affiliation to selected families (*Apiaceae*, *Asteraceae*, *Boraginaceae*, *Brassicaceae*, *Chenopodiaceae*, *Fabaceae*, *Lamiaceae*, *Poaceae* and other families), species life form (annual species, perennial herbs and woody plants), importance for the neighbourhood (weeds, crops, endangered species, invasive and expansive species and others) and species origin

(apophytes, archeophytes and neophytes). Criteria were selected so that the vegetation structure could be viewed from various perspectives. The representation of plant species by families and their life forms should inform about the vegetation structure in botanical terms. The representation of plant species by their significance for the surrounding environment and by origin allows to ascertain relations and links with adjacent ecosystems. Particularly the structure of vegetation by the origin of plant species gives an idea about the degree of vegetation disruption by human civilisation. Apophytes are native plants, synanthropic species of local origin, typically growing on disturbed lands (Janicka et al., 2020). Archeophytes are 'old-comers' alien plant species introduced after and before the discovery of the Americas (Czarnecka et al., 2020; Lautenbach et al., 2017). Neophytes are post-1500 alien species, invaders which have already become an important component of many ecosystems (Bauer et al., 2015). It is exactly the share of neophytes, which can indicate disturbances and changes in the structure of vegetation induced by humans. Neophytes change the vegetation structure, compete with native plant species and alter food supply for animals, which may cause changes in the whole ecosystem. As the species are of clearly invasive characters, landfills may become sources of their diaspores. The organisation of plant species according to the selected criteria was made in line with Grulich (2012), Pyšek et al. (2012) and Danihelka et al. (2012). The obtained data were processed using multivariate statistical techniques, detrended correspondence analysis (DCA) and segment analysis using the software Canoco 5.0. (Ter Braak and Šmilauer, 2012). Data on the vegetation from the monitored landfills have the nature of multidimensional data of high heterogeneity. DCA analysis is a method appropriate for their evaluation, allowing to determine relations between the vegetation and effects of the environment. DCA results express relationships between the surveyed locality and the occurrence of selected plant species, or their groups. DCA results are expressed graphically to show the selected plant species, their groups and sites as points denoted with their abbreviated names. The position of individual points and the distance between them express relationships between the occurrence of the respective plant species or their groups and the surveyed locality. The nearer the plant species point is to the point of the locality, the more the locality is typical of its occurrence.

Results and discussion

Vegetation is one of the most important components of terrestrial ecosystems. Vegetation links the soil and atmosphere; thus, it is a sensitive indicator of environmental change (Koda et al., 2013; Vaverková et al., 2018, 2020). According to Koda et al. (2013, 2022) and Vaverková et al. (2018, 2019) landfill can be characterised with typical synanthropic flora, colonised by plant species from the group of neophytes and archeophytes. The two studied landfill sites were monitored for 10 years (2008–2018) during the growing season. During this period, 299 plant species were identified, of which 78 (26%) existed before the construction and operation of the landfills. Specifically, 174 plant species were determined in the Petrůvky landfill area, and 202 plant species were recognised at the Zdounky site. Details of the list of species at the two landfills and their classification degrees according to four criteria are presented in Supplemental Appendix 1.

Figure 4 shows the number of plant species identified at the two monitored landfill sites, which were classified according to four selected criteria: family, life form, importance, and origin.

The criteria of Importance and Origin demonstrate that significant differences exist between the two sites. In the Zdounky locality, the number of invasive and expansive species and neophytes is much higher than that found in Petrůvky (Figures 4 and 5). Thus, the Zdounky site appears to create more favourable conditions for the occurrence of environmentally problematic species.

In general, the representation of neophytes is higher in warmer and fertile localities (Hüse et al., 2016; Petrášová et al., 2013; Szymura et al., 2018), and the Zdounky site follows this pattern as documented in Table 1. As to the origin of the identified plant species, a majority of them belong to apophytes (native species), which were found at 62% in the Zdounky locality, followed by archeophytes (20%) and neophytes (18%). In the Petrůvky locality, apophytes constituted about 80% of the identified species, followed by archeophytes (16%) and neophytes (at about 4% 5%). Thus, the two localities differed significantly in the proportion of the respective plant species groups. The share of neophytes which are species of high invasive potential and species changing the composition and functioning of ecosystems represent a danger for the surrounding ecosystems. The results show that the species composition of landfill vegetation may also be affected by altitude (Petrášová et al., 2013; Šebesta et al., 2021), since at the Petrůvky site, which is situated at a higher altitude (405 m a.s.l.) than the Zdounky site (251–280 m a.s.l.), neophytes, invasive and expansive species are suppressed. A number of studies conducted in the CR conclude that exactly the fertile regions of lower altitudes are favourable for the occurrence of invasive neophytes because many of them come from warm and dry areas (Pyšek et al., 2012). In apophytes and archeophytes, a longer period that the species had for adaptation to less favourable living conditions can be assumed; therefore, their incidence rate is higher at the Petrůvky site. The occurrence of some plant species is also influenced by different landfill management practices and by the location of landfills within the landscape (Figure 1). Both surveyed landfill sites are dominated by perennial herbs, which constitute more than 50% of all the identified plant species. Perennial species were found primarily on the restored parts of the landfill and/or on other surfaces. The representation of annual species was lower (24% in the Petrůvky locality and 29% in the Zdounky locality). These species occurred especially at places of active landfilling, that is at often-disturbed places. The representation of woody plants was up to 15% and consisted primarily of self-seeded woody plants, or remainders of the original vegetation on land margins. Generally, the composition and richness of plant species on the landfills is diverse and includes species of different importance for the landfill environment (Tintner and

