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v Praze

Technologické hodnocení aktivátorů biologické transformace organické hmoty

Disertační práce

Obor:	Technika výrobních procesů
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Prohlášení

Prohlašuji, že jsem disertační práci na téma „Technologické hodnocení aktivátorů biologické transformace organické hmoty“ vypracoval samostatně pod vedením školitele doc. Ing. Petra Šařce, Ph.D. a s použitím literatury, která je citována a uvedena v příslušné bibliografii. Tištěná a elektronická verze práce se doslovně shodují.

JMÉNO A PŘÍJMENÍ: Ing. Václav Novák

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Poděkování

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Abstrakt

Disertační práce se zabývá problematikou efektu pomocných půdních látek v reakci na prohlubující se problémy spojené s půdními degradacemi. Konkrétně byl zkoumán aktivátor biologické transformace organické hmoty NeOsol, aktivátor biologické transformace statkových hnojiv Z'Fix a biouhel. Tyto pomocné půdní látky mají potenciál zlepšovat stav půdy a zvyšovat účinnost statkových hnojiv.

Cílem práce je ověření vlivu aplikace statkových hnojiv v kombinaci s pomocnými půdními látkami především na změnu fyzikálních vlastností půdy a sekundárně pak na stav vegetace. K dosažení těchto cílů byly založeny ve spolupráci se zemědělskými podniky po České republice víceleté polní pokusy. Předložená práce se zabývá hodnocením těchto látek z pohledu změny pedokompakce, půdní infiltrace, energetické náročnosti potřebné na zpracování půdy, výnosů zemědělských plodin a stavu vegetace. K hodnocení výše zmíněných faktorů byla prováděna nejen terénní měření, ale byly využity i metody Dálkového průzkumu Země.

Disertační práce přináší nová zjištění v problematice pomocných půdních látek. Dlouhodobá aplikace aktivátoru biologické transformace organické hmoty NeOsol v kombinaci se statkovými hnojivy dle všeho vede ke snížení tahového odporu a zvýšení výnosů zemědělských plodin. Ošetření statkových hnojiv pomocí aktivátoru Z'Fix způsobilo zlepšení půdní infiltrace, snížení tahového odporu, zlepšení stavu vegetace a zvýšení výnosů zemědělských plodin.

Výsledky, kterých bylo dosaženo v rámci předložené disertační práce mohou sloužit ke snížení environmentálních rizik při hospodaření na zemědělských půdách a k zefektivnění zemědělské produkce.

Klíčová slova: statková hnojiva, pomocné půdní látky, objemová hmotnost půdy, penetrační odpor, infiltrační schopnost, tahový odpor, NeOsol, Z'Fix, biouhel

Abstract

This Dissertation deals with soil amendments in the context of present severe issues with soil degradation. Activator of biological transformation of organic matter NeOsol, activator of biological transformation of farmyard manure Z'Fix, and biochar were investigated. These soil amendments are trusted to impact soil conditions positively and concurrently enhance the effect of farmyard manure.

The objective of the Dissertation is to clarify the influence of soil amendments in combination with farmyard manure, firstly in relation to the soil's physical properties and secondly to the crop status. Multiannual experiments were founded in cooperation with agricultural companies in the Czech Republic. Related studies investigate the effect of selected amendments in the context of pedocompaction, water infiltration, energy demand for soil tillage, crop yield, and vegetation status. Terrestrial measurements, the same as distant sensing methods, were utilized for data acquisition.

The Dissertation provides new findings on the topic of soil amendments utilization. Long-term application of farmyard manure combined with NeOsol apparently reduces the unit draft while increasing the crop yield. Farmyard manure treated by Z'Fix positively influenced water infiltration, unit draft, crop status and yield.

Outputs of the Dissertation, when applied to the practice, might be helpful for reducing environmental risks related to soil management. Such as, it might also help increase the efficiency of agricultural production.

Keywords: farmyard manure, soil amendments, soil bulk density, cone index, soil infiltration, implement draft, NeOsol, Z'Fix, biochar

Obsah

1 Úvod

Disertační práce se zabývá hypotézami v problematice využití pomocných půdních látek sloužících ke zlepšení půdních vlastností. Tato problematika je v současnosti velice aktuální, neboť z důvodu značného poklesu živočišné produkce v posledních desetiletích chybí v zemědělském půdním fondu dostatek organické hmoty. To má v konečném důsledku zásadní negativní vliv na kvalitu a úrodnost zemědělské půdy. Živočišná produkce vždy představovala přidanou hodnotu pro produkci rostlinnou z pohledu navracení organické hmoty do půdy.

Počátek poklesu stavů hospodářských zvířat přišel se změnou politického režimu v devadesátých letech a s ohledem na současnou zemědělskou politiku lze očekávat, že se tento trend bude držet i nadále. Změna klimatu, současný růst populace, zábory půdy – to jsou jen některé z výzev pro současné zemědělství. Na tuto výrobní oblast jsou tak kladeny čím dál vyšší nároky s důrazem na efektivní využívání zdrojů a udržitelnost.

Jednou ze strategií, jak podpořit zlepšování kvality půdy a také jak využít potenciálu stále se snižujícího objemu statkových hnojiv, mohou být právě pomocné půdní látky. Jedná se o látky, které zlepšují stav půdy či zvyšují účinnost hnojiv. V této disertační práci byl zkoumán jednak aktivátor biologické transformace organické hmoty NeOsol, dále pak aktivátor biologické transformace statkových hnojiv Z’Fix a biouhel.

Výzkumná část předložené disertační práce je složena z komentovaného souboru sedmi odborných článků, které byly publikovány v indexovaných vědeckých periodikách či na konferencích. Všechny tyto publikace prošly recenzním řízením a splnily požadavky, které jsou kladeny na tento typ publikačních výstupů. Jednotlivé odborné články obsahují původní vědecké studie, které se pojí k tématu předkládané disertační práce. Jsou obsaženy v přílohách této práce a jednotlivě okomentovány. Řazení předložených publikací bylo zvoleno s ohledem na jejich návaznost. Studie se vzájemně doplňují či rozšiřují zkoumanou problematiku, a mapují tak autorův výzkum v rámci jeho postgraduálního studia.

2 Přehled o současném stavu problematiky

Současné zemědělství využívá k maximalizaci produktivity celou řadu moderních technologií, mezi něž se řadí senzorika, umělá inteligence, dálkový průzkum Země, Big Data, Internet věcí (IoT) a další. Tyto technologie umožňují snižování vstupů nezbytných pro zemědělskou produkci a zároveň zajišťují dosahování vyšších výnosů (Rose et al., 2021). Tento koncept, který využívá moderní technologie a přístupy k zohledňování variability výrobního prostředí, se obecně označuje jako Precizní zemědělství. V kontextu této praxe není výjimkou, že jsou na pozemcích minimalizovány náhodné přejezdy pomocí technologie CTF (Controlled Traffic Farming), dochází k variabilnímu hnojení pomocí senzorů umístěných na zemědělských strojích či se objevují první průkopníci polní robotiky.

Je patrné, že současné zemědělství prochází díky rozvoji na poli technologií a vědeckým poznatkům zásadní změnou. Tento stav poznání s sebou však nenese pouze pozitivní jevy, ale klade také vyšší nároky na zodpovědnost v péči o krajinu s ohledem na ochranu životního prostředí a udržitelnost.

Intenzifikace zemědělství společně se změnami v osevních postupech, kdy dochází k upřednostňování ekonomicky výhodnějších plodin, zrychluje degradační procesy v půdě (Žížala & Kristenová, 2012). Problematika půdní degradace přitom není novým fenoménem, datuje se přibližně k roku 3500 př.n.l., kdy zemědělci začali využívat vysoce erodovatelné půdy na strmých svazích (Montgomery, 2012). Ve 21. století však půdní degradace ohrožuje více než jednu třetinu pevniny planety Země. O závažnosti půdních degradací není sporu, jsou proto zařazeny i ve strategii na ochranu půdy Soil Thematic Strategy od Evropské komise (Lal, 2015).

Na národní úrovni je téma půdní degradace zařazeno ve Strategii resortu Ministerstva České republiky (dále jen "Národní strategie") s výhledem do roku 2030. Jedná se o cíl A.8 – Zvyšování ochrany půdy v době klimatické změny s ohledem na udržitelné hospodaření a na komplexní rozvoj a tvorbu krajiny, který uvádí jako dílčí cíl (Ministerstvo zemědělství České republiky, 2016): *Zastavení degradace zemědělské půdy zejména nadměrnou erozí, utužením*[1]*, úbytkem organické hmoty a kontaminací*

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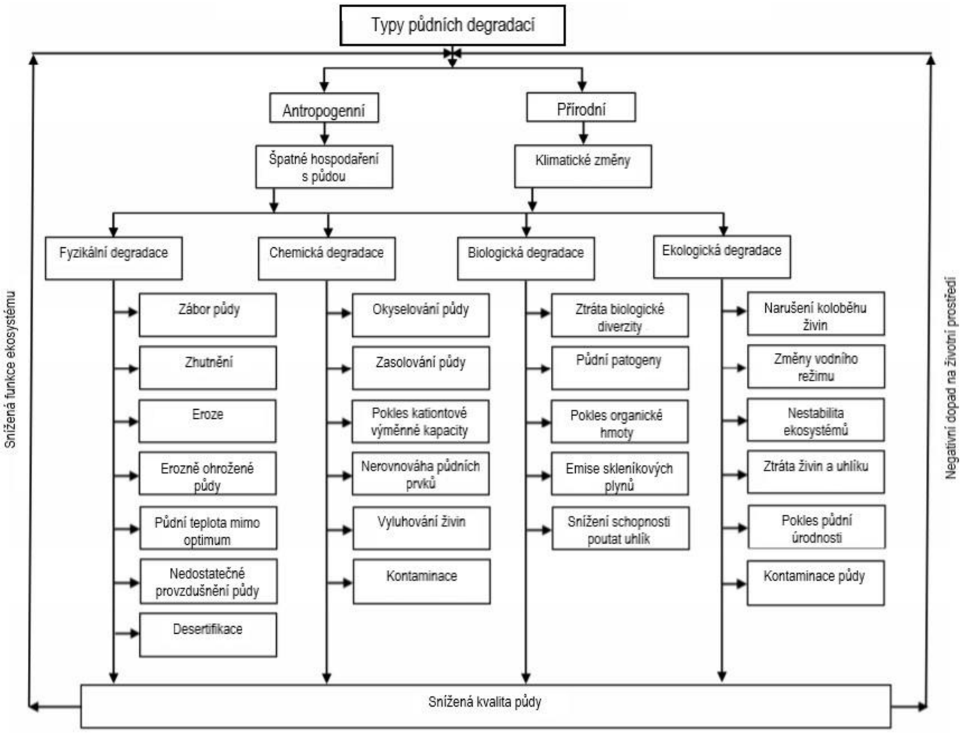
[1] Pravděpodobně se má jednat o půdní zhutnění – pozn. autora.

v exponovaných územích ČR a dále eliminovat vyčerpání živin nevhodnými způsoby obhospodařování.

Na problematiku půdních degradací lze nahlížet z více hledisek. Jedno z možných rozdělení popsal Lal (2015), který prezentoval jejich rozdělení z hlediska působících faktorů (obrázek 1).

Obrázek 1 Rozdělení půdních degradací



Zdroj: (Lal, 2015), přeložil autor

Eroze půdy, která je jedním z hlavních procesů vedoucích k půdní degradaci, má za následek ztrátu organické hmoty, která v konečném důsledku vede ke ztrátě schopnosti půdy zadržovat vodu a živiny (Pimentel, 2006). V současné době je v České republice ohrožena vodní erozí více než polovina zemědělské půdy, u větrné eroze se jedná o více než čtvrtinu rozlohy zemědělské půdy (Žízala & Kristenová, 2012). Ztráty půdy způsobené erozí se dají v České republice vyčíslit na zhruba 4,3 miliard Kč ročně (Podhrázská et al., 2016). V naprosté většině případů postihuje eroze svrchní vrstvu půdy, která je klíčová pro zajištění optimálních podmínek pro rostlinnou produkci. Mimo místních dopadů má eroze půdy za následek také významné dopady i mimo lokalitu jako je například odnos půdy do vodních toků (Scheurer et al., 2009). S ohledem na klimatickou změnu a celosvětově zvýšenou variabilitu prostorové i časové distribuce srážek se předpokládá, že bude jev půdní eroze nabývat na intenzitě (Nearing et al., 2004; Papalexiou & Montanari, 2019).

Dalším neméně závažným typem půdní degradace, která je zařazena v Národní strategii, je půdní zhutnění. Půdní zhutnění v České republice v současné době ohrožuje zhruba 40 % zemědělských půd (Ministerstvo zemědělství České republiky, 2022). Zhutnění půdy snižuje obsah pórů v půdách, to vede ke zhoršené dostupnosti vody a živin pro rostliny, omezení růstu kořenového systému, omezení přístupu vzduchu pro kořenový systém rostlin, ale také ke snížení aktivity půdních mikroorganismů (Hamza & Anderson, 2005). Mimo tyto zmíněné negativní aspekty může půdní zhutnění snížit výnos polních plodin až o 50 % v závislosti na hloubce a úrovni zhutnění (Hamza & Anderson, 2005; Sidhu & Duiker, 2006). Míra zhutnění může být značně prostorově variabilní. Existuje zde závislost zhutnění půdy na intenzitě, rozložení provozu zemědělských strojů a také na půdním zpracování. Zatímco vlastnosti ve svrchní vrstvě půdy se mohou v krátkodobém horizontu lišit (v důsledku sezónních postupů při obhospodařování půdy a klimatické změny), zhoršené vlastnosti v podorničí mohou přetrvávat po desetiletí (Alaoui & Diserens, 2018).

Na odolnost půdy proti degradaci má vliv i optimální obsah organické hmoty v půdě. Zajištění aplikace optimálního množství organické hmoty do půdy má pozitivní účinky na fyzikální, chemické a biologické vlastnosti půdy (Gai et al., 2019; Thomas et al., 1996). V podmínkách České republiky je roční spotřeba nehumifikovaných organických látek zhruba 4 až 4,5 $t.ha^{-1}$. Toto množství je z 50 až 60 % zajištěno pomocí posklizňových zbytků. Zbývající část je třeba doplňovat pomocí organických hnojiv (Škarpa, 2014).

Jak již bylo zmíněno v úvodu této práce, v posledních desetiletích lze pozorovat významné snižování stavu hospodářských zvířat. S tímto snižováním souvisí také problém nedostatku organické hmoty v půdě (Sálusová, 2018). Živočišná výroba patří v zemědělství k nejnáročnějším pracovním odvětvím, které klade vysoké nároky nejen na materiál a organizaci práce, ale také na pracovní síly (Věžník et al., 2013). Zatímco před rokem 2004 byla Česká republika soběstačná v rámci živočišné výroby, v současnosti je do jisté míry závislá na dovozu zejména vepřového a drůbežího masa (Věžník et al., 2017). S ohledem na ekonomickou situaci chovu hospodářských zvířat, kdy se například ziskovost krav bez tržní produkce mléka v České republice pohybuje na nízkých 2,15 % (Syrůček et al., 2017), lze jen těžko očekávat opětovný výrazný nárůst živočišné produkce.

Toto tvrzení navíc podporuje odhad, který tvrdí, že v rámci společné zemědělské politiky Evropské Unie a Zelené dohody pro Evropu (v současnosti známé spíše pod anglickým názvem Green Deal) lze předpokládat úbytek hospodářských zvířat o 10–15 % (Jongeneel et al., 2021).

Hledat cesty, které povedou k udržitelné zemědělské produkci, považuje autor této disertační práce za klíčové. Je třeba zajistit vhodné podmínky pro pěstování dostatečného množství potravin pro stále rostoucí populaci, přičemž je třeba brát v potaz, že rozloha zemědělské půdy se rapidně snižuje – v České republice dochází denně k záboru až 25 hektarů půdy (Janků et al., 2016). Z tohoto tvrzení je zřejmé, že na zemědělskou půdu budou kladeny nároky jako nikdy v historii.

Jak již bylo zmíněno výše, jednou z možností jak zlepšit půdní prostředí je navracení organické hmoty zpět do půdy, například ve formě tradičních statkových hnojiv. S ohledem na předpoklad snižování stavů hospodářských zvířat je však třeba hledat i jiné strategie, které pomohou zajistit udržitelné zemědělství. Jednou z možných cest může být využití pomocných půdních látek.

2.1 Pomocné půdní látky

Pomocné půdní látky jsou v české legislativě definovány zákonem 299/2021 Sb. – O hnojivech, pomocných půdních látkách, pomocných rostlinných přípravcích a substrátech a o agrochemickém zkoušení zemědělských půd:

> *Pro účely tohoto zákona se rozumí:*
>
> *a) hnojivem látka obsahující živiny pro výživu kulturních rostlin a lesních dřevin, pro udržení nebo zlepšení půdní úrodnosti a pro příznivé ovlivnění výnosu či kvality produkce*
>
> *b) statkovým hnojivem hnůj, hnojůvka, močůvka, kejda, sláma, jakož i jiné zbytky rostlinného původu a další vedlejší produkty vzniklé chovem hospodářských zvířat, vznikající zejména v zemědělské prvovýrobě, nejsou-li dále upravovány*
>
> *c) pomocnou půdní látkou látka bez účinného množství živin, která půdu biologicky, chemicky nebo fyzikálně ovlivňuje, zlepšuje její stav nebo zvyšuje účinnost hnojiv*
>
> *d) pomocným rostlinným přípravkem látka bez účinného množství živin, která jinak příznivě ovlivňuje vývoj kulturních rostlin nebo kvalitu rostlinných produktů.*

V následujících podkapitolách jsou podrobněji popsány pomocné půdní látky, které byly použity v rámci disertační práce.

2.1.1 Aktivátor biologické transformace organické hmoty NeOsol

Tento přípravek spadá do kategorie pomocných půdních látek, konkrétně je označován jako aktivátor biologické transformace organické hmoty a je vyráběn společností Olmix Group (dříve PRP Technologies). NeOsol funguje na bázi dolomitického vápence a vápenatých sedimentů s použitím technologií MIP (Mineral Inducer Process) a SEADRY (SEAweed DRY extracts for underground life stimulation). Patentovaný technologický postup MIP spočívá v aktivaci buněčných metabolismů pomocí řízeného přísunu určitých minerálních prvků, které jsou v přesně definovaných formách a poměrech. Technologie SEADRY používá výtažků z mořských řas, které mohou být metabolizovány půdní mikroflórou. Tyto technologie dle výrobce příznivě stimulují biologickou aktivitu, která poté pozitivně působí na půdu i plodiny (Olmix Group, 2022).

Přípravek splňuje zákonem stanovené limity obsahu rizikových prvků v miligramech na kilogram sušiny: kadmium – 1,5 mg.kg^{-1}; olovo – 30 mg.kg^{-1}; rtuť – 0,5 mg.kg^{-1}; arsen – 20 mg.kg^{-1}; chrom – 50 mg.kg^{-1}. Tento přípravek se aplikuje pomocí rozmetadel minerálních hnojiv. Chemické složení toho přípravku je popsáno v tabulce 1.

Tabulka 1 Chemické složení přípravku NeOsol

Vápník ve formě CaO	28 %
Hořčík ve formě MgO	15,9 %
Spalitelné látky v sušině	25 %
Neutralizační hodnota	49 %
Hodnota pH	8–10

Zdroj: (Olmix Group, 2022)

Dle metodiky českého distributora je aplikace tohoto přípravku vhodná pro všechny půdní typy i druhy bez ohledu na způsob zpracování půdy. Nejlepších výsledků by mělo být dosaženo při aplikaci na strniště, bezprostředně po sklizni plodin. Následující doporučenou operací je mělká podmítka. Tím by mělo dojít k okamžitému nástupu účinku a k optimalizaci rozkladu posklizňových zbytků (Václavík, 2018).

Doporučené dávkování se pohybuje pro obiloviny, ozimou řepku a mák setý v rozmezí 150–300 kg.ha^{-1}. Pro kukuřici na siláž je doporučené dávkování v rozmezí 200–300 kg.ha^{-1} (Olmix Group, 2022).

Přípravek nesl původní obchodní název PRP SOL, se změnou vlastníka firmy se v současné době distribuuje pod názvem NeOsol. Z tohoto důvodu je v přiložených publikacích používán i předchozí obchodní název PRP SOL.

2.1.2 Aktivátor biologické transformace statkových hnojiv Z'Fix

Dalším aktivátorem, tentokrát pro biologickou transformaci statkových hnojiv, je přípravek Z'Fix. Aktivátor je vyráběn společností Olmix Group a má certifikaci pro použití v ekologickém zemědělství. Jedná se o granulát, který je vyroben na bázi vápenatých a hořečnatých uhličitanů s příměsí mikroelementů. Dle principů MIP je tento přípravek určen k regulaci kvasných procesů ve statkových hnojivech a v kompostech. Přípravek primárně slouží ke zlepšení welfare a čistoty zvířat ve stájových chovech, neboť může být aplikován přímo do hluboké podestýlky (Olmix Group, 2022). Složení tohoto přípravku lze najít v tabulce 2.

Tabulka 2 Složení přípravku Z`Fix

Organické látky	5,0 %
CaO	37,5 %
MgO	4,4 %
Na_2O	3,9 %
SO_3	0,7 %
K_2O	0,5 %
P_2O_5	0,1 %
N celkový	0 %
Železo	2000 $mg.kg^{-1}$
Mangan	150 $mg.kg^{-1}$
Zinek	30 $mg.kg^{-1}$

Zdroj: (Olmix Group, 2022)

Aplikace přípravku Z'Fix je možná i v přítomnosti dobytka, přičemž množství a doba použití přípravku se liší dle druhu hospodářských zvířat. Přípravek Z'Fix lze také použít ex post pro všechny druhy statkových hnojiv (Olmix Group, 2022).

Dle metodiky českého distributora je maximálního účinku tohoto přípravku dosaženo po jednom až dvou týdnech, a to v závislosti na teplotě a vlhkosti vzduchu ve stáji. Z tohoto důvodu je doporučováno jej použít u podestýlky, která je využívána déle než tři týdny (Petrtýl, 2018).

Tento přípravek byl v roce 2021 oceněn zlatou medailí na veletrhu Animal Tech v Brně za *Inovativní přípravek s významným přínosem pro živočišnou výrobu*. Ocenění udělila redakce časopisu Náš chov (Profi Press).

2.1.3 Biouhel – Agrouhel

Biouhel je pomocná půdní látka, která je často označována jako půdní kondicionér a která je příkladem tzv. oběhového hospodářství (cirkulární ekonomiky). Hlavní složkou je stabilní uhlík, který je vytvořen z biomasy. Biomasa se zahřívá na teploty mezi 300 a 1000 °C pod nízkou (nejlépe nulovou) koncentrací kyslíku. Tento materiál lze přirovnat k dřevěnému uhlí. Jediný rozdíl mezi ním a biouhlem je v záměru použití. Z pohledu fyzikálně-chemického se však jedná o ten samý materiál (Verheijen et al., 2010).

V rámci experimentů, které jsou popsány v přílohách II, III, IV byl využit biouhel od tuzemského výrobce ze Zlína společnosti BIOUHEL.CZ s.r.o., s obchodním označením Agrouhel.

Agrouhel je vyroben ze směsi, která obsahuje (BIOUHEL.CZ, 2022):

separát z digestátu (kukuřice) 30–40 %
drcenou obilnou slámu 30–40 %
drcenou biomasu z údržby zeleně 20–40 %

Výroba Agrouhlu probíhá pyrolýzou o teplotě 450–470 °C, doba trvání pyrolýzy je 20–30 minut, složení tohoto přípravku se nachází v tabulce 3.

Tabulka 3 Složení přípravku Agrouhel

Spalitelné látky ve vysušeném vzorku	min. 45 %
Sušina	min. 60 %
Celkový uhlík jako C v sušině	min. 45 %
Celkový dusík jako N v sušině	min. 1 %
Celkový fosfor jako P_2O_5 v sušině	16 (±20 %) mg.kg^{-1}
Celkový draslík jako K_2O v sušině	17 (±20 %) mg.kg^{-1}
Vápník jako CaO v sušině	56,3 (±20 %) mg.kg^{-1}
Hořčík jako MgO v sušině	6,6 (±20 %) mg.kg^{-1}
Hodnota pH	9–11

Zdroj: (BIOUHEL.CZ, 2022)

Obsah rizikových prvků splňuje zákonem stanovené limity v miligramech na kilogram sušiny: kadmium – 1 mg.kg^{-1}, olovo – 10 mg.kg^{-1}, rtuť – 1,0 mg.kg^{-1}, arzen – 20 mg.kg^{-1}, chrom – 50 mg.kg^{-1} (BIOUHEL.CZ, 2022).

2.2 Současný stav poznání aktivátorů biologické transformace

V současné době není problematika efektu aktivátorů na vlastnosti půdy příliš vědecky prozkoumaná. Výzkum se zatím orientoval spíše na otázku welfare zvířat. Látal et al. (2015) uvádí, že aktivátor biologické transformace statkových hnojiv Z'Fix může zlepšit stájové prostředí a snížit emisní zátěž NH_3. Zároveň bylo zjištěno, že ošetřený hnůj aktivátorem vykazoval zvýšení kvality a obsahu živin. Další studie tyto závěry potvrzuje a zároveň hodnotí ekonomický dopad při ošetření hnoje aktivátorem Z'Fix. Hnůj, který byl ošetřen, vykazoval nejen zvýšený obsah živin, ale také 35% snížení emisí NH_3. Při použití aktivátoru Z'Fix do hluboké podestýlky lze dle autorů dosáhnout snížení spotřeby slámy o 35 %. Celková úspora byla vyčíslena na 1369 Kč.dobytčí jednotka^{-1}.rok^{-1} (Šařec, Látal, et al., 2017).

Již se objevují studie, které popisují vliv aktivátorů na vlastnosti půdy. Výzkum, který probíhal na těžkých půdách, ukazoval v prvním roce od aplikace příznivý vliv na fyzikální půdní vlastnosti. Jednalo se o změnu penetračního odporu, objemové hmotnosti půdy a tahového odporu. Při použití hnoje a výše zmíněných aktivátorů došlo ke snížení tahového odporu o 3 % (Šařec & Žemličková, 2016). Navazující práce hodnotila tříleté výsledky. Byla potvrzena zlepšená homogenita půdního prostředí. Při použití hnoje a aktivátorů biologické transformace činil pokles tahového odporu 5 %. Autoři poukazují na pozitivní vliv aktivátorů u těžkých půd (Šařec & Novák, 2017b). Tyto výsledky jsou v souladu se zjištěním studie od Urbanovičová et al. (2018). Ta uvádí, že aktivátor biologické transformace organické hmoty příznivě ovlivňuje půdní zhutnění, a to do hloubky 30 cm. Dále bylo v této studii popsáno zlepšení půdní infiltrace a snížení tahového odporu o 5,71 %. Naopak Dumbrovský et al. (2011) nezaznamenal u tříletých výsledků na těžkých půdách žádné zlepšení fyzikálních vlastností půdy po aplikaci 200 kg.ha^{-1} přípravku PRP SOL. Půda na sledované lokalitě na konci experimentu stále vykazovala známky degradace. Kotorová et al. (2015) doporučuje na základě experimentů používat přípravek PRP SOL u těžkých půd při přímém setí v bezorebných zemědělských systémech. Kováč et al. (2017) popsal, že přípravek PRP SOL má pozitivní efekt při pěstování pohanky, zejména potom při konvenčním zpracování půdy.

Výsledky použití aktivátorů na hlinitých půdách, v prvním roce po aplikaci, poukazovaly na nárůst tahového odporu o 0,38 %, nejednalo se však o statisticky významnou změnu (Žemličková & Šařec, 2016). Z hlediska infiltračních schopností půdy v prvním roce po aplikaci u hlinité půdy nebylo možné potvrdit či vyloučit příznivé účinky aktivátorů (Šařec & Novák, 2016). Tohoto výsledku bylo dosaženo i po dvou letech používání těchto přípravků. Nicméně bylo dosaženo snížení objemové hmotnosti půdy a to zejména ve svrchní vrstvě. Výsledné hodnoty penetračního odporu neprokázaly pozitivní efekt kombinace hnoje s aktivátory (Šařec & Novák, 2017a). Pospíšilová et al. (2016) uvádí, že účinky aktivátoru PRP SOL jsou významně ovlivněny dávkou, půdním typem, ročníkem, a také časovým efektem. Autoři doporučují aplikovat dávku v rozmezí 150–600 kg.ha^{-1}.

S ohledem na těsný vztah půda-rostlina je možné hodnotit vliv těchto aktivátorů i pomocí stavu vegetace. Šařec et al. (2017) uvádí, že kombinace statkového hnoje a aktivátorů má pozitivní vliv na hodnoty vegetačního indexu NDVI (Normalized Difference Vegetation Index) a to zejména během hlavních růstových fází. Dle výsledků indexu MSI (Moisture Stress Index) byly rostliny na takto ošetřené půdě také méně stresovány nedostatkem vody. Borowiak et al. (2016) uvádí pozitivní efekt přípravku PRP SOL na fotosyntézu a růst rostlin. Momentální stav rostlin samozřejmě značně ovlivňuje také výsledný výnos plodin. Sulewska et al. (2018) zjistila pozitivní vliv kombinace přípravků PRP SOL a PRP EBV, na výnos a hmotnost tisíce zrn, při pěstování lupiny žluté. Hřivna (2010) ve své práci uvádí, že přípravek PRP SOL a PRP EBV pozitivně ovlivňuje výnos sladovnického ječmene. Kombinací těchto dvou přípravků bylo dosaženo nejvyšších mechanických znaků zrna.

Autoři těchto studií se často shodují v názoru, že je třeba tyto přípravky podrobit dlouhodobému výzkumu, který bude probíhat na více lokalitách tak, aby byly zajištěny výsledky napříč variabilními půdními, topografickými i klimatickými podmínkami.

2.3 Současný stav poznání biouhlu

Z rostoucího počtu vědeckých studií na téma využití biouhlu lze usuzovat, že právě udržitelnost je jedním z trendů současného hospodaření člověka v krajině.

Důvodem, proč měnit vstupní biomasu na biouhel, je, že zatímco uhlík v podobě biouhlu vydrží v půdě stovky či tisíce let tak ve formě rostlinného materiálu by se jednalo o desítky let (Verheijen et al., 2010). Právě vysoký obsah uhlíku z něj dělá zjevně prospěšný materiál pro půdní prostředí. Tento obsah se však liší dle použitého materiálu a také dle podmínek, za kterých pyrolýza probíhá. Obsah uhlíku může dosahovat až 90 %. Předpokládá se, že tento materiál zvyšuje sekvestraci uhlíku v půdě (Ippolito et al., 2017).

Využití pyrolýzy se tedy ukazuje jako efektivní řešení zpracování zbytkového odpadu ze zemědělské výroby a je také slibným nástrojem pro snižování skleníkových plynů (Lehmann et al., 2006; Tamelová et al., 2019).

Mnoho vědeckých studií se zaměřuje na fyzikální či chemické vlastnosti samotného biouhlu (Conti et al., 2016; Rosa et al., 2014; Yuan et al., 2015). Část vědeckých studií se zaměřuje na chování biouhlu v půdním profilu (Lehmann et al., 2006; Rasa et al., 2018). Diskutována bývá také otázka potenciální ekotoxicity (Zhang et al., 2020).

Nicméně výsledky, které se týkají fyzikálních vlastností půd po aplikaci biouhlu, naznačují, že může být odpovědný za snížení objemové hustoty půdy (Razzaghi et al., 2020). S ohledem na vysokou porozitu může biouhel podporovat kapacitu zadržování vody v půdním profilu, která může být využita rostlinami v období bez srážek (Kizito et al., 2015; Tanure et al., 2019). Lei & Zhang (2013) pro vyšší schopnost zadržovat vodu doporučují používat biouhel, který byl vyroben za vyšších teplot pyrolýzy. Ukázalo se, že účinek snížení objemové hustoty půdy a kapacity zadržování vody v půdě silně koreluje s velikostí částic biouhlu. Celkový účinek je však ovlivněn také půdním typem (Verheijen et al., 2019). Kalu et al. (2021) uvádí, že je třeba sledovat účinky biouhlu v dlouhodobém časovém horizontu. Jejich studie popisuje pozitivní vliv biouhlu na fyzikální vlastnosti půdy. Tento vliv však postupně v průběhu osmiletého pokusu opět vymizel. Z hlediska dlouhodobého účinku na výnos plodin nebyl zaznamenán žádný významný účinek. Vliv biouhlu na fyzikální vlastnosti půdy a stav vegetace je ovlivněn typem biouhlu, jeho aplikační dávkou, typem půdy, plodinou a časovým odstupem od aplikace biouhlu (Blanco-Canqui, 2021). Ajayia & Horn (2017) uvádí zlepšení stability půdních agregátů po aplikaci biouhlu. V důsledku toho předpokládají, že půda bude lépe odolávat mechanickým stresům – jako například přejezdům zemědělských strojů.

Burrell et al. (2016) uvádí, že účinky biouhlu a jeho schopnost ovlivňovat řadu půdních funkcí z něj potenciálně činí atraktivní dlouhodobou investici do půdy.

3 Cíle disertační práce

Cílem disertační práce je ověření vlivu aplikace fermentovaných statkových hnojiv v kombinaci s pomocnými půdními látkami na změnu fyzikálních vlastností půdy a stav vegetace. Konkrétními řešenými pomocnými půdními látkami jsou aktivátory biologické transformace organické hmoty a statkových hnojiv, a biouhel.

Hypotézy, na které by měla dát disertační práce odpověď, zní:

I. Použití aktivátoru biologické transformace statkových hnojiv má pozitivní vliv na snížení energetické náročnosti při zpracování půdy.
II. Použití aktivátoru biologické transformace organické hmoty v kombinaci se statkovým hnojivem vede ke statisticky významnému poklesu penetračního odporu.
III. Aplikace aktivátoru biologické transformace organické hmoty společně se statkovým hnojivem vykazuje statisticky významné snížení hodnot objemové hmotnosti půdy.
IV. Ošetření statkového hnojiva pomocí aktivátoru biologické transformace statkových hnojiv vede ke zlepšení infiltračních vlastností půdy.
V. Aplikace aktivátoru biologické transformace statkových hnojiv pozitivně ovlivňuje stav vegetace a výnos plodin.

4 Zvolené metody zpracování

V následující kapitole je popsána metodika, která vedla k naplnění cílů disertační práce. Jsou zde popsány jednotlivé lokality provozních a poloprovozních pokusů, na kterých docházelo k aplikaci aktivátoru biologické transformace organické hmoty NeOsol, aktivátoru biologické transformace statkových hnojiv Z'Fix a biouhlu. Sledována a vyhodnocována byla data nejen o fyzikálních vlastnostech půdy, ale také o stavu vegetace.

4.1 Charakteristika experimentálních pozemků

Pro omezení vlivu místního prostředí byly studie prováděny na více lokalitách. Experimentální plochy byly založeny vždy s ohledem na tvar pozemku. Zároveň byla vynechána místa, která jsou exponována častým přejezdem zemědělské techniky – souvratě, vjezdy na pole.

4.1.1 Lokalita Paseka (Příloha I)

Olomoucký kraj, řepařská výrobní oblast, průměrná nadmořská výška 568 metrů nad mořem, průměrná roční teplota 7,8 °C, průměrný roční úhrn srážek 708 mm. Experimenty probíhaly na pozemcích společnosti VEPASPOL Olomouc, a.s., která je součástí koncernu MJM Agro, a.s.. Společnost se úzce specializuje na výrobu jatečných prasat a na vlastní odchov selat. Společnost VEPASPOL Olomouc, a.s. mimo jiné vlastní bioplynovou stanici a v době trvání experimentů vlastnila 40 hektarů polí.

Výsledky průzkumu půdního profilu na Lokalitě Paseka jsou uvedeny v tabulce 4. Půdní typ na této lokalitě je kambizem psefitická.

Tabulka 4 Pedologický průzkum na Lokalitě Paseka provedený v termínu 17. září 2014

	Hloubka (m)		Jednotka
	0,00–0,30	0,30–0,60	
Obsah jílu (<0,002 mm)	7	5	%
Obsah prachu (0,002–0,05 mm)	61	23	%
Obsah práškového písku (0,05–0,1 mm)	4	8	%
Obsah písku (0,1–2 mm)	28	64	%
Obsah humusu	2,15	0,38	%
Kationtová výměnná kapacita	90	27	mmol.kg^{-1}
pH (KCl)	5,81	6,11	

4.1.2 Lokalita Větřkovice (Příloha II)

Moravskoslezský kraj, obilnářsko-řepařská výrobní oblast, průměrná nadmořská výška 462 metrů nad mořem, průměrná roční teplota 7,7 °C, průměrný roční úhrn srážek 802 mm. Pokusy probíhaly na pozemcích společnosti ZOD Slezská Dubina. Družstvo hospodaří na výměře 1443 ha zemědělské půdy a zabývá se chovem zhruba 280 kusů dojnic a 250 kusů masného skotu. Mimo zemědělskou činnost provozuje ZOD bioplynovou stanici a fotovoltaickou elektrárnu.

Výsledky průzkumu půdního profilu na Lokalitě Větřkovice jsou uvedeny v tabulce 5. Půdní typ na této lokalitě je luvizem modální.

Tabulka 5 Pedologický průzkum na Lokalitě Větřkovice provedený v termínu 12. dubna 2017

	Hloubka (m)		Jednotka
	0,00–0,30	0,30–0,60	
Obsah jílu (<0,002 mm)	10	18	%
Obsah prachu (0,002–0,05 mm)	69	70	%
Obsah práškového písku (0,05–0,1 mm)	3	2	%
Obsah písku (0,1–2 mm)	18	10	%
Objemová hmotnost půdy	1,38	1,45	$g.cm^{-3}$
Obsah humusu	2,8	2,3	%
Kationtová výměnná kapacita	124	118	$mmol.kg^{-1}$
pH (KCl)	4,4	4,5	

4.1.3 Lokalita Rapotín (Příloha III, IV)

Olomoucký kraj, obilnářská výrobní oblast, v blízkosti obce Rapotín. Průměrná nadmořská výška 345 metrů nad mořem, průměrná roční teplota 7,1 °C, průměrný roční úhrn srážek je na úrovni 705 mm. Poloprovozní pokusy probíhaly na pozemcích společnosti Agrovýzkum Rapotín, s.r.o.. Výsledky průzkumu půdního profilu na Lokalitě Rapotín jsou uvedeny v tabulce 6. Půdní typ na této lokalitě je fluvizem glejová.

Tabulka 6 Pedologický průzkum na Lokalitě Rapotín provedený v termínu 17. září 2014

	Hloubka (m)		Jednotka
	0,00–0,30	0,30–0,60	
Obsah jílu (<0,002 mm)	27	22	%
Obsah prachu (0,002–0,05 mm)	53	50	%
Obsah práškového písku (0,05–0,1 mm)	3	5	%
Obsah písku (0,1–2 mm)	17	23	%
Objemová hmotnost půdy	1,38	1,66	$g.cm^{-3}$
Obsah humusu	1,93	1,09	%
Kationtová výměnná kapacita	122	92	$mmol.kg^{-1}$
pH (KCl)	5,13	5,4	

4.1.4 Lokalita Sloveč (Příloha V, VI, VII)

Středočeský kraj, výrobní oblast řepařská v blízkosti obce Sloveč, průměrná nadmořská výška 212 metrů nad mořem, průměrná roční teplota 9,4 °C a průměrný roční úhrn srážek na úrovni 550–600 mm. Poloprovozní a provozní pokusy probíhaly na pozemcích ZS Sloveč, a.s.. Zemědělská společnost Sloveč hospodaří na 3 000 ha. Chová průměrně 450 kusů dojnic, které jsou v systému chovu s tržní produkcí mléka. Roční průměrná výroba hnoje dosahuje 12 000 tun.

Výsledky průzkumu půdního profilu na Lokalitě Sloveč (Příloha V, VII) jsou uvedeny v tabulce 7. Půdní typ na této lokalitě je černozem pelická.

Tabulka 7 Pedologický průzkum na Lokalitě Sloveč provedený v termínu 13. srpna 2014

	Hloubka (m)		Jednotka
	0,00–0,30	0,30–0,60	
Obsah jílu (<0,002 mm)	48	60	%
Obsah prachu (0,002–0,05 mm)	32	39	%
Obsah práškového písku (0,05–0,1 mm)	2	1	%
Obsah písku (0,1–2 mm)	18	0	%
Objemová hmotnost půdy	1,46	1,48	$g.cm^{-3}$
Obsah humusu	3,89	1,44	%
Kationtová výměnná kapacita	278	272	$mmol.kg^{-1}$
pH (KCl)	7,18	7,21	

4.2 Sběr dat

V následujících podkapitolách je všeobecný popis jednotlivých metod a přístrojů, které byly použity s ohledem na cíle disertační práce. Podrobnější informace k jednotlivým metodickým postupům lze nalézt v přílohách této práce.

4.2.1 Penetrační odpor

Hodnoty penetračního odporu byly měřeny pomocí penetrometru PEN 70 (ČZU, Praha). Penetrometr splňuje standardy dle American Society of Agricultural and Biological Engineers – S313.3.

Měření penetračního odporu bylo prováděno dvakrát ročně pro každou variantu, vždy minimálně v počtu deseti měření na jednu variantu. Vzhledem k vláhovým podmínkám v půdě docházelo k měření na jaře a na podzim.

4.2.2 Redukovaná objemová hmotnost půdy

Vzorky neporušených půdních vzorků byly odebrány pomocí sady na odběr Kopeckého fyzikálníchválečků o objemu 100 cm^3 (Eijkelkamp, Nizozemsko). Vzorky byly následně přepraveny do laboratoří ČZU v Praze a analyzovány s ohledem na standard Geotechnického průzkumu a zkoušení – Laboratorní zkoušky zemin – Část 2: Stanovení objemové hmotnosti – ČSN EN ISO 17989-2.

4.2.3 Infiltrační vlastnosti půdy

Pro měření infiltračních vlastností půdy byly použity dvě metody:

1) Metoda Simplified Falling-Head, kterou popsal Bagarello et al. (2013). Pro měření byly použity kruhové infiltrometry o průměru 0,15 m (ČZU, Praha) a vlhkostní sonda Theta Probe (Delta-T Devices, UK).
2) Metoda užívající simulátor deště (ČZU, Praha). Jako médium byla použita voda obarvená potravinářským barvivem E133. Odkrytý půdní profil byl následně nasnímán digitálním fotoaparátem a analyzován pomocí softwaru Gwyddion 2.30 (Český metrologický institut, Brno) a softwaru ImageJ (National Institutes of Health, USA).

4.2.4 Tahový odpor

Měřící souprava se vždy skládala z taženého a tažného traktoru s pracovním nářadím – dle možností jednotlivých zemědělských podniků. Pro měření tahového odporu byl použit tenzometrický dynamometr S-38/200 kN (Lukas, ČR). K ukládání dat byla použita měřící ústředna NI CompactRIO (National Instruments Corporation, USA), vzorkovací frekvence byla 0,1 vteřiny. Pro přiřazení prostorových souřadnic k jednotlivým naměřeným hodnotám byl využit software Trimble Business Center 2.70 (Trimble, USA). Velikost tahového odporu byla spočítána dle standardu American Society of Agricultural and Biological Engineers – ASAE D497.6.

4.2.5 Stav vegetace

In situ měření

Stav porostů polních plodin byl hodnocen pomocí několika ručních senzorů, které zajišťovaly nedestruktivní sběr dat popisujících jednotlivé stěžejní vlastnosti vegetace. CCM 300 (Optisciences, USA) byl využit pro měření obsahu chlorofylu v listech (Leaf Chlorophyll Content). GreenSeeker (Trimble, USA) umožnil hodnocení celkové kondice vegetačního pokryvu pomocí indexu NDVI. Dále byl využit N-Pen (Photon Systems Instruments, Drásov) pro stanovení obsahu dusíku v rostlině a indexu NDGI (Normalized Difference Greenneess Index).

Výnos byl vážen pomocí nápravové váhy DINI ARGEO WWSB16t (DINI ARGEO, Itálie).

Dálkový průzkum Země

Stav vegetace byl také dále hodnocen s pomocí metod Dálkového průzkumu Země. V naprosté většině případů byly využity volně dostupné snímky z družicového systému Sentinel-2 (Evropská kosmická agentura). S využitím volně dostupných softwarů, jako například SNAP (ESA), QGIS (QGIS Development Team) nebo interaktivní platformy Google Earth Engine (Google), byly počítány jednotlivé vegetační indexy. NDVI (Normalized Difference Vegetation Index) umožňoval stanovení obsahu zelené nadzemní biomasy, NDWI (Normalized Difference Water Index) definoval obsah vody v listech a tím pádem pomohl detektovat případný vodní stres, LAI (Leaf Area Index) poté pomohl určit listovou plochu zkoumané vegetace

4.3 Statistické zpracování

Metoda statistického zpracování dat byla vybrána s ohledem na konkrétní výzkumnou otázku. Zároveň byl vždy zohledněn charakter datového souboru, především jeho rozdělení. V případě, že byl splněn předpoklad normálního rozložení dat, byly použity silnější parametrické metody. Při nesplnění podmínek normality dat byla vybrána odpovídající neparametrická metoda. Vzhledem k tomu, že byla většinou hodnocena variabilita dat napříč jednotlivými experimentálními plochami, byla často využívána parametrická analýza variance (ANOVA) nebo její neparametrická alternativa v podobě Kruskal-Wallisova testu. Pro stanovení konkrétních rozdílů bylo pak vždy prováděno i mnohonásobné porovnání.

Pro statistické zpracování byl využit software STATISTICA (StatSoft). Analýza dat pak byla prováděna také v prostředí RStudio (R Core Team) vždy s aktuální verzí R (R Core Team) a příslušnými balíky.

5 Seznam přiložených publikací

- **Publikace I**

Novák, V., Šařec, P., & Křížová, K. (2021). Physical properties of a soil under a pig slurry application and organic matter activators. Research in Agricultural Engineering, 67 (4), 199–207.

- **Publikace II**

Šařec, P., Novák, V., & Křížová, K. (2019). EFFECT OF ORGANIC FERTILIZERS, BIOCHAR AND OTHER CONDITIONERS ON MODAL LUVISOL. TAE 2019-7th International Conference on Trends in Agricultural Engineering, 494–499.

- **Publikace III**

Novák, V., Křížová, K., Šařec, P., & Látal, O. (2019). EFFECTIVE DOSE OF BIOCHAR WITHIN THE FIRST YEAR AFTER APPLICATION. TAE 2019-7th International Conference on Trends in Agricultural Engineering, 422–428.

- **Publikace IV**

Novák, V., Křížová, K., & Šařec, P. (2020). Biochar dosage impact on physical soil properties and crop status, Agronomy Research, 18(4), 2501–2511.

- **Publikace V**

Šařec, P., Látal, O., Novák, P., Holátko, J., Novák, V., Dokulilová, T., & Brtnický, M. (2020). Changes in soil properties and possibilities of reducing environmental risks due to the application of biological activators in conditions of very heavy soils. Agronomy Research, 18(4), 2581–2591.

- **Publikace VI**

Novák, V., Šařec, P., Křížová, K., Novák, P., & Látal, O. (2021). Soil physical properties and crop status under cattle manure and Z'Fix in Haplic Chernozem. Plant, Soil and Environment, 67(7), 390–398.

- **Publikace VII**

Novák, V., Šařec, P., Křížová, K., Novák, P., & Látal, O. (2022). Potential Impact of Biostimulator NeOsol and Three Different Manure Types on Physical Soil Properties and Crop Status in Heavy Soils Conditions. Sustainability, 14(1), 438.

5.1 Komentář k publikaci I[2]

Tato publikace hodnotí účinek aktivátoru PRP SOL a Z'Fix v kombinaci s prasečí kejdou na fyzikální vlastnosti půdy.

Výzkum probíhal na lokalitě Paseka. Úzkou specializací podniku je výroba vepřového masa, odchov selat a výroba energie (bioplynová stanice). I proto probíhal v letech 2015–2017 výzkum, který hodnotí výše zmíněné aktivátory v kombinaci s kejdou prasat na monokultuře kukuřice. Jedná se tedy o reálné podmínky provozu tohoto podniku.

Velikost jednotlivých pokusných parcel byla 0,5 ha. Každoročně byla dávkována kejda v množství 50 $m^3.ha^{-1}$; PRP SOL v dávce 200 $kg.ha^{-1}$; Z'Fix v dávce 0,33 kg.dobytčí $jednotka^{-1}.měsíc^{-1}$, NPK bylo dávkováno u všech variant dle výživových normativů. Chemická a fyzikální analýza půdy je podrobně popsána v Příloze I, Tabulce 1. Chemická analýza ošetřené a neošeřené kejdy aktivátorem Z'Fix se potom nachází v Příloze I, Tabulce 2.

V rámci studie byly posuzovány změny hodnot penetračního odporu, redukované objemové hmotnosti půdy, infiltrační vlastnosti půdy a změny v tahových odporech. Výsledky a jejich statistické vyhodnocení se nachází v Příloze I, Tabulce 4. Použitím aktivátorů a kejdy prasat došlo téměř ve všech hloubkách v průběhu let k nárůstu penetračního odporu – oproti samotnému použití neošetřené kejdy. U všech sledovaných variant došlo také k nárůstu redukované objemové hmotnosti půdy oproti původnímu stavu. Ve druhém a třetím roce pokusu dosahovala nejnižších hodnot varianta, u které byla použita kejda s přípravkem PRP SOL. Dle doporučení USDA (United States Deparment of Agriculture) však tento nárůst nijak neomezoval vývoj rostlin, neboť nepřekročil limitní hodnoty pro tento typ půdy, které jsou stanoveny na 1,55 $g.cm^{-3}$.V průběhu experimentu docházelo meziročně k postupnému snižování hodnot nasycené hydraulické vodivosti téměř u všech variant – mimo variantu kde byla aplikována prasečí kejda ošetřená aktivátorem Z'Fix. Ve třetím roce tohoto experimentu bylo u všech variant zaznamenáno statisticky významné zvýšení hodnot nasycené hydraulické vodivosti půdy vůči kontrolní variantě. Varianta bez aktivátorů dosahovala v druhém a třetím roce experimentu nejnižších hodnot. Z pohledu tahových odporů půdy docházelo ve sledovaném období ke kontinuálnímu nárůstu hodnot u všech variant. Aplikace ošetřené kejdy prasat aktivátorem

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[2] Výzkum, ze kterého vychází Publikace I, byl podpořen projekty TA ČR TH02030169, IGA 2018:31180/1312/3116, IGA 2020:31180/1312/3103 a projektem MZE RO0418.

Z'Fix vykazovala po celou dobu trvání experimentu statisticky významně nižší hodnoty tahového odporu oproti kejdě neošetřené. Při porovnání rozdílů relativních hodnot vztažených ke kontrolní (neošetřené) variantě došlo mezi lety 2015 až 2017 ke zvýšení hodnoty tahového odporu o 20 % – u varianty, kde byly používány oba aktivátory. I když publikace nehodnotila vliv výše zmíněných přípravků na výnos, je vhodné zmínit, že mimo první rok sledovaného období bylo zjištěno zvýšení výnosů při použití aktivátorů. K tomu docházelo jak při použití aktivátorů odděleně, tak v kombinaci, kde docházelo k nejvyššímu nárůstu výnosů.

5.2 Komentář k publikaci II[3]

Publikace II hodnotí účinek kravského hnoje, kompostu, biouhlu a aktivátorů na fyzikální vlastnosti půdy (redukovaná objemová hmotnost půdy, penetrační odpor, tahový odpor). V prvním a částečně i v druhém roce po jejich aplikaci.

Na experimentálním pozemku na lokalitě Větřkovice bylo v roce 2017 založeno 8 pokusných variant o rozloze 0,51 ha na variantu: N-1 – kravský hnůj + Z'Fix; N-2 kravský hnůj + Z'Fix + NeOsol; N-3 – kravský hnůj; N-4 – kravský hnůj + NeOsol; N-5 – NeOsol; N-6 – NPK; N-7 – kompost; N-8 – biouhel. Dávka kravského hnoje byla 50 $t.ha^{-1}$, aktivátoru NeOsol 150 $kg.ha^{-1}$, biouhlu 15 $t.ha^{-1}$, kompostu 50 $t.ha^{-1}$.

S ohledem na závislost značné části fyzikálních půdních vlastností na aktuální vlhkosti půdy byly hodnoty převedeny na relativní a vztaženy k variantě N-6, kde bylo aplikováno pouze hnojivo NPK. Na základě naměřených hodnot byl zaznamenán pokles penetračního odporu u variant s kravským hnojem N-1–N-4 až do hloubky 0,16 m. Varianta ošetřená biouhlem vykazovala statisticky významné rozdíly ve srovnání s variantami ošetřenými aktivátory. Použitím biouhlu došlo ke snížení redukované objemové hmotnosti půdy, naopak při použití kompostu a hnoje se Z'Fix došlo k navýšení této hodnoty. U variant N-1 a N-2 došlo k nárůstu tahového odporu mezi lety 2017 a 2018, tato skutečnost může být vysvětlena změnou v rozkladu hnoje právě díky zmíněným aktivátorům. U ostatních variant došlo ke snížení tahového odporu. Nejvyšší výnos rostlin byl zaznamenán u variant N-1 a N-2, kde byl použit aktivátor Z'Fix, dále následovala varianta s biouhlem.

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[3] Publikace vznikla za podpory TA ČR TH02030169 a IGA 2018:31180/1312/3116.

Výsledky *Publikace II* naznačují příznivý efekt biouhlu a kravského hnoje na redukovanou objemovou hmotnost půdy, hodnoty penetračního odporu a tahové odpory. V závěru této publikace je zmíněn fakt, že je třeba pokračovat ve výzkumu, neboť je z krátkodobých výsledků obtížné stanovovat závěry pro praxi.

5.3 Komentář k publikaci III[4]

S ohledem na výsledky z *Publikace II* a zvyšující se zájem o biouhel jakožto pomocnou půdní látku hodnotily následující dvě studie možnosti využití biouhlu ke zlepšení fyzikálních vlastností půdy a stavu vegetace. Biouhel představuje zajímavé řešení zpracování biologického odpadu a jeho následné využití. Většina studií o biouhlu se zabývala vstupním materiálem pro jeho výrobu, způsobem zpracování či vlivem biouhlu na chemické vlastnosti půdy. Vhodnému dávkování však zatím nebyla věnována dostatečná pozornost. Proto byl založen experiment hodnotící dávku biouhlu v prvním roce od aplikace. Z důvodu udržitelnosti byl využit biouhel od tuzemské společnosti BIOUHEL.CZ.

Maloparcelový pokus na lokalitě Rapotín (s rozměry jednotlivých pokusných ploch 15 x 30 m) s biouhlem v dávce 15t.ha^{-1} z roku 2014 byl rozšířen o čtyři další maloparcely s odstupňovanými dávkami biouhlu (15, 30, 45, 60 t.ha^{-1}) v roce 2017. Naměřené hodnoty penetračního odporu nepřinesly žádné statisticky významné rozdíly. Studie byla dále zaměřena na stav vegetace. Data popisující vegetaci byla sbírána ve fázi kukuřice BBCH 18 a BBCH 32. Vegetační index NDVI nepřinesl žádné statisticky významné rozdíly hodnot mezi variantami. Ty byly pozorovány až při hodnocení obsahu chlorofylu, kde byly zaznamenány statisticky významné rozdíly mezi variantami u obou termínů měření. Nicméně mezi dávkou 15 t.ha^{-1} z roku 2014 a 60 t.ha^{-1} z roku 2017 nebyl pozorován v roce 2018 žádný statisticky významný rozdíl. Nejvyšší výnos byl zaznamenán u varianty, kde bylo aplikováno množství biouhlu o dávce 60 t.ha^{-1}. Důvodem nejvyššího výnosu u nejvyšší dávky bude pravděpodobně schopnost biouhlu vázat vodu a tím zlepšit vláhové podmínky v půdě. Ve sledovaném roce pokusu byl úhrn srážek ve vegetačním období nižší s ohledem na dlouhodobý srážkový normál. Výsledky potvrzují vliv biouhlu na růst plodin a také na nutnost pohlížet na tuto pomocnou půdní látku v dlouhodobém časovém horizontu.

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[4] Publikace vznikla ve spolupráci s Agrovýzkumem Rapotín, za podpory TA ČR TH02030169 a IGA 2018:31180/1312/3116.

5.4 Komentář k publikaci IV[5]

Tato publikace přímo navazuje na experiment a výsledky z *Publikace III* a uzavírá výzkum autora této práce v rámci problematiky biouhlu. Metodika pokusu byla shodná s předchozí publikací, jen zde docházelo navíc k hodnocení varianty, u které bylo aplikováno pouze hnojivo NPK.

Výsledky této studie hodnotily výsledky z vegetační sezóny 2019. Výzkum nepotvrdil pozitivní vliv na fyzikální vlastnosti půdy (penetrační odpor, redukovaná objemová hmotnost půdy) po dvou, respektive pěti letech působení této pomocné půdní látky. Výsledky indexu NDVI a NDGI neprokázaly žádné statisticky významné rozdíly mezi variantami. Statisticky významných změn bylo dosaženo u obsahu chlorofylu v listech pšenice ozimé, ve dvou termínech měření – BBCH 34 a 37. U BBCH 34 došlo k významné změně hodnot pro varianty z roku 2017 v dávkách 15 a 60 $t.ha^{-1}$. U BBCH 37 byly zaznamenány statisticky významné rozdíly mezi variantou 15 $t.ha^{-1}$ biouhlu z roku 2014 a zbylými variantami – s výjimkou u varianty 60 $t.ha^{-1}$, kde nebyl statisticky významný rozdíl. Skutečnost, že rozdíly ve stavu vegetace byly reflektovány pouze tímto ukazatelem (na rozdíl od NDVI a NDGI) souvisí nejspíše s citlivostí ručního senzoru pro měření obsahu chlorofylu v listech. Ačkoliv studie neprokázala pozitivní vliv biouhlu na fyzikální vlastnosti půdy, potvrdila zjištění, že záleží na dlouhodobém časovém horizontu těchto pomocných půdních látek. Účinek dávky 15 $t.ha^{-1}$ aplikované před pěti lety nevykazoval statisticky významný rozdíl s účinkem dávky 60 $t.ha^{-1}$ aplikované o 3 roky později. Závěrem je v této publikaci poukázáno na nezbytnost zaměřit se na časový efekt biouhlu.

5.5 Komentář k publikaci V[6]

Tato studie srovnává působení aktivátorů NeOsol a Z'Fix v kombinaci s kravským hnojem po pěti letech trvání experimentu. Byly hodnoceny nejen fyzikální, ale také chemické vlastnosti půdy. S ohledem na zaměření této disertační práce budou dále popsány jen výsledky fyzikálních vlastností půdy.

Sledovaný pozemek se nacházel na Lokalitě Sloveč. Celkem byly v této publikaci posouzeny 4 varianty – kravský hnůj + Z'Fix (varianta I), kravský hnůj + Z'Fix + NeOsol

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[5] Publikace vznikla za podpory projektu TA ČR TH02030169 a projektu IGA 2019:31180/1312/3104.

[6] Publikace vznikla ve spolupráci s kolegy z Mendelovy univerzity v Brně za podpory projektů TA ČR TH02030169 a projektu IGA 2019:31180/1312/3104.

(varianta II), kravský hnůj (varianta III), hnojivo NPK (varianta IV). Rozloha každé varianty byla 0,7 ha. Jednotlivé dávky jsou uvedeny v Příloze V, Tabulce 2. Všechny změny fyzikálních vlastností půdy jsou hodnoceny v relativních hodnotách, vztaženy k variantě IV. U varianty I došlo v roce 2018 ke snížení penetračního odporu v celé měřené hloubce půdního profilu, nicméně se nejednalo o statisticky významný výsledek. Snížení penetračního odporu u všech měřených hloubek bylo pozorováno i u varianty III, ale zde se jednalo v hloubkách 0,08, 0,20 a 0,24 m o statisticky významné snížení. Výsledky redukované objemové hmotnosti půdy nepřinesly statisticky významné rozdíly mezi způsobem ošetření půdy. U varianty III však došlo ke snížení o 13,4 %, u varianty I byla změna v poklesu redukované objemové hmotnosti půdy nejnižší. Z hlediska tahového odporu došlo ke snížení při použití ošetřeného hnoje přípravkem Z'Fix v průměru o 3 %, nejednalo se však o statisticky významnou změnu. Tento pokles lze však vyjádřit úsporou nafty při zpracování půdy zhruba 0,3 $\mathrm{l.ha^{-1}}$. Použití aktivátorů v kombinaci s kravským hnojem ukázalo zlepšení v půdním profilu, i když výsledné hodnoty nebyly vždy statisticky významné.

5.6 Komentář k publikaci VI[7]

Publikace VI hodnotí tříletý experiment s aktivátorem Z'Fix, respektive posuzuje jeho vliv na fyzikální vlastnosti půdy a stav vegetace, v kombinaci s kravským hnojem. Na rozdíl od předchozích studií autora se nezaměřuje na poloprovozní pokusy, ale na užití aktivátoru v zemědělské praxi.

Varianty, které se nacházely na Lokalitě Sloveč, měly pro kravský hnůj rozlohu 5 ha (varianta FYM). Stejnou rozlohu měla i varianta pro kravský hnůj ošetřený aktivátorem (varianta FYM_ZF). Kontrolní varianta s NPK (varianta C) měla rozlohu 1 ha. V rámci studie byly hodnoceny vegetační sezóny 2018–2020.

Hodnoty penetračního odporu nepřinesly statisticky významné rozdíly mezi jednotlivými variantami, nicméně naměřené hodnoty poukazují na patrný trend snížení penetračních odporů při aplikaci organické hmoty do půdy. V druhém a třetím roce experimentu byly hodnoty penetračního odporu u varianty FYM_ZF nižší ve srovnání s variantou FYM či s variantou C – v hloubkách 8–20 cm.

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[7] Publikace vznikla ve spolupráci s kolegy z Mendelovy univerzity v Brně a za podpory projektů TA ČR TH02030169, IGA 2021:31180/1312/3102, MZE RO0418.

Využití simulátoru deště přináší lepší představu o schopnosti půdní infiltrace než metoda Simplified Falling-Head pro nasycenou hydraulickou vodivost. Zatímco metoda Simplified Falling-Head poskytuje bodovou informaci, u simulátoru deště se jedná o informaci do jisté míry plošnou. V roce 2018 a 2020 byl indikován statisticky významný rozdíl mezi variantou C a variantou FYM_ZF. Bez ohledu na tento fakt bylo zlepšení infiltračních vlastností půdního profilu u varianty FYM_ZF zaznamenáno v celé sledované hloubce půdního profilu. U tahového odporu půdy došlo ke statisticky významnému poklesu potřebné energie na zpracování půdy v letech 2018 a 2020 u varianty FYM_ZF. Stejně jako u infiltračních vlastností půdy bylo i zde dosaženo nejlepších výsledků u varianty FYM_ZF. Stav porostů polních plodin byl hodnocen pomocí spektrálního indexu NDVI, přičemž zdrojem distančních dat zde byly snímky z družicového systému Sentinel (ESA). Varianta s ošetřeným kravským hnojem vykazovala v sezóně 2018 lepší stav vegetace v převážné většině dostupných satelitních snímků. V sezóně 2020 bylo dosaženo lepšího stavu vegetace u této varianty pro všech 11 termínů. Těchto výsledků bylo dosaženo i u výnosů. Ve srovnání s variantou C došlo ke statisticky vyššímu výnosu u varianty FYM_ZF. U cukrové řepy došlo v průměru ke zvýšení výnosu o téměř 6 t.ha^{-1} oproti variantě s NPK a o 2,57 tha^{-1} oproti hnoji neošetřenému, stejně tak došlo ke zvýšení cukernatosti. U pšenice došlo ke zvýšení výnosu u ošetřeného hnoje o 1,06 t.ha^{-1} oproti kontrole a o 0,53 t.ha^{-1} ve srovnání s hnojem neošetřeným. Porovnání ošetřeného a neošetřeného hnoje za sledované období potvrdilo v průměru o 4,5 % nižší energetickou náročnost při zpracování půdy. To by při 50 % účinnosti přenosu energie a spotřebě 20 l.ha^{-1} znamenalo snížení spotřeby paliva o 0,45 l.ha^{-1}.

5.7 Komentář k publikaci VII[8]

Časový efekt působení zkoumaných pomocných půdních látek se ukázal být jedním z klíčových faktorů. V návaznosti na *Publikaci V* hodnotí *Publikace VII* vliv půdního přípravku NeOsol v rámci šestiletého polního experimentu. Opět byly hodnoceny především změny fyzikálních vlastností půdy, stavu vegetace pomocí vegetačních indexů NDVI, NDWI, LAI a výnosu. Oproti předchozím studiím bylo využito pro posouzení stavu vegetace prostředí Google Earth Engine, který s využitím jazyka JavaScript zajišťuje rychlé a efektivní zpracování dat dálkového průzkumu Země. Využití tohoto nástroje

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[8] Publikace vznikla ve spolupráci s kolegy z Mendelovy univerzity v Brně, za podpory projektů TA ČR TH02030169, IGA 2020:31180/1312/3103, MZE RO0418.

v rámci analýz distančních dat je časově nenáročné a umožňuje pracovat s družicovými snímky čistě online, bez potřeby instalace příslušného SW, či jejich stahování do lokálního zařízení. Tím je zajištěna významná časová úspora při jejich zpracování.

Pozemek se nacházel na Lokalitě Sloveč. Celkem jsou ve studii hodnoceny tři vegetační sezóny. Jedná se o roky 2015, 2017, 2020, tedy roky, jimž předcházela aplikace statkových hnojiv. Podrobnější informace o aplikaci lze nalézt v Příloze VII, Tabulce 2. Na sledovaném pozemku se nacházelo celkem 8 variant – 3 typy hnojů: kravský (varianta – catt), prasečí (varianta – pig), drůbeží (varianta – pou) v kombinaci s přípravkem NeOsol (značení variant stejné jako u hnoje + SOL). Dále byla na sledovaném pozemku varianta s hnojivem NPK (varianta NPK) a také s aktivátorem NeOsol (varianta NPKSOL).

Z pohledu vlivu aplikace přípravku NeOsol v kombinaci s hnojivy na snížení energetické náročnosti při zpracování půdy došlo v prvním termínu k nárůstu tahového odporu. Avšak ve třetím termínu došlo ke statisticky významnému snížení tahového odporu při použití aktivátoru NeOsol o 2,9 %. Rozdíl mezi prvním a třetím termínem poukazuje na nutnost zkoumat tyto přípravky v dlouhodobém časovém horizontu. Redukovaná objemová hmotnost půdy ve většině termínů nevykazovala statisticky rozdílné hodnoty. Lze však sledovat jisté trendy, například postupné zvýšení objemové hmotnosti při užití aktivátoru bez statkových hnojiv (varianta NPKSOL). Stejných výsledků bylo dosaženo také u nasycené hydraulické vodivosti, kdy docházelo k postupnému snižování infiltrační schopnosti půdy u varianty NPKSOL – v porovnání s variantou NPK. Stav vegetace byl hodnocen pomocí indexů NDVI, NDWI a LAI. Mezi jednotlivými variantami s aplikací NeOsol a bez aplikace nebyl zjištěn statisticky významný rozdíl. Výsledky však poukazují na důležitost přidávání organické hmoty do půdy, které se ve větší míře projevuje v dlouhodobém časovém horizontu. Z celkového pohledu došlo ke statisticky významnému zvýšení výnosů plodin při použití aktivátoru NeOsol.

Tyto výsledky se v zemědělské praxi mohou projevit zvýšením efektivity zemědělské výroby a zároveň snížením nákladů při zpracování zemědělské půdy.

6 Diskuze

Z výsledků, kterých bylo dosaženo v rámci této disertační práce, je patrné, že pomocné půdní látky, respektive aktivátory, mají pozitivní vliv na některé fyzikální vlastnosti půdy a stav vegetace.

Podnikání v zemědělství, stejně jako jakékoliv jiné dlouhodobě udržitelné odvětví lidské činnosti, vyžaduje ziskovost. Zpracování půdy se řadí mezi nejvíce energeticky náročné operace v zemědělské výrobě (Tabatabaeefar et al., 2009). V konvenčním zemědělství při zpracování půdy orbou je spotřebováno více než 50 % paliva jen na přípravu půdy a setí (Moitzi et al., 2019). Z tohoto důvodu byla v této disertační práci zařazena *Hypotéza I*, která byla potvrzena výsledky *Publikace I*. Ošetřená kejda prasat aktivátorem biologické transformace statkových hnojiv vykazovala při každoroční aplikaci statisticky nižší hodnoty tahového odporu ve srovnání s kejdou neošetřenou. Zjištěné výsledky jsou v souladu s výsledky které publikoval Šařec & Novák (2017b). Při aplikaci ošetřeného kravského hnoje, v porovnání s hnojem neošetřeným či anorganickým hnojivem, bylo zjištěno statisticky významné snížení tahového odporu, a to vždy v prvním roce po aplikaci, také u *Publikace VI*. Pozitivní vliv aktivátoru biologické transformace statkových hnojiv naznačují také výsledky *Publikace V*. U této publikace však nebylo snížení tahového odporu statisticky významné, ačkoliv dosahovalo průměrně 3% snížení. Jedná se o zásadní zjištění, neboť snižování spotřeby fosilních paliv by mělo být jedním z hlavních cílů udržitelné rostlinné produkce (Rashidi et al., 2013).