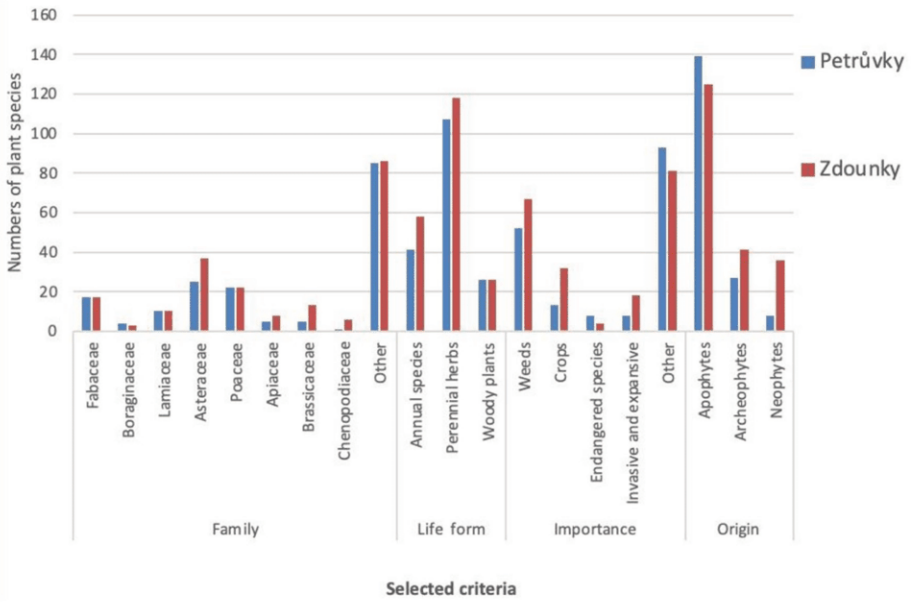


Figure 4. The number of plant species detected at the monitored landfills in Petrůvky and Zdounky.

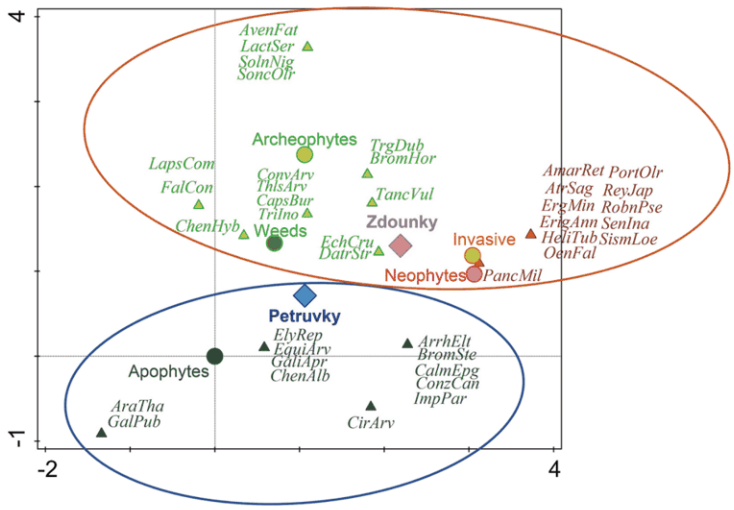


Figure 5. Relationships between the surveyed sites and some plant species or plant groups.

Klug, 2011; Vaverková et al., 2019). For example, on landfill grounds of the Upper Silesian Coal Basin in Poland (Rostański, 2006), a relatively high species diversity was found – with 581 species representing more than 20% of the Polish vascular flora. A similar number of species was found on post-industrial heaps in the CR (Pyšek et al., 2003). The phyto-sociological and floristic research conducted on landfills in Lipiny Stare (Wołomin commune) and Radiowo in Warsaw, Poland (Koda et al., 2017), confirmed the great importance of spontaneous processes of vegetation changes in restoration sites and plant covers (Dyguś, 2010). About 200 species of vascular plants representing more than 20 families were found on these Polish landfills. The richest species turned out to be complex families (*Asteraceae*), grasses (*Poaceae*) and legumes (*Fabaceae*). Many species belonging to *Asteraceae* and *Poaceae* produce high numbers of seeds adapted to wind dispersal

(Chichizola et al., 2021), which can easily reach the surroundings. According to Kornaś and Medwecka-Kornaś (2002), habitats subjected to strong anthropogenic stresses are dominated by non-native species (anthropophytes). The presence of invasive species at the two sites may become problematic because these may spread from the landfills into the adjacent natural ecosystems, pushing out native plants (Song et al., 2018), and impairing the food chain and other relationships among living organisms (Plaza and Lambertucci, 2017). These invasive species include *Arrhenatherum elatius*, *Calamagrostis epigejos*, *Impatiens parviflora* and *Tanacetum vulgare*. At the Petrůvky site, the above-mentioned plant species are augmented by *Tragopogon dubius*. At the Zdounky locality, the range of these plant species is broader and includes, in addition to those mentioned above, *Erigeron annuus*, *Reynoutria japonica*, *Robinia pseudacacia*, *Senecio inaequidens* and *Oenothera fallax*. Prach et al. (2014) considered *R. pseudoacacia* as an alien species that forms dense, species-poor stands dominated by nitrophilous species in the herb layer, which is not acceptable from the restoration point of view. Moreover, according to Cortinovis and Caloni (2013), this plant can poison humans and livestock, causing gastroenteritis, abdominal pain, posterior paralysis and ultimately death, especially in horses. Invasive species have been seen to spread to farmland areas dominating cultivated crops with weeds (Shackleton et al., 2019; Sheridan et al., 2017). Plant species capable of this behaviour (*Conyza anadensis* and *Bromus sterilis*) were identified at both landfill sites. In addition to these two, *Bromus hordeaceus* was found at the Petrůvky site and *Amaranthus retroflexus*, *Atriplex sagittata*, *Eragrostis minor*, *Helianthus tuberosus*, *Portulaca oleracea* and *Sisymbrium loeselii* were identified at the Zdounky site. In that respect, the Zdounky landfill site can be classified as risky in the sense that it can be a source of plant invasion into the adjacent ecosystems and to the farmland.

Plant species considered as common field weeds were identified in both localities. The most important ones were: *Capsella bursa-pastoris*, *Cirsium arvense*, *Convolvulus arvensis*, *Elytrigia repens*, *Equisetum arvense*, *Galium aparine*, *Chenopodium album*, *Thlaspi arvense*, *Tripleurospermum inodorum* and others. In addition, the Zdounky site exhibited some other important weed species such as: *Avena fatua*, *Datura stramonium*, *Echinochloa crus-galli*, *Chenopodium hybridum*, *Lactuca serriola*, *Solanum nigrum*, *Sonchus oleraceus* and others, which were mostly thermophiles. This is in line with the research conducted by Cimalová (2016) who confirmed that ruderal vegetation units occurring in the landfill mostly consist of xerophilous and thermophilic vegetation units. Important weed species occurring only at the Petrůvky site were *Arabidopsis thaliana*, *Fallopia convolvulus*, *Galeopsis pubescens*, *Lapsana communis* and others – mainly winter weeds or species of early spring weeds.

Landfills create conditions for the occurrence of endangered plant species, too. Vaverková et al. (2013) identified endangered and in the CR protected species in areas next to landfill sites, such as *Polygala chamaebuxus*, *Juniperus communis* and *Epipactis helleborine*. Endangered and protected plant species may be remainders of populations existing on the site prior to the establishment of the landfill, or their propagules may have been brought to the landfill along with the garden waste. For a majority of rare plant species found at the two landfill sites, a reasonable assumption is that they are likely to have been introduced there via garden and household waste. Recent evidence suggests that diaspores of non-native plant species could have been brought to the landfill along with the garden waste (Vaverková et al., 2019). It is evident from the study published by Rusterholz et al. (2012) that numerous non-native horticultural plant species escape from garden waste. Several rare species can survive in waste for a very long time thanks to specific conditions at landfill sites. Such species at the Zdounky site included *Carex distans*, *Cornus mas*, *Delphinium elatum* and *Scorzonera hispanica*. Endangered and protected species identified at the Petrůvky locality included *E. helleborine*, *Euphorbia amygdaloides*, *Filago arvensis*, *Filago lutescens*, *Myosorus minimus*, *Myosotis discolor*, *P. chamaebuxus*, *Verbascum densiflorum* and *Veronica dillenii*. The preservation and existence of these small populations of rare species is problematic given the landfilling activities. It is planned to monitor these populations in the future and to control how they would adapt to the conditions at the two landfill locations.

The potential sources and types of plant propagules at landfills are influenced by the composition of waste deposited there, by methods of storage, and by the manner of waste processing at a particular landfill site. Despite the fact that the two investigated landfills are classified under the same category, their management and location in the landscape differ. Song et al. (2018) proved that vegetation mowing which is commonly used to control biomass should be performed carefully and that mowing is one of the main causes of invasion of *E. annuus*.

The comparison of vegetation at the two localities provides some indications on some issues to be aware of during and after the restoration of closed landfill cells. After the cells are closed, the impact of waste and the spreading of unwanted vegetation into the surroundings needs to be minimised. The Zdounky landfill has a lower percentage of restored surface than the Petrůvky landfill, creating a risk of weeds and invasive species spreading into adjacent agrocoenoses. Agrocoenoses around the Zdounky site were established artificially, and thus, they are very sensitive to changes of existing ecological factors. Invasive and weed plant species spreading from the landfill may invade farmlands, suppress yields, and force farmers to increase the use of pesticides, which may put a burden on the environment (another ecological load).

The location of landfills in the landscape may significantly influence the surrounding environment as well. The Petrůvky landfill is at 2/3 surrounded by forests (Figure 1(a)), which represent a climax stage of succession where the species composition does not change significantly (Wang et al., 2006). Forest is an optimum state of the natural environment, where the spreading of invasive species and weeds is minimised (Brown et al., 2005).

The function of a forest in the landscape is irreplaceable because it slows down runoff, thus preventing soil erosion and stabilising slopes (Guo et al., 2020), while reducing soil desiccation and wind velocity. Forest is an ecosystem with the highest wind resistance (Bozali, 2020), which reduces wind velocities contributing to lower deflation of small waste fractions and to decreased spreading of propagules of weed or invasive plant species. Apart from forests, there are also meadows surrounding the Petrůvky landfill. A so-called marginal effect (ecotone) that arises between the forest margin and the meadows has a typical species diversity and represents the environment (Du et al., 2020; Stašiov et al., 2019), which is far more stable than the agrocoenoses around the Zdounky landfill. Hence, the potential impact of invasive plant species and weeds at the Petrůvky landfill appears to be lower. Depots of biologically decomposable waste from gardens, and debris from the maintenance of public parks and other green urban areas may be sources of propagules of weeds and invasive plants (Andersen et al., 2010; Vaverková et al., 2020). The composting plant operating on the premises of the Zdounky landfill represents a potential risk of spreading unwanted species.

Daily activities in the active part of the landfill body, such as waste transportation and handling favour the propagation of field weeds and invasive plant species. By contrast, the restored parts of the landfill are not exposed to major disturbances and the vegetation on them is regularly maintained. Such conditions are rather suitable for the existence of perennials and native species (apophytes).

Domesticated plant species (archeophytes) and field weeds occur at both landfill sites; therefore, we may consider them as species favouring landfill conditions. The finding is consistent with the findings of past studies by Wong et al. (1992), Chan et al. (1997) and Vaverková et al. (2019). The content of species considered as weeds exceeded 30% on both of the sites. Thus, we can say that landfills can become sources of weed fruits and seeds, which may spread into adjacent farmland areas (Vaverková et al., 2019, 2020).

Conclusion

Landfill conditions are favourable for plant species considered as invasive or field weeds. Therefore, landfills can become sources of their spreading and through them may negatively influence the landfill surroundings. Our research results suggest that landfills in more fertile areas create good conditions for neophytes to which invasive plant species belong. On the other hand, landfill conditions are also good for the survival of endangered plant species that are resistant to occasional disturbances on the landfill. Differences in the species composition of plants on the surveyed landfills also result from the different landfill management. The landfill in Zdounky features frequent changes and lower intensity of vegetation control on active landfill surfaces, which provides favourable conditions for neophytes and invasive plant species. In this respect, the Petrůvky landfill is a less favourable site; nevertheless, neophytes and invasive plant species were identified there as well. A majority of the identified plant species belong to apophytes. The species composition of landfills is diverse and subject to changes. The results indicate that landfills should be subjected to the regular biomonitoring of vegetation species composition. The landfill management should use targeted regulation of unwanted – particularly invasive – species, create conditions favourable for native plant species and provide for the as early as possible restoration of the filled cells. It has been confirmed that vegetation provides a unique opportunity to study the environmental effects of landfill management. The novelty of this work is that vegetation monitoring (biomonitoring) can positively contribute to the evaluation of impacts of landfills on the environment. Moreover, to evaluate the role of landfill sites as plant invasion epicentres to improve policy related to waste management. This research opens a new door to studying the vegetation for the assessment of other localities such as land degraded areas or urban brownfield sites. Further research is needed to fully explore the potential applications of vegetation monitoring (biomonitoring).