V úvodu této práce byly popsány problémy pedokompakce, tato problematika byla posouzena v rámci *Hypotézy II a III*. Výsledky, kterých bylo dosaženo v rámci *Publikace I, II* a *V* nepotvrdily *Hypotézu II*. Aktivátor biologické transformace organické hmoty neprokázal vliv na statistické snížení penetračního odporu, respektive pedokompakci. Toto zjištění je v souladu s výsledky, které publikovala Podhrázská et al. (2012), tedy že použití aktivátoru biologické transformace organické hmoty nemá pozitivní vliv na snížení půdního zhutnění.

Otázka půdního zhutnění ve svrchní vrstvě půdy byla řešena v rámci *Hypotézy III*. Ačkoliv se *Publikace I* zabývala touto problematikou a varianta kejdy s aktivátorem NeOsol vykazovala mírně nižší hodnoty objemové hmotnosti půdy, nejednalo se o statisticky významnou změnu. Toto zjištění je v souladu s výsledky *Publikace II*, kde došlo ke snížení objemové hmotnosti půdy v kombinaci aktivátoru NeOsol se statkovým hnojivem, ale nejednalo se o statisticky významnou změnu. S ohledem na výsledky *Publikace VII* nebyla *Hypotéza III* potvrzena. Současná aplikace aktivátoru transformace organické hmoty NeOsol a statkového hnojiva nepřinesla dlouhodobě statisticky významné snížení hodnot objemové hmotnosti půdy. Výsledky částečně potvrzují závěry studie Žemličková & Šařec (2016), kde aplikace přípravku NeOsol bez kombinace s organickou hmotou nepřispěla ke snížení objemové hmotnosti půdy.

Půdní infiltrace je považována za jednu z klíčových funkcí půdy. Degradacemi půdy však dochází ke snížené schopnosti půdy infiltrovat vodu (Chyba et al., 2014). Tato problematika byla zkoumána v rámci *Hypotézy IV*. Výsledky z *Publikace I* naznačily pozitivní vliv aktivátoru Z'Fix, jelikož v posledním roce došlo u ošetřené kejdy ke statisticky významnému zvýšení nasycené hydraulické vodivosti půdy. Ostatní varianty vykazovaly kontinuální pokles schopnosti infiltrace. Tento výsledek je v souladu s výsledky z *Publikace VI*, kde ošetřený kravský hnůj vykazoval v každém roce nejvyšší schopnosti infiltrace. V prvních letech po aplikaci byla změna statisticky významná ve srovnání s variantou, kde bylo aplikováno pouze NPK. Tyto dosažené výsledky potvrdily *Hypotézu IV*. Zlepšení infiltrační schopnosti půdy po aplikaci ošetřeného hnoje aktivátorem Z'Fix je v souladu se výsledky, které publikoval Šařec & Novák (2017b).

Zajištění dostatečných výnosů plodin v požadované kvalitě patří k základním požadavkům kladeným na rostlinnou výrobu v zemědělské praxi. *Hypotéza V* se zabývá problematikou výnosů a stavu vegetace po aplikaci ošetřeného statkového hnojiva pomocí aktivátoru biologické transformace statkových hnojiv. Výsledky z *Publikace I* naznačují pozitivní vliv ošetřeného statkového hnojiva na výnos plodin. V druhém a třetím roce pokusu byly výnosy při aplikaci ošetřeného statkového hnojiva (v tomto případě kejdy) vyšší ve srovnání s hnojivem neošetřeným. S ohledem na pouze jednu hodnotu pro variantu nelze učinit jednoznačný závěr. Stejného výsledku bylo dosaženo i u *Publikace II*. Výsledky *Publikace VI* potvrdily *Hypotézu V*. Stejně jako u předchozích výsledků z *Publikace VI* se první rok po aplikaci aktivátoru jeví jako zásadní pro statisticky prokazatelné rozdíly. Byl prokázán pozitivní vliv na výnos cukrové řepy a ozimé pšenice. U cukrové řepy navíc byla vyšší cukernatost v bulvách. Výsledky dálkového průzkumu Země v roce 2018 a 2020 dokazují pomocí vegetačního indexu NDVI pozitivní vliv aktivátoru na stav vegetace. Toto zjištění je v souladu se zjištěním Šařec et al. (2017), kde byl prokázán pozitivní vliv aktivátoru biologické transformace statkových hnojiv na snížení vodního stresu u rostlin pomocí indexu MSI, což přispívá k lepšímu stavu vegetace.

7 Přínos a další směr vývoje

Výsledky, kterých bylo dosaženo v rámci předložené disertační práce, mohou sloužit ke snížení environmentálních rizik při hospodaření na zemědělských půdách a k zefektivnění zemědělské produkce. Práce přináší výsledky dlouhodobých pokusů s aktivátory na odlišných lokalitách s různými typy statkových hnojiv.

S přibývajícím poznáním, možnostmi detailnějšího monitoringu zemědělských půd a se snižováním statkových hnojiv bude dle autora této práce docházet k rozšiřování nabídky pomocných půdních látek na trhu. Tento fakt bude dávat velký prostor pro ověřování účinků těchto látek. Na rozdíl od přesně řízených laboratorních experimentů jsou polní pokusy často ovlivněny aktuálními klimatickými podmínkami a pro prokázání skutečného efektu pomocných půdních látek je třeba provádět dlouhodobé výzkumy na různých lokalitách a za různých podmínek hospodaření.

Z hlediska dalšího výzkumu aktivátoru biologické transformace organické hmoty NeOsol a aktivátoru biologické transformace statkových hnojiv Z'Fix by dle autora této práce bylo zajímavé pracovat s různým dávkováním těchto přípravků.

Předkládaná disertační práce neprokázala pozitivní vliv biouhlu Agrouhel na fyzikální vlastnosti půdy a stav vegetace. Byl však zjištěn rozdílný efekt biouhlu s odstupem od aplikace. S ohledem na tuto skutečnost považuje autor této práce za zajímavé věnovat se výzkumu biouhlu v dlouhodobém časovém horizontu.

7.1 Závěr

Disertační práce autora představuje přehled problematiky aktivátorů biologické transformace organické hmoty a statkových hnojiv, respektive jejich dopadu na fyzikální vlastnosti půdy a stav vegetace. Prvotní výzkum autora byl doplněn mimo sledované aktivátory také o biouhel, kterému je v současné době věnována značná pozornost.

I přesto, že nebyly všechny hypotézy této disertační práce potvrzeny, předkládaná disertační práce prokázala pozitivní účinek aktivátorů na fyzikální vlastnosti půdy a stav vegetace. Ačkoliv je aktivátor biologické transformace statkových hnojiv Z'Fix primárně určen ke zlepšení stájového prostředí, výsledky v této disertační práci prokázaly jeho příznivý sekundární vliv na snížení energetické náročnosti při zpracování půdy, zlepšení infiltračních vlastností půdy, pozitivní vliv na stav vegetace a výnos plodin.

Původní vědecké hypotézy u aktivátoru biologické transformace organické hmoty NeOsol nebyly potvrzeny. Přípravek NeOsol neprokázal v kombinaci se statkovým hnojivem pozitivní vliv na snížení penetračního odporu a snížení hodnot objemové hmotnosti půdy. Bylo však zjištěno, že aktivátor NeOsol v kombinaci se statkovými hnojivy způsobuje při dlouhodobém používání statisticky významné snížení tahového odporu a zvýšení výnosu plodin.

Výsledky disertační práce popisují aspekt působení pomocných půdních látek na stav půdy a vegetace v reálných podmínkách. Jako takové přináší konkrétní informace, které jsou využitelné v zemědělské praxi ve snaze zajistit co nejvyšší efektivitu a zároveň udržitelnost současné rostlinné produkce.

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9 Přílohy

Příloha I

Physical properties of a soil under a pig slurry application and organic matter activators

Novák, V., Šařec, P., & Křížová, K. (2021). Physical properties of a soil under a pig slurry application and organic matter activators. *Research in Agricultural Engineering*, 67(4), 199–207. https://doi.org/10.17221/84/2020-RAE https://doi.org/10.17221/84/2020-RAE

Physical properties of a soil under a pig slurry application and organic matter activators

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Abstract: To investigate the effects of organic matter activators combined with a pig slurry on a soil's physical properties, a field experiment was carried out in a monoculture of corn (2015–2017). Three pig slurry application variants complemented with the activators in question, i.e. with PRP SOL spread directly on the soil surface (*SOL*), with Z'fix added to the slurry during the pig housing (*ZF*) and with a combination of both PRP SOL and Z'fix (*ZF_SOL*), were compared with just the pig slurry (*C*) under an equal dose of nitrogen and a uniform growing technology. According to the results, a positive effect of the penetration resistance with the pig slurry and the activators of organic matter (Z'fix and PRP SOL) was not proven. The saturated hydraulic conductivity was demonstrably better achieved with the Z'fix activator, but PRP SOL activator also provided a certain improvement. The largest change in the unit draught was observed in the *ZF_SOL* application (20% increase). The results seem ambiguous; however, they give a good indication of the activators' effect in practice. Nevertheless, the findings would certainly benefit from further verification.

Keywords: agricultural management; field experiment; penetration resistance; soil organic matter; unit draught

Currently, crop production is limited due to various challenges, such as the growing population, a decrease in the total agricultural area, climate change related issues, soil erosion, or lack of soil organic matter. At the same time, when farmers deal with the implementation of Agriculture 4.0 practices, it is necessary to also focus on the elementary issues and solve them with respect to the environment and sustainability. Regarding the soil conditions, many biological and physical properties are related to the content of the soil organic matter as one of the key soil components (Smith et al. 1999; Manna et al. 2007). From a long-term point of view, the use of organic fertilisers returns organic matter to the soil, where it ensures increased biological activity and, thus, increases crop yields. The positive influence of organic fertilisers on a soil's physical, chemical, and physicochemical properties has been confirmed many times (Barzegar et al. 2002; Herencia et al. 2007). Rational fertilisation management can improve not only soil porosity, infiltration capacity, and hydraulic conductivity, but it also usually helps to decrease the soil bulk density (Haynes and Naidu 1998).

In the Czech Republic, a decline in animal production can be observed in recent times. It is undeniably associated with a reduced production of organic matter that could be returned to the field in the form

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of an organic fertiliser. According to the Czech Statistical Office (2020), cattle breeding has decreased to the current 40% level compared to the 1990 level, the situation with pigs is even worse, which currently sits at 31% of the 1990 level. This phenomenon is very likely one of the reasons for the significant soil organic matter losses. Thus, it is necessary to look for new technologies of sustainable land management. One of these approaches may be the utilisation of soil amendments. Also, activators of biological transformation of organic matter might have great potential, since they are claimed to improve soil properties. According to the manufacturer, PRP SOL is a soil conditioner and should boost the biological activity of the soil and, thus, improve its fertility (PRP Technologies, France). Z'fix is a dust-free pearled pellet designed to enhance the agronomic quality of manure, slurry, and compost (PRP Technologies, France). Nevertheless, the role of these substances still has not been sufficiently described. The positive effect of PRP SOL on the soil enzymatic activity was confirmed by the study of Niewiadomska et al. (2018). Although this product cannot be considered a conventional fertiliser, PRP SOL can replace the traditional fertilisation of spring barley without a negative effect on the grain yield (Sulewska et al. 2016). There is a great lack of scientific studies regarding the activators, although a few do exist. In one of the previous studies, an increase in the soil bulk density, and also in the implemented draught of the machine, was detected. Concurrently, an increase in the yield of silage maize was observed (Šařec et al. 2019). These results are also confirmed by the study of Šindelková et al. (2019) who concludes that the use of these products leads to a better water management and nutrient uptake. Therefore, activators should provide convenient conditions for organic matter decomposition in the soil and, thus, to affect the soil properties. In terms of the economy, soil activators help to reduce the actual energy demand by various management tasks, such as the soil tillage (Novák and Šařec 2017).

Since the actual impact of the above-mentioned soil amendments is not described sufficiently yet, this study aims at verifying the effect of organic matter activators combined with a pig slurry on a soil's physical properties. The activators under investigation should, due to their composition and to their succeeding effect in the soil profile, amplify the positive influence of the organic matter and, therefore, provide more convenient conditions in terms of the soil management and crop growth. The penetration resistance and bulk density were studied as important pedocompaction indicators in real farm conditions with the assumption that their values were expected to decrease with the activators used. The other variables in question were the implemented draught, since soil tillage is one of the most energy-intensive operations in agriculture, and the saturated hydraulic conductivity, which is one of the most important hydrophysical characteristics. As a matter of fact, the unit draught, penetration resistance, and bulk density were expected to decrease, while the saturated hydraulic conductivity should have increased under the effect of the used activators.

MATERIAL AND METHODS

Site and crop management. The study experiment was established in 2014 near the village of Paseka in the Olomouc region, in the Czech Republic (49°47'170"N, 17°13'143" E, 270 m a.s.l.). The 6.3 ha agricultural plot was divided into smaller parcels in order to apply the different agricultural management and crop rotating systems. The terrain on the experimental area has practically no sloping. The soil type is classified as Cambisol. According to the United States Department of Agriculture (USDA 2019), the soil texture is Silt Loam at a depth of 0–0.3 m and Sandy Loam at a depth of 0.3–0.6 m. From an agronomic point of view, this is a poor-quality soil with a high skeleton content. The soil properties at the beginning of this experiment are given in Table 1. The crop rotation over the study period started with winter wheat (2014) followed by a monoculture of maize (2015–2017) variety LM GENER FAO 250. The fact that the agricultural business runs, as many others do, a biogas plant, and is, thus, forced to in-

Table 1. Chemical and physical soil properties at the beginning of field experiment (2014)

Soil property	Soil depth (cm)	
	0–30	30–60
Clay (< 0.002 mm) (%)	7.00	5.00
Silt (0.002–0.05 mm) (%)	61.00	23.00
Very fine sand (0.05–0.10 mm) (%)	4.00	8.00
Fine sand (0.10–2 mm) (%)	28.00	64.00
C : N	6.72	7.08
Humus content (%)	2.15	0.38
pH (KCl)	5.81	6.11

Table 2. Pig slurry chemical analysis for "*C*" as the pure untreated pig slurry, and "*ZF*" representing pig slurry treated by Z'fix

Variant	Dry matter (%)	N (NH_4^+)	N ($kg\cdot t^{-1}$)	P_2O_5 ($kg\cdot t^{-1}$)	K_2O ($kg\cdot t^{-1}$)	CaO ($kg\cdot t^{-1}$)	MgO ($kg\cdot t^{-1}$)	pH
C	5.9	0.61	4.7	3.0	1.9	3.4	0.72	7.6
ZF	5.9	0.83	5.6	3.6	2.4	4.2	1.05	9.0

C – pig slurry + NPK; *ZF* – pig slurry treated by Z'fix + NPK

creasingly grow maize, led to the particular crop rotation. Four plots 50 m × 100 m (0.5 ha) were treated each year by a pig slurry (Table 2) and by the selected activators in the combinations described below.

PRP SOL is a soil activator manufactured by the PRP technologies company (France) on the basis of dolomitic limestone, limestone and calcareous sediments and produced in the form of a brown-coloured granulate. This composition of calcium, magnesium and trace elements is claimed to improve the soil fertility by positively influencing the soil structure and its biological activity. Crops cultivated on plots treated by PRP SOL should ingrain faster and, thus, have a richer root system. The vegetation should also emerge easier, and the canopy is then evenly well-balanced. Secondly, the organic matter Z'fix activator was investigated. It is a granulate constructed on the basis of calcium and magnesium carbonates with an addition of other macro- and micronutrients (potassium, sodium, sulfur, iron, manganese). Z'fix is manufactured by PRP Technologies as well. It is produced under a patented technology, MIP (mineral inducer process), that ensures regulation of the fermentation processes in organic fertilisers and composts.

The Z'fix treatment involves the application of the activator to the pig slurry first. Here, the dosage was 0.33 $kg\cdot head^{-1}\cdot month^{-1}$. The yearly dosage of PRP SOL was 200 $kg\cdot ha^{-1}$ of agricultural plot. The pig slurry itself was applied in a yearly dose of 50 $m^3\cdot ha^{-1}$. The NPK dose corresponded to a nutrient normative, that is 170 $kg\cdot ha^{-1}$ of nitrogen, 35 $kg\cdot ha^{-1}$ of phosphorus, and 200 $kg\cdot ha^{-1}$ of potassium.

For the purpose of this study, the treatment variants are labelled as follows: *C* (pig slurry + NPK); *SOL* (pig slurry + PRP SOL + NPK); *ZF* (pig slurry treated by Z'fix + NPK); *ZF_SOL* (pig slurry treated by Z'fix + PRP SOL + NPK).

Data acquisition and processing. The soil's physical properties were studied twice a year in the three-year experiment period during field visits. Mostly, spring and autumn terms were chosen; however, the data acquired in the spring term were preferred because the soil profile was more likely to be evenly saturated by water. Figure 1 summarises the rainfall conditions during the 2015–2017 period compared to the long-term normal. A PEN 70 penetrometer (CULS Prague) was used for the evaluation of the penetration resistance. The penetration resistance profiles at ten evenly distributed sampling points were recorded for each variant. Per variant, three undisturbed soil samples for the bulk density evaluation were taken by Kopecky cylinders (volume 100 cm^3). These samples were analysed according to CSN EN ISO 17892-2. The unit draught was measured by a dynamometer with an S-38/200kN strain gauge (Lukas, Czech Republic). The dynamometer was placed between two tractors, where the working tractor was a Case Maxxum with a disc harrow – tillage depth of 8.5 cm in 2015; a New Holland T7.270 with a disc harrow – tillage depth of 8 cm in 2016, and a New Holland T7.270 with a tine cultivator at a tillage depth of 19 cm in 2017. For the data collection, the NI CompactRIO system (National Instruments Corporation, USA) was used with a sampling frequency of 0.1 seconds. The GPS position for these data was recorded by the Trimble Business Center 2.70 software (Trimble, USA). The soil infiltration capacity was measured with the circular infiltrometers (each 0.15 m in diameter) according to the simplified falling-head (SFH) method that enabled one to convert the infiltration into the saturated hydraulic conductivity. A known amount (0.5 L) of water was applied to the infiltrometer. The time of the infiltration was measured alongside the soil moisture before and after the water application. The soil moisture was measured by a ThetaProbe (Delta-T Devices Ltd., UK), with ten sampling points per variant. The spatial distribution of the sample points was a rectangular matrix corresponding to the number of samples taken for the individual variables.

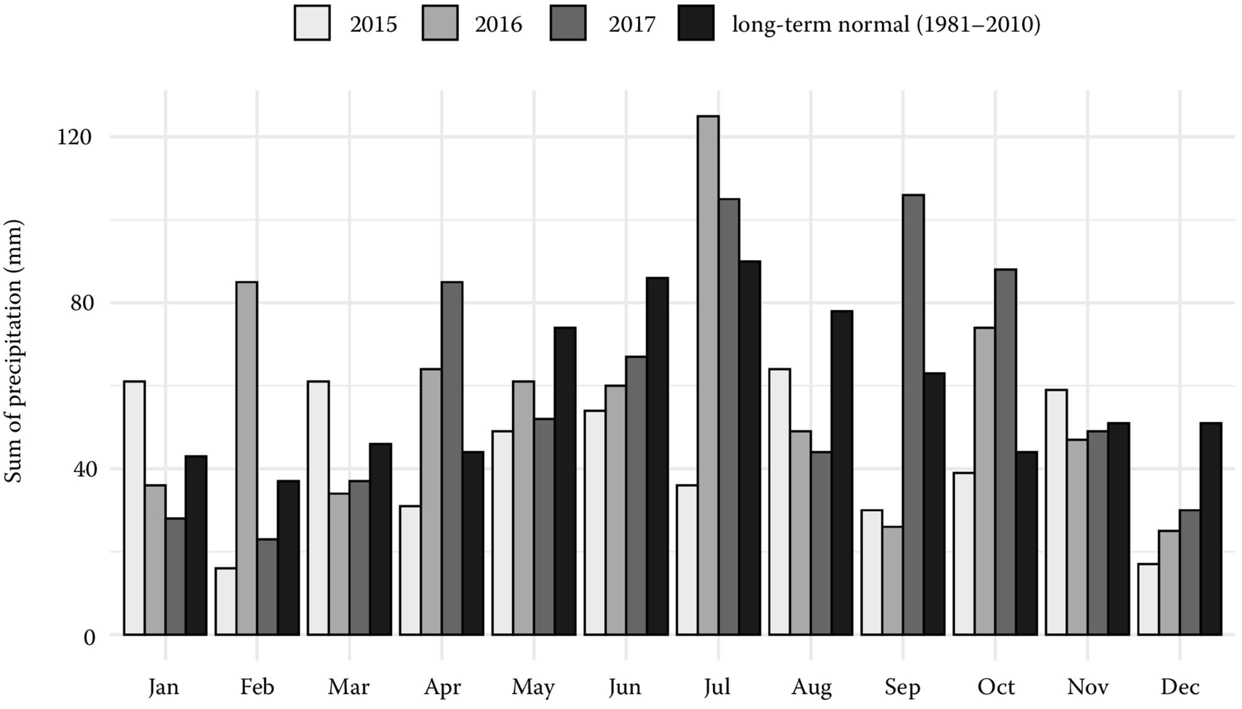

Figure 1. Rainfall conditions reported by the Czech Hydrometeorological Institute during cropping seasons 2015, 2016 and 2017 compared to a long-term normal

The acquired dataset was further processed in R (R Core Team, 2020) using the packages tidyverse, reshape2 and psych; MS Excel (Microsoft Corporation, USA), and Statistica 12 (Statsoft Inc., USA). Since the normality of the data was not met, the non-parametric Kruskal-Wallis variance test was used to determine the potential differences in the soil properties between the experimental variants and activators.

RESULTS AND DISCUSSION

Although this study focuses primarily on the physical properties of the soil, the potential effect of the investigated activators should have been reflected in the crop yield also. As shown in Table 3, there was no obvious increase in the yield among treated variants in the first year of the experiment. However, in the following two years, the activator treated variants' yield was higher compared to the control, while the best performing treatment, in terms of the yield, appeared to be the combination of both activators (*ZF_SOL*).

Bulk density. The values of the reduced bulk density are shown in Figure 2. Compared to the initial state, there was an increase in the reduced bulk density in all the variants. The most significant increase was observed by the variant with the pig slurry treated by Z'fix. These results were similar to a study (Rimovsky and Bauer 1996) in which the reduced soil bulk density increased after a slurry application. The treatment by Z'fix, in opposite to the original assumption, seemed to boost this increase. According to the USDA (2019), in the case of this particular soil texture, reduced bulk density values of less than 1.4 g·cm^{-3} are considered convenient for plant growth, a value exceeding 1.55 g·cm^{-3} already affects the root growth and values greater than 1.65 g·cm^{-3} restrict the root growth

Table 3. Maize yield (33% dry matter) achieved in investigated treatment variants for investigated cropping seasons

Variant	2015 (t·ha^{-1})	2016 (t·ha^{-1})	2017 (t·ha^{-1})
C	33.7	37.6	37.6
SOL	32.6	38.4	38.4
ZF	32.3	38.6	39.6
ZF_SOL	32.9	39.2	42.7

C – pig slurry + NPK; *SOL* – pig slurry + PRP SOL + NPK; *ZF* – pig slurry treated by Z'fix + NPK; *ZF_SOL* – pig slurry treated by Z'fix + PRP SOL + NPK

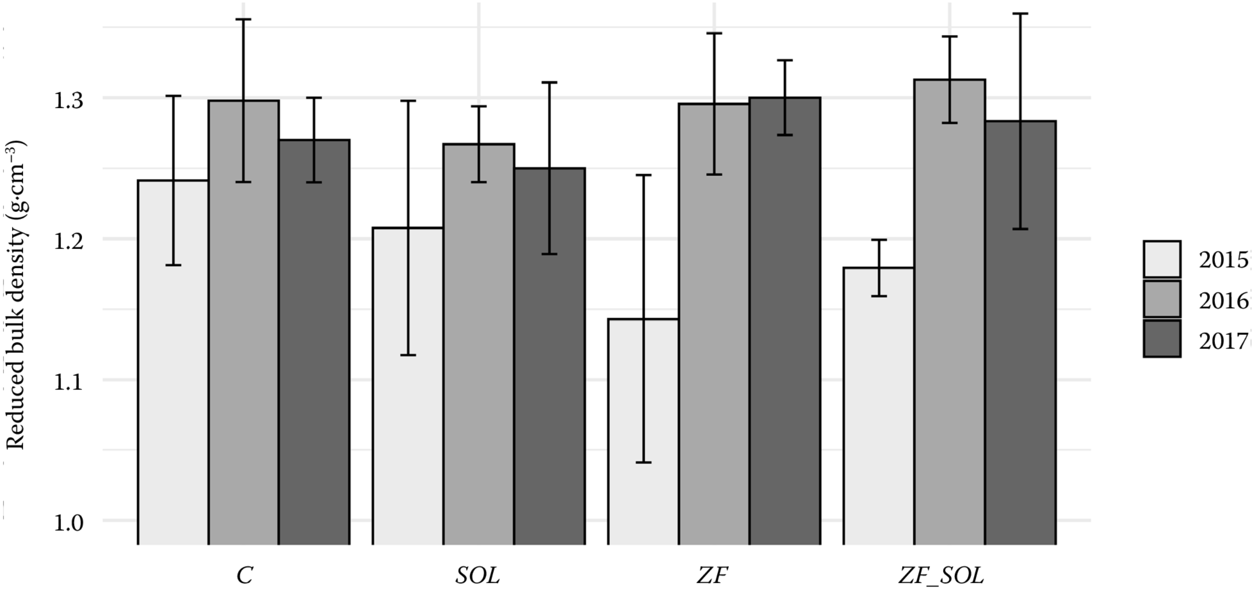

Figure 2. Reduced bulk density acquired using the Kopecky's cylinders (100 cm^3), error bars representing the standard deviation

entirely. From the point of view of the soil density, it is, therefore, clear that the soil of the experimental location does achieve ideal values for root growth. However, the results were not statistically evaluated due to the insufficient number of samples for the statistical analysis.

Penetration resistance. The results of the penetration resistance measurements are illustrated in Figure 3. The results attained at the beginning of the experiment (2015) did not show any statistically significant differences among the variants. In 2016, significant differences were registered at the depths of 0.08 and 0.16 meters. At both depths, the penetration resistances between the variants *ZF* (pig slurry treated by Z'fix) and *C* (pig slurry) differed significantly with the value of the *ZF* variant being higher. In a similar manner, the value of the *ZF* variant at 0.08 m differed significantly when also compared to the variant *ZF_SOL* (pig slurry treated by Z'fix + SOL). In 2017, a significant difference was only observed at a shallower depth of 0.04 meters. Compared to the control variant, there was a statistically

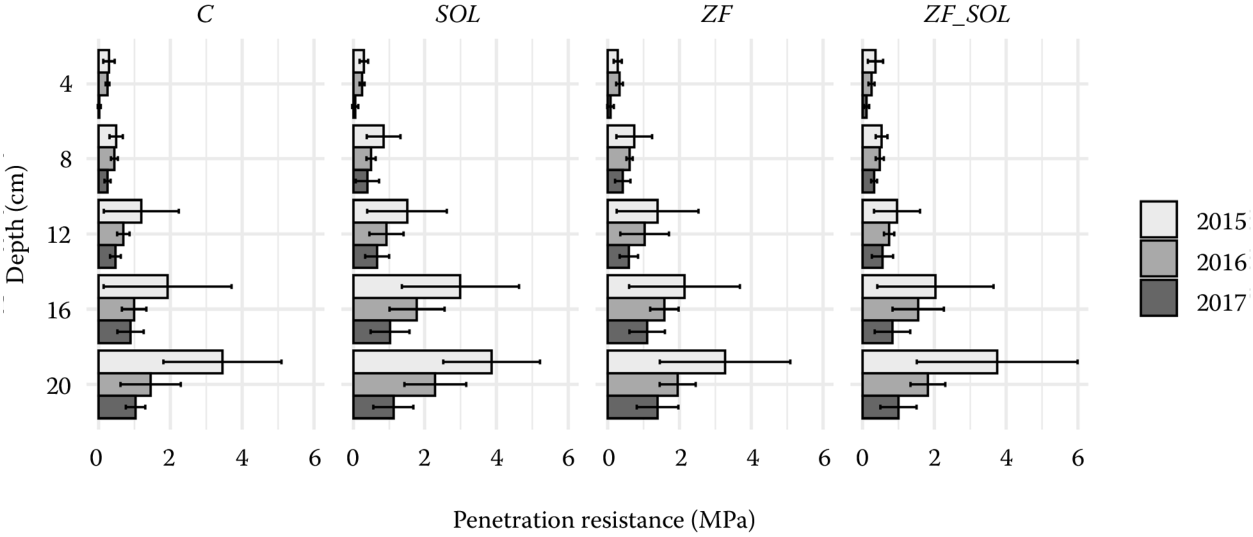

Figure 3. Penetration resistance in specific soil profile depths, acquired by the penetrometer PEN, error bars representing the standard deviation

significant increase in the penetration resistance within the *ZF_SOL* variant. De Smet et al. (1991) described an increase in the soil penetration resistance after a pig slurry application. Podhrázská et al. (2012) stated that there was no improvement in the soil compaction in topsoil after the use of PRP SOL. According to the results of this study, the positive effect of the activators on the organic matter, i.e. Z'fix and PRP SOL, was not proven. On the contrary, instead of ameliorating the negative impact of the slurry on the penetration resistance, Z'fix particularly seemed to aggravate it.

Saturated hydraulic conductivity. There are several methods for measuring the saturated hydraulic conductivity, Chyba et al. (2017), in their study, emphasised the convenience of the SFH method for use in practice. At the beginning of the experiment (2015), the variants *SOL* and *ZF_SOL* reached the highest values (Figure 4). However, the differences in the values that year were not statistically significant. In the following experimental years, the values of the saturated hydraulic conductivity, with the exception of variant *ZF*, gradually decreased. Since the control variant showed the biggest drop, it proved to be significantly different when compared to all the three variants with the activators in 2017 (Table 4). Urbanovičová et al. (2018), in their study, mentioned that the soil infiltration increased by 2 mm·h^{-1} in a soil treated by PRP SOL. The variant where PRP SOL was applied showed the highest infiltration values. Dumbrovský et al. (2011) mentioned the fact that the use of PRP SOL does not demonstrably improve the properties of the soil infiltration, but in comparison with the untreated soil, it stabilises these values more. According to the results of this study, the Z'fix treatment demonstrated the most beneficial effect concerning the saturated hydraulic conductivity. PRP SOL also produced an improvement though.

Unit draught. Tillage is one of the most energy-intensive operations in agriculture. Figure 5 shows the values of the unit draught in 2015, 2016 and 2017. Since the measurement conditions and tillage implements differed among the individual years, the assessment of the values relative to the control variant should be stressed. The results in the first year of the experiment were certainly influenced by the previous management system. It is possible to observe significant differences between the variants with the untreated pig slurry (*C* and *SOL*), and the variants with the pig slurry treated by Z'fix (*ZF* and *ZF_SOL*), with the latter having lower values. In 2016, the unit draught of variant *ZF_SOL*

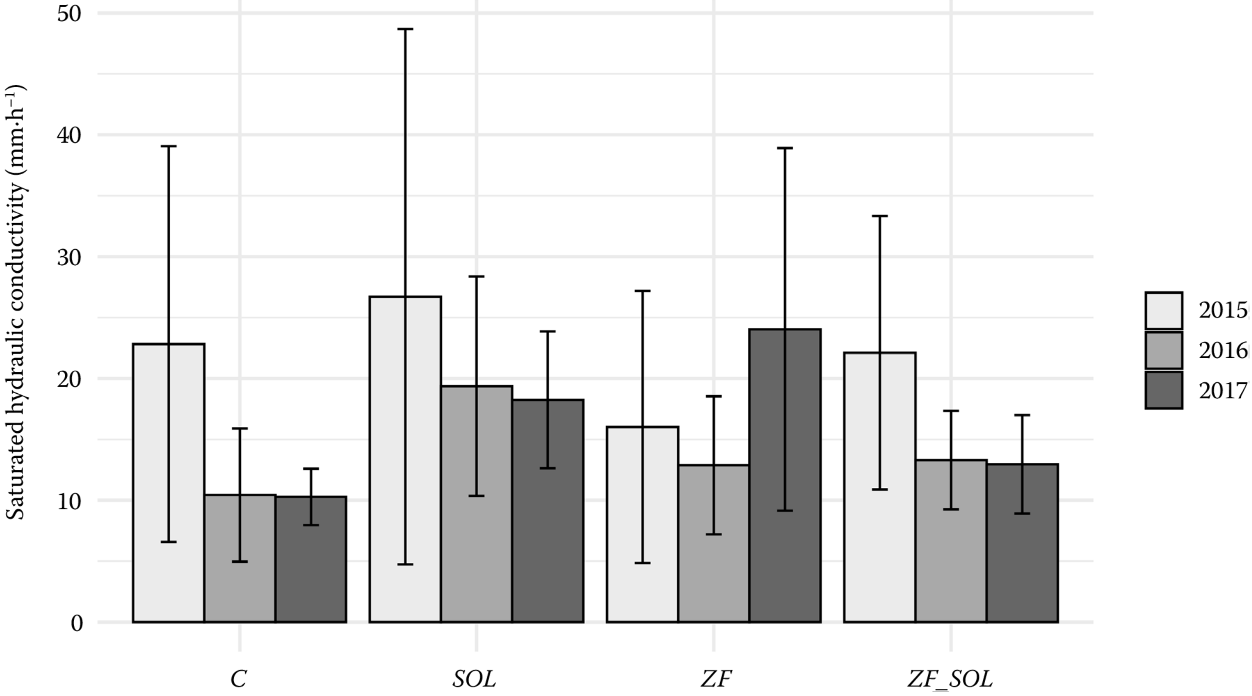

Figure 4. Saturated hydraulic conductivity measured according to the SFH method, error bars representing the standard deviation

SFH – simplified falling-head method

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Table 4. Mean values of investigated physical soil properties, and results of Kruskal-Wallis variance test

Penetration resistance (MPa) at depth	variant	2015				2016				2017			
		mean	*C*	*SOL*	*ZF*	mean	*C*	*SOL*	*ZF*	mean	*C*	*SOL*	*ZF*
0.04 m	*C*	0.29	–	–	–	0.25	–	–	–	0.02	–	–	–
	SOL	0.29	0.89	–	–	0.24	1	–	–	0.05	0.517	–	–
	ZF	0.28	0.97	0.89	–	0.33	0.14	0.14	–	0.08	0.236	0.517	–
	ZF_SOL	0.36	0.85	0.85	0.85	0.25	1	1	0.16	0.11	**0.042**	0.236	0.517
0.08 m	*C*	0.49	–	–	–	0.44	–	–	–	0.25	–	–	–
	SOL	0.84	0.26	–	–	0.49	0.52	–	–	0.39	0.33	–	–
	ZF	0.74	0.7	0.7	–	0.61	**0.014**	0.078	–	0.42	0.13	0.38	–
	ZF_SOL	0.53	0.7	0.26	0.7	0.48	0.383	0.969	**0.034**	0.32	0.28	0.63	0.56
0.12 m	*C*	1.19	–	–	–	0.69	–	–	–	0.47	–	–	–
	SOL	1.50	0.67	–	–	0.92	0.74	–	–	0.66	0.53	–	–
	ZF	1.39	0.91	0.77	–	1.03	0.24	0.74	–	0.59	0.53	0.78	–
	ZF_SOL	0.96	0.91	0.67	0.89	0.74	0.51	1	0.47	0.56	0.74	0.62	0.62
0.16 m	*C*	1.92	–	–	–	0.99	–	–	–	0.89	–	–	–
	SOL	2.99	0.66	–	–	1.78	0.056	–	–	1.02	0.76	–	–
	ZF	2.14	0.74	0.69	–	1.58	**0.026**	0.622	–	1.10	0.76	0.76	–
	ZF_SOL	2.03	0.74	0.69	0.74	1.55	0.189	0.622	0.849	0.83	0.76	0.76	0.76
0.20 m	*C*	3.45	–	–	–	1.45	–	–	–	1.03	–	–	–
	SOL	3.87	1	–	–	2.29	0.084	–	–	1.12	0.76	–	–
	ZF	3.27	1	1	–	1.95	0.084	0.303	–	1.39	0.72	0.72	–
	ZF_SOL	3.75	1	1	1	1.82	0.151	0.296	0.595	1.00	0.76	0.76	0.72
Infiltration ($mm \cdot h^{-1}$)	*C*	22.82	–	–	–	10.43	–	–	–	10.27	–	–	–
	SOL	26.71	0.76	–	–	19.36	0.11	–	–	18.24	< **0.001**	–	–
	ZF	16.02	0.71	0.71	–	12.87	0.42	0.23	–	24.04	< **0.001**	0.739	–
	ZF_SOL	22.11	0.76	0.85	0.71	13.30	0.23	0.23	0.8	12.95	**0.021**	0.02	0.08
Unit draft ($kN \cdot m^{-2}$)	*C*	29.31	–	–	–	39.09	–	–	–	53.82	–	–	–
	SOL	29.98	0.414	–	–	39.44	0.798	–	–	56.75	**0.0307**	–	–
	ZF	25.09	< **0.001**	< **0.001**	–	34.53	< **0.001**	< **0.001**	–	51.60	**0.048**	< **0.001**	–
	ZF_SOL	26.53	**0.0277**	**0.0039**	0.156	39.08	**0.042**	0.203	< **0.001**	59.47	< **0.001**	0.086	< **0.001**
Bulk density ($g \cdot cm^{-3}$)	*C*	1.24	–	–	–	1.30	–	–	–	1.27	–	–	–
	SOL	1.21	–	–	–	1.27	–	–	–	1.25	–	–	–
	ZF	1.14	–	–	–	1.30	–	–	–	1.30	–	–	–
	ZF_SOL	1.18	–	–	–	1.31	–	–	–	1.28	–	–	–

Statistically significant on a significance levels $\alpha = 0.05$ in bold; *C* – pig slurry + NPK; *SOL* – pig slurry + PRP SOL + NPK; *ZF* – pig slurry treated by Z'fix + NPK; *ZF_SOL* – pig slurry treated by Z'fix + PRP SOL + NPK

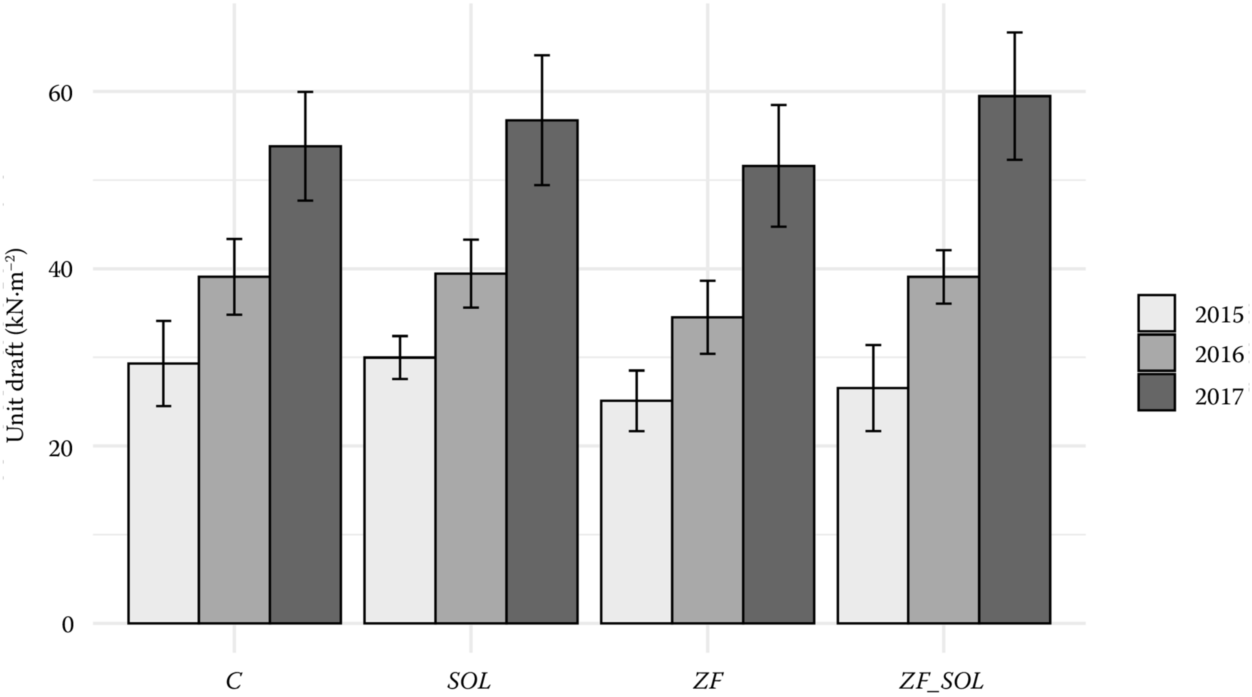

Figure 5. Unit draft obtained by dynamometer with strain gauge S-38/200kN, error bars representing the standard deviation

raised to the level of variants *C* and *SOL*, thus, only leaving the variant *ZF* to be significantly different. In 2017, the variant *ZF_SOL* continued its increase relative to the control variant, and the variant *SOL* also joined this trend. All three variants presented significant differences compared to the control variant, with the variants *SOL* and *ZF_SOL* having higher values and the variant *ZF* having lower values. The largest change could be observed in *ZF_SOL*, where the increase in the unit draught value was 20% relative to the control variant between the years 2015 and 2017. In a similar way, an increase of 10.3% was attained concerning the variant *ZF*, and mere 3.2% increase within the variant *SOL*. The study written by Urbanovičová et al. (2018) mentioned a decrease in the energy intensity for the soil treatment by 5.71% during the soil treatment with PRP SOL, which was, therefore, not confirmed.

CONCLUSION

The results evaluate the effect of using organic matter activators alongside a pig slurry application, which was taken as the control. After three years of applying the activators together with the pig slurry, significant differences among the variants were observed in some cases. Contrary to the initial assumption, the effect was mostly adverse, i.e. increasing values, concerning the soil bulk density, penetration resistance, and unit draught. Namely, the variant with the pig slurry treated by Z'fix (*ZF*) increased the values of the soil bulk density and penetration resistance. The unit draught of the tillage implement was amplified particularly when applying the pig slurry treated by Z'fix and *SOL* (*ZF_SOL*). On the other hand, the activators had a significant positive effect, i.e. increasing values, on the soil infiltration. Particularly in the case of the *SOL* and *ZF* variants. The results seem ambiguous, but provide a good indication of the effects of the activators in practice. It must be taken into consideration that the study does not provide a thorough assessment of the activators, but is aimed merely at their impact on the soil's physical properties. For instance, the study does not assess the effect of the Z'fix activator on the pig housing welfare, nor the effect of the activators on the crop yield. In order to explore the ways of operation of the activators in the soil, a thorough laboratory experiment would have to be accomplished. Since only a few studies on this topic can be found, and regarding the results proving certain impacts on the soil's physical properties, it is highly recommended to focus on selected soil amendments in the fvuture to acquire long-term results.

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Příloha II

EFFECT OF ORGANIC FERTILIZERS, BIOCHAR AND OTHER CONDITIONERS ON MODAL LUVISOL

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EFFECT OF ORGANIC FERTILIZERS, BIOCHAR AND OTHER CONDITIONERS ON MODAL LUVISOL

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Abstract
The paper assesses changes in soil physical properties, i.e. bulk density, cone index, and implement draft, after the application of organic fertilisers, i.e. manure and compost, and manure and soil conditioners, Z'fix, NeoSol, and biochar. Biochar and traditional manure demonstrated favourable influence on soil bulk density, cone index and tillage implement draft. The manure treated by Z'fix demonstrated higher bulk density and draft, though it reached highest silage maize yields. Compost and NeoSol exhibited increased bulk density, but reduced draft on the opposite.

Key words: *cattle manure; NeoSol; Z'fix; compost; cone index; bulk density.*

INTRODUCTION

Over the past few decades, the demands on agricultural production have been growing rapidly. The pressure increases mostly due to the climate change, changes in crop rotation, decreasing area of the arable land, reduction of livestock farming. According to the Czech Statistical Office (*Sálusová, 2018*), cattle production has declined by more than half in the past 30 years. Intensification of agriculture has caused the lack of quality soil organic matter (SOM) that is on the European scale one of the staple causes of decreasing soil productivity (*Stolte et al., 2016*). This phenomenon causes a reduction in the diversity and fertility of arable land and it is associated with other soil degradation issues *(Gardi, Jeffery & Saltelli, 2013*). Besides soil fertility, SOM is associated with soil structure and other properties (*Walsh & McDonnell, 2012*). It is also known that organic matter naturally reduces soil compaction (*Chakraborty & Mistri, 2017*), which is a very serious issue. Only in Europe, even about 33 million hectares are threatened by soil compaction (*Alaoui & Diserens, 2018*). Compaction strongly affects root growth, since the conditions of water and gas transport in the soil are not optimal (*Stolte et al., 2016*). Of course, this situation often results in reduced crop yield. Soil compaction can be easily measured by cone penetrometer. Bulk density is another frequently used option for measurement (*Odey, 2018*).

Organic materials added to soil profile have a beneficial effect on reclaiming and improving the physical quality of degraded soil (*Are et al., 2017*). The application of manure or compost contributes to the increasing content of SOM (*Panagos et al., 2015*). The use of manure improves the physical, biological and chemical properties of soil (*Ludwig et al., 2007*). The manure or directly soil can be treated with so called activators or conditioners that still are not thoroughly explored. However, current studies suggest that activators improve soil properties and plant growth conditions (*Borowiak et al., 2016*). Thus when using activators, there are not only economic benefits, e.g. a reduction of the energy intensity of soil tillage (*Šařec & Žemličková, 2016*), but also a contribution to the environmental sustainability of agriculture (*Šařec & Novák, 2017*).

In recent years, biochar has gained the considerable attention. This carbon-based product of pyrolysis is made mostly of waste plant (*Mukherjee & Lal, 2013*). It is a highly porous material that affects water retention capacity (*Rasa et al., 2018*), and therefore improves soil properties. However, effect of biochar applied into the soil strongly depends on input material for the pyrolysis process and also on the pyrolysis temperature (*Lei & Zhang, 2013*).

The authors of these studies generally agree that activators and biochar should be tested on different soil types and conditions. Therefore, this study aims to determine the effect of activators, compost, and biochar for soil physical properties after one year of application.

MATERIALS AND METHODS

In 2017, experimental variants were established near the town of Větřkovice in the Moravian-Silesian Region of the Czech Republic (N 49°47.232', E 17°50.028', 501 m a. s. l.). In 2018, silage maize (LG 30.248, FAO 250) was grown on the plot, while it was sown on the 26th April 2018 and harvested on the 30th August 2018. Soil type of the filed was *Modal Luvisol*, and soil texture defined as loam soil. Soil properties are presented more in detail in Tab. 1. The experimental area was divided into eight smaller plots of 170 x 30 m for each variant. Fertilization management of individual variants is shown in Tab. 2. NeoSol (PRP Technologies, France) was used as the activator of biological transformation of soil organic matter. Biochar was used in the same way. Z'fix (PRP Technologies, France) was used as the activator of manure. It was applied to the bedding of cattle deep litter housing at a recommended weekly dose. These conditioners cannot be considered as fertilizers due to their low content of active components. Dosage of cattle manure was 50 $t \cdot ha^{-1}$ (2017), of NeoSol 150 $kg \cdot ha^{-1}$ (2017, 2018), of biochar 15 $t \cdot ha^{-1}$ (2017), of compost 50 $t \cdot ha^{-1}$ (2017), and of additional NPK according to crop common practice (2017, 2018). All the other field operations and material applied did not differ among variants.

Tab. 1 Soil properties of the field prior to the experiment in 2017

	Soil depth (m)	
	0.00–0.30	0.30–0.60
Soil Aggregate Stability - SAS (%)	62.9	54.7
pH/KCl	4.4	4.5
Humus content (%)	2.8	2.3
Humic Acid / Fulvic Acid ratio	1	2.1
Microbial biomass carbon - Cmic ($\mu g \cdot g^{-1}$)	3.28	2.23
C / N ratio	9.55	5.50

The registered penetrometer PEN 70 (CULS Prague) was used to determine the cone index, while ten measurements were done for each variant. Soil moisture was measured by Theta Probe (Delta-T Devices Ltd, UK). To obtain undisturbed soil samples from the depth of 0.05 to 0.10 m and subsequently soil bulk density, Kopecky cylinders with a volume of 100 cm^3 were utilized. The implement draft was measured by dynamometer with strain gauge S-38/200kN (Lukas, the Czech Republic). This device was placed between two tractors. The working tractor was John Deere 6150R (rated engine power 111.9 kW) in 2017, and Fendt 826 Vario (rated engine power 190.9 kW) in 2018. In both years, six furrow plough PHX 6-30 was used as an implement. On each variant, there were several crossings of the measuring set. First, overall draft of the pulled tractor and working implement were measured. The plough worked at a constant speed, and the tillage depth was checked after each pass. After that, the same measurements were carried out with implement not working in order to obtain only machinery rolling resistances and forces induced by potential field gradient. The system NI CompactRIO (National Instruments Corporation, USA) was used for data collection with sampling frequency of 0.1 s. Acquired data were assigned to individual variants using Trimble Business Center 2.70 (Trimble, USA). Measuring dates were 10th September 2017 and 10th October 2018. Data was processed by MS Excel (Microsoft Corp., USA) and Statistica 12 (Statsoft Inc., USA).

Tab. 2 Fertilization of individual variants and maize silage yields in 2018

Variant	Fertilization	Yield ($t \cdot ha^{-1}$)
N-1	Cattle manure with Z'Fix + NPK	44.2
N-2	Cattle manure with Z'Fix + NeoSol + NPK	43.2
N-3	Cattle manure + NPK	41.6
N-4	Cattle manure + NeoSol + NPK	42.4
N-5	NeoSol + NPK	40.2
N-6	NPK - Control	38.2
N-7	Compost + NPK	41.8
N-8	Biochar + NPK	42.8

RESULTS AND DISCUSSION

The variants attained higher silage maize yield than the control (Tab. 2). The variants with manure treated by Z'fix (N-1 and N-2) attained the highest yields, most probably due to its high nitrogen content (*Šařec, Látal & Novák, 2017*). High yield was reached also by the biochar variant (N-8), which is in accordance with the findings of *Are et al.* (2017). NeoSol (N-5) demonstrated favourable effect as well, which confirms the work of *Borowiak et al.* (2016).

All the measured values were analyzed relative to the control Variant N-6 rather than analyzing the absolute values. In this way, differing weather conditions of individual years were allowed for. Bulk density values related to the average value of respective control Variant N-6 that are displayed in Fig. 1 did not differ significantly according to the *Analysis of Variance* with regard to both factors separately, i.e. to the variant and to the measurement date, nor with regard to their combination. Nevertheless, there is a visible bulk density increase after the application of compost (N-7) and of manure treated with Z'fix (N-1 and N-2). The manure treated in such a way contains less straw that is in addition more decomposed and is therefore denser. The condition of the compost was the same case. On the other hand, bulk density slightly decreased after the biochar application (N-8). *Are et al.* (2017), *Mukherjee & Lal* (2013) and *Lei & Zhang* (2013) described also bulk density reduction after biochar application. On the contrary, *Are et al.* (2017) found bulk density reduction also after veticompost application.

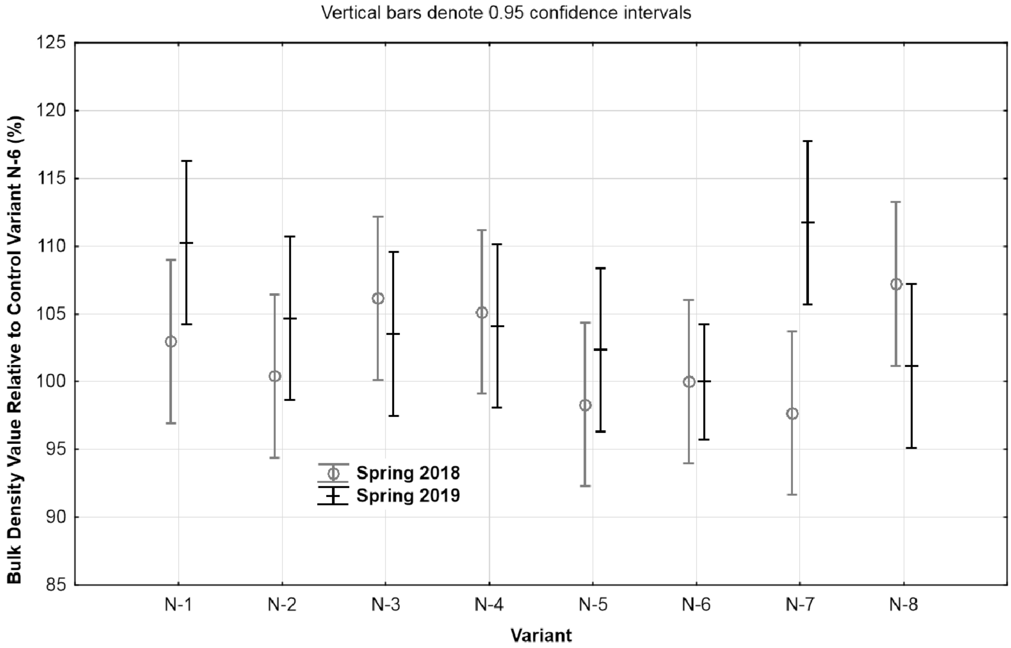

Fig. 1 Graph comparing relative differences of bulk density values from the depth of 0.05 to 0.10 m in spring 2018 and 2019 for individual variants (Variant N-6 as 100%)

Since cone index values depend strongly on soil moisture, they were measured also in spring, i.e. on 22nd April 2018 and on 23rd April 2019, when soil moisture was more likely to be homogenous. Cone index values were again analyzed relative to the control Variant N-6, as is presented in Fig. 2. The *Analysis of Variance* did not prove statistically significant differences for the combination of all the factors in question, i.e. measurement date, variant and depth. Considered separately though, factors' average cone index differences were statistically significant. For the variants with manure application, i.e. N-1 to N-4, cone index values decreased at shallow depths to up to 20 cm. This corresponds with the findings of *Celik et al.* (2010) and *Šařec & Žemličková* (2016). Deeper on the other hand, the values generally slightly increased for the mentioned variants. Since the manure application had taken place before the first measurement was carried out, the increased cone index values below tilled profile cannot be assigned to the additional pass of a manure spreader. The variants with NeoSol and compost used, i.e. N-5 and N-7, demonstrated no evident pattern except for the increased cone index average at the depth of 24 cm. The application of biochar (N-8) decreased cone index values at shallower depths without having increased them deeper.

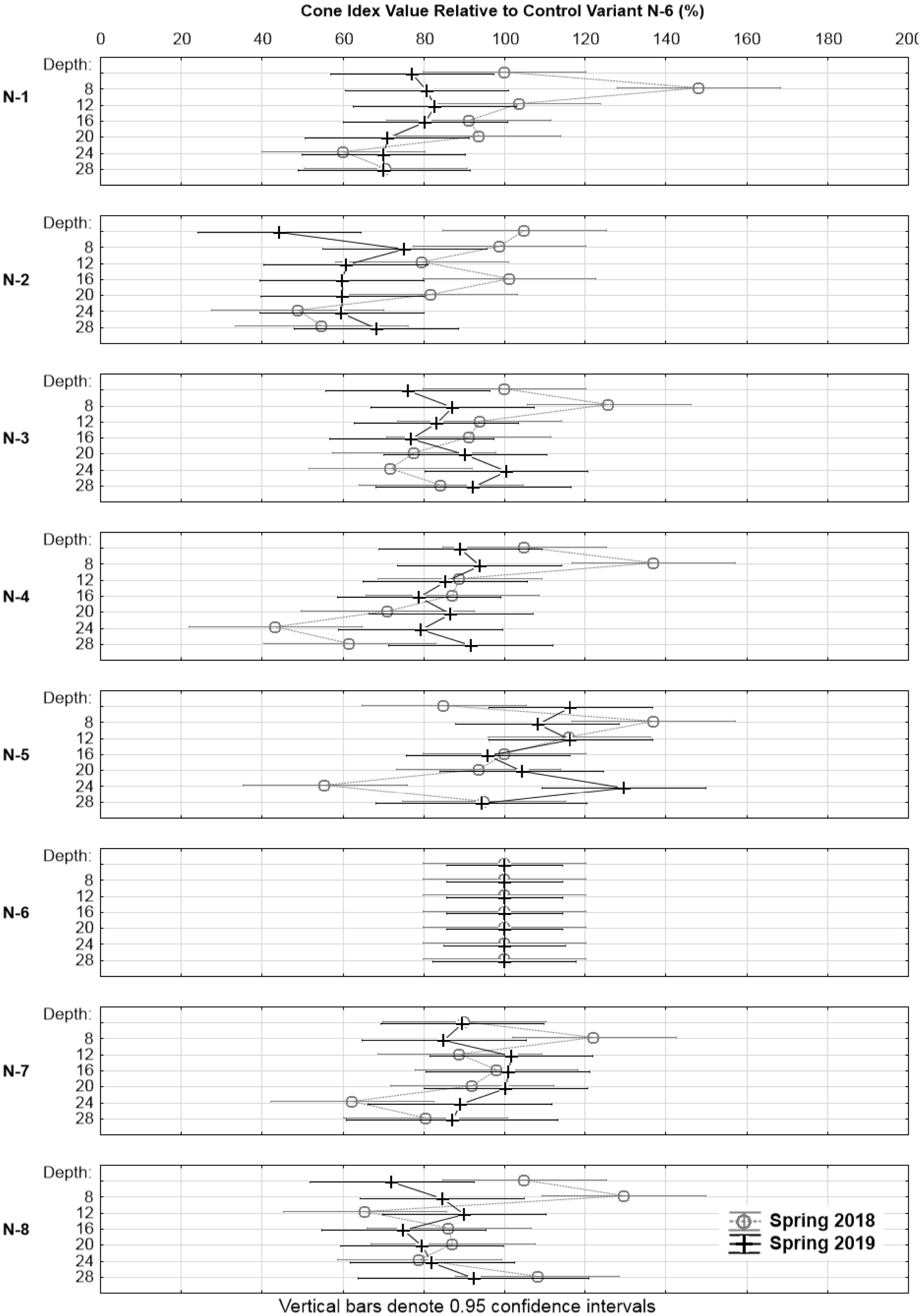

Fig. 2 Graphs comparing relative differences of soil cone index values in spring 2018 and 2019 for individual variants (Variant N-6 as 100%)

Implement draft was measured in autumn, i.e. on 10th October 2017 prior to the application of manure and other substances, and on 10th September 2018. Tillage depth attained in average 0.210 m in 2017 and 0.206 m in 2018. Soil moisture differed statistically significantly ($p = 4.89504643598622 \cdot 10^{-23}$) having been 27.6% vol. in 2017 and 13.1% vol. in 2018. The decreased moisture caused an increase in overall unit implement draft across all variants, i.e. from 63960.88 $N \cdot m^{-2}$ in 2017 to 65929.05 $N \cdot m^{-2}$ in 2018. The difference was highly significant ($p = 0.000845$), although the implement used was the same for both years. Draft values were therefore assessed relative to the control Variant N-6, as is shown in Fig. 3. The *Analysis of Variance* confirmed statistically significant differences with respect to the variants, but measurement date and the combination of both factors proved insignificant. Generally, average implement draft values decreased relative to the control, with the exception of the manure treated by Z'fix (N-1 and N-2), which was denser than the untreated one as mentioned above.

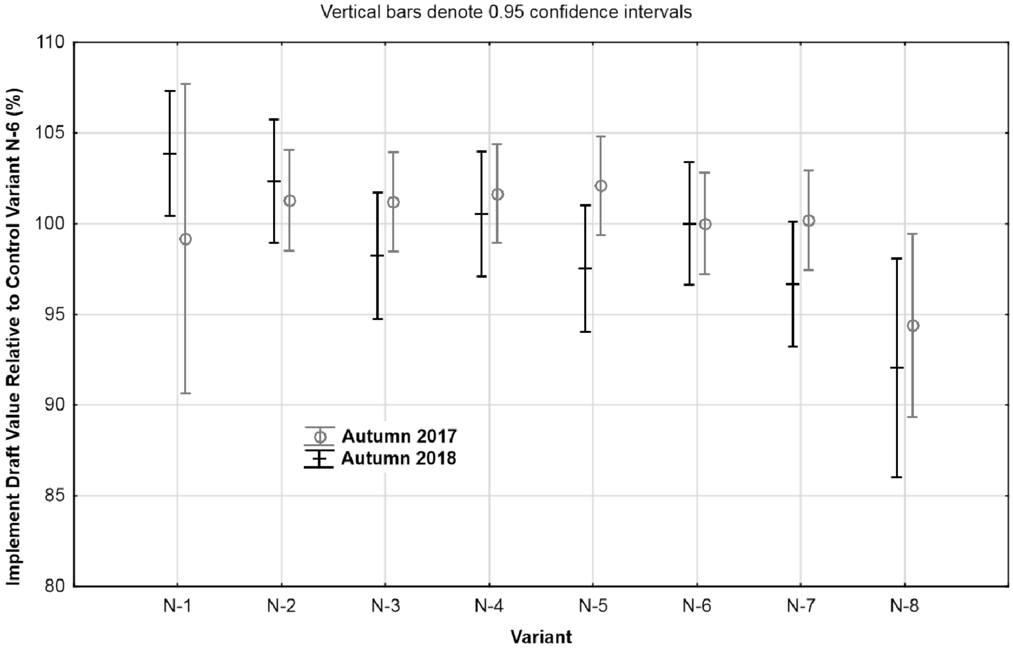

Fig. 3 Graph comparing relative differences of implement unit draft values in autumn 2017 and 2018 for individual variants (Variant N-6 as 100%)

CONCLUSIONS

The experiment focused on the effect of organic fertilizers and conditioners on soil physical properties was conducted. Biochar demonstrated favourable influence on soil bulk density, cone index and tillage implement draft. The same can be to some extent stated on the effect of traditional manure. The manure treated by Z'fix demonstrated higher bulk density and draft, though it reached highest silage maize yields. Compost and NeoSol exhibited increased bulk density, but reduced draft on the opposite. It is necessary to carry on with the research for a prolonged period, so that changes can manifest themselves.

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Příloha III

EFFECTIVE DOSE OF BIOCHAR WITHIN THE FIRST YEAR AFTER APPLICATION

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EFFECTIVE DOSE OF BIOCHAR WITHIN THE FIRST YEAR AFTER APPLICATION

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Abstract

Uneven spatial and temporal distribution of precipitation is becoming a major issue of modern agriculture. Biochar, as a natural soil conditioner, is supposed to modify soil properties and enhance water infiltration. Field experiment was conducted in order to evaluate the effective dose and its impact on soil and vegetation properties within the first season. Four small-scale plots were established within a maize field in 2017. Each plot was treated with a different dose of biochar. Penetration resistance measurements were carried out to indicate physical soil properties. Concurrently, the chlorophyll content and Normalized Difference Vegetation Index were estimated. Acquired data variability was calculated and evaluated in relation to results of measurement conducted on the plot that was established in 2014. A conclusion was drawn that biochar stimulates crop growth and the improvement reached by a lower amount after longer period may be substituted by a higher dose in the first season.

Key words: *maize; soil properties; chlorophyll content; spectral index; drought.*

INTRODUCTION

Nowadays, modern agriculture faces numerous challenges. Most of them are caused by rapid population growth, while the area of agricultural land is simultaneously decreasing. According to Czech Statistical Office (*2018*), more than one third of agricultural land in the Czech Republic was lost in the past 100 years. Concurrently, intensive farming systems have depleted the soil by using mineral fertilizers and various pesticides, very often in overdoses. In connection with the application of these substances, soil compaction has become increasingly serious issue. This phenomenon has had a negative effect, mainly on water infiltration (*Chyba, Kroulík, Krištof, Misiewicz, & Chaney, 2014*). It consequently reduces soil biodiversity and changes roots growth that affects a wide range of key functions staple for crop production (*Stolte et al., 2016*). The root system has a significant effect on plant health, not only the density and length of the roots, but as well the root volume and surface area, which are very important for plant growth (*Saleem, Law, Sahib, Pervaiz, & Zhang, 2018*). It is generally known that crop yields depend not only on soil fertility, but also on the alterations of physical and hydraulic soil properties (*Gülser, Ekberli, & Candemir, 2016*). Crops access to water sources during drought periods has become one of the key factors defining crop yields in the Central European region (*Žalud et al., 2017*). In the Czech Republic, drought is the second most extensive natural disaster (*Potop, Možný, & Soukup, 2012*) and therefore plans on how to prevent crop water stress status must be developed. One promising solution could be the utilization of biochar (*Fischer et al., 2019*).

Biochar is a very stable carbon-based material, which is usually produced from waste biomass during the pyrolysis process. The waste material is usually subjected to the decomposition process and thus it becomes a source of CO2 emissions. On the contrary, biochar production is considered to be environmentally clean technology, since most of the carbon is incorporated into the pyrolysis product (*Bordoloi et al., 2019*). This material is supposed to be applied directly into the soil where it acts as a soil conditioner (*Zhao & Zhou, 2019; Fang, Zhan, Ok, & Gao, 2018*). Many studies were undertaken to monitor the influence of biochar on soil properties. It was confirmed that the soil physical properties had improved, such as the decrease of penetration resistance or bulk density (*Jien, 2019*). Additionally, due to high organic content and high total pore volume, biochar increased water and nutrient retention (*Abel et al., 2013*) and also reduced the mobility of some organic and inorganic pollutants in a soil profile (*Bolan et al., 2014*). Regarding this, biochar application on an agricultural plot is beneficial and results in higher crop yields (*Agegnehu, Srivastava, & Bird, 2017*) since naturally all these soil properties benefit plant status as well. Although there are many studies about biochar and its impact on soil properties, the dosing is an issue which has not gained very much attention so far. Hence the main aim of the study was to evaluate biochar dose influence on soil and crop properties within a maize field after one year after biochar application.

MATERIALS AND METHODS

Site and crop management

The study was conducted within an agricultural plot located near the Šumperk town in the Olomouc region, Czech Republic (49° 59' 8.8296" N, 16° 59' 47.0904" E). In total 13.24 ha field was divided into plots with a variable area and also varying agricultural management. Besides biochar, the area dedicated to examining its impact on the soil and crop properties was treated by standard complex fertilizers (N, P, K). According to the FAO Soil Units, the soil type was classified as Gleyic Luvisols, which are usually developed on flat surfaces. Practically no sloping of the plot enables a wide-row crops cultivation without any erosion exposure. In the 2018 growing season, LAVENA variety of a maize crop was cultivated; sown on the 26th April 2018 and harvested on the date 27th August 2018. Biochar used for this study was produced from plant biomass and wooden waste in the Czech Republic. Tab. 1 gives technical specifications more in detail. Five small-scale plots 15 x 30 m with a different dose of microgranular biochar were examined within this study (Tab. 2), where specific doses were applied into the soil profile ± 25 cm during standard tillage in the autumn of 2017.

Tab. 1 Technical specifications of biochar used for the study

Total C in dry matter	min 45	[%]
Total N in dry matter	min 1	[%]
Total P (P_2O_5) in dry matter	16	[%]
Total K (K_2O) in dry matter	17	[%]
pH	9-11	-
Particle size < 2 mm	min 40	[%]
Particle size > 10 mm	max 10	[%]

Tab. 2 Specific doses of biochar applied to small-scale plots under investigation and related maize yield from the 2018 growing season.

Plot code	Biochar dose [t ha^{-1}]	Year of application	Yield [t ha^{-1}]
B15c	15	2014	51.9
B15	15	2017	50.8
B30	30	2017	53.0
B45	45	2017	54.6
B60	60	2017	55.8

Weather conditions

The growing season of 2018 is generally considered extremely dry compared to past years. This drought period was caused not only by high temperatures, but also by sporadic and insufficient rainfall. These conditions had a negative impact on crop yield, specifically 30–40% loss on maize yields in the area of interest (*Intersucho, 2019*). Fig. 1 provides information about the temperature trend and Fig. 2 about precipitation during year-long time period compared to the long-term normal (1981–2010) in the Olomouc region according to the data of Czech Hydrometeorological Institute.

Terrestrial measurements and Data Analysis

On two occasions, on-site terrestrial measurements were conducted in order to acquire empirical soil and vegetation data. The first visit, the 5th June 2018, focused on the leaf development stage (BBCH 18) while the second, 3rd July 2018, concentrated on the stem elongation stage (BBCH 32).

There were 9 sampling points regularly distributed within each of the examined plots, where all measurements were focused.

Regarding the soil properties, penetration resistance (PR) data was obtained during the first field visit. Soil moisture was measured using Theta Probe (Delta-T Devices Ltd, UK). PR was measured using the registered penetrometer PEN 70 (CULS, Prague).

To determine crop condition, Leaf Chlorophyll Content (LCC) was measured using CCM 300 sensor (OptiSciences, USA) that works with proven chlorophyll fluorescence ratio (F735 nm/F730 nm), in three repetitions for each sampling point. Concurrently, a spectral index was derived based on images captured by GreenSeeker handheld sensor (Trimble, USA). This device is designed to calculate NDVI as a basic indicator of vegetation greenness.