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Supplemental material

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Environmental consequences and the role of illegal waste dumps and their impact on land degradation

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ABSTRACT

Landfilling is an anthropogenic activity that may causes land degradation and pollution. During the landfilling of waste, a wide range of pollutants can be released into the environment, e.g. landfill gases and leachate. The existence of illegal landfills is an increasing global problem. Illegal uncontrolled refuse storage areas, commonly referred to as "illegal waste dumps" (IWD), occur most frequently on forest margins, in ditches, on the peripheries of inhabited areas as well as at other places. IWD contaminate soils, pollute water, change vegetation, ecosystem functionality, and pose land degradation. It was hypothesized that IWD can disturb the species composition of native vegetation and create space for synanthropic as well as invasive plant species. These species may then spread from the IWD and affect the species composition of the natural ecosystems. The objective of this study was to search localities with the occurrence of IWD (within the Slovak Republic), to identify the types of waste, to assess the vegetation species composition, and based on the obtained results to determine the environmental impact. The monitored sites contained primarily municipal refuse and construction and demolition waste. The municipal refuse included plastic materials, glass and textiles. Tiles, pieces of concrete and insulation materials represented the construction and demolition waste. The results show that IWD represent specific habitats for plants. What is more, disturb the species composition of native vegetation and create space for the enforcement of synanthropic species as well as invasive plant species. The novelty of this work is that monitoring of vegetation can positively contribute to the evaluation of impacts of IWD on the environment. IWD should be removed and the concerned localities should be cleared, restored and reclaimed.

1. Introduction

Landfilling is one of the currently most widespread methods used in the final life cycle (disposal) of discarded products (Koda et al., 2013; Vaverková and Adamcová, 2015; Wong et al., 2015; Koda et al., 2016; Hamid et al., 2018; Vaverková et al., 2018a). Landfilling is an anthropogenic activity that may causes land degradation and result in the contamination and/or degradation of the soil/water (Dąbrowska et al., 2018; Koda et al., 2018; Vaverková et al., 2018b). According to Keesstra et al. (2018) in European countries, land degradation is characterized in policy documents with two aspects: physical degradation and chemical degradation. Soil compaction, soil subsidence, organic matter (OM) decline, diffuse pollution, and biodiversity decline, are often not taken into account (Keesstra et al., 2018). The same author emphasizes the role of properly functioning soils that can generously provide their ecosystem services for the achievement of the Sustainable Development Goals (SDG) (Keesstra et al., 2016). IWD have been identified as a serious problem existing at a significant scale, which can have a major impact on the quality and health of the soil. Many countries have pointed out problems entailed by these IWD (Jordá-Borrell and Ruiz-Rodrígez, 2014; D'Amato et al., 2018; Wright et al., 2018). Illegal uncontrolled refuse storage areas occur most frequently on forest margins, in ditches, on the peripheries of inhabited areas as well as at other places. IWD contaminate soils, may pollute water and bring out changes in the land surface. As recently pointed by Keesstra et al. (2016), the sustainability of human societies depends on the wise use of natural

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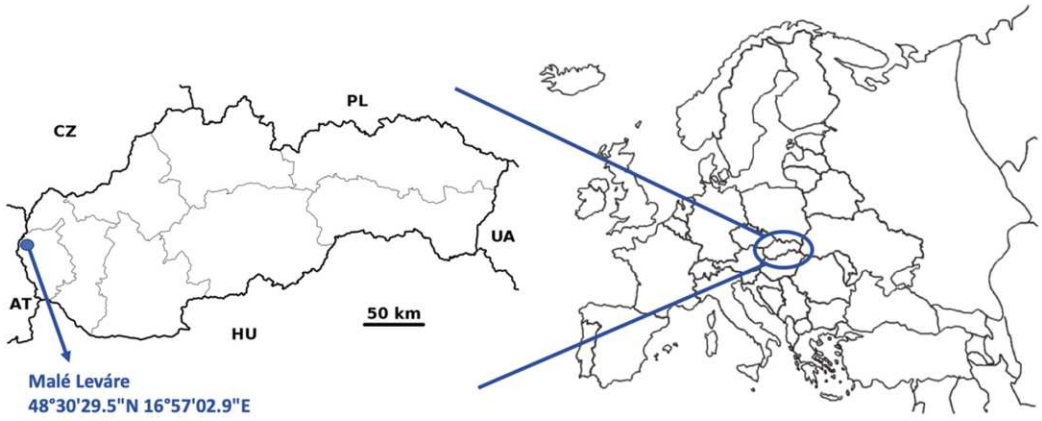


Fig. 1. Illegal waste dumps location.

resources. Moreover, soils contribute to basic human needs like food, clean water, and clean air, and are a major carrier for biodiversity. Soil has been pointed out to be of high importance to realize SDG. Land Degradation Neutrality (LDN) sets the ambitious goal of stabilizing or increasing the amount and quality of land resurces necessary to support ecosystem functions and services and enhance food security across the globe (Solomun et al., 2018). Therefore, the existence of IWD should not be neglected, above all because IWD continues to be a serious issue in advanced and developing countries. Research conducted in Germany, Austria (Allgaier and Stegmann, 2006), Ireland (Doak et al., 2007), France (Biotto et al., 2009), Italy (Silvestri and Omri, 2008; Carriero et al., 2018) and Serbia (Vasiljević et al., 2012) demonstrates seriousness of the problem and suggests that analysis of IWD is challenging.

Vegetation can be critical indicator that characterizes land degradation and at the same time the direction of restoration works (Mao et al., 2018). Berendse et al. (2015) concluded that protection and restoration of diverse plant communities is essential to minimize soil erosion.