Statistical testing on the influence of specified doses on above-mentioned variables was entirely conducted in an open-source software environment R (*R Core Team, 2018*; *Wickham, 2009*). Since the data did not meet the assumption for using one-way ANOVA, Kruskal-Wallis distribution-free test was used to evaluate the data variability.

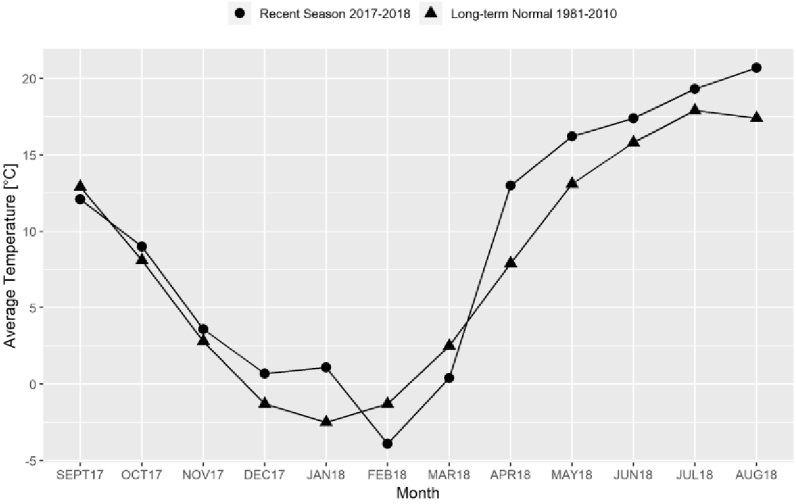

Fig. 1 Temperature conditions in the Olomouc region in the recent season compared to a long-term normal (1981–2010).

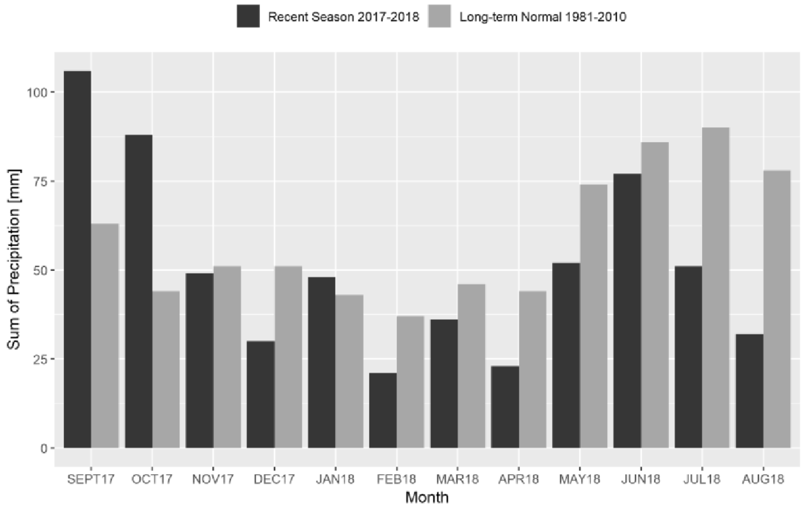

Fig. 2 Precipitation conditions in the Olomouc region in the recent season compared to a long-term normal (1981–2010).

RESULTS AND DISCUSSION

First, the influence of specified biochar doses on soil PR was examined. However, statistical analysis showed that there was no significant difference found between the examined plots. PR as a soil factor may reduce crop growth and yields in its higher values (*Colombi, Torres, Walter, & Keller, 2018*; *Haider, Steffens, Moser, Müller, & Kammann, 2017*). For maize, the top 10 cm of a soil profile is considered the most crucial due to the importance of shoot-borne nodal roots within its root system (*Colombi et al., 2018*). Since PR is a function of soil water content (*Dec, Dörner, & Balocchi, 2011*) and many studies described an increase of soil moisture when treated by biochar (*Haider et al., 2017*), the performance of this soil conditioner may not be considerable in a drought period. Nevertheless, (*Bengough, McKenzie, Hallett, & Valentine, 2011*) determined the value of 3 MPa as a threshold, since when PR becomes a limiting factor for root elongation. The data indicated that the topsoil profile values were below that critical 3 MPa threshold despite the drought period. Therefore, it is likely the short period of biochar effect produced no relevant results in terms of PR.

Regarding the impact of biochar addition on crop yield, current studies do not provide consistent results. Non-economic benefits, such as a decrease in nitrate leaching or an increase in organic carbon in a soil profile rather than direct impact on yield, are highlighted (*Aller et al., 2018*; *Haider et al., 2017*). Spectral index NDVI did not give significant statistical results. For maize, NDVI value is typically increasing during the growing season till the beginning of canopy senescence (*Verhulst et al., 2011*). Study of *Liu et al.* (*2018*) compares the performance of NDVI and chlorophyll fluorescence in periods of drought detected in winter wheat. Their conclusion supports the fact that NDVI is able to indicate a rather a long-term drought conditions, while solar-induced chlorophyll fluorescence appears to be a good indicator of the early drought period.

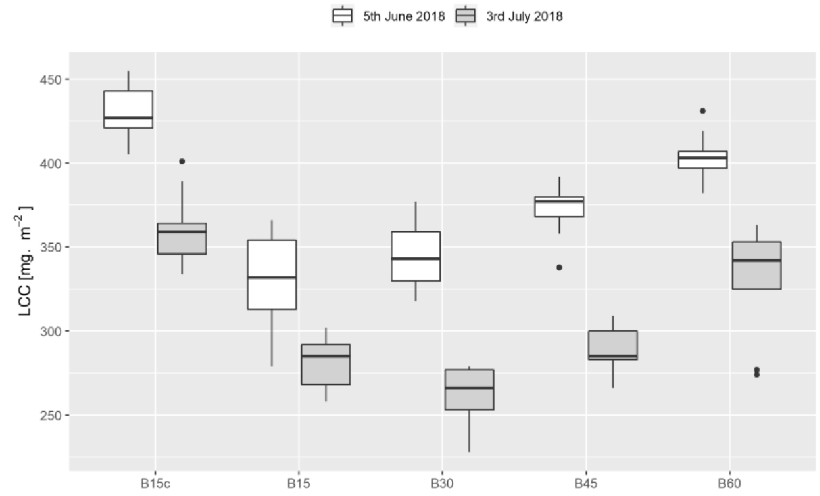

Fig. 3 Leaf Chlorophyll Content (LCC) data variability measured using CCM 300 chlorophyll meter during both field visits.

NDVI is correlated closely with LCC, regarding the study of *Cui, Li, & Zhang* (*2009*). However, in contrast with NDVI values measured in this study, LCC provided significant results for both sampling terms (Fig. 3). Nevertheless, there was no significant difference between plots B15c and B60, even though the latter plot had been treated with four times a higher dose. This, in some way, opens a discussion about the effective biochar management. *Pandit et al.,* (*2018*) conducted a three-year (six cropping seasons) field experiment in Nepal with the aim to evaluate the biochar dosage mostly from an economic perspective. According to their results, 15 t ha-1 is the optimum. Eventually, *Gavili, Moosavi, & Kamgar Haghighi (2019)* point out the fact that based on specific biochar used, higher doses may have had a negative impact on the soil salinity levels. Apparently, the time, respectively the duration of biochar effect, is also a crucial factor, since the impact of the highest dose with short effect duration (B60) on LCC levels may be considered equal to the lowest dose after four years appearance in a soil profile (B15c). Moreover, multi-year studies often describe that there is no observable effect on a crop growth until at least the second or third year (*Pandit et al., 2018*). This study, nevertheless, gained significant results (LCC) already in the first year after biochar application even though there were no alterations recorded by soil properties, very likely because of the drought period.

CONCLUSIONS

Biochar has gained a lot of attention in recent years. Besides its substantial environmental influence, since it is produced from organic waste material, it is considered to have various positive effects in the field of crop production. This study aimed to evaluate the impact of specific biochar dosage on soil properties together with the growth of maize in the first year after biochar application. Based on the results, it was concluded that biochar stimulates the crop growth. Additionally, the improvement reached by a lower dose over longer period may be substituted by a higher dose already in the first season. However, there are some concerns about the negative influence of high doses of biochar in terms of increasing soil salinity levels as well as being economically demanding. Since there are mainly non-economic benefits highlighted in the studies, such as increasing organic carbon levels or decreasing nitrate leaching, the biochar application should not be considered as a tool for increasing economic income in the first place. To better observe biochar dose effects on soil properties and crop growth alterations, a multi-year study is required. However, the influence of increasing dose on LCC may be observed already within the first year.

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Příloha IV

Biochar dosage impact on physical soil properties and crop status

Novák, V., Křížová, K., & Šařec, P. (2020). Biochar dosage impact on physical soil properties and crop status, *Agronomy Research*, 18(4), 2501–2511.

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Biochar dosage impact on physical soil properties and crop status

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Abstract. In the context of climate change and the ongoing population growth, current agriculture inevitably faces many challenges. Long periods of drought are often followed by shorter periods of heavy precipitation and degraded soil is often unable to retain the rainfall water properly. Apart from common organic fertilizers, soil amendments are currently considered a promising solution that might improve soil quality. The most discussed one is biochar, a natural soil conditioner that might under certain conditions improve soil properties. This study is based on the experiment that was established in 2017 in order to determine the impact of biochar dosage and it's effect over time. Four parcels approximately 15×30 m were designed in Rapotín, Czech Republic. Each of them was treated with a specific dose of biochar (15, 30, 45, 60 t ha^{-1}), and selected soil physical properties such as penetration resistance and reduced bulk density were then measured at the beginning of the cropping season 2019. In addition, vegetation properties were investigated with the use of handheld sensors repeatedly during the season on winter wheat. The dataset contained information about chlorophyll and nitrogen content as well as Normalized Difference Vegetation Index estimations. Acquired values were later compared with the results obtained from the fifth variant founded in 2014 with a 15 t ha^{-1} dose and from the control variant. Although the dosage levels applied were quite substantial, no significant difference was found when evaluating selected soil properties. Crop response gave similar results. Any of the examined characteristics differed among the 2017 variants and control. Nevertheless, when compared to the 2014 variant, clearly different results were detected. Thus, this study concluded that the effect of biochar dosage is might not be as significant factor, however, the time effect likely is. Therefore, the study has to continue and soil/crop properties will be observed in the upcoming season as well.

Key words: soil conditioner, penetration resistance, reduced bulk density, handheld sensor, vegetation index.

INTRODUCTION

Ensuring sufficient quantity and quality of foodstuff while protecting the environment is one of today's agricultural dilemmas. Today, the situation is dire due to various constraints related to soil properties such as soil degradation, soil compaction or carbon losses, all of which are often mentioned topics not only among scientific literature. Essentially, compacted soil has low water infiltration capacity, which is a crucial fact in terms of agricultural drought mitigation (Chyba et al., 2014). Consequently, there are significant constraints in nutrients uptake under soil compaction, namely nitrogen uptake might decrease by 30% by spring wheat (Kuht & Reintam, 2004). Moreover, the infiltration capacity is jeopardized even more during long drought periods or large amounts of precipitation in short periods of time. Due to reduced infiltration capacity, floods may occur, affecting the surrounding landscape. These negative changes are very often strengthened by anthropogenic activities, here in particular by the intensification of the agricultural practice (Kopittke et al., 2019). Also, the impact of ongoing climate change must be considered. Despite the undeniable progress in crop breeding and field management, drought still causes significant fluctuations which affect crop growth during the whole cropping season resulting in yield losses (Potopová et al., 2015).

Biochar is a carbon-rich material referred to as a soil conditioner. Its potential in terms of drought-related agricultural issues is an ongoing discussion in recent scientific studies. Primarily, the carbon content of this material is considered apparently beneficial. Depending on the properties of biomass as the input for the pyrolysis process as well as the pyrolysis conditions, the carbon content can reach up to 90%. Therefore, this material is believed to increase carbon sequestration application activities (Ippolito et al., 2017). Moreover, biochar processing can provide an efficient treatment of residual waste from food production, when taken as an input biomass (Tamelová, et al., 2019). Utilizing the waste biomass in this manner is a promising instrument for reducing greenhouse gases produced by agricultural practice (Lehmann et al., 2006).

The intrinsic links between soil and plants are undeniable facts. By means of the vegetation state, soil properties can be indirectly determined. With developments in the field of technology in recent decades, various non-destructive methods can be used to determine vegetation properties. While using the satellite imagery is suitable for larger areas, for smaller plots UAV (Unmanned Aerial Vehicles) or a variety of handheld devices is more appropriate (Tunca et al., 2018). The major difference between these two methods is the form of information which the devices provide. Apparently, the latter is used rather for direct measurement, while gathering mainly the point information. Those can be interpolated through various algorithms to acquire the spatial information about the plot as a whole. However, when requiring such data, UAVs are more recommended to be used, since today a very high resolution can be achieved by most of the sensors on the market. Spectral responses of different kinds of surface materials has been studied extensively and the achievements resulted in the development of Remote Sensing practices. Based on source imagery, hundreds of spectral indices are not only used describe plant properties. The NDVI (Normalized Difference Vegetation Index) was one of the first indices describing the vegetation biomass and health and it is one of the most widespread used even till today (Li et al., 2019). Furthermore, the nitrogen content in a plant material is one of the key indicators for predicting yields and vegetation status (Cartelat et al., 2005), since closely correlated with the chlorophyll content (Yoder & Pettigrew-Crosby, 1995).

As mentioned above, many studies look at biochar, however, the subject is often focused on physical or chemical properties of the biochar itself (de la Rosa et al., 2014; Yargicoglu et al., 2015; Yuan et al., 2015; Conti et al., 2016) or its general behaviour when applied to the soil profile respectively (Lehmann et al., 2006; Rasa et al., 2018; Razzaghi et al., 2019). The question of potential ecotoxicity is being also discussed

(Zhang et al., 2020). Nevertheless in terms of its effect, other biochar-based studies suggest that it may be responsible for reducing the soil bulk density and increase water infiltration and later availability for plants (Razzaghi et al., 2019; Tanure et al., 2019). It has been shown that the effect on reducing bulk density of the soil as well as on water-holding capacity is strongly correlated with the particle size. However, the entire effect may vary depending also on the soil type (Verheijen et al., 2019).

Although there have been many studies published on the subject of biochar, the experiment described in this paper is focused on its dosage rather than the effect itself. The objective here is to determine the potential differences in soil and crop performance based on the specific levels of biochar dose. Its impact on soil physical properties and related crop growth are about to be evaluated.

MATERIALS AND METHODS

Site and crop management

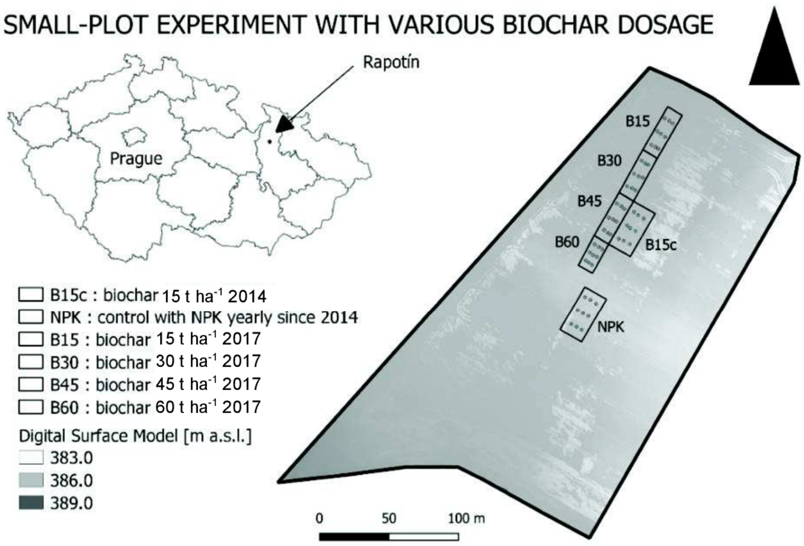

Figure 1. Experimental plot location and small-plots treatment specification.

This study was undertaken in the Czech Republic on agricultural plot located near the town of Šumperk in the Olomouc region (49° 59' 8.8296" N, 16° 59' 47.0904" E). The 13.24 ha field was divided into smaller plots with a variable area and also varying agricultural management. Five small-plots approximately 30×15 m treated by biochar in specific doses have been chosen for this study (Fig. 1). A control has also been included and marked as ‘NPK’ since the whole area was, besides investigated soil conditioners and fertilizers, treated by standard complex fertilizers (N, P, K) in a dose of 280’kg’ha^{-1} that is in accordance with the common practice. According to the FAO Soil Units, the soil type was classified as Gleyic Luvisols, which usually develops on flat surfaces. Complex soil analysis was undertaken before biochar application to obtain information about initial soil conditions (Table 1). Practically no sloping of the plot enables a wide-row crops cultivation without any erosion exposure. Crop rotation in recent years started with maize (2015) followed by in growing season 2019. *Proteus* (Soufflet Agro) wheat variety was sown on the 24th October 2018 and cultivated till the harvest date 10th August 2019. According to the producer it is semi-early to mid-late wheat with excellent resistance to laying flat and healthy leaf development. Disc harrow was used in 2014–2016 and 2018 at depths 9–12 cm, while in 2017 reversible plough at a depth of 25 cm was used during the soil tillage.

Table 1. Results of soil analysis that has been undertaken by the research company Agrovýzkum Rapotín in 2014

	Soil profile [cm]		
	0–30	30–60	
Clay (< 0.002 mm)	27	22	[%]
Clay particles (< 0.01 mm)	40	34	[%]
Silt (0.01–0.05 mm)	40	38	[%]
Fine sand (0.05–0.1 mm)	3	5	[%]
Sand (0.1–2 mm)	17	23	[%]
Bulk density	1.38	1.66	[g cm^{-3}]
Total porosity	47.72	38.91	[%]
Volumetric moisture	34.35	29.95	[%]
Humus content	1.93	1.09	[%]
pH (KCl)	5.13	5.4	–

Biochar used for this study was produced from plant biomass and wood waste in the Czech Republic by the company BIOUHEL.CZ. Table 2 gives its technical specifications more in detail. The dosage levels were designed intentionally high to assure the substantial difference in an effort to establish some threshold that defines the biochar effectivity. Since the common practice works with 10–15 t ha^{-1}, the doses for this experiment were 15, 30, 45 and 60 t ha^{-1}.

Table 2. Technical specifications of biochar used for the study as provided by the BIOUHEL.CZ company

Total C in dry matter	min 45	[%]
Total N in dry matter	min 1	[%]
Total P (P_2O_5) in dry matter	16	[%]
Total K (K_2O) in dry matter	17	[%]
pH	9–11	–
Particle size < 2 mm	min 40	[%]
Particle size > 10 mm	max 10	[%]

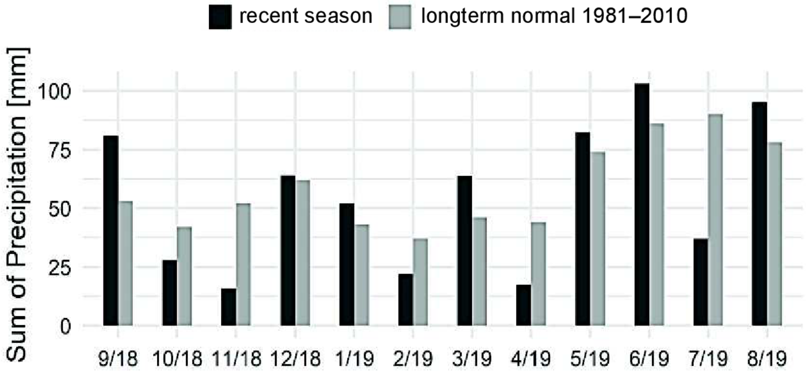

Figure 2. Precipitation condition in cropping season 2019 in comparison with the long term normal according to the Czech Hydrometeorological Institute.

Figs 2, 3 Represent meteorological conditions of the investigated cropping season. As shown on Fig. 2, the rainfall varied considerably in comparison with the long-term normal. In general, the total amount of precipitation in 2019 was 45.1 mm lower. The especially low amount of precipitation during April must have had a critical impact on the crop development. Furthermore, the temperature during this period exceeded the long-term normal during the entire season, excluding the month of May (Fig. 3). The range of temperature differences varied from -2.2 °C to 4.7 °C, however, the overall average temperature resulted in 1.6 °C higher than normal.

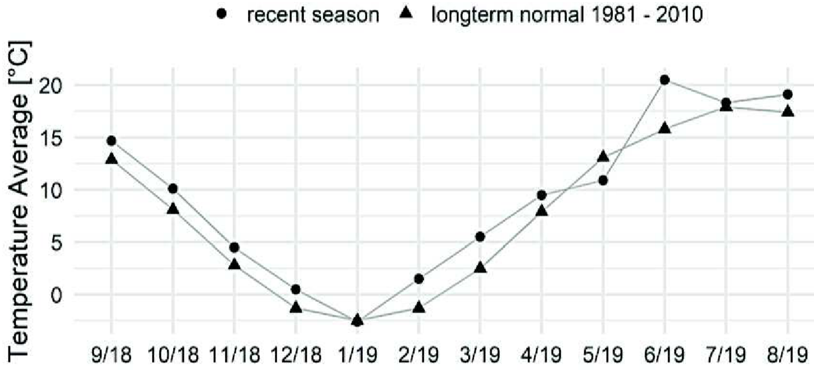

Figure 3. Monthly average temperature in cropping season 2019 in comparison with the long term normal according to the Czech Hydrometeorological Institute.

Data Acquisition and Processing

Field visits and in-situ terrestrial measurements were undertaken on the 18th April (term I; BBCH 30), 8th May (term II; BBCH 34) and 24th May 2019 (term III; BBCH 37) to obtain the terrestrial data. Soil physical properties were measured solely at the beginning of the cropping season (term I) in a period when the soil profile was saturated with water, as it is a common practice. For the information regarding Reduced Bulk Density, (BD) standard Kopecky's cylinders were used. Furthermore, Penetration Resistance (PR) of the soil profile was investigated. Using the instrument PEN 70, developed by Czech University of Life Sciences in Prague exclusively for these kinds of measurements. PR values in depths 4, 8, 12, 16 and 20 cm were recorded. Crop status data was monitored within all field visit terms. Namely it was Leaf Chlorophyll Content (LCC) measured by the CCM-300 sensor (OptiSciences), nitrogen content (N) and derived Normalized Difference Greenness Index (NDGI) measured by N-Pen (Photon Systems Instruments) and last Normalized Difference Vegetation Index (NDVI) acquired by GreenSeeker sensor (Trimble). 9 sampling points were established within each small-plot. Its GPS coordinates were recorded and the exact spot was marked by the red plastic pin to ensure the consistency of measurements in the exact spot.

The whole dataset was then processed in an open-source environment of R Studio (R Core Team, 2019) using packages tidyverse (Wickham et al., 2019), readxl (Wickham and Bryan, 2019), reshape2 (Wickham, 2007), pgirmess (Giraudoux, 2018) and multcompView (Graves et al., 2019).

The distribution of data was tested using the Shapiro-Wilk normality test in order to choose an appropriate statistical test. Since the data was not confirmed to be normally distributed, non-parametric statistical testing had to be utilized. To determine potential differences among investigated variables based on the biochar dose, the Kruskal-Wallis test was used instead of ANOVA.

RESULTS AND DISCUSSION

First of all, BD has been used to describe soil profile conditions. Since the process of collecting such data is time-consuming, the amount of information has been used for initial description of soil environment rather than for statistical testing. As shown by Fig. 4, the control (NPK) has the lowest values, while the B60 has the highest. According to the United States Department of Agriculture, the ideal bulk densities for plant growth related to present soil texture is lower than 1.10 g cm^{-3}. The bulk density which affects root growth is 1.49 g cm^{-3} and bulk densities that restrict root growth are higher than 1.58 g cm^{-3} (United States Department of Agriculture, 2019). Based on this recommendation, NPK performed the best, while by B60 the volume density limit was exceeded and the root growth was likely restricted. Variant B15c is still below USDA limit which on one hand affects the root growth, but still there is no root growth restriction. While a large number of studies have reported positive effects of biochar on soil bulk density (Walters & White, 2018; Alotaibi & Schoenau, 2019; Oni et al., 2020), there was no improvement observed in this study after two years from biochar application.

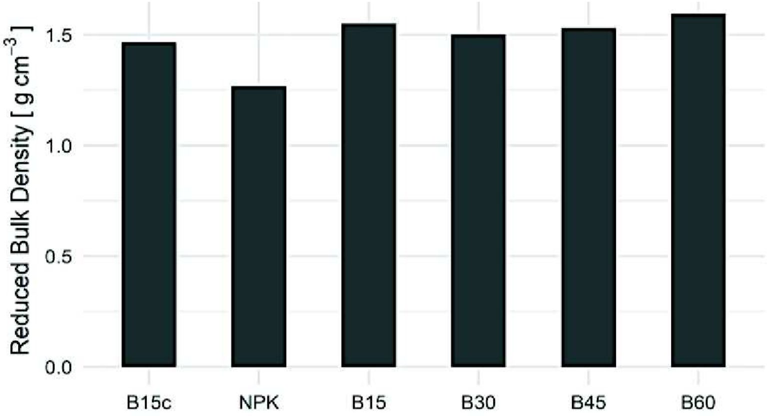

Figure 4. Values of reduced soil bulk density (0–0.05 m) - 18th April 2019.

PR results are illustrated by Fig. 5, where all investigated depths are represented. Nonetheless, neither here statistically significant difference has been observed among the variants (see also Table 3). Based on the results of other studies conducted on changes in PR, biochar is considered to reduce penetration resistance in the upper layers of the soil without increasing it in the deeper layers (Ahmed et al., 2017; Šařec et al., 2019). This is in accordance also with another study, where PR was reduced in the upper part of the sandy loam soil, but by loamy fine sand soil any influence of biochar on penetration resistance was observed (Obia et al., 2017). The measurement of soil physical parameters was undertaken in the springtime (term I) when higher water saturation of soil profile is expected. However, the precipitation in April 2019 was lower more than 50% less the normal precipitation rate. For this reason, the potential of biochar could not be sufficiently demonstrated. Otherwise, this would probably result in a decrease of PR, mainly due to the porosity of the biochar and thus its ability to retain water.

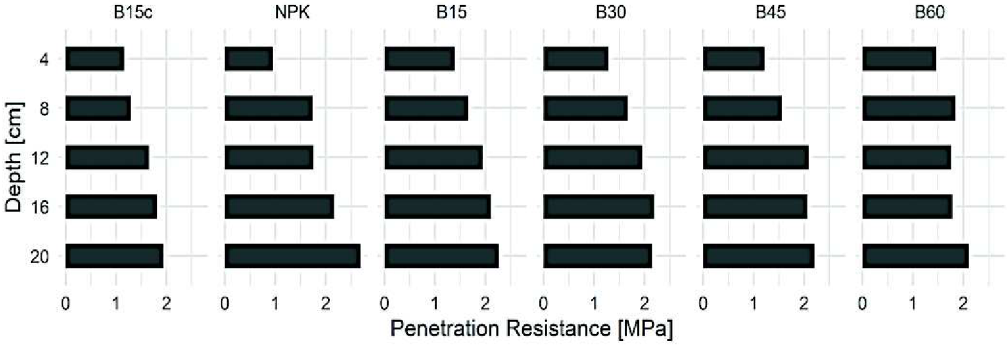

Figure 5. Soil penetration resistance values recorded during the term I in selected depth levels.

Regarding the crop growth indicators, results have been rather homogeneous as well. Table 3 provides the complex overview of Kruskal-Wallis analysis results. As shown here, only the LCC has indicated some significant differences, namely in term II and term III (see also Fig. 6).

Table 3. Kruskal-Wallis test of variance describing the variability of LCC (Leaf Chlorophyll Content), N (nitrogen content), NGDI (Normalized Difference Greenness Index) and PR (soil Penetration Resistance) in relation to small-plots treated by different dose of biochar

	Term	*p*-value	B15c	NPK	B15	B30	B45	B60
LCC	I	0.062	a	a	a	a	a	a
	II	0.023	ab	ab	a	ab	ab	b
	III	< 0.001	a	b	b	b	b	ab
N	I	0.235	a	a	a	a	a	a
	II	0.494	a	a	a	a	a	a
	III	0.344	a	a	a	a	a	a
NDGI	I	0.234	a	a	a	a	a	a
	II	0.489	a	a	a	a	a	a
	III	0.344	a	a	a	a	a	a
NDVI	I	0.035	a	a	a	a	a	a
	II	0.570	a	a	a	a	a	a
	III	0.192	a	a	a	a	a	a
	depth							
PR	4	0.129	a	a	a	a	a	a
	8	0.155	a	a	a	a	a	a
	12	0.740	a	a	a	a	a	a
	16	0.536	a	a	a	a	a	a
	20	0.230	a	a	a	a	a	a

First of all, there is apparently a difference in sensitivity of the sensors used. Although they are designed to indicate different properties, LCC are trusted to be highly correlated with the nitrogen content in a biomass (Evans, 1983). Therefore, similar results among those variables were expected. While the CCM 300 sensor measures the LCC as the chlorophyll fluorescence ratio utilizing the wavelengths assigned to the Red Edge region (CFR = 735 nm /700 nm), the N-Pen calculates the NDGI index according to the information in wavelengths of 560 nm (Green) and 780 nm (NIR). Secondly, the influence of meteorological conditions may explain the LCC data variability. As mentioned above, April was a significantly warm and dry period, which very likely affected the results recorded during the term I. During the month of May, when term II and III measurements taken, precipitation was rich and the recorded temperatures were lower. Such a combination very likely restored the suitable conditions for crop growth and therefore, the differences among the plots could be observed. The study of Tanureet al. (2019) suggest that the impact of biochar on crop growth parameters is strongly influenced by the level of drought. While under the regular conditions, biochar-enriched soils promote the photosynthesis and stomatal conductance, drought conditions cause the slowing down of these processes even more than seen in a control.

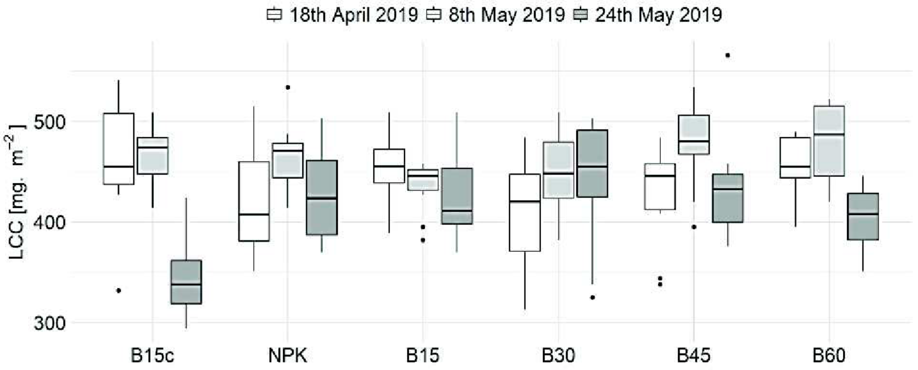

Figure 6. Leaf Chlorophyll Content obtained by CCM 300 handheld sensor during the term I, II and III among investigated small-plot variants.

During term II a significant difference was observed between B15 and B60. However, the situation became clearer in term III, when the chlorophyll content levels were significantly different by B15c compared to all variants with biochar established in 2017, excluding B60, and the control. This trend is in accordance with the previous study conducted on this small-plot experiment in 2018 (Novák et al., 2019). The conclusion of that study conducted on maize crops described the relation of crop growth parameters on variant with the longer biochar effect (B15c) and the largest dose (B60). The results of the term III confirm this conclusion, since B15c is related with the B60 only. Overall the results do not prove any other significant difference between the control NPK and any of the biochar amended variants in regard to the chlorophyll content. A similar conclusion was described by Li et al. (2020), where anatomical traits such as plant height or leaf area reflected the biochar amendment rather than the physiological parameters.

CONCLUSIONS

Based on the results of this study as well as of those from the previous year, the conclusion was drawn that so far the examined substantially different doses do not have any significant influence on i) soil penetration resistance as one of the staple soil physical properties ii) neither on crop growth physiological parameters. The sole observable differences may be found by LCC when comparing the four-year biochar effect to the control and lower-doses two-year biochar variants. Thus, the time effect seems to be more staple factor compared to dosage. Since it is so, this experiment will be observed also in the following seasons to confirm this statement.

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Příloha V

Changes in soil properties and possibilities of reducing environmental risks due to the application of biological activators in conditions of very heavy soils

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Changes in soil properties and possibilities of reducing environmental risks due to the application of biological activators in conditions of very heavy soils

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Abstract. This study aims at verifying the effect of farmyard manure (FYM) and of selected activators (Z'fix and NeoSol) on changes of soil properties. Their application should lead to improvement of soil physical properties and of organic matter fixation, to reduction of environmental risks, e.g. of tillage energy requirements. Experimental variants (0.7 ha each) were as follows: I (FYM with Z'fix); II (FYM with Z'fix + NeoSol); III (FYM); IV (Control NPK only). FYM was applied at rates: 50 t ha^{-1} (2014); 30 t ha^{-1} (2016). Additional NPK fertilizer (I–IV) was applied according to annual crop nutrient normative. The agent Z'fix was used as an activator of FYM biological transformation (5.5 kg t^{-1}). The agent NeoSol was used as soil activator (200 kg ha^{-1}; annually). In order to verify the effect, cone index, bulk density, tillage implement draft and chemical soil components (Humus, C/N ration and N_{tot}) were measured annually. Compared to the control, the application of FYM combined with the mentioned agents (I–III) increased N_{tot} more than two times. Moreover, it decreased (I–III) bulk density by 8.7%. Tillage implement draft decreased by 3% after the application of FYM with Z'fix (I, II). The study confirmed that FYM application combined with utilization of activators positively influenced soil fertility and helped to reduce environmental risks.

Key words: cone index, implement draft, bulk density, nitrogen, humus, C/N ratio, farmyard manure.

INTRODUCTION

The requirements posed on agricultural production have been raising fast recently. Moreover, these demands are likely to continue rising even faster in the future. The pressure intensifies mostly due to decreasing area of the arable land, the climate change, reduction of livestock farming, changes in crop rotation. For example in the Czech Republic, cattle production has diminished to less than a half of the volume existing 30 years ago (Sálusová, 2018). One of the consequences, even boosted by the intensification of agriculture, is the shortage of valuable soil organic matter (SOM) that contributes to a declining soil production ability on the European scale (Stolte et al., 2016). According to Gardi et al. (2013), this trend leads to a decline of the soil fertility and farmland diversity, as well as to other degradation problems. Walsh & McDonnell (2012) claim that SOM is linked not only to the fertility, but also to other properties, e.g. soil structure. SOM is likewise regarded as inherently reducing soil compaction (Chakraborty & Mistri, 2017). It is a major issue not just in Europe, where around 33 million hectares are reported to be threatened by this phenomenon (Alaoui & Diserens, 2018). Alakukku (1996) claims that the compaction adversely affects hydraulic soil properties, porosity, stability and other soil characteristics. According to Stolte et al. (2016), the compaction significantly affects root growth of plants, because it adversely affects the soil settings important for movement of gas and water. The situation thus often results in reduced crop yields. Amplified soil cone index and bulk density can be detected as a result of harmful soil compaction. Therefore, they are frequently used options of soil compaction measurement (Odey, 2018).

Any organic matters supplied to a degraded soil generally help to rectify its physical attributes (Are et al., 2017). The share of SOM is obviously advanced by applying compost or manure (Panagos et al., 2015). Manure application thus helps to amend the chemical, biological and physical soil characteristics (Ludwig et al., 2007). Liang et al. (2013), McLaughlin et al. (2002) and Peltre et al. (2015) conveyed that manure treatment substantially diminished draft of soil tillage implements. Prolonged application and higher rates produced advanced reduction. It is important in terms of economy and operation, since according to Larson & Clyma (1995), soil tillage operations account for a considerable share of the energy spent in crop production.

In order to rectify soil properties, so-called activators could be applied into any organic material, e.g. deep litter bedding of cattle housing, or straightway to soil. For the present, their effect have been studied only partially. Latest findings nevertheless imply that conditions for cultivating plants may be improved through their use (Borowiak et al., 2016). On one hand, it conveys economic advantages such as a decrease of tillage implement draft resulting in lower fuel consumption (Šařec & Žemličková, 2016). On the other, it may help agriculture to become more sustainable (Šařec & Novák, 2017). On the other hand, repeated application of an activator directly to soil and continuing conventional tillage did not generate any enhancement in terms of physical properties of soil, e.g. water content in soil, soil compaction, density, porosity (Podhrázská et al., 2012). In general, the mentioned works suggest the activators to be verified in different conditions.

This study is focused on assessing the effect of activators and farmyard manure (FYM) on selected soil physical and chemical properties at a five-year field trial.

MATERIALS AND METHODS

During 2014–2018, a field experiment was accomplished at a site near Městec Králové in the Central Bohemia at the altitude 265 m above sea level. The subject of interest was the topsoil (0–0.3 m) from soil type Gleyic Phaeozem. The experimental plot entailed very heavy soil texture. Therefore, the field was hard to till. At the depth from 0 to 0.3 m, the content of clay particles of the size under 0.01 mm accounted for 62% of weight. Particular soil characteristics at the start of the field trial are presented in Table 1.

Table 1. Particular chemical and physical characteristics of soil in the trial field in 2014

	Soil depth (m)	
	0.00–0.30	0.30–0.60
Clay (< 0.002 mm) (%)	48	60
Silt (0.002–0.05 mm) (%)	32	39
Very fine sand (0.05–0.10 mm) (%)	2	1
Fine sand (0.10–0.25 mm) (%)	18	0
Soil texture (USDA)	clay	clay
Humus content (%)	3.89	1.44
Bulk density (g cm^{-3})	1.46	1.48
Total porosity (%)	46.15	43.99
Volumetric moisture (%)	35.65	40.20
CEC - cation exchange capacity (mmol kg^{-1})	278	272
pH (H_2O)	7.50	7.82
pH (KCl)	7.18	7.21

The experimantal plot had a rectangular shape, was about 150 meters wide, and was positioned to avoid headland and to be homogenous. The rectangle was divided lengthwise each 45 meters to form four 0.7 ha variants varying in fertilizer and activator application. The spatial distribution had to be kept basic due to an operational character of the trial. NPK 15-15-15 (Lovofert, Czech Rep.) and cattle manure were the fertilizers applied. NeoSol (PRP Technologies, France) and Z'fix (PRP Technologies, France) were the activators applied. NeoSol was used at the time of stubble cultivation as the activator of biological transformation of soil organic matter. NeoSol composes of a matrix of magnesium and calcium carbonates, and of mineral elements. Z'fix was put at a recommended weekly dose directly into bedding of cattle deep litter housing as the activator of biological transformation of manure. Z'fix is formed by a granular mixture of carbonates and mineral salts. Both these activators are assumed to enhance environment for the transformation of organic matter. They cannot be classified as fertilizers due to their low share of active substances. Different treatments of individual variants and the crops grown are shown in Table 2. Apart from these treatments, all the other operations carried out and material applied did not differ among the variants. Reduced soil tillage technology was employed consisting firstly from shallow disk harrowing and subsequent deeper soil loosening to the depth of at least 20 cm using a tine cultivator.

Table 2. Application rates of individual variants of field trial and crop rotation in the trial field

Variant	Fertilization	Application rates for production year and crop (t ha^{-1})			
		2014/15 silage maize	2015/16 spring barley	2016/17 winter wheat	2017/18 silage maize
I	FYM[A] with Z'fix	50	0	30	0
II	FYM with Z'fix + NeoSol[B]	50 + 0.2	0 + 0.2	30 + 0.2	0 + 0.15
III	FYM	50	0	30	0
IV	Control - NPK only	according to crop demand and local practice			

[A]Farmyard manure of cattle origin; [B]Modified activator NeoSOL has been used with a changed dosage from the year 2017 onwards (formerly PRP SOL).

In order to assess soil physical properties, cone index and bulk density were measured in spring, while tillage draft was measured after harvest each year. Apart from the tillage draft, there were ten repetitions performed annually for each of the variants and variables. The tillage draft measurement was of continuous nature resulting in thousands of records. Only data from starting and final year were evaluated in this article. In order to measure cone index, the PEN 70 penetrometer constructed at the CULS Prague was used. Penetrometer was designed to meet the ASABE standards, i.e. with a tip cone angle of 30°, and tip area of 100 mm^2. Kopecky cylinders (volume of 100 cm^3) were employed in order to acquire undisturbed soil samples and subsequently soil bulk density. The sampling depth reached 0.05 to 0.10 m. The volumetric moisture was attained using Theta Probe (Delta-T Devices Ltd, UK). The draft of chosen farm cultivation machinery was evaluated using drawbar dynamometer with strain gauges S-38 /200 kN/ (LUKAS, the Czech Republic). The measurement was performed after harvest and prior to the first soil tillage operation, i.e. disk harrowing, each year. The drawbar dynamometer was positioned between two tractors. The sample rate of data acquisition system NI CompactRIO (National Instruments Corporation, USA) was set at 0.1 s. Within each variant, multiple machinery passes were performed. The measurements were carried out with the tillage implement either working or towed only. This enabled to discern among the implement draft, rolling resistance, and surface incline influence. The working speed was maintained constant. Acquired data were processed using Trimble Business Center (Trimble, USA), MS Excel (Microsoft Corp., USA) and Statistica (Statsoft Inc., USA).

Soil samples for chemical analysis were taken at two depths (0–0.15 m and 0.15–0.30 m) at the beginning and at the end of the vegetation period, but only the topsoil was assessed in the paper. Soil auger was used to take four summary samples composed of eight partial samples from each variant. The summary samples were dried, cleared of plant and animal residues, sieved and homogenized. The final sample (1 kg) was obtained from the summary samples by quartering.

RESULTS AND DISCUSSION

The paper is focused mainly on comparing starting conditions, i.e. the year 2014, with the resulting conditions after the five trial years, i.e. the year 2018. Fig. 1 display precipitation and monthly average temperatures of the year 2018 compared to the year 2014. In 2018, the weather was both remarkably warm and arid over the entire vegetative period. The preceding years 2016 and 2017 were also warm and short of precipitations.

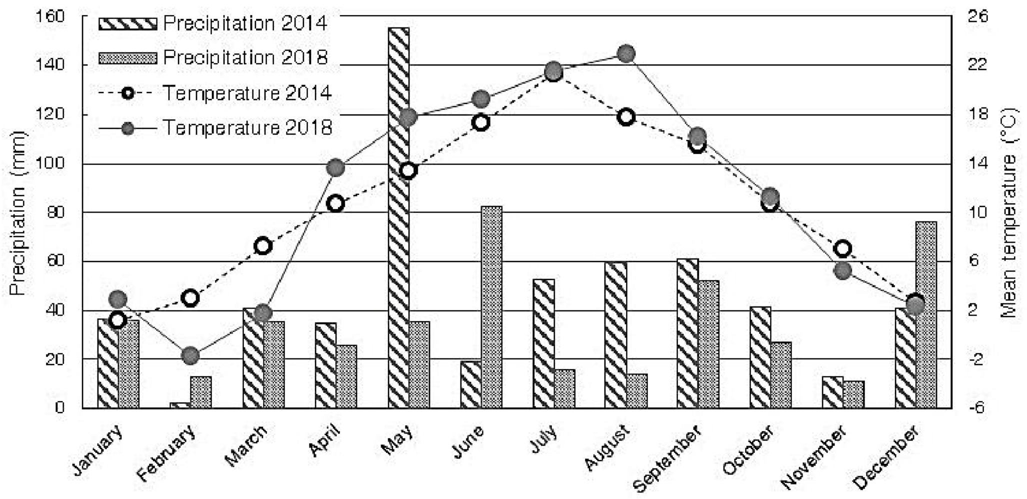

Figure 1. Graph of monthly precipitation and mean temperatures at the experimental site in the years 2014 and 2018.

Table 3. The averages of soil physical properties, and of draft of tillage implements for 2014 and 2018 regardless of trial variants

		2014	2018	Index	*p*
Soil physical properties in spring:					
Vol. moisture at 0.00–0.05 m (%)		17.305^{a}	15.570^{b}	0.90	0.02992
Bulk density at 0.05–0.10 m (g cm^{-3})		1.384^{a}	1.235^{b}	0.89	0.00104
Cone index (MPa)	at 0.04 m	0.608^{a}	0.540^{a}	0.89	0.45405
	0.08 m	0.875^{a}	1.333^{b}	1.52	0.00025
	0.12 m	1.067^{a}	1.450^{b}	1.36	0.01236
	0.16 m	1.200^{a}	1.746^{b}	1.46	0.00487
	0.20 m	1.675^{a}	2.087^{a}	1.25	0.05361
	0.24 m	2.158^{a}	2.568^{a}	1.19	0.11921
	0.28 m	2.517^{a}	3.061^{b}	1.22	0.00524
	0.32 m	2.783^{a}	3.422^{b}	1.23	0.00103
Draft measurement after harvest:					
Tractor		JD 9570 RT	JD 9570 RT		
Engine power (HP)		570	570		
Implement		tine cultivator	tine cultivator		
Implement type		Köckerling Vario 480	Köckerling Vario 480		
Working width (m)		3	3		
Working depth (m)		10.358^{a}	16.529^{b}	1.60	0.00000
Working speed (km hour^{-1})		7.026^{a}	11.300^{b}	1.61	0.00000
Overall implement draft (N)		74.821^{a}	78.492^{b}	1.05	0.02157
Unit draft (N m^{-2})		240.775^{a}	158.290^{b}	0.66	0.00000

Concerning statistical evaluation, *t-test* at the significance level of 0.5 was used.

Elementary physical characteristics of soil are depicted in Table 3. Springtime volumetric soil moisture exhibited a statistically significant difference between the two years. This clearly increased the values of cone index, which was susceptible to soil moisture. Illustrative aggregate values at different depths presented in Table 3 display statistically significant differences except at the depths of 0.20 and 0.24 m. On the other hand, overall soil bulk density across the variants decreased. The difference was also significant. Concerning draft measurement after harvest in autumn, immediate conditions were exceptionally favourable for tillage in 2018. Machinery used was the same in both years, but working depth could have been set by 60% deeper in 2018 and the working speed reached by 61% higher value. The overall implement draft thus attained higher value, but the unit draft allowing for the working width and depth was significantly lower in 2018.

Since the conditions substantially differed over the monitored period, the differences of the parameters relative to the average of the control Variant IV provide more information than their absolute values.

Implement draft was measured in a stubble field after the harvest. Manure and other material was applied afterwards. Draft values were evaluated in comparison to the control Variant IV, as is shown in Fig. 2.

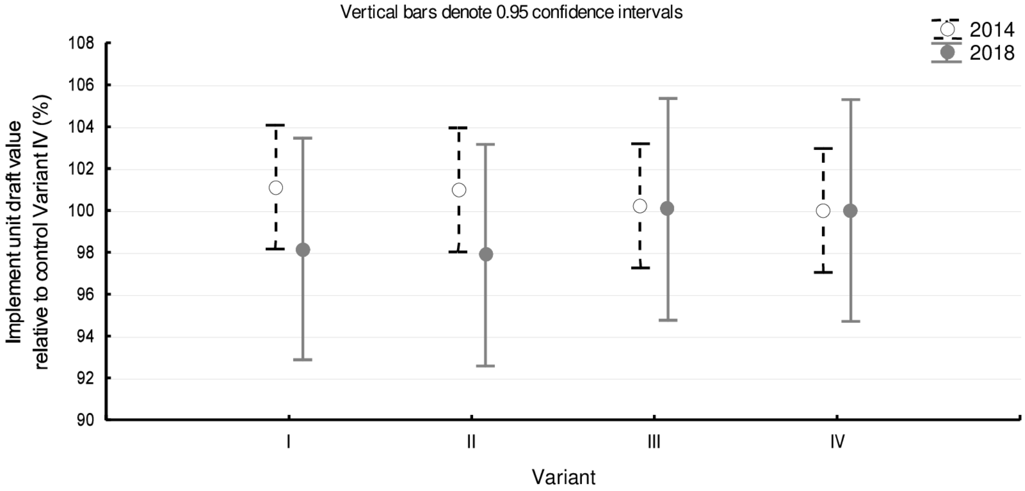

Figure 2. Graph comparing relative differences of implement unit draft values for individual variants in autumn 2014 and 2018 (Variants: I – FYM with Z'fix; II – FYM with Z'fix + NeoSol; III – FYM; IV – Control as 100%).

The *Analysis of Variance* did not confirm any significant differences with respect to the variants, measurement date and the combination of both factors. Generally, average implement draft values decreased relative to the control particularly after the application of FYM with Z'fix (Variants I and II), where the relative decrease attained 3% in average. The findings of Liang et al. (2013), McLaughlin et al. (2002), and Peltre et al. (2015) on draft reduction after manure application are consistent with the trial results, where it was intensified by the influence of activators.

Fig. 3 shows bulk density values related to the average value of respective control Variant IV. As the above mentioned Table 3 already suggested, they differed significantly according to the measurement date. However according to the *Analysis of Variance*, bulk density values did not differ significantly with regard to the variant, nor with regard to its combination with the measurement date. Nevertheless, there is a visible relative bulk density decrease particularly after the application of FYM (Variant III) by 13.4% and after the application of FYM with Z'fix combined with the application of NeoSol (Variant II) by 8.8%. The application of FYM treated with Z'fix (Variant I) presented the lowest decrease. The production of manure using Z'fix requires fewer straw. The manure is consequently more decomposed and thicker. The results are in accordance, though not statistically verified, with Schjønning et al. (1994), who claimed that prolonged time without any fertiliser treatment caused increased soil bulk density and soil strength than manure or inorganic fertilizer treatments, and Jehan et al. (2020), who reported soil bulk density and soil strength having decreased with increase in level of dairy manure. Also Bogunovic et al. (2020) observed a decrease in bulk density after FYM application. On the other hand, Chen et al. (2020) detected no such changes.

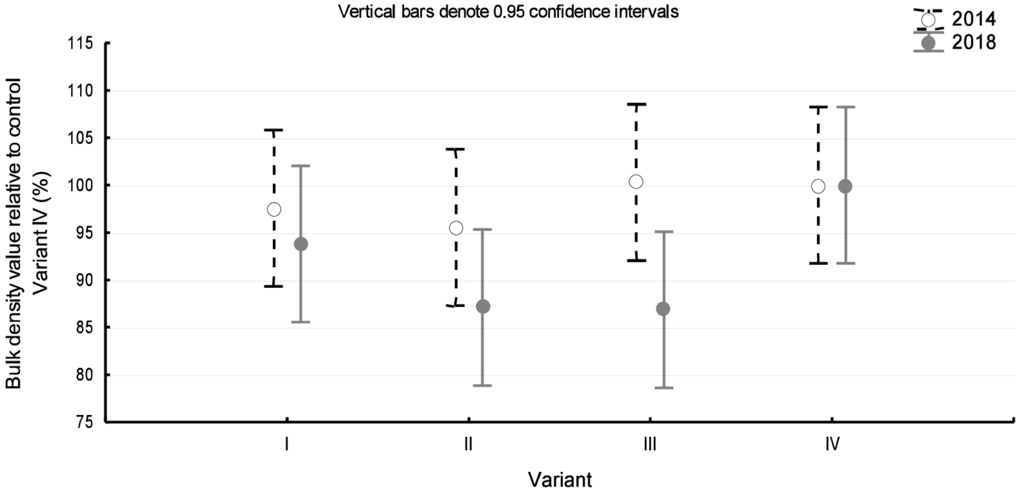

Figure 3. Graph of relative soil bulk density values from the depth of 0.05 to 0.10 m for individual variants in spring 2014 and 2018 (Variants: I – FYM with Z'fix; II – FYM with Z'fix + NeoSol; III – FYM; IV – Control as 100%).

Since cone index depends intensely on soil moisture, it was measured also in spring, when soil moisture was more probable to be homogenous. Cone index values were yet again compared to the control Variant IV, as is presented in Fig. 4. Though actual values increased from 2014 to 2018 (see Table 3), relative differences compared to Variant IV decreased. The *Analysis of Variance* did not find any significant difference for the combination of all the factors in question, i.e. measurement date, variant and depth, nor for the separate factors except for the measurement date. When considering the combinations of the measurement date with the depth or with the variant, differences were statistically significant.

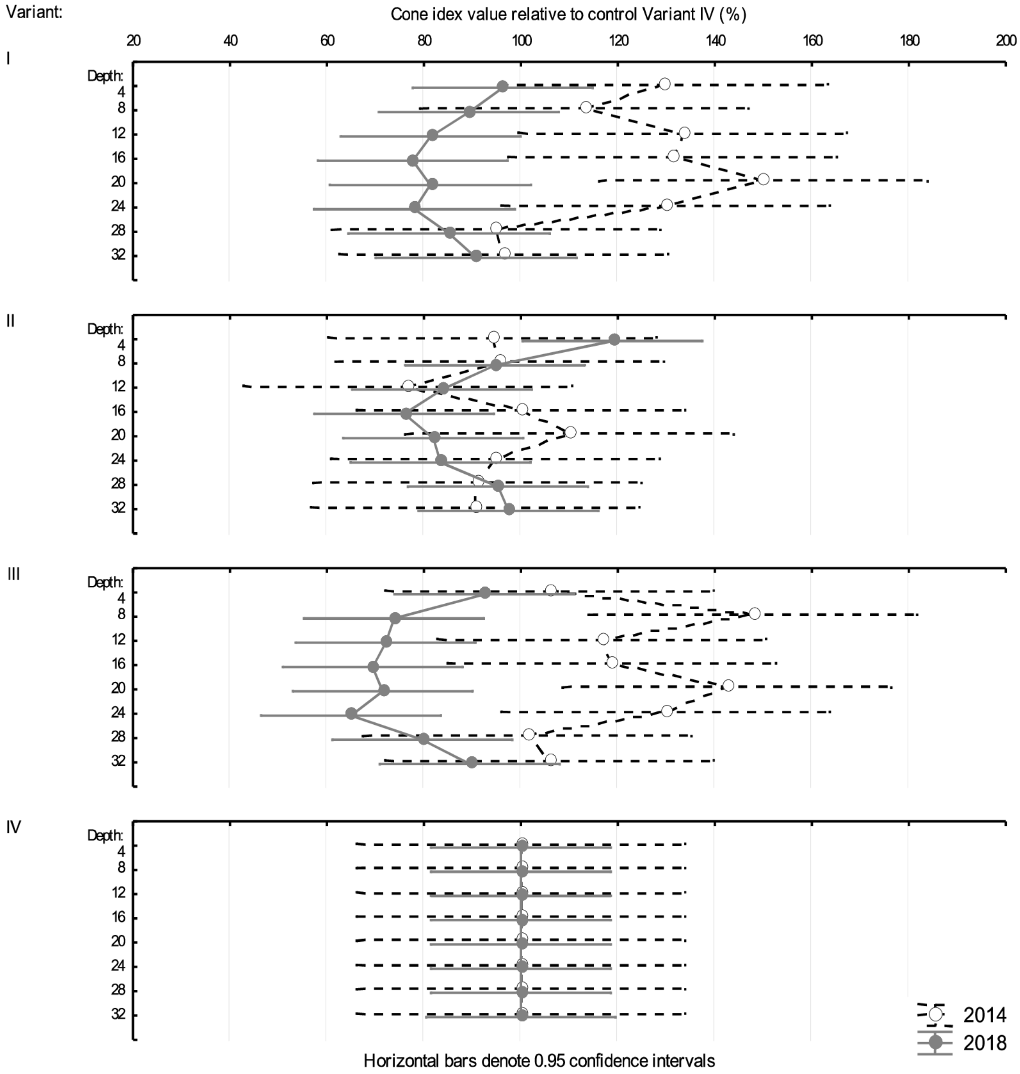

Figure 4. Graph comparing relative differences of cone index values to the depth up to 0.32 m for individual variants in spring 2014 and 2018 (Variants: I – FYM with Z'fix; II – FYM with Z'fix + NeoSol; III – FYM; IV – Control as 100%).

With the *Analysis of Variance* performed separately for each variant using the measurement date and depth as the only factors, the differences were more comprehensible. Within Variant I (FYM with Z'fix) and II (FYM with Z'fix + NeoSol), data formed one homogeneous group. In the case of Variant III (FYM) though, there was a statistically significant difference for the combination of both mentioned factors (*ANOVA*, $n = 160$, $p = 0.04198$) and data formed three homogeneous groups (see Table 4). Compared to the year 2014, the decrease of relative cone index values of the year 2018 for Variant III (FYM) at the depths of 0.08, 0.20 and 0.24 m was statistically significant. This result matches with those of Šařec & Žemličková (2016), Celik et al. (2010) and Luo et al. (2020).

Table 4. Homogenous groups of relative cone index values of Variant III (FYM) according to *Turkey HSD test* (*ANOVA*, $n = 160$, $P > 0.05$)

Trial date	Depth (cm)	Mean cone index value relative to the control Variant IV (%)	Homogenous groups 1	2	3
2018	24	64,9682	****		
2018	16	69,4444	****		
2018	20	71,4859	****	****	
2018	12	72,0930	****	****	
2018	8	73,8255	****	****	
2018	28	79,6460	****	****	
2018	32	89,4479	****	****	****
2018	4	92,4528	****	****	****
2014	28	101,2821	****	****	****
2014	4	105,8824	****	****	****
2014	32	105,8824	****	****	****
2014	12	116,6667	****	****	****
2014	16	118,7500	****	****	****
2014	24	129,8246		****	****
2014	20	142,5000			****
2014	8	147,8261			****

Table 5 presents the results of soil chemical analysis. It is apparent that pH changed particularly when the activators, i.e. Z'fix and NeoSol, were used. The pH reaction could be assessed as neutral to alkaline. The content of total nitrogen increased mainly after FYM with Z'fix application (Variants I and II). C/N ration can be evaluated as high to good and decreasing again particularly after FYM with Z'fix application. Humus content can be rated as good to high one. The FYM combination with the soil activator NeoSol had a beneficial effect on its creation. When considering the humus type, the increased humic over fulvic acids ratios of the Variants I to III can be regarded as beneficial.

Table 5. Results of chemical analysis of soil samples for individual variants in 2014 and 2018 (Variants: I – FYM with Z'fix; II – FYM with Z'fix + NeoSol; III – FYM; IV – Control)

Variant	Year	pH (KCl)	N_{tot} (%)	C/N ratio	Humus (%)	HA/FA ratio[A]
I	2014	6.98	0.3	9.45	4.84	1
I	2018	7.44	0.62	4.43	4.76	1.08
I	*Index*	*1.066*	*2.067*	*0.469*	*0.983*	*1.080*
II	2014	7.07	0.27	10.56	5.01	0.99
II	2018	7.48	0.67	4.57	5.23	1.02
II	*Index*	*1.058*	*2.481*	*0.433*	*1.044*	*1.030*
III	2014	7.1	0.32	9.07	4.94	1.01
III	2018	7.44	0.54	4.92	4.55	1.08
III	*Index*	*1.048*	*1.688*	*0.542*	*0.921*	*1.069*
IV	2014	7.17	0.32	8.66	4.76	1.02
IV	2018	7.01	0.4	6.6	4.55	0.98
IV	*Index*	*0.978*	*1.250*	*0.762*	*0.956*	*0.961*

[A] Humic to Fulvic acids ratio.

The activators of organic matter and their outcomes relate to the topics that are not thoroughly studied. Since the type of organic fertilizers used is altering, i.e. more compost and waste from biogas plants instead of manure and slurry, the increased significance of such activators of organic matter can be anticipated

CONCLUSIONS

The research aimed at the influence of organic fertilizers and activators on particular soil physical and chemical properties was carried out. Generally, the farmyard manure (FYM) and the activators showed positive effect, although not always statistically significant. Significant proved the differences in cone index values compared to the control when applying untreated FYM, where there was a reduction at the depths of 0.08, 0.20 and 0.24 m. After the application of FYM treated with Z'fix, unit implement draft decreased by 3% compared to the control variant. This difference was not confirmed statistically though, and neither were the following ones mentioned. Nonetheless given the average tractive efficiency of around 50% and the fuel requirements of tillage at the level of 20 L ha^{-1}, the 3% reduction in draft would represent 0.3 L ha^{-1} of fuel savings. This application of FYM treated with Z'fix also most of all increased the total nitrogen content. On the other hand, bulk density was mostly reduced by applying untreated FYM. The activators of organic matter should examined further on and at more locations in order to verify the results.

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Příloha VI

Soil physical properties and crop status under cattle manure and Z'Fix in Haplic Chernozem

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Soil physical properties and crop status under cattle manure and Z’Fix in Haplic Chernozem

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Abstract: A three-year experiment was conducted to investigate the effect of Z’Fix on soil physical properties and crop status. Z’Fix is an agent recommended as an addition to animal bedding to prolong its function and to lower ammonia emissions in stables. Concurrently, a positive effect on organic matter transformation in resulting manure is claimed. The experiment involved control, farmyard manure (FYM), and farmyard manure with Z’Fix (FYM_ZF) as variants. In-field sampling was conducted for cone index, water infiltration and implement a unit draft, where the latter two showed significant differences in favour of FYM_ZF. Also, concerning crop yields, FYM_ZF consistently attained the highest values, followed by FYM throughout all three seasons. Furthermore, remotely sensed data were analysed to describe crop status *via* normalised difference vegetation index where significant differences were found across all variants. Based on the study, FYM_ZF demonstrated positive effects both on soil properties and crop conditions.

Keywords: organic fertiliser; biological transformation; field experiment; pedocompaction; remote sensing

The positive effect of soil organic matter (SOM) on the physical, chemical and biological soil properties has already been well described. A high SOM level is related to improved soil properties resulting in higher water infiltration and nutrients accessibility. According to Lal (2020), SOM increases the available water capacity for all soil types. Besides others, such a list of benefits leads to increased biomass and eventually crop yields (Bauer and Black 1994, Berzsenyi et al. 2000, Önemli 2011). Farmyard manure is one of the most common ways to reintroduce quality organic matter to the soil. Compared to synthetic fertilisers, manure application strongly and positively affects the relative yield by increasing soil organic carbon storage, soil nutrients, and soil pH (Cai et al. 2019, Voltr et al. 2021). However, due to various socio-economic changes over the recent 30 years, there has been a significant decrease in animal husbandry in the Czech Republic. The numbers of cattle were reduced by 60% (Czech Statistical Office 2021). Therefore, the amount of produced organic fertiliser is limited nowadays. Together with still more intensive agricultural practice, it results in a serious lack of SOM that is further related to a number of other environmental issues, for example, to low water infiltration ability leading to surface

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runoff and related soil erosion (Matula 2003). In contrast with the benefits in the form of quality organic matter, it is necessary to pay attention to the negative aspects of livestock breeding as well. According to the estimates, livestock farming accounts for 18% of greenhouse gases. The largest source of these gases is cattle breeding, which accounts for about 65% (Gerber et al. 2013). The optimisation of organic fertiliser production with respect to their environmental footprint is therefore undeniably necessary. Manure agents are the substances that are used by farmers to enhance the welfare of animals, control produced odours, and eventually increase fertiliser value (Cluett et al. 2020). Z'Fix (Olmix Group, Bréhan, France) is one representative of such agents. It is a dust-free pearled pellet, which can be added to deep animal bedding, but it is applicable to all types of farm fertilisers (manure, slurry, compost). Some studies already evaluated the effect of Z'Fix both on animal welfare and organic fertiliser properties. When applied directly to straw bedding, the fermentation process is enhanced, resulting in better manure quality. The higher nutrient content was also determined (Šařec et al. 2017a). In combination with pig slurry, it is trusted to increase crop yield and micronutrients content (Mozdzer and Chudecka 2017). Nevertheless, the exact impact on major soil physical properties was not yet sufficiently described. Reduced bulk density after application of manure treated by Z'Fix was examined by Šařec et al. (2017b), where the conclusion confirmed the positive effect of Z'Fix compared to control (NPK) on heavy soils. Since this activator is claimed to positively influence SOM, the objective of this study is to verify this statement in a three-year study conducted in real conditions. Hypotheses that are about to be verified are related to (a) reduction of cone index and implement a unit draft, and (b) increase of the infiltration ability of the soil. Moreover, the secondary impact of Z'Fix on crop status is about to be examined *via* spectral index derived from remotely sensed data.

MATERIAL AND METHODS

Farmyard manure agent Z'Fix. Z'Fix is an activator of the biological transformation used in stables to enhance the quality of bedding by controlling the fermentation process of organic matter. The primary benefit here is animal welfare; the manufacturer, however, claims that there is also a secondary effect for resulting organic fertiliser. Z'Fix is produced in the form of granules based on calcium and magnesium carbonates with an admixture of micro- and macro-elements (potassium, sodium, sulphur, iron, manganese), which is designed to regulate fermentation processes in manure and compost. The composition of Z'Fix is: organic matter – 5%, Ca – 26.8%, Mg – 2.7%, Na – 2.88%, S – 0.28%, K – 0.42%, P – 0.04%, Fe – 2 000 ppm; Mn – 150 ppm, Zn – 30 ppm. The patented MIP (mineral inducer process) technology uses bioactive properties of minerals and specific trace elements in order to stimulate the biological reactions of the plant and the microflora within the soil.

The site and crop management. The field experiment was conducted near the town of Městec Králové, Central Bohemian Region, Czech Republic (50°12'56.8''N, 15°19'50.6''E, 235 m a.s.l.) during 2018–2020 cropping seasons. The experimental field of the farm company ZS Slovečč, a.s. involved three smaller plots according to the agricultural management. The area of the control variant (C) was 1 ha, while the variant with pure farmyard manure (FYM) and farmyard manure treated by Z'Fix (FYM_ZF) had 5 ha. The distribution of experimental variants was performed with respect to the dimensions of the field.

According to the national system, the soil type is Haplic Chernozem. According to the USDA triangle diagram, it is clay loam soil. Selected chemical properties of the soil on the monitored plot are shown in Table 1.

NPK fertiliser was applied at the rate corresponding to the farm-specific agricultural standards concerning crop demand for pure nutrients. Cattle manure (FYM and FYM_ZF) dosages were as follows: 2017 – 50 t/ha; 2019 – 30 t/ha. Concerning the FYM_ZF variant, Z'Fix was applied at the rate of 1 kg/head/week directly to deep bedding. The composition characteristics of manure and manure treated by

Table 1. Chemical soil properties

		Soil depth (cm)	
		0–30	30–60
C	(%)	3.1	2.7
C/N ratio		9.7	6.9
pH_{KCl}		7.1	7.2
K	(ppm)	797	697
Ca		7 532	8 036
Mg		350	337
P		159	123

Table 2. Cattle manure chemical analysis for variants FYM (farmyard manure) and FYM_ZF (farmyard manure with Z'Fix)

Variant	Dry matter	N	C:N	P	K	Ca	Mg	pH
	(%)			(%)				
FYM	23.1	0.56	22.3:1	0.162	0.573	0.35	0.096	8.4
FYM_ZF	23.6	0.69	18.1:1	0.179	0.739	0.458	0.12	9.4

Z'Fix are shown in Table 2. The crop rotation system during the investigated seasons was as follows: sugar beet (2018), poppy (2019), and winter wheat (2020). Since soil properties are strongly influenced by water content, the information about precipitation is given in Figure 1.

Data acquisition and processing. To assess the physical soil properties, two field visits were accomplished each year. Cone index (CI), water infiltration (WI), and implement unit draft (IUD) were investigated. CI was measured in spring terms when the soil profile was more likely to have been evenly saturated with water. The measurements of the IUD and WI took place in the autumn terms, i.e., it followed the crop harvest, as it was a common practice for this kind of measurements.

CI is a staple indicator of pedocompaction, where higher values negatively impact the crop's ability to penetrate the soil profile and thus create a rich root system. CI is basically a measure of soil resistance against a cone with precisely described geometric properties (angle, area). To obtain such data, the penetrometer PN70 was developed at the Czech University of Life Sciences Prague. This custom-made device meets all requirements of the agriculture normative ASAE S313.3 (ASABE). Measurements of CI were conducted in the spring term of each cropping season with ten repetitions per variant.