IWD can be assessed by using plant species; nevertheless, there is no typical plant species occurring on the sites because they contain diverse sources of waste materials which may array of hazardous substances. However, these localities can be characterized as synanthropic with the typical flora (Bryant et al., 2017). Synanthropic vegetation typically occurs near settlements and splits into two subsets: ruderal and segetal. In the case of dumps, we speak of ruderal vegetation as it occurs on disturbed places in towns, villages or other sites in some way affected by humans, being left to spontaneous development (Chytrý, 2009). These localities are very diverse and include building estates, rubbish heaps, ruins, dumping grounds, railways, abandoned quarries, gravel pits and the like. This type of vegetation occurs on diverse soil types (Ujhazy, 2014; Żołnierz et al., 2016). According to Wania et al. (2006), sites affected by human activities are typically colonized by allochthonous plant species in the form of neophytes or archeophytes. Connell and Slatyer (1977) maintain there are three possible models of succession, the process being based on relationships between populations participating in succession: (1) model of mediation (one species prepares soil prior to a further modification of abiotic conditions of the environment; (2) model of tolerance (plant species neither promote nor suppress the growth of other species, winning the ground gradually thanks to slower growth, longevity a limited spreading; (3) model of inhibition (early stage of succession prevents other species from taking roots – shading, competition, depletion of nutrients). The younger stage of succession is generally more susceptible to disturbance than the older stages. The persistence of allochthonous dominant plant species on specific sites can be very long. In the later stages of succession, the engagement of invasive communities is restrained by the already developing herb or woody layers (Bastl et al., 1997).

Vegetation succession of IWD is manifold depending on waste composition and decomposition. All this influences the consequent species composition and succession. Waste can be a source for spreading expansive and invasive plant species such as *Atriplex* sp., *Chenopodium* sp., *Amaranthus* sp., *Sisymbrim* sp. (Jehlík, 1998). These species are dangerous for autochthonous plants, which are pushed out by them, slowly disappear from the landscape and become endangered (Laštůvka and Šťastná, 2014). These species alter the functioning of ecosystems, too, by disturbing competition and predatory behaviour, which can lead to reduced biodiversity or loss of indigenous species (Mooney, 2005).

The existence of IWD is an environmental problem in most countries. However, its research is limited by availability and creditability of data in this issue. Current studies of IWD are focused only on geographical aspects or on causes of their coming to existence (lacking awareness about the environment, deficient waste management systems and role of municipal administration) (Ferrara, 2011; Jordá-Borrell and Ruiz-Rodrígez, 2014; Di Fiore et al., 2017; Carriero et al., 2018; D'Amato et al., 2018; Wright et al., 2018).

On the basis of the above reasoning, it was hypothesized that IWD can disturb the species composition of native vegetation and create space for the enforcement of synanthropic as well as invasive plant species. These species may then spread from the IWD and affect the species composition of the natural ecosystems.

The primary objective of this study was to search localities with the occurrence of IWD in the defined rural area of Western Slovakia, to (1) identify the types of waste, (2) to assess the vegetation species composition, (3) and based on the obtained data to define relationships between waste types and vegetation growing on the IWD for future land restoration reclamation, rehabilitation.

2. Material and methods

2.1. Characterization of localities

The research took place on two sites in the municipality of Malé Leváre, Malacky District, Bratislava Region, Slovak Republic (SR) (Fig. 1). Geographical location of the municipality is defined by coordinates 48°30′ northern latitude and 16°58′ eastern longitude. Cadastral area of the municipality is 2140 ha and the number of

inhabitants is 1208. The surveyed sites occurred near the built-up area with a good access for cars. Site I with the GPS coordinates 48°30′N, 16°57′E was situated on a sunny place near the built-up area and consisted of balks and unkempt vegetation. This locality was dominated by *Robinia pseudoacacia.* Site II with the GPS coordinates 48°30′N, 16°58′E was situated in a mixed forest. The occurring vegetation included *Pinus sylvestris*, *Robinia pseudoacacia*, but also *Sambucus nigra.*

2.2. Assessment of vegetation on illegal dumps

The research of plant species consisted in the mapping of localities with the occurrence of IWD. On selected sites with IWD, six permanent plots were established, each of 16 m^2. These plots were studied by using the form of phytocoenological relevés. The phytocoenological relevés were made during the growing season three times a year – in spring (April), summer (July) and autumn (September). Each relevé contained a general part with information on the locality (name, altitude, GPS coordinates, area size and date) and a practical part. The practical part included a list of all plant species occurring on the plot with the cover in individual storeys (E3-tree layer, E2-shrub layer, E1-herb layer, E0-moss layer) and total cover of the plot. The degree of plant species coverage was determined by using the modified Braun-Blanquet 9-membered coverage scale (Table 1), which replaced the 7-membered Braun-Blanquet scale (van der Maarel, 2013). The total number of phytocoenological relevés was 18.

2.3. Research of waste composition

Within the survey of plants, we also recorded the occurrence of waste. Photographs documented each permanent plot and occurring waste types were recorded. The monitoring of these IWD took place from 2014 to 2017. The composition of waste did not change markedly. The occurring waste types were divided into categories such as inert waste, hazardous waste and other waste (communal waste) and classified according to the Decree of the Ministry of the Environment No. 365/2015 Coll., Establishing the Waste Catalogue, based on the regulations of the European Union (EU). The complete classification of waste types occurring on the investigated IWD is presented in Table 2.

2.4. Methodology of statistics

The phytocoenological relevés were processed by using the multivariate analysis of ecological data in the Canoco 4.0 programme (Ter Braak, 1998). The detrended correspondence analysis (DCA) was used to calculate gradients in large and typify ecological community data. The relation between the detected vegetation and waste types was assessed by using the Canonical Correspondence Analysis (CCA). Significance testing by using the Monte Carlo test included recalculation of 999 permutations.

Table 1
The ordinal transform of Braun-Blanquet cover abundance scale.