WI was examined using a rain simulator. This instrument was designed to measure not only parameters of erosion but also soil infiltration characteristics using a color dye. Usually, blue dye as a solution of water and brilliant blue (E 133) is used to spray the surface by the rain simulator for a period of 1 h. Such an application is followed by a 5 h break, during which the blue dye penetrates the soil profile. Afterwards, the soil profile is removed to a depth of approximately 40 cm and photographed. This method of infiltration characteristics assessment is based on image analysis (Figure 2). In the case of this study, the measurement was repeated three times per each variant. The soil profile was captured by a digital camera and further analysed by computer software Gwyddion 2.30 (Brno, Czech Republic). The pre-processing procedure involved cutting the image according to precisely located pins in order to analyse the exact same area recurrently, determining colour zones, and eliminating low-size soil particles to avoid errors caused by reflection. Further, the image was converted to a binary image, where the black colour defined the soil profile, and the white colour indicated the infiltrated area. In

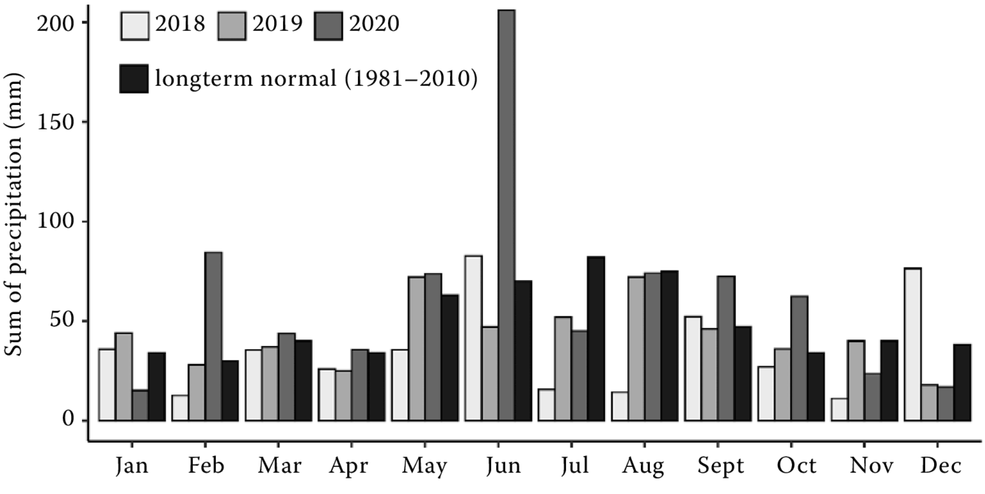

Figure 1. Rainfall conditions during investigated cropping seasons compared to a longterm normal

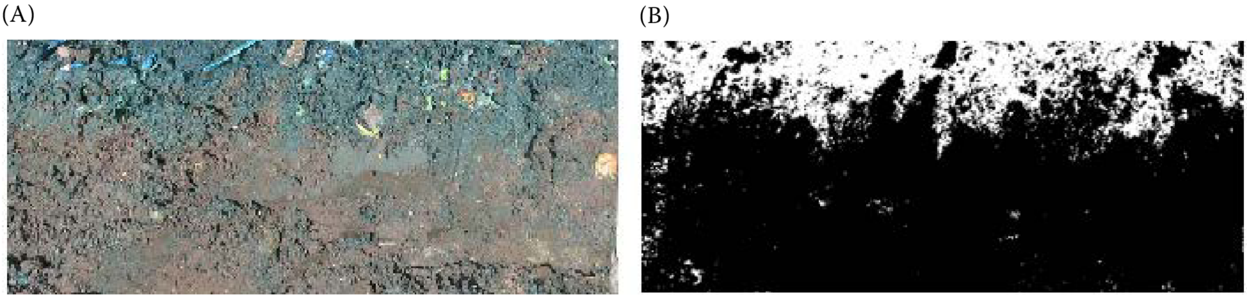

Figure 2. Water infiltration assessed by the rainfall simulator *via* (A) a digital image converted to (B) a binary image

this format, the image was also processed in ImageJ software (LOCI, Madison, USA), where the total image area was calculated together with the determination of percentages representing soil profile (black) and infiltrated part of it (white).

Energy demand for soil tillage is commonly described by the IUD. The IUD was determined using a drawbar dynamometer with strain gauge S-38/200kN (Lukas, Prague, Czech Republic) placed between the towing and the towed tractor. The IUD was measured using a tine cultivator Köckerling Vario 480 (Verl, Germany), during several passes of the machinery across each variant. The measurement was conducted under a constant speed and at a set tillage depth (2018 – 11 cm; 2019 – 17 cm; 2020 – 7 cm). The tillage depth was checked after each pass. In order to determine the potential influence of terrain slope and the rolling resistance of the towed tractor, machinery passes were repeated with the tillage implement, not in work. Data was collected using the system NI CompactRIO (National Instruments Corporation, Austin, USA), the sampling rate frequency was 0.1 s. GPS location was assigned to measured values using Trimble Business Center 2.70 (Trimble, Sunnyvale, USA).

Crop yields were measured using three separate passes of a harvester per each variant. The yield was weighed after each pass. When relevant, samples were taken to ascertain representative characteristics of the harvested product.

Since the set of soil properties has a direct impact on cropped vegetation, crop status within investigated variants was also evaluated. In the presented study, freely available Sentinel-2 satellite images (European Space Agency) with atmospheric correction and 10 m spatial resolution were collected and processed to obtain the normalised difference vegetation index (NDVI). NDVI is considered as a common indirect indicator of vegetation greenness and health (Rouse et al. 1974) and is often used to describe actual crop status. Each variant was then described by the mean value of NDVI of all pixels within its boundary.

Statistics. The acquired dataset of all investigated soil and crop properties was eventually statistically analysed with the aim to describe potential differences between investigated variants. The required homogeneity of variances for ANOVA utilisation was not met in the case of soil physical properties; therefore, a non-parametric Kruskal-Wallis test of variance was applied. Nevertheless, remotely sensed data met the ANOVA requirements, and so NDVI variance was evaluated using a standard parametric test (ANOVA with random effect of the term) followed by Tukey *HSD* (honestly significant difference) test for multiple comparisons. For all the computations, the R version 4.0.4 (R Core Team 2021) with packages *readexcel*, *tidyverse*, and *reshape2* was utilised. Plots were further generated using the *ggplot* package (Vienna, Austria).

RESULTS AND DISCUSSION

Table 3 provides the results of the Kruskal-Wallis variance test for all investigated soil properties. CI was monitored in soil profile depths of 4, 8, 12, 16, and 20 cm. Although there was no statistically significant difference between variants, the trend depicted in Figure 3 shows the lowest values within FYM_ZF compared to the other two variants almost at all depth levels. In terms of WI, FYM_ZF performed the best since the analysis showed a significant difference compared to C in 2018 and 2020, i.e., in the years straight after the manure application. The situation in particular soil profile levels is presented in Figure 4, where FYM_ZF shows the best infiltration characteristics at all depths and years. Eventually, IUD results indicated significant differences in FYM and FYM_ZF compared to C in seasons 2018 and 2020, i.e., again instantly after the manure application. Figure 5 provides the overview

Table 3. Descriptive statistics of investigated physical soil properties within variants C (control), FYM (farmyard manure), and FYM_ZF (farmyard manure with Z'Fix)

	Variant	2018			2019			2020		
		mean ± SD	C	FYM	mean ± SD	C	FYM	mean ± SD	C	FYM
CI (MPa)										
4 cm	C	0.35 ± 0.334	–	–	0.43 ± 0.134	–	–	0.55 ± 0.127	–	–
	FYM	0.422 ± 0.406	0.8	–	0.4 ± 0.125	0.97	–	0.55 ± 0.085	0.91	–
	FYM_ZF	0.39 ± 0.281	0.8	0.84	0.42 ± 0.123	0.97	0.97	0.58 ± 0.199	0.91	0.91
8 cm	C	1.17 ± 0.587	–	–	0.83 ± 0.125	–	–	0.99 ± 0.247	–	–
	FYM	1 ± 0.568	0.68	–	0.83 ± 0.2	0.72	–	0.89 ± 0.233	0.45	–
	FYM_ZF	0.94 ± 0.712	0.59	0.68	0.77 ± 0.067	0.72	0.72	0.8 ± 0.125	0.13	0.48
12 cm	C	2.04 ± 0.532	–	–	1.07 ± 0.267	–	–	1.33 ± 0.424	–	–
	FYM	1.289 ± 0.528	0.4	–	0.94 ± 0.158	0.53	–	1.12 ± 0.355	0.36	–
	FYM_ZF	1.2 ± 0.506	0.4	0.54	0.9 ± 0.141	0.32	0.53	1.07 ± 0.350	0.2	0.62
16 cm	C	2.04 ± 0.532	–	–	1.45 ± 0.493	–	–	1.62 ± 0.450	–	–
	FYM	1.744 ± 0.332	0.45	–	1.09 ± 0.238	0.092	–	1.53 ± 0.291	0.91	–
	FYM_ZF	1.75 ± 0.453	0.45	1	1.01 ± 0.166	0.058	0.509	1.45 ± 0.328	0.91	0.91
20 cm	C	2.36 ± 0.497	–	–	1.71 ± 0.547	–	–	1.99 ± 0.482	–	–
	FYM	2.011 ± 0.289	0.42	–	1.25 ± 0.242	0.054	–	2.03 ± 0.416	0.62	–
	FYM_ZF	2.25 ± 0.54	0.73	0.45	1.24 ± 0.299	0.054	0.787	1.8 ± 0.422	0.57	0.57
UID (kN/m^2)	C	105.11 ± 4.131	–	–	170.8 ± 5.376	–	–	246.571 ± 14.095	–	–
	FYM	104.62 ± 5.833	0.82	–	172.77 ± 4.973	0.29	–	243.47 ± 14.340	0.26	–
	FYM_ZF	97.86 ± 6.713	**< 0.001**	**< 0.001**	168.82 ± 6.766	0.29	0.1	233.43 ± 15.319	**< 0.001**	**< 0.001**
WI (%)	C	22.724 ± 8.566	–	–	22.34 ± 3.195	–	–	12.76 ± 3.163	–	–
	FYM	30.243 ± 13.447	0.325	–	36.827 ± 4.853	0.0591	–	22.253 ± 5.003	0.198	–
	FYM_ZF	48.975 ± 18.093	**0.034**	0.146	53.02 ± 5.256	0.0097	0.0591	34.82 ± 5.391	**0.013**	0.198

Results of Kruskal-Wallis variance test (significance level $P < 0.05$ in bold). SD – standard deviation; CI – Cone index; IUD – implement unit draft; WI – water infiltration

for all three seasons. Furthermore, vegetation status expressed by means of NDVI was evaluated, and results are presented in Table 4. Even though three different crops were evaluated, statistically significant differences were indicated by ANOVA in all levels ($P < 0.01$). The secondary impact of a particular treatment on crop status is also demonstrated by yield information provided in Table 5. The best yields were consistently attained by FYM_ZF, followed by FYM throughout all three seasons. As demonstrated

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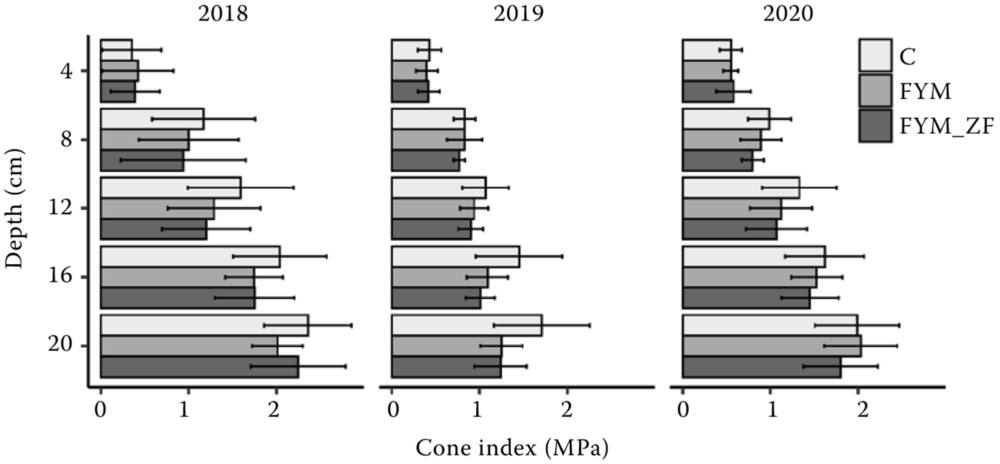

Figure 3. Cone index acquired by the penetrometer PN70, error bars representing standard deviation. C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

in Table 5, the differences in yields were significant between FYM_ZF and C in the case of sugar beet and winter wheat. Also, the sugar content reached by FYM and FYM_ZF was significantly higher than the one attained by C.

CI represents a staple soil property since it is closely related to root architecture and thus also a water uptake (Colombi et al. 2018). CI around 2.5 MPa is considered the threshold where higher values directly restrict the plant growth (Whalley et al. 2007). In the case of this study, this threshold was not reached within any variant, nor depth. However, positive effects of Z'Fix treatment may be observed through the reduced CI values in comparison with control and pure manure. The study of Celik et al. (2010) confirms that the application of organic fertilisers leads to a reduction in CI. In our study, FYM_ZF performs even better than FYM in most of the cases, and this beneficial effect, even though not significant, is likely to be supported by Z'Fix addition. The reduction of CI in upper layers of the soil profile is in line with findings of the study of Čermáková et al. (2019). When CI was lower when using Z'Fix.

The results of WI using a rain simulator showed a trend that was maintained during all monitored seasons. These results seem to be very interesting, as they do not provide a simple point information since the area under investigation involves approx. 4 square meters of the soil profile. The highest WI was always achieved by the FYM_ZF variant. In addition, there were statistically significant differences between C and FYM_ZF each season following manure application. The results clearly show an improvement of infiltration conditions for the FYM_ZF variant,

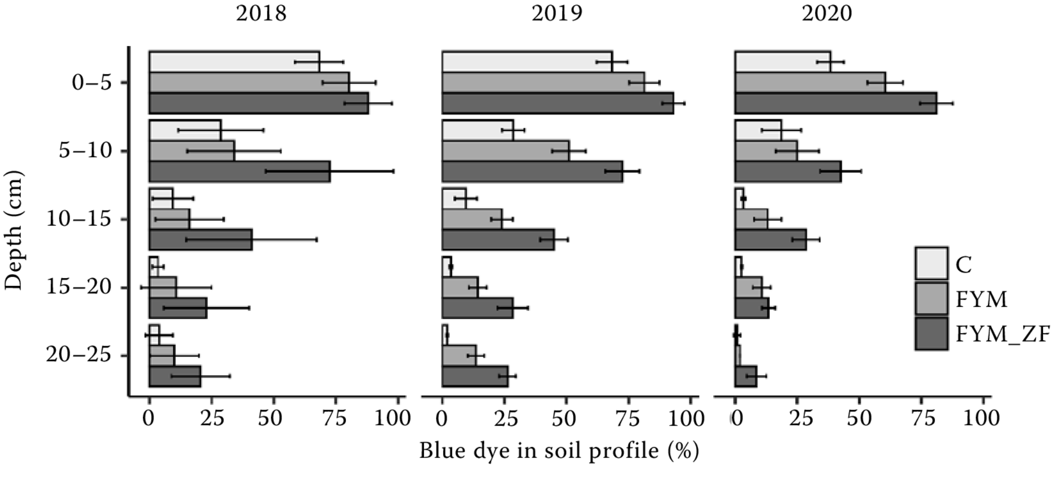

Figure 4. Percentage of infiltrated area (WI) using rainfall simulator in specific levels error bars representing the standard deviation. C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

Table 4. Descriptive statistics of normalised difference vegetation index (NDVI) (best performing variant in bold) and results of ANOVA with random effect (term) through Tukey *HSD* (honestly significant difference) test (*sowing date; $^{\times}$harvest date)

Sugar beet 31. 3. 2018* 23. 10. 2018$^{\times}$	Tukey *HSD*	19. 4.	21. 4.	29. 4.	4. 5.	21. 5.	26. 5.	3. 7.	5. 7.	22. 8.	27. 8.	29. 8.	18. 9.	28. 9.	11. 10.
FYM	b	0.231 ± 0.010	0.225 ± 0.008	0.219 ± 0.009	0.276 ± 0.010	0.635 ± 0.052	0.742 ± 0.034	0.883 ± 0.006	0.823 ± 0.007	0.577 ± 0.026	0.593 ± 0.026	0.602 ± 0.025	0.640 ± 0.031	**0.663** ± 0.035	**0.672** ± 0.035
FYM_ZF	c	**0.234** ± 0.010	**0.231** ± 0.009	**0.226** ± 0.009	**0.286** ± 0.010	**0.705** ± 0.062	0.781 ± 0.040	**0.886** ± 0.009	**0.827** ± 0.012	**0.605** ± 0.045	**0.627** ± 0.045	**0.626** ± 0.041	**0.646** ± 0.051	0.651 ± 0.045	0.648 ± 0.038
C	a	0.227 ± 0.010	0.223 ± 0.008	0.219 ± 0.009	0.280 ± 0.008	0.700 ± 0.024	**0.781** ± 0.013	0.881 ± 0.007	0.819 ± 0.010	0.556 ± 0.022	0.569 ± 0.024	0.581 ± 0.022	0.597 ± 0.031	0.603 ± 0.030	0.610 ± 0.028
Poppy 1. 3. 2019* 26. 7. 2019$^{\times}$		1. 4.	4. 4.	21. 4.	26. 5.	3. 6.	5. 6.								
FYM	b	0.213 ± 0.014	0.181 ± 0.016	0.254 ± 0.020	**0.859** ± 0.008	**0.929** ± 0.004	**0.908** ± 0.005								
FYM_ZF	c	0.222 ± 0.011	0.195 ± 0.011	0.265 ± 0.013	0.857 ± 0.008	0.927 ± 0.004	0.904 ± 0.006								
C	a	**0.227** ± 0.009	**0.206** ± 0.011	**0.271** ± 0.009	0.857 ± 0.011	0.925 ± 0.008	0.904 ± 0.010								
Winter wheat 4. 10. 2019* 23. 7. 2020$^{\times}$		31. 10.	30. 11.	24. 3.	29. 3.	5. 4.	8. 4.	20. 4.	23. 4.	28. 4.	8. 5.	18. 5.			
FYM	b	0.395 ± 0.056	0.661 ± 0.065	0.801 ± 0.039	0.755 ± 0.038	0.723 ± 0.034	0.751 ± 0.029	0.824 ± 0.017	0.846 ± 0.015	0.835 ± 0.015	0.856 ± 0.012	0.897 ± 0.011			
FYM_ZF	c	**0.454** ± 0.025	**0.738** ± 0.030	**0.852** ± 0.022	**0.815** ± 0.022	**0.783** ± 0.023	**0.803** ± 0.022	**0.838** ± 0.016	**0.855** ± 0.015	**0.840** ± 0.015	**0.864** ± 0.011	**0.898** ± 0.008			
C	a	0.351 ± 0.030	0.584 ± 0.031	0.761 ± 0.032	0.738 ± 0.038	0.712 ± 0.035	0.746 ± 0.033	0.811 ± 0.021	0.834 ± 0.018	0.826 ± 0.018	0.853 ± 0.013	0.890 ± 0.011			

C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

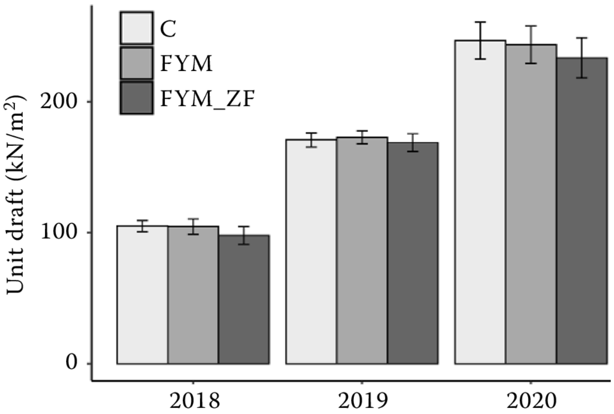

Figure 5. Implement unit draft obtained by dynamometer with strain gauge S-38/200kN, error bars representing the standard deviation. C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

as well as the general effect of manure and other organic matter, but to a lesser extent than when using activators. Concerning the fact that the WI is influenced by the bulk density (Chyba et al. 2017), WI results of the present study concurrently confirm the conclusions of the study of Šařec et al. (2017b), which described the favourable effect of Z'Fix on soil properties, bulk density, respectively.

The reduction in IUD within FYM_ZF is in line with the results obtained in previous small-plots one-year studies on two different soil types, where cattle manure treated by Z'Fix was applied (Šařec and Žemličková 2016, Žemličková and Šařec 2016). Tillage is one of the most energy-intensive operations in agriculture. The implement draft of FYM_ZF decreased by 4.5% (three-years average) compared to FYM. This decrease might result in fuel savings of about 0.45 L/ha (assuming average power delivery efficiency of around 50% and the fuel requirements of tillage operations at the level of 20 L/ha). However, the benefit is not only linked directly to fuel consumption and costs but also to the reduced emissions produced during tillage (Lal et al. 2019). Finally, vegetation conditions were evaluated. A total of 31 satellite images between 2018–2020 were analysed to derive the NDVI index. The beneficial effect of the Z'Fix during the emergence phase could be observed by sugar beet (2018) and wheat (2020). However, the effect was uncertain in 2019 (Table 4). Z'Fix seemed to maintain beneficial even during the drought periods. Although the months of July and August were really dry in 2018 (Figure 1), FYM_ZF kept showing the highest NDVI values. This observation is in line with the statement of Šařec et al. (2017b), which declares that Z'Fix can alleviate the stress of vegetation in the dry season.

Table 5. Descriptive statistics of yield parameters during the period of field experiment and results of one-way ANOVA through Tukey *HSD* (honestly significant difference) test (statistically significant results with $P < 0.05$ marked as bold)

Year	Variable	Variant	Mean ± SD	C	FYM
2018	sugar beet yield (t/ha)	C	55.19 ± 2.38	–	–
		FYM	58.60 ± 1.84	0.150	–
		FYM_ZF	61.17 ± 1.33	**0.020**	0.295
	sugar content (%)	C	19.00 ± 0.46	–	–
		FYM	21.80 ± 0.70	**0.002**	–
		FYM_ZF	22.20 ± 0.30	**0.001**	0.629
2019	poppy yield (t/ha)	C	0.82 ± 0.10	–	–
		FYM	0.89 ± 0.06	0.555	–
		FYM_ZF	0.97 ± 0.07	0.126	0.473
	poppy seed and straw mix yield (t/ha)	C	1.41 ± 0.09	–	–
		FYM	1.49 ± 0.07	0.496	–
		FYM_ZF	1.56 ± 0.09	0.141	0.576
2020	winter wheat yield (t/ha)	C	7.60 ± 0.27	–	–
		FYM	8.13 ± 0.20	0.322	–
		FYM_ZF	8.66 ± 0.62	**0.044**	0.322

SD – standard deviation; C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

Eventually, based on the above-described results, the following conclusions can be drawn. CI and IUD were mostly reduced when using agent Z'Fix for manure treatment. Concurrently, WI status was found to be superior over the other variants. All those described effects on the soil environment also positively influenced the plant status indicated by NDVI and finally resulted in higher yields during investigated cropping seasons, especially in drought periods. With respect to the sustainability of agricultural production, these findings are directly applicable to the agricultural practice; nevertheless, it is necessary to verify them further under different conditions (various soil types, manures, and climatic conditions, etc.).

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Příloha VII

Potential Impact of Biostimulator NeOsol and Three Different Manure Types on Physical Soil Properties and Crop Status in Heavy Soils Conditions

Novák, V., Šařec, P., Křížová, K., Novák, P., & Látal, O. (2022). Potential Impact of Biostimulator NeOsol and Three Different Manure Types on Physical Soil Properties and Crop Status in Heavy Soils Conditions. *Sustainability*, 14(1), 438.

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Article

Potential Impact of Biostimulator NeOsol and Three Different Manure Types on Physical Soil Properties and Crop Status in Heavy Soils Conditions

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Abstract: This study was conducted to understand the long-term influence of biostimulator NeOsol in combination with different manure types on soil's physical properties and crop status. NeOsol is a soil biostimulator that should stimulate the biological reactions of the soil profile and improve the soil's physical and chemical properties. A six-year experiment was conducted with eight treatments: NPK, cattle manure, pig manure, poultry manure, and the same four treatments with the NeOsol added on top. The in situ sampling of soil properties provided data on unit draft (UD), bulk density (BD), and saturated hydraulic conductivity (SHC). Furthermore, remotely sensed data were analyzed to describe crop status via three selected vegetation indices (VI), and crop yields were assessed last. The variants treated with NeOsol demonstrated decreases in UD over time; BD, SHC, and VI did not significantly change. The impact on yield was significant and increased over time. When comparing the variants with manure application to those without one, the cattle manure led to significantly higher SHC; the pig manure led to significantly lower UD and BD but significantly higher SHC and yield; and the poultry manure led to significantly lower UD and BD but higher yield.

Keywords: bulk density; unit draft; saturated hydraulic conductivity; yield; Sentinel-2

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1. Introduction

The growing population and the impacts of climate change are the major drivers of a significant revolution in current agriculture. Today, farmers around the globe are under substantial pressure to ensure still-higher yields in a limited area. In doing so, they must adjust their common management to actual environmental policies. Although the impacts of changing climate vary among regions and by crop, it is clear that responsible strategies must be adopted on a global scale [1] Research-based technologies began to be implemented in the 1950s [2] Collecting, processing, and transferring data into practice are some of the cornerstones of precision agriculture, one of the staple concepts of the ongoing Agriculture 4.0 [3] Properly interpreted results then enable practitioners to (a) increase productivity, (b) reasonably allocate sources, (c) adapt agricultural management, and (d) avoid food waste [4] Along with the rapid development in technology over recent decades, significant efforts have been undertaken to design and apply technologies helping to fight emerging food production issues [5].

Soil fertility is a major factor for sustainable agriculture [6]. Soil properties, including infiltration and soil structure stability may be improved with manure application. The method, rate, and timing of manure application should be considered to reduce environmental impacts, e.g., soil erosion [7]. Soil erosion by water is an outcome of two main processes: firstly, the detachment of soil particles from the soil surface by raindrop impact, and secondly, the transport of the detached particles by raindrop splash or surface runoff. Hence, the structure stability of the soils affects the rate of soil erosion. Management practices [8] used to control runoff include contouring, strip cropping, conservation tillage, terraces, and buffer strips. More than one runoff-control practice may be necessary for protection in areas with high runoff potential. Current intensive agricultural management often fatigues the soil to an extreme extent in some regions, so fertility has to be restored by a fertilizer supply [9]. Generally, organic fertilizers act as natural products while manufactured mineral fertilizers mostly consist of ideal combinations of NPK nutrients. Although mineral fertilizers appear to be an easy solution to soil fertility issues, it concurrently has many other negative impacts on the surrounding environment as a whole. Thus, properly managed organic fertilizers are the preferable option, since it is commonly known that they positively influence both chemical and physical soil properties [10]. Nevertheless, the amount of produced organic fertilizers has decreased in Europe over recent decades as animal husbandry (such as cattle and pigs) has been significantly reduced [11]. Therefore, new approaches are being researched and tested to exploit the positive features of organic fertilizers as much as possible. NeOsol (previously PRP SOL) is manufactured by Olmix Group (France) as a soil microbial biomass activator. When applied to a soil profile, it is supposed to stimulate soil biological activity and hence promote hummus synthesis. Various studies have already been conducted to describe NeOsol's actual impact on (a) soil properties, (b) plant status, (c) crop yields, and (d) compost properties. According Spychalski et al. [12], PRP SOL significantly influenced the chemical properties of soil by increasing pH and available form of magnesium, as well as by decreasing available forms of potassium. Enhanced water and nutrient uptake [13], favorable effects on soil compaction and the moisture status of the top layer [14], and reductions in the force required by soil tillage [15] were observed. Furthermore, beneficial impacts on the enzymatic activity of sand and clay soils were described by Bielińska et al. [16]. Naturally, enhanced soil properties directly impact crop growth. This was the subject of a study by Borowiak et al. [17], where PRP SOL had a positive effect on the photosynthesis rate and plant growth of spring barley and maize. PRP SOL was found to significantly enhance chlorophyll content in the leaf blades of ryegrass [18]. Various studies have also described higher yields of soybean [19], potatoes [20], and the dry matter of calendula [21] with the use of PRP SOL. Porro and Pedò [22] found that grape vines on vineyards treated with PRP SOL were in better physiological and eco-physiological condition than controls, and the taste of the final products was fruitier and more floral. The biostimulative potential of the PRP SOL was studied in combination with municipal compost, where the total contents of nickel, manganese, lead, and their soluble forms in soil were observed [23]. Furthermore, the application of compost in combination with PRP SOL had a significantly positive impact on wheat grain yield [24].

Although the above-mentioned studies addressed the topic of the biostimulator NeOsol, this study was aimed at verifying the effectiveness of this soil agent and its effect on enhancing the outcome of the three types of manure in a six-year experiment in real agricultural conditions. The hypotheses to be verified are as follows: the use of this soil agent would lead to (a) reductions in implement unit draft and bulk density, (b) increase in saturated hydraulic conductivity, (c) enhancement of crop growth, and (d) increase in crop yield.

2. Materials and Methods

2.1. Biostimulator NeOsol

NeOsol is manufactured by Olmix Group (Bréhan, France) as a granular biostimulator of vital soil functions. This soil agent uses the patented technology MIP (Mineral Inducer Process). It exploits the bioactive properties of minerals and specific trace elements to stimulate the biological reactions within the soil profile. More specifically, it uses iron, manganese, copper, and boron to stimulate enzymatic reactions involved in the transformation of raw organic matter, especially humification (α-glucosidase, β-glucosidase, etc.). In addition to MIP technology, NeOsol also uses SEAweed DRY algae extracts, which are rich in nutrients, for soil biota stimulation.

This biostimulator is declared to contain 28.0% *w/w* of CaO, 15.9% *w/w* of MgO, and 98.9% *w/w* of dry matter, from which the combustible substances create 7% w/DMw. The pH varies from 8 to 10, i.e., it is strongly alkaline.

The recommended dose ranges between 100 and 200 kg ha^{-1}, depending on crop and local soil conditions. The application is conducted after harvest in the same manner as granular mineral fertilizers, i.e., it is sprinkled on a soil's surface.

2.2. Site and Crop Management

A six-year study was undertaken within the experimental field near the town of Městec Králové in Central Bohemia of the Czech Republic (50°14.256′ N, 15°20.705′ E, 235 masl.). In terms of soil conditions, initial sampling was conducted at the beginning of the experiment in 2014 after the harvest of barley, and the characteristics are given in Table 1. The experiment was based on heavy soil (Gleyic Phaeozem), often referred to as difficult in terms of soil tillage management. In terms of texture, the soil fell into the clay category according to the USDA texture triangle.

Table 1. Analysis of the chemical and physical composition of the soil conducted at the beginning of the experiment in 2014.

	Soil Profile Depth (m)		**Unit**
	0.00–0.30	**0.30–0.60**	
Clay (<0.002 mm)	48	60	% *w/w*
Silt (0.002–0.05 mm)	32	39	% *w/w*
Very fine sand (0.05–0.10 mm)	2	1	% *w/w*
Fine sand (0.10–0.25 mm)	18	0	% *w/w*
Bulk density	1.46	1.48	g cm^{-1}
Porosity	46.15	43.99	% *w/w*
Hummus content	3.89	1.44	% *w/w*
Cation exchange capacity	278	272	mmol kg^{-1}
Volumetric moisture	35.65	40.20	% *v/v*
pH (KCl)	7.18	7.21	

The experimental field was divided into smaller plots with a rectangular area of 45 × 140 m (0.63 ha) per variant. These small plots were arranged with respect to the shape of the experimental field, and the headlands were left out. The characteristics of the treatments of particular variants with manure of different origin or with NeOsol are depicted in Table 2. Standard NPK mineral fertilizer was applied during vegetation to top up the nutrients contained in manure so that the recommended [25] full dose of nutrients for a specific crop grown was attained. Of course, the variant NPK, i.e., the control variant, was left without any additional treatment and the recommended full NPK dose including ground fertilization in autumn. This complex of treatments finally provided a set of eight variants, where all the subsequent samplings were undertaken.

The crop rotation system in the experimental field was carried out according to standard local practice. The agricultural business was located in a sugar beet production region with the crop rotation of cereals, corn, and either oilseed rape, or sugar beet. The latter two should not rotate in the same field. The standard crop rotation of the trial field included oilseed rape. The schedule of each field management practice during the experiment period is presented by Table 3. All types of manure were applied in fall using a manure spreader, while the NeOsol application proceeded immediately after harvest by a fertilizer spreader.

Table 2. Treatment of individual variants during the experimental period (2014–2020).

Variant	Treatment NPK [1]	Manure	NeOsol
NPK	Yes—full rate	No	No
NPKSOL	Yes—full rate	No	Yes
catt	Yes—top-up rate	Yes—cattle	No
cattSOL	Yes—top-up rate	Yes—cattle	Yes
pig	Yes—top-up rate	Yes—pig	No
pigSOL	Yes—top-up rate	Yes—pig	Yes
pou	Yes—top-up rate	Yes—poultry	No
pouSOL	Yes—top-up rate	Yes—poultry	Yes

[1] NPK application rate was calculated to top up the nutrients contained in manure so that the recommended [25] full dose of nutrients was attained in kg ha^{-1}: corn (N 185; P 30; K 190); winter wheat (N 180; P 35; K 95); spring barley (N 140; P 30; K 80).

Table 3. Crop rotation and agricultural management during the experimental period (2014–2020).

Season	Sowing Date	Harvest Date	Crop	NeOsol (kg ha^{-1})	Cow Manure (t ha^{-1})	Pig Manure (t ha^{-1})	Poultry Manure (t ha^{-1})
2014	-	-	Barley	200	50	40	10
2015 Term I	14.4.2015	27.8.2015	Corn	200	-	-	-
2016	23.3.2016	5.8.2016	Spring barley	200	50	20	8
2017 Term II	2.11.2016	4.8.2017	Winter wheat	150	-	-	-
2018	10.4.2018	3.8.2018	Corn	150	-	-	-
2019	5.10.2018	24.7.2019	Winter wheat	150	30	20	10
2020 Term III	15.10.2019	30.7.2020	Winter wheat	150	-	-	-

2.3. Data Acquisition and Processing

Data assessment was performed for three terms selected to follow in the same interval after the manure application, i.e., in 2015 (Term I), 2017 (Term II), and 2020 (Term III). Hereby, the potential influence of uneven interval between the treatment and measurements was eliminated. The soil's physical properties were sampled by in situ measurements performed either in spring (bulk density and saturated hydraulic conductivity) or autumn (unit draft). To acquire data on unit draft (UD), a dynamometer with S-38/200 kN strain gauges (Lukas, Prague, the Czech Republic) was placed in a horizontal position between two tractors. Firstly, measurements were accomplished with the tillage implement at a working depth and a constant speed in order to measure the overall draft of the pulled tractor and the working implement. The working depth was verified by measurement after each pass. Secondly, the not-working implement was used to measure the rolling resistance and the force induced by the potential field gradient. These were deduced from the overall draft in order to calculate the implement draft. The direction of passes was also taken into account. With regard to common agricultural practices, measurements were made with different types of implements and at different depths of soil tillage. A Köckerling Vario 480 tine cultivator was operated at depths of 11 cm (2015—Term I) and 7 cm (2020—Term III). Furthermore, a Horsch Terrano 8 FG tine cultivator was operated at 15 cm (2017—Term II). There were several passes done with each variant and the non-working and working implements, and GPS data were recorded by Trimble Business Center 2.70 (Trimble, Sunnyvale, California, USA). Simultaneously, raw UD data were collected using the NI CompactRIO system (National Instruments Corporation, Austin, Texas, USA). The sampling frequency for both GPS and UD was 0.1 s.

Furthermore, bulk density (BD) was determined via soil samples obtained using a soil sample ring kit (Eijkelkamp, Giesbeek Netherlands). The volume of each ring was 100 cm^3, and sampling was performed in three repetitions per variant. Further BD soil sample processing involved analysis in the laboratories of the Engineering Faculty of the Czech University of Life Sciences in Prague according to the national standard CSN EN ISO 17892-2.

Saturated hydraulic conductivity (SHC) was measured according to the simplified Falling-head method of Bagarello et al. [26]. It uses circular infiltrometers (in this case, 0.15 m diameter) and a known amount of water (0.5 l), which is subsequently poured on the soil surface in the area of the infiltrometer. Volumetric soil moisture was measured with a Theta Probe (Delta-T Devices, Ltd., UK) before and after water application. The time of water infiltration was measured for the later calculation of the final SHC value K_{fs} (Equation (1)).

$$K_{fs} = \frac{(\Delta\theta)}{(1-\Delta\theta)t_\alpha}\left[\frac{D}{\Delta\theta} - \frac{\left(D+\frac{1}{\alpha^*}\right)}{(1-\Delta\theta)}\ln\left(1+\frac{(1-\Delta\theta)D}{(\Delta\theta)\left(D+\frac{1}{\alpha^*}\right)}\right)\right] \quad (1)$$

here: $\Delta\theta$ = difference between initial soil moisture content and saturated soil moisture content; D = the ratio of V (volume of water) and A (area of a cylinder), which is the water level corresponding to the water volume; t_α = infiltration time; and α = constant according to Elrick et al. [27].

Potential differences in the soil's physical properties between investigated treatments were determined through one-way (factor: term) or factorial (factors: term; manure type; NeOsol treatment) analyses of variance (ANOVA) and Tukey HSD post-hoc tests.

2.4. Crop Status

A secondary effect of the investigated treatments on crops within selected variants was further determined. For this purpose, remotely sensed data were utilized because they result from a simple and widely used non-destructive method used to acquire spatial data of crop status.

The European Space Agency (ESA) provides freely available remotely sensed imagery taken by the constellation of Sentinel satellites. In this case, cloud-free multispectral data of the Sentinel-2 were utilized. Basic vegetation indices, namely the Normalized Difference Vegetation Index (NDVI) as a basic indicator of plant health and greenness [28], the Normalized Difference Water Index (NDWI) that provides information on water contents in plant tissues [29], and the Leaf Area Index (LAI) that describes the robustness of vegetation canopy [30], were calculated. This set of indicators complexly describes a canopy in terms of nutrient and water saturation. Since the Sentinel-2 data were not yet available in 2015 and 2016, the above-mentioned indices were calculated only for the following cropping seasons: 2017, 2018, 2019, and 2020.

The whole process of indices calculation was carried out in the Google Earth Engine (GEE), as it provides a convenient online environment where every step is controlled by JavaScript code. This saves a user from time-consuming, one-by-one image processing and ensures the repeatability of the same processing steps for every image in a collection. Using GEE, pre-processed and ready-to-use imagery does not have to be downloaded to a local computer because they are directly processed on the server. For the purpose of this study, a zonal statistics summary of three vegetation indices was exported in a text file and further processed in RStudio 1.4.1717, with R version 4.1.0 [31]. Potential differences in crop performance between investigated treatments were determined through analysis of variance (ANOVA) with the random effect of the image acquisition date to minimize the influence of varying index values through the cropping season.

Finally, crop yield was recorded using a combine harvester and a trailer positioned on a DINI ARGEO WWSB 16t portable static axle scale (DINI ARGEO S.r.l., Modena, Italy). The grain yield was weighed after each of set of three passes of the combine harvester per variant.

3. Results

3.1. Unit Draft

UD results are given in Figure 1, which also shows the multiple comparison analysis results based on Tukey's HSD test. The differences among investigated seasons were highly influenced by varying soil moisture during soil tillage, the type of the tillage implement used, and the depth of tillage. Therefore, comparisons of variants' UD were performed separately according to the particular terms by the one-way ANOVA. Statistically significant differences were detected for both pig manure variants, i.e., pig and pigSOL. Compared to NPK, NPKSOL, catt, and cattSOL, the pig manure variants attained considerably lower UD at Terms II and III. Pure pig manure variant (pig) values significantly differed from those obtained by NPK, NPKSOL, and catt at Term I. Otherwise, no notable differences were found. In the case of pigSOL, there was a gradual reduction in UD (relative to the NPK variant), overall reaching more than 10%. This decrease could result in fuel savings of about 1 L ha^{-1} (assuming an average power delivery efficiency of around 50% and the fuel requirements of tillage operations at a level of 20 L ha^{-1}).

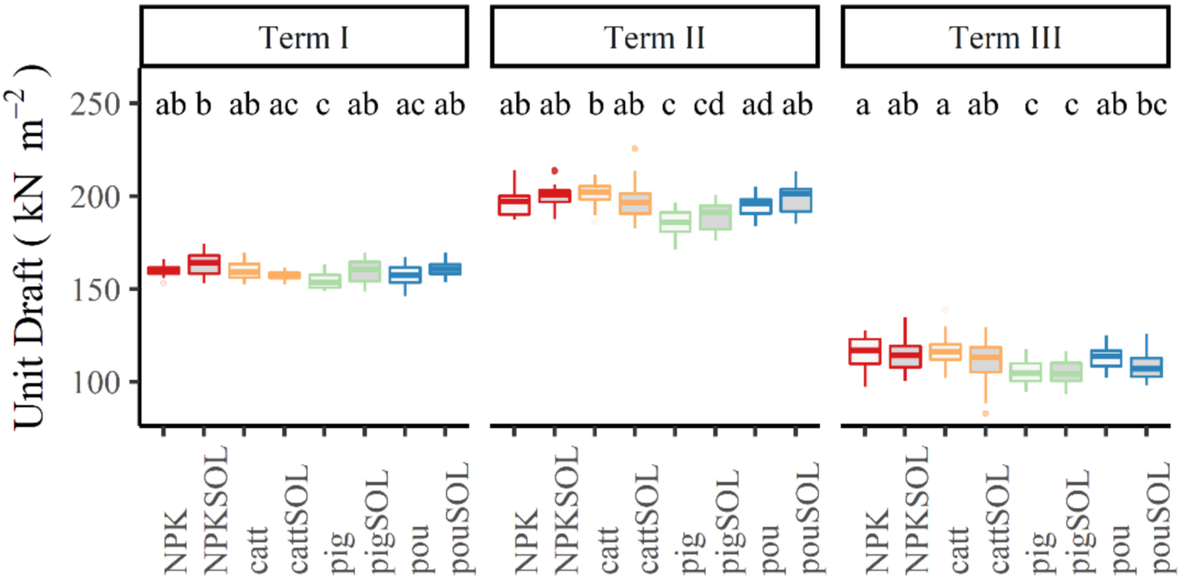

Figure 1. Unit draft within variants during the three investigated seasons. Error bars indicate the standard deviation, and letters represent multiple comparisons according to the results of Tukey's HSD test.

Additionally, the factorial (manure type; NeOsol treatment) ANOVA was employed separately for each of the terms. Concerning NeOsol treatment, Terms I and III presented significantly different results. Though variants treated with NeOsol attained higher UD values at Term I, the values become significantly lower at Term III. This fact suggests the favorable influence of the NeOsol activator on UD over a prolonged period of time. Regarding manure type, Term I presented significantly better (i.e., lower) UD values for the variants where cattle and particularly pig manure had been applied compared to the variants without any manure. At Term II, only both pig manure variants presented significantly lower UD values compared to all the other variants. The same outcome regarding the pig manure variants was present at Term III. Moreover, both variants with poultry manure showed significant and favorable differences compared to the variants without manure application.

3.2. Bulk Density

Figure 2 shows the results of soil bulk density analysis after calculating the final values. In general, BD is a relatively constant indicator that has a key effect on, for example, soil infiltration. At Term I, relatively homogeneous values could be observed, though they changed during the following years. In this regard, the overall difference between Term I and II was found to be statistically significant. A degressive reduction in BD could be observed, particularly with the application of poultry manure and pigSOL. The importance of organic matter in soil is reflected in the highest BD values of variants without any type of manure supply, i.e., NPK and NPKSOL. Furthermore, the NPKSOL variant demonstrated a gradual increase in values during the monitored periods. The pig variant always presented higher BD values than the pigSOL variant. Applying the factorial (term; manure type; NeOsol treatment) analysis of variance though the factor of NeOsol, i.e., regardless of manure type and term, demonstrated no significant differences. Concerning manure type, pig and poultry showed significantly lower BD values than variants where no manure was applied, with the poultry manure's BD values significantly differing compared to the cattle manure. Regarding individual terms, Term II provided significant decreases in BD compared to Term I.

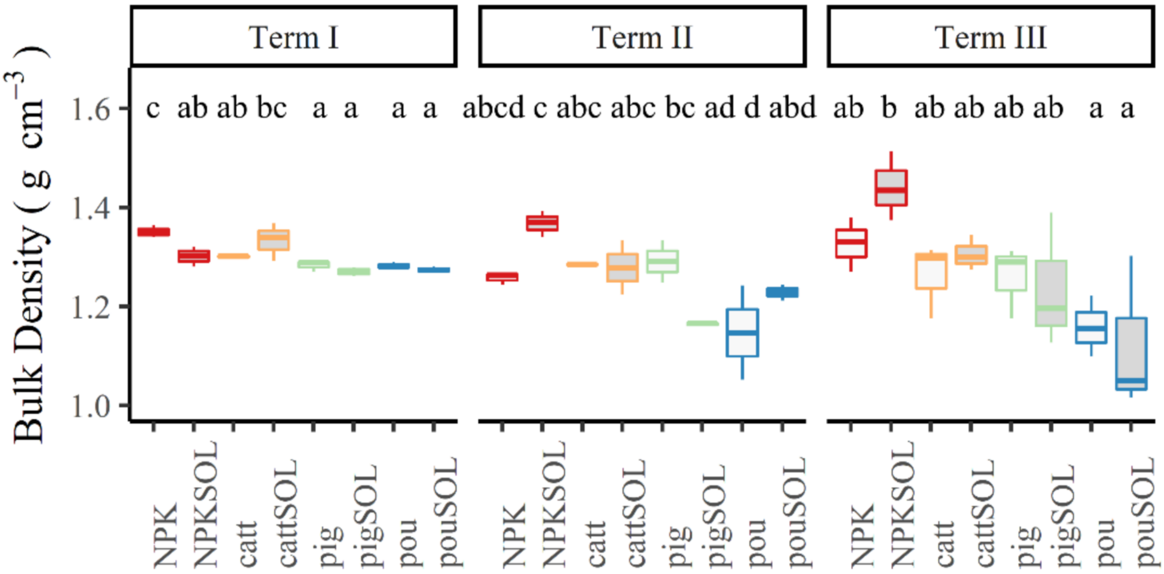

Figure 2. Bulk density within variants during the three investigated seasons. Error bars indicate the standard deviation, and letters represent multiple comparisons according to the results of Tukey's HSD test.

3.3. Saturated Hydraulic Conductivity

SHC results are presented in Figure 3. The values significantly differed among the terms, since the SHC was strongly influenced by the condition of the upper layer of the soil. Within the factorial (term; manure type; NeOsol treatment) analysis of variance, no significantly different values could be observed over the trial period between the variants, including those with/without the NeOsol biostimulator, although certain trends could be observed regarding the type of manure. The long-term use of pig manure and (particularly) cattle manure led to significantly improved SFH values compared to the variants without manure treatment. The SHC of both variants with cattle manure significantly surpassed the SHC values of variants with poultry manure. An adverse trend could be observed for the NPKSOL variant, where there was a constant decrease in SHC compared to the NPK variant. The addition of SOL to poultry manure increased the SHC value at each term, but this difference was not statistically significant.

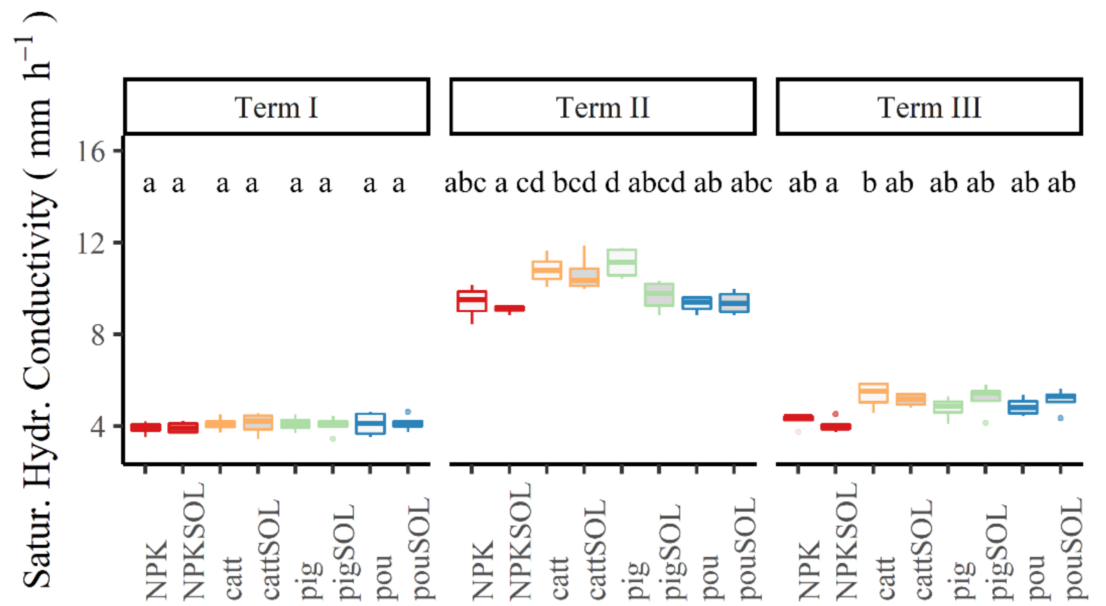

Figure 3. Saturated hydraulic conductivity within variants during the three investigated seasons. Error bars indicate the standard deviation, and letters represent multiple comparisons according to the results of Tukey's HSD test.

3.4. Vegetation Indices

The NDVI, NDWI, and LAI were generated from as many cloud-free Sentinel-2 images as there were available. These indexes introduced the spatial information of crop status in terms of (a) plant health, (b) water content, and (c) leaf area. Figure 4 depicts trends of the chosen indices through investigated cropping seasons that brought an overview information of the crop development, mostly in terms of the time effect of the used treatments.

ANOVA with the random effect of the date was performed to examine the potential diverse impact of treatments on both soil and crop status. Multiple comparisons are given in Table 4, where the gray highlighted lines represent the results of paired variants. These comparisons were supposed to answer the question of whether the NeOsol addition to the usual treatment was beneficial in terms of crop growth. It can be seen that no significant difference was found in any of these paired groups in any season. Some significant differences were observable for other variants. Those, however, appeared mostly between the control variant (NPK and NPKSOL) and variants enriched by organic matter of any kind. Hence, the effect of NeOsol addition was not verified when evaluating crop status. When focusing on the latest season (2020), the LAI was probably the most sensitive indicator, since it was also able to detect the differences among various manure types (e.g., poultry manure performed better than cattle).

Table 4. Multiple comparisons of crop status derived from three selected vegetation indices based on Tukey's HSD test. Paired variants (with/without NeOsol) are highlighted by gray color, and statistical significance levels are in bold as follows: $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***).

	NDVI				**NDWI**				**LAI**			
	2017	**2018**	**2019**	**2020**	**2017**	**2018**	**2019**	**2020**	**2017**	**2018**	**2019**	**2020**
NPK–NPKSOL	−0.0049	−0.0037	0.0007	−0.0040	−0.0074	0.0062	−0.0018	−0.0069	−0.1032	0.1544	−0.0075	−0.0427
NPK–catt	−0.0126	−0.0159	−0.0125	**−0.0328** ***	−0.0225	−0.0225	**−0.0243** **	**−0.0493** ***	−0.2705	−0.0196	−0.1401	**−0.3302** ***
NPK–cattSOL	−0.0121	−0.0107	−0.0087	**−0.0256** ***	−0.0218	−0.0144	−0.0195	**−0.0385** ***	−0.2154	0.1198	−0.1054	**−0.2519** **
NPK–pig	−0.0107	**−0.0368** *	**−0.0173** *	**−0.0352** ***	−0.0232	−0.0312	**−0.0291** ***	**−0.0529** ***	−0.2540	−0.4654	−0.2331	**−0.4828** ***
NPK–pigSOL	**−0.0182** *	**−0.0410** **	**−0.0191** **	**−0.0384** ***	**−0.0333** *	−0.0338	**−0.0284** **	**−0.0554** ***	−0.3051	−0.9308	**−0.3241** **	**−0.5624** ***
NPK–pou	−0.0125	**−0.0403** **	**−0.0226** ***	**−0.0384** ***	**−0.0291** *	−0.0206	**−0.0290** **	**−0.0545** ***	−0.1564	−0.8391	**−0.3627** ***	**−0.5481** ***
NPK–pouSOL	−0.0129	−0.0316	**−0.0188** **	**−0.0354** ***	**−0.0289** *	−0.0215	**−0.0249** **	**−0.0519** ***	−0.1757	−0.6348	**−0.3284** **	**−0.5207** ***
NPKSOL–catt	−0.0077	−0.0123	−0.0132	**−0.0288** ***	−0.0150	−0.0287	**−0.0225** *	**−0.0425** ***	−0.1673	−0.1739	−0.1325	**−0.2874** ***
NPKSOL–cattSOL	−0.0072	−0.0070	−0.0094	**−0.0216** ***	−0.0144	−0.0206	−0.0178	**−0.0316** ***	−0.1122	−0.0346	−0.0979	**−0.2092** *
NPKSOL–pig	−0.0059	**−0.0331** *	**−0.0180** *	**−0.0312** ***	−0.0158	**−0.0374** *	**−0.0273** **	**−0.0460** ***	−0.1508	−0.6198	−0.2256	**−0.4401** ***
NPKSOL–pigSOL	−0.0133	**−0.0373** *	**−0.0198** **	**−0.0343** ***	−0.0259	**−0.0400** *	**−0.0266** **	**−0.0485** ***	−0.2019	**−1.0852** *	**−0.3165** **	**−0.5197** ***
NPKSOL–pou	−0.0076	**−0.0366** *	**−0.0233** ***	**−0.0344** ***	−0.0217	−0.0268	**−0.0273** **	**−0.0476** ***	−0.0532	**−0.9935** *	**−0.3551** **	**−0.5054** ***
NPKSOL–pouSOL	−0.0081	−0.0279	**−0.0195** **	**−0.0314** ***	−0.0214	−0.0277	**−0.0231** *	**−0.0450** ***	−0.0725	−0.7892	**−0.3209** **	**−0.4780** ***
catt–cattSOL	0.0005	0.0053	0.0038	0.0072	0.0006	0.0081	0.0048	0.0109	0.0551	0.1393	0.0347	0.0783
catt–pig	0.0018	−0.0209	−0.0048	−0.0024	−0.0007	−0.0087	−0.0048	−0.0035	0.0165	−0.4458	−0.0931	−0.1526
catt–pigSOL	−0.0056	−0.0251	−0.0066	−0.0056	−0.0108	−0.0113	−0.0040	−0.0060	−0.0346	−0.9113	−0.1840	**−0.2323** **
catt–pou	0.0001	−0.0243	−0.0101	−0.0056	−0.0067	0.0019	−0.0047	−0.0051	0.1142	−0.8196	−0.2226	**−0.2179** *
catt–pouSOL	−0.0003	−0.0156	−0.0063	−0.0027	−0.0064	0.0010	−0.0006	−0.0026	0.0949	−0.6153	−0.1884	−0.1905
cattSOL–pig	0.0013	−0.0261	−0.0086	−0.0096	−0.0014	−0.0168	−0.0096	−0.0144	−0.0386	−0.5851	−0.1278	**−0.2309** **
cattSOL–pigSOL	−0.0061	−0.0303	−0.0103	−0.0127	−0.0115	−0.0194	−0.0088	−0.0169	−0.0897	**−1.0506** *	−0.2187	**−0.3105** ***
cattSOL–pou	−0.0004	−0.0296	−0.0139	−0.0128	−0.0073	−0.0062	−0.0095	−0.0160	0.0590	**−0.9589** *	**−0.2573** *	**−0.2962** ***
cattSOL–pouSOL	−0.0009	−0.0209	−0.0101	−0.0098	−0.0070	−0.0071	−0.0054	−0.0134	0.0397	−0.7546	−0.2231	**−0.2688** **
pig–pigSOL	−0.0074	−0.0042	−0.0017	−0.0031	−0.0101	−0.0026	0.0008	−0.0025	−0.0511	−0.4655	−0.0909	−0.0796
pig–pou	−0.0017	−0.0034	−0.0053	−0.0032	−0.0059	0.0106	0.0001	−0.0016	0.0977	−0.3738	−0.1295	−0.0653
pig–pouSOL	−0.0022	0.0053	−0.0015	−0.0002	−0.0057	0.0097	0.0042	0.0010	0.0783	−0.1695	−0.0953	−0.0379
pigSOL–pou	0.0057	0.0007	−0.0035	0.0000	0.0042	0.0132	−0.0007	0.0009	0.1488	0.0917	−0.0386	0.0143
pigSOL–pouSOL	0.0052	0.0094	0.0002	0.0029	0.0044	0.0123	0.0035	0.0035	0.1295	0.2960	−0.0044	0.0417
pou–pouSOL	−0.0005	0.0087	0.0038	0.0029	0.0003	−0.0009	0.0042	0.0026	−0.0193	0.2043	0.0342	0.0274

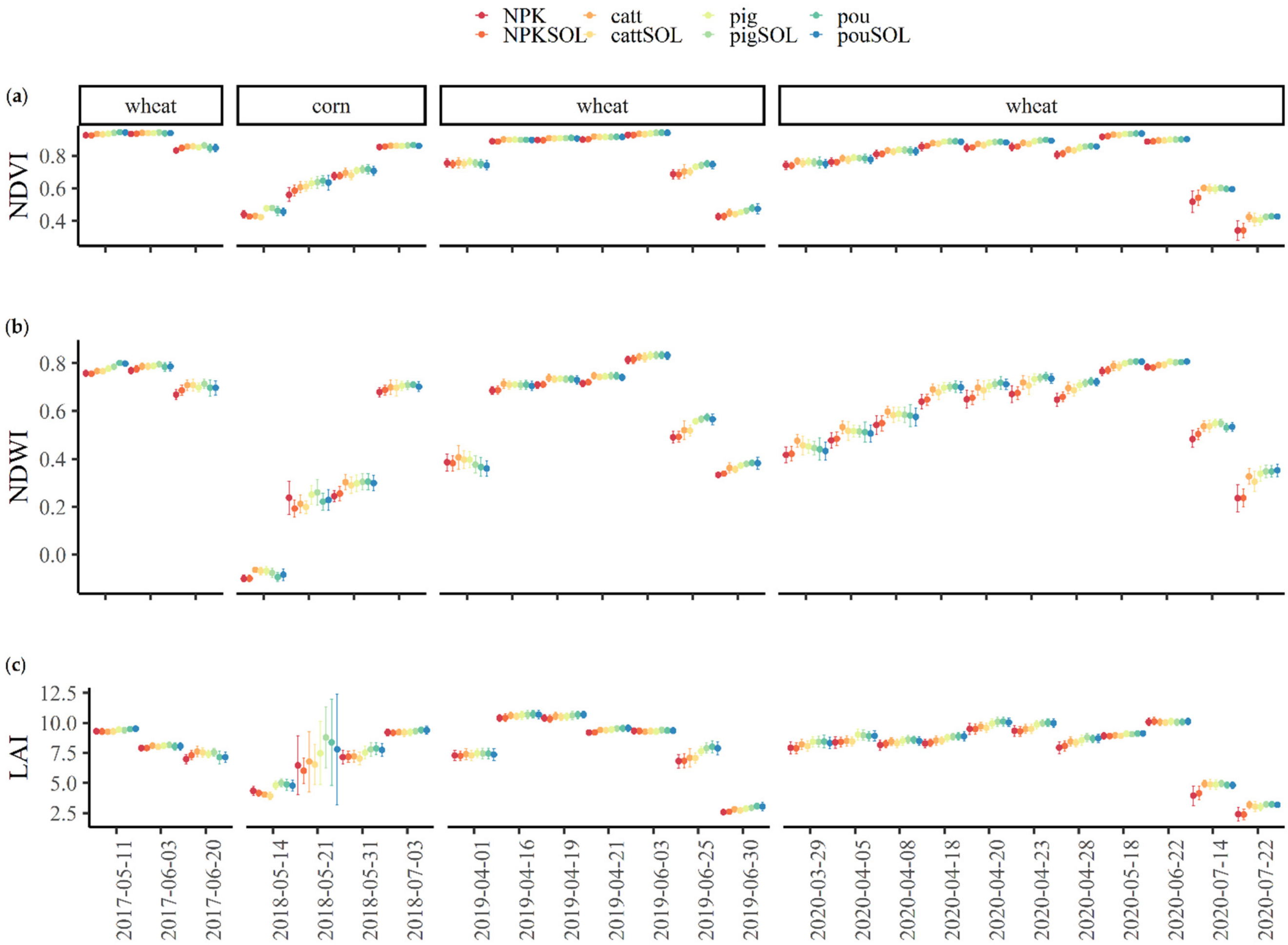

Figure 4. Crop status in terms of (**a**) crop health and biomass represented by the Normalized Difference Vegetation Index (NDVI), (**b**) crop water content status represented by the Normalized Difference Water Index (NDWI), and (**c**) canopy leaf area represented by the Leaf Area Index (LAI). Indices were derived from Sentinel-2 satellite imagery during the 2017-2020 cropping seasons. Error bars represent the standard deviation of index (pixel) values within each investigated small plot.

3.5. Yield

Table 5 presents the results of crop yields. When primarily focusing on variations between paired variants differing only in NeOsol content, higher yields were clearly obtained by the variants enriched with NeOsol, particularly at Terms II and III. This was also the case for cattle and pig manure in all three terms. Regarding poultry manure, the effect was observed at Terms II and III. NeOsol addition also had a beneficial effect on yield in the case of the NPK variant at Terms II and III. When applying the factorial (term; manure type; NeOsol treatment) analysis of variance, the overall difference between variants treated with NeOsol and the untreated variants was found to be significant. At the last term, the difference was most profoundly demonstrated. The pig and poultry manure types showed significantly higher yields than the variants where no manure was applied. When assessing the results separately within individual terms, the corn yields of the pigSOL and pou variants were significantly higher than most of the others. Term II did not demonstrate any significant differences among winter wheat yields. At Term III, however, almost all the variants reached significantly higher yields than the NPK variant.

Table 5. Descriptive statistics of yield (Mean ± Std. Dev.) during the terms of the field experiment and the results of one-way ANOVA through Tukey's HSD test.

Variant.	**Term I** **Corn (t ha^{-1})**	**Term II** **Winter Wheat (t ha^{-1})**	**Term III** **Winter Wheat (t ha^{-1})**
NPK	32.9 ± 0.7 (a)	7.71 ± 0.35 (a)	7.36 ± 0.33 (a)
NPKSOL	32.3 ± 0.8 (a)	7.95 ± 0.33 (a)	8.11 ± 0.32 (b)
catt	32.5 ± 0.7 (a)	8.43 ± 0.42 (a)	7.93 ± 0.21 (ab)
cattSOL	33.1 ± 0.7 (ab)	8.48 ± 0.42 (a)	8.29 ± 0.40 (b)
pig	32.1 ± 1.0 (a)	7.71 ± 0.36 (a)	8.11 ± 0.18 (b)
pigSOL	35.7 ± 0.6 (c)	8.10 ± 0.46 (a)	8.38 ± 0.22 (b)
pou	34.8 ± 0.8 (bc)	7.62 ± 0.30 (a)	8.11 ± 0.19 (b)
pouSOL	32.3 ± 0.9 (a)	7.90 ± 0.41 (a)	8.32 ± 0.19 (b)

4. Discussion

UD is a commonly used metric for assessing energy demand during soil tillage, since it gives the information about the energy necessary for tillage tools to loosen the topsoil. Soil tillage is the most energy-demanding operation in the crop production process, and a decrease in fossil fuel usage should be the crucial goal in sustainable crop production [32]. UD is highly influenced by soil moisture content, tillage depth, and operation speed [33]. The study of Liang et al. [34] concluded that the application of manure has reduced the energy demand of tillage. In case of our study, the results regarding pig and poultry manure confirm Liang's results, though less so for cattle manure. The results regarding the pig manure are in line with the work of Mclaughlin et al. [35], who reported that repeated applications of manure are reflected in reduced tillage energy. The results concerning cow manure with NeOsol are, however, not in line with the work of Žemličková and Šařec [36], who reported an increase in unit draft at one year after application. Urbanovičová et al. [15] described a decrease in tension force at ploughing by 5.71% after three applications of NeOsol compared to an untreated plot. All three applications were carried out within the years 2015–2016, and the draft of a plough was only measured at the end of the experiment. Tuba et al. [37] also reported a considerable decrease in plough draft after NeOsol treatment in their three-year experiment. In this study, we only observed a significant decrease in UD by 2.9% after six years of NeOsol treatment.

BD is an important indicator of soil compaction. BD values vary with the time delay from soil tillage. Immediately after tillage, values are lowest and tend to increase during the season due to climatic factors and mechanical load exerted on the soil surface [38,39]. According to the USDA [40], the ideal bulk density for optimal plant growth on soils with a clay content of more than 45% is lower than 1.1 g cm^{-3}. In case of this study, this threshold was exceeded for each term. The pigSOL variant achieved better results in comparison to the pure pig manure. Schjonning et al. [41] reported that long-term cattle manure application led to the decline in soil BD, and Hemmat et al. [42] reported that different BD values were more influenced by the application rate of manure than the manure origin. The results regarding the NPKSOL variant in our study are in line with Urbanovičová et al. [15], who found an increase in BD in the topsoil with NeOsol. The long-term results regarding the pigSOL variant also confirm the results of Šařec and Žemličková [43], who found that the application of NeOsol in combination with pig manure led to an improvement in BD in the topsoil.

SHC is a staple hydrogeological parameter that describes a soil's ability to infiltrate water and distribute it further to the crop root system. Our observations concerning SHC or infiltration rate in general are by and large consistent with past ones [44,45], which have shown improvements in infiltration processes and reductions in surface runoff rates and soil loss for soils with various organic soil treatments from livestock production. Apart from different types of organic matter, some activators have also been examined. Particularly, biochar [46] was found to significantly increase the final infiltration rate and significantly reduce soil loss. However, in our study, NeOsol did not demonstrate any such effect.

The major advantage of the utilization of remote sensing data in agriculture is the fact that a canopy can be easily observed in a non-destructive manner with a high temporal resolution (5 days for Sentinel-2 at the equator in ideal meteorological conditions). This results in a complex set of data that provides information about crop development during the cropping season. Figure 4 and Table 4 illustrate this kind of information, and even though no significant difference between paired variants has so far been observable, the timeline shows a clear trend. Starting at the 2017 season with almost no difference between treatments, the significance increased over time. In 2020, strong differences between NPK, NPKSOL, and the variants with any manure can be clearly observed in every comparison level by all three indices. NeOsol's contribution to higher chlorophyll content has already been described in several studies [17,18,20,47]. It is therefore likely that the desired impact of the management of crop status might be detected in the following seasons, e.g., over a longer time span after NeOsol application.

The NDWI was calculated to gain information regarding crop water content, which was closely related to the SHC soil property. Šindelková, Badalíková, and Kubíková [13] stated that improvements in soil properties using activators leads to preferable utilization of water and nutrient uptake by plants. Nonetheless, though SHC results (Figure 3) demonstrate the only difference between the NPKSOL and the catt variant at Term III, crop water status via the NDWI differed on several more levels. Here again, the major advantage of spatial data is noticeable, as they provide more accurate information than point sampled data.

Sustainable agriculture is necessary to provide careful nutrient management, which is important for increasing soil organic carbon due to improving agricultural productivity and maintaining ecosystem health [48]. One of the possibilities may be the application of manure, which improves soil fertility even in combination with mineral fertilizers [49]. On the other hand, the application of inorganic fertilizers directly leads to higher yields by providing nutrients that encourage crop growth [50]. In both years of the mentioned experiment, the yield of winter wheat grain significantly increased and almost proportionally to the increasing doses of compost. The application of the soil improver on the background of compost further significantly increased the grain yield. However, the soil improver applied in the control treatment, without compost, had an insignificant impact on the wheat yield [24]. Several experiments were conducted to verify the effect of PRP SOL (now NeOsol) on yields with diverse outcomes. The PRP SOL activator proved to be a useful soil additive for calendula growing, as it was found to increase the yield of dry matter of flowerheads [21]. PRP SOL can also replace the inorganic fertilizing of spring barley with phosphorus and potassium without grain yield losses [51]. Another study [52] of a two-year soybean experiment did not show any statistically significant increase in yields when using the SOL activator. Conversely, PRP SOL in combination with urea was found to have a positive effect in terms of increased soybean yield [19]. Our observations have proven the significant effects of NeOsol on yield, which were intensified after a prolonged application, i.e., at the last term of the experiment.

This experiment verified beneficial effect of the NeOsol activator on crop yield and the unit draft of tillage implements after a prolonged application. In an agricultural practice, this may manifest in higher revenues from crops and lower fuel consumption of soil tillage.

5. Conclusions

We carried out a six-year experiment on the biostimulator NeOsol and three manure types of different origin (cattle, pig, and poultry) that were applied either alone or in a combination in order to assess their influence on soil's physical properties and crop status in real agricultural conditions. The evaluation focused on three terms when manure had been applied beforehand.

Concerning unit draft (UD), the overall influence of NeOsol regardless of time development was not significant. However, though at Term I, variants treated with NeOsol attained higher UD values, the values become significantly lower at Term III (by 2.9%).

This fact suggests the favorable influence of the NeOsol activator on UD over a prolonged period of time. The variants with manure application, particularly pig manure (by 6.5%) and poultry manure to some extent (by 2.1%), attained significantly lower UD values than those without treatment. Regarding soil bulk density (BD), NeOsol did not show any significant influence, whereas pig manure (by 6.7%) and particularly poultry manure (by 10.3%) presented significantly lower values compared to the variants without any manure.

No significantly different values of saturated hydraulic conductivity (SHC) could be observed between the variants including those with/without the NeOsol biostimulator over the whole trial period. On the other hand, pig manure (by 12.4%) and particularly cattle manure (by 15.9%) application led to significantly decreased SFH values compared to the variants without manure treatment.

NeOsol's effect on several vegetation indices (VI) proved inconclusive as opposed to the variants enriched by the manure of any origin. When assessing yield, however, NeOsol's effect was significant. At the last term of the experiment, the difference in winter wheat yield reached 5.0%. A similar outcome was produced by manure application, where the variants with pig and poultry manure presented 3.8% and 2.7% higher average yields, respectively, than the other treatments. At Term III, the difference was significant even for all three manure types, i.e., cattle, pig, and poultry manure surpassed the yields of variants without manure by 4.8%, 6.6%, and 6.2%, respectively.

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