Ordinal transform values	Cover interpreted interval	Average cover interval
r	1–2 individuals	0.01
+	1%	0.5
1	1–5%	3
2	5–25%	–
2m	ca. 5%	5
2a	5–15%	10
2b	15–25%	20
3	25–50%	37.5
4	50–75%	62.5
5	75–100%	87.5

Table 2
Classification of waste types found on the surveyed IWD.

Waste Codes	List of Waste
16 01 99	Wastes not otherwise specified
17 01 01	Concrete
17 01 02	Bricks
17 01 03	Tiles and ceramic products
17 06 04	Insulation materials not listed under 17 06 01 and 17 06 03
17 08 02	Gypsum-based building materials not specified under 17 08 01
20 01 01	Paper and cardboard
20 01 02	Glass
20 01 11	Textile materials
20 01 38	Wood not specified under 20 01 37
20 01 39	Plastic materials
20 01 40	Metals
20 02 01	Biologically decomposable material
20 02 02	Soil and stones
20 03 99	Communal wastes not otherwise specified

3. Results and discussion

3.1. Results of phytocoenological relevés

The composition of plant species was developing and changing in each monitored period (Table 3). The diversity of species was the highest in the first period (spring) and gradually decreased in the other two periods. Both localities exhibited the greatest cover in the herb layer E1. In this first period, woody plants still did not start their development. In general, Plot I showed the occurrence of 16 plant species. In the second period, there were only 6 plant species and the same number of plant species was recorded in the third period. Dominant plant species occurring on Plot I included particularly *Bromus erectus*, which is not a synanthropic species. Common synanthropic species occurring on Plot I were *Lamium purpureum* and *Chelidonium majus*. These species were found in all phytocoenological relevés from the locality in all periods. In addition to these species, there were also non-synanthropic species occurring on the plot, viz. species ranking with cultural plants - *Lactuca sativa* and *Chenopodium quinoa.*

In the first period, Plot II was more diverse than Plot I not only as to the number of species but also in their total cover. The number of plant species recorded on Plot II in the first period amounted to 25. Dominant on this plot in the first period were woody plants in their juvenile stage. The shrub layer E2 in this locality was represented by *Ribes nigrum.* Herbs were abundant too, and were represented by synanthropic species similar to those on Plot I. However, due to different conditions, there were also other autochthonous species such as *Viola reichenbachiana* or *Humulus lupulus,* but also the rare reed grass species *Carex buxbaumii* or *Coriandrum sativum*, which is cultivated on fields and in gardens.

The second period or research showed that compared with the first period, the permanent plots had lower numbers of species. Although the total cover did not change markedly, the degree of coverage in the respective storeys changed. The tree layer was the greatest in a majority of the phytocoenological relevés. Shrubs that did not occur in the first period were abundant in this second period of research. By contrast, the herb layer exhibited the least cover. On Plot I, there were on average 4 species. One permanent plot showed the occurrence of *Vitis vinifera*, a cultural plant species occurring there likely as a remainder of vineyard orchards. The number of plant species on Plot II was considerably reduced (by a half). In this period, the woody plants moved into the shrub and tree layers. Dominant species in the tree layer was *Alnus glutinosa* followed by other woody plants occurring in the first period in juvenile stage. The shrub layer then exhibited the occurrence of smaller woody plants with the sole representative of shrubs being *Ribes nigrum*. The herb layer had the least cover.

Species diversity was the lowest in the third period. Total degree of

Table 3
Mean cover of plants growing on the monitored IWD.

Name of the plant species	Legend	Assessment date and locality (mean cover in percent)					
		April		July		September	
		Plot I	Plot II	Plot I	Plot II	Plot I	Plot II
Acer negundo jv.	*Ace negu*		0.0				
Alnus glutinosa	*Aln glut*		31.7		79.2		70.8
Arthriscus cerefolium	*Art cere*	0.0					
Artemisia vulgaris	*Art vulg*	3.3				2.7	
Ballota nigra	*Bal nigr*		0.0				
Bromus erectus	*Bro erec*	87.5		8.7			
Bromus sterilis	*Bro ster*		1.0				
Bromus tectorum	*Bro tec*	20.8	20.8		0.0		
Campanula alliariifolia	*Cam alli*		0.0				
Carex buxbaumii	*Car buxb*		3.3		0.2		0.2
Consolida orientalis	*Con orie*	0.0					
Coriandrum sativum	*Cor sati*		21.8				
Elymus repens	*Ely repe*	20.8					
Fallopia convolvulus	*Fal conv*		0.0		0.0		
Galium aparine	*Gal apar*	1.0	3.7				
Geranium pusilum	*Ger pusi*	0.2					
Geum urbanum	*Geu urban*		1.0				
Humulus lupulus	*Hum lupu*		3.3		2.7		0.2
Chelidonium majus	*Che maju*	15.2	37.5	3.7	5.3	3.0	0.2
Chenopodium album	*Che albu*	2.8					
Chenopodium quinoa	*Che quin*	0.0					
Impatiens parviflora	*Imp parvi*		0.0				
Lactuca sativa	*Lac sati*	0.0					
Lactuca serriola	*Lac serr*	0.0					
Lamium purpureum	*Lam purp*	11.7	7.7				
Lathyrus clymenum	*Lat clym*	0.0					
Lycium barbarum jv.	*Lyc barb*	0.0					
Parthenocissus quinquefolia	*Par quin*					1.7	
Prunus padus jv.	*Pru paJv.*		0.0				
Prunus padus E2	*Pru paE2*		5.0		8.3		1.0
Prunus padus E3	*Pru paE3*		40.0		37.5		48.3
Quercus jv.	*Que jv.*		0.0				
Ribes nigrum E1	*Rib niE1*		13.5		4.3		
Ribes nigrum E2	*Rib niE2*				3.3		2.7
Robinia pseudoacacia E2	*Rob psE2*			12.5			12.5
Robinia pseudoacacia E3	*Rob psE3*	9.3	1.0	62.5	12.5	70.8	
Robinia pseudoacacia jv.	*Rob psJv.*						0.0
Sambucus nigra E2	*Sam niE2*		33.3		1.7		0.2
Sambucus nigra E3	*Sam niE3*		3.3		19.2		13.5
Sambucus nigra jv.	*Sam niJv.*		0.0				
Solidago canadensis	*Sol cana*		1.7				
Stellaria media	*Ste medi*	1.0	14.3				
Urtica dioica	*Urt dioi*	13.5	20.8	21.8	1.7	13.5	
Veronica hederifolia	*Ver hede*	2.7	7.7				
Viola reichenbachiana	*Vio reic*		3.7		0.3		0.2
Vitis vinifera	*Vit vini*			6.7		12.5	

coverage was high though. This period of research in the autumn showed the greatest cover in the tree layer. The storey was represented by species occurring in the preceding periods. On the other hand, the lowest cover was recorded in the herb layer, which was represented on average by 3 species of which some occurred only in this period as in the case of *Parthenocissus quinquefolia* and *Artemisia vulgaris* occurring on Plot I. The herb layer on Plot II was represented only in the low degree of coverage.

Our research showed that many species were gradually proliferating and spreading. In this case, those were namely woody plants, which considerably competed with herbs by their growth. Both localities showed the occurrence of *Robinia pseudoacacia* as a common species in the region. Herbs occurring in both localities included *Bromus tectorum* as well as *Lamium purpureum*, *Stellaria media*, and *Veronica hederifolia*, which occurred in the first period of research. *Urtica dioica* was recorded on both plots only in the first and second periods. The phytocoenological survey revealed one species (*Chelidonium majus*) occurring on both plots in all research periods. Apart from the above-mentioned synanthropic species, there were also invasive species such as *Acer negundo*, *Lycium barbarum*, *Impatiens parviflora* or *Solidago canadensis* occurring in the localities; their degree of coverage was however only negligible as compared with the important invasive species of *Robinia pseudoacacia.*

3.2. Results of waste composition

Wastes occurring on Plot I and Plot II are communal wastes and construction debris. Catalogue numbers of waste types occurring on the monitored permanent research plots are presented in Table 4. Inert wastes were mainly construction and demolition waste, which were left there during the research period. Their composition did not change in the course of research, only their structure changed due to decay. Plot I exhibited in particular the inert refuse consisting of tiles and bricks in addition to communal waste (plastic materials, paper, glass and textiles). This plot exhibited also the occurrence of biologically decomposable waste from gardens (green waste, soil and bamboo rods). Plot II showed a great amount of glass and plastic materials. In addition, there were metal wastes, which were corroded. This locality contained inert

Table 4
Waste types detected on the surveyed IWD and on the individual phytocoenological relevés.

Waste types	Locality and relevé number					
	I			II		
	1	2	3	4	5	6
Wastes not otherwise specified	16 01 99					
Concrete				17 01 01		17 01 01
Bricks			17 01 02			
Tiles and ceramic products	17 01 03				17 01 03	
Insulation materials not listed under 17 06 01 and 17 06 03					17 06 04	
Gypsum-based building materials not listed under 17 08 01	17 08 02					
Paper and cardboard			20 01 01			
Glass	20 01 02	20 01 02		20 01 02	20 01 02	20 01 02
Textile materials	20 01 11	20 01 11				
Wood not listed under 20 01 37	20 01 38					
Plastic materials	20 01 39	20 01 39	20 01 39	20 01 39	20 01 39	20 01 39
Metals				20 01 40	20 01 40	
Biologically decomposable waste			20 02 01			
Soil and stones			20 02 02			

wastes such as concrete, tiles and insulation materials too. In general, the wastes occurring on Plots I and II did not show to have a significant influence on the composition of vegetation. Species occurring on these investigated IWD were mainly synanthropic. However, on one permanent plot, we recorded also cultural crops together with the biologically decomposable waste. Therefore, we assume that the plant species were brought to the dumps along with the waste.

3.3. Results of statistical processing methodology

Results of CCA analysis evaluating the relationship between the plant species and the waste types were significant at a level of significance $\alpha = 0.001$ for all canonical axes. Based on the CCA analysis (Fig. 2) the detected waste types and plant species can be classified in five groups by their common occurrence.

The first group consisted of plant species that occurred in the close vicinity of waste types 17 01 02 (bricks), 20 01 01 (paper and cardboard), 20 02 01 (biologically decomposable refuse), and 20 02 02 (soil and stones) (brown marked on Fig. 2). The group included *Artemisia vulgaris*, *Arthriscus cerefolium*, *Bromus erectus*, *Consolida orientalis, Chenopodium album, Chenopodium quinoa*, *Lactuca sativa*, *Lactuca serriola*, *Lycium barbarum*, and *Vitis vinifera.* The plant species are not indigenous and not typical of these sites. Therefore, we can assume that they were brought to the localities along with the biologically decomposable waste. Here, the waste is apparently an important source of propagules of numerous species belonging to cultivated crops (*Chenopodium quinoa*, *Lactuca sativa*, *Vitis vinifera*).

The second group consisted of waste types numbers 17 01 01 (concrete), 20 01 40 (metals), 17 06 04 (insulation materials) and 20 03 99 (wastes from the category of communal waste not otherwise specified – in this case it was seat filling material) (blue marked on Fig. 2) and plant species occurring in this group were *Acer negundo jv., Alnus glutinosa, Ballota nigra, Bromus sterilis, Campanula alliariifolia, Carex buxbaumii, Coriandrum sativum, Fallopia convolvulus, Galium aparine, Geum urbanum, Humulus lupulus, Impatiens parviflora, Prunus padus jv., Prunus padus E2, Prunus padus E3, Quercus jv., Ribes nigrum E1, Ribes nigrum E2, Robinia pseudoacacia jv., Sambucus nigra E2, Sambucus nigra E3, Sambucus nigra jv., Solidago canadensis, Stellaria media* and *Viola reichenbachiana.* These are species belonging primarily to the native vegetation (*Alnus glutinosa, Carex buxbaumii, Prunus padus, Viola reichenbachiana*). However, the site is affected by human activities and occurrence of wastes, which leads to the incidence of synanthropic species (*Ballota nigra, Galium aparine, Geum urbanum, Sambucus nigra*). Disturbed sites are favourable for the occurrence of invasive species such as *Acer negundo, Impatiens parviflora, Robinia pseudoacacia* and *Solidago canadensis*, which were found here.

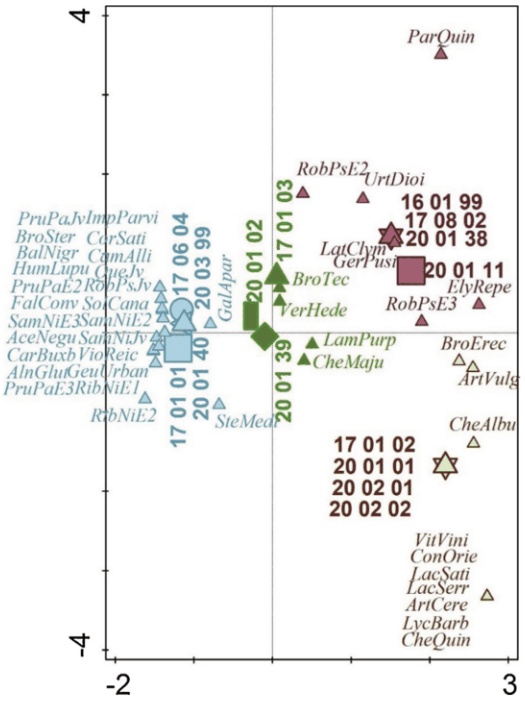


Fig. 2. Ordination diagram expressing the relationship between plant species and waste types (*F-ratio = 1.9*; *P-value = 0.001*).

The third group contained waste types 17 01 03 (tiles and ceramic products), 20 01 02 (glass), 20 01 39 (plastic materials) (green marked on Fig. 2). These waste types were detected on a majority of monitored sites. Plant species occurring together with these wastes were *Chelidonium majus*, *Lamium purpureum*, *Veronica hederifolia* and *Bromus tectorum* – plant species typical of sites affected by human activities and occurring on disturbed sites.

The fourth group consisted of waste types 17 08 02 (gypsum-based construction materials other than those mentioned in 17 08 01), 16 01 99 (wastes not otherwise specified – a rubber mat from the car), 20 01

11 (textile materials), 20 01 38 (wooden materials) (red marked on Fig. 2). These waste types were connected with the occurrence of *Elymus repens*, *Urtica dioica, Lathyrus clymenum, Geranium pusilum, Parthenocissus quinquefolia,* and *Robinia pseudoacacia.* Apparently, these waste types created conditions favourable for *Robinia pseudoacacia*, which subsequently affected the occurrence of the other plant species. The plant species of *Robinia pseudoacacia* significantly contributes to nitrogen content in the soil, which promotes the occurrence of nitrophilous vegetation (*Elymus repens*, *Urtica dioica, Geranium pusilum*), hence altering the species composition of native vegetation.

Our research results demonstrate that IWD disturb the species composition of native vegetation. This disturbance reflects namely in the occurrence of synanthropic plant species such as *Chelidonium majus* or *Sambucus nigra.* Further on, it opens the space for invasive plant species such as *Acer negundo, Impatiens parviflora, Robinia pseudoacacia* and *Solidago canadensis*. The waste itself may create conditions favourable for the occurrence of some species or contain propagules of allochthonous plant species. Thus, the IWD may be sources for the invasion of allochthonous plant species and influence the species composition of surrounding vegetation.

These sites are not aesthetic; they impair landscape appearance as well as the composition of naturally occurring vegetation. They also represent a risk of the occurrence of invasive plant species and a potential risk of environment contamination (Vaverková et al., 2019).

IWD represent a range of land degradation threats caused by uncontrolled and non-specific composition of wastes types occurring on them because hazardous wastes may have diverse toxic effects however, research provided on non-sanitary landfills in Hong Kong (Wong and Yu, 1989; Wong et al., 1992; Chan et al., 1997) confirmed that a restored non-sanitary landfill served as a suitable habitat for plants tolerant to pollutions (e.g. landfill gas and leachate) (Wong et al., 2016).

A great part of the IWD in the surveyed area consisted of inert waste types, especially those of group 17. Although the wastes are considered to be inert, they may be potential sources of the contamination of soils or groundwater by heavy metals (HM) or other pollutants (Butera et al., 2014; Yu et al., 2018). These types of waste may react with atmospheric depositions and precipitation water, which may lead to pH change and leaching of pollutants from the construction and demolition waste (Kaegi et al., 2017; López-Uceda et al., 2018; Yu et al., 2018). These reactions are hard to control since the IWD are not monitored.

Moreover, inert wastes may contain a great amount of harmful compounds (Huang et al., 2017; Saca et al., 2017; Yu et al., 2018): organic pollutants such as polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB) as well as inorganic elements. PAHs may originate from the contact with fractions containing tar (e.g. asphalt). While PCBs may originate from the contamination of PCB-containing products such as sealing materials and dyes, inorganic contaminants may originate from the use of alternative fuels (e.g. refuse). Cement, concrete and bricks may contain coal, ash or pollutants normally occurring in natural raw materials. These wastes may represent a serious problem for the environment because harmful inorganic compounds can be leached there into. Our research was focused on the influence of IWD on the vegetation species composition, the impacts of land degradation, and will continue by particular physical and chemical analyses of the contaminated sites.

4. Conclusion

Land Degradation Neutrality sets the goal of stabilizing or increasing the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security across the globe. There is an increasing pressure on land, and due to improper use (e.g. illegal waste dumps), land resources are quickly degrading, which is creating pressure on the remaining land. Illegal waste dumps have impacts on soil health, land degradation and land management. Moreover, illegal waste dumps may represent specific habitats for plants. One of the more significant findings to emerge from this study is that illegal waste dumps disturb the species composition of native vegetation and create space for the enforcement of synanthropic species as well as invasive plant species such. These allochthonous species may then spread from the illegal waste dumps and affect the species composition of natural ecosystems. The novelty of this work is that monitoring of vegetation can positively contribute to the evaluation of impacts of illegal waste dumps on the land degradation and land management. Illegal waste dumps should be removed, and the concerned localities should be reclaimed, rehabilitated or restored in accordance with the principles of Sustainable Development Goals to avoid further land degradation and promote land restoration.

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