EFFECT OF SUBSOILING AND SUBSEQUENT USE OF COMPACTOR PLUS SOWING ON SELECTED PHYSICAL PROPERTIES OF SOIL

VLIV PODRÝVÁNÍ A NÁSLEDNÉHO ZPRACOVÁNÍ PŮDY KOMPAKTOREM PLUS SETÍ NA VYBRANÉ FYZIKÁLNÍ VLASTNOSTI PŮDY

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Abstract
Soil compaction may have negative impact on the production of crops and subsoiling can be used to eliminate it. In this study, we attempted to find out the effect of subsoiling and subsequent conventional way (compared with the use of conventional way = the use of compactor plus winter crop sowing) performed at the beginning of this experiment (in the year 2019, winter crop = *Brassica napus*) on bulk density, water flow in soil (the method of blue colour infiltration) and some other physical soil properties. The use of subsoiling and subsequent conventional way (compared with the use of conventional way) led to significant ($P<0.05$) improvement of bulk density at a depth of 15 cm (April 2020); non-significant ($P > 0.05$) improvement of bulk density was found out at a depth of 35 cm. In September 2020, the values of bulk density in both variants were similar to the values obtained before the variants of this experiment were established. The effect of subsoiling and subsequent conventional way (compared with the use of conventional way) on volumetric soil water content (at depths of 15 cm and 35 cm) was not significant ($P > 0.05$) in April 2020 and September 2020. The dye coverage was higher because of subsoiling only in October 2019 (not in the years 2020 and 2021).

Keywords: agrotechnology, brilliant blue, chernozems, crop rotation, total porosity

INTRODUCTION

Soil compaction may have negative impact on the production of crops (e.g., Hallet and Bengough, 2013; Ghosh and Daigh, 2020); different effects of soil compaction on plant roots are stated in the publications by Hamza and Andersen (2005); Burr--Hersey et al. (2017) etc. For example, different factors and field operations (practices) which could lead to subsoil compaction etc. are stated in the review articles by Alakukku et al. (2003) and Chamen et al. (2003) etc. Further, the practical techniques on how to avoid, delay or prevent soil compaction were reviewed by Hamza and Anderson (2005); Bertollo et al. (2021) stated alleviation of soil compaction using cover crops. Bulk density (= mass dry soil/ bulk volume soil) and total porosity (= total pore volume/bulk volume soil) are frequently used to characterise the state of soil compaction (e.g., Alakukku, 1996; Håkansson and Lipiec, 2000; Alaoui and Helbling, 2006); according to Lal and Shukla (2004), the normal range of bulk density in relation to plant growth is 0.7–1.8 g cm^{-3}. Bulk density is influenced by the type of minerals, soil organic matter content, texture etc. (Hanks and Ashcroft, 1980; Al-Shammary et al., 2018 etc.).

The aim of subsoiling is to eliminate soil compaction; subsoiling is according to Kautz et al. (2013) etc. one of the strategies to increase subsoil resources access for plant roots. Nevertheless, results of different studies indicated that subsoiling may not result in better yields; for example, Evans et al. (1996) stated a one-time subsoiling had very little effect on plant growth (*Zea mays* L.) and no effect on grain yield; Soltanabadi et al. (2008) reported the used subsoiling had no significant effect on root length, seed yield, thousand seed mass, plant dry mass and oil content (sunflower). The effects of soil cultivation (and subsoiling), crop rotations and cover crops on different soil properties (bulk density, total porosity, macroporosity, minimum air capacity, volumetric water content, infiltration rate, soil aggregates, organic matter content etc.) were studied by De Azevedo et al. (1999), Soltanabadi et al. (2008), Rusu et al. (2013), Chen et al. (2014), Lamptey et al. (2017), Feng et al. (2018), Wang et al. (2019), Haruna et al. (2020), Naeem et al. (2020) etc.

Different tracers (e.g., brilliant blue, methylene blue, Vitasyn-Blue AE 85, pyranine, lissamine, rhodamine, deuterium, Br^-, Cl^-, NaBr plus sulforhodamine) were used to study preferential paths of water infiltration into soil. In these studies, the effect of different preparations or compaction (or different methods of soil loosening etc.), the effect of afforestation (arable land, young and old afforestation, ancient forest), the transport of phosphorus (the effect of soil texture and moisture etc.), the influence of residual plastic mulch fragments or root channels, the influence of termites activity (semi-arid savannas) etc. were examined (e.g., Bowman and Gibbens, 1992; Gächter et al., 1998; Alaoui and Helbling, 2006; Stone and Wilson, 2006; Olsson et al., 2007; Zumr and Císlerová, 2007; Wahren et al., 2009; Nobles et al., 2010; Jiang et al., 2017; Kroulík et al., 2018; Grant et al., 2019; Guo et al., 2019; Marquart et al., 2020). For example, Kulli et al. (2003) studied the effect of a sugar beet harvester (the effect of a single versus multiple passage) on the flow paths of water using brilliant blue. Stein et al. (1998), for example, presented a figure with the soil stained using methylene blue (5 – 40 cm) – ecological agriculture without plant protection chemicals and commercial fertilizers since 1924. The authors stated the effect of ecological agriculture was visible to a depth of 30 cm; Bebej et al. (2017) studied the interaction of brilliant blue with soil.

Brilliant blue was used in different laboratory and field experiments. In these experiments, Kovaříček et al. (2010) used 40 dm^3 of 0.3% brilliant blue solution (blue food colour) per m^2, Alaoui and Helbling (2006) applied 10 g of brilliant blue powder diluted in 1 L water per m^2 and it was subsequently flushed with 30 L of water (a constant rate 30 mm h^{-1}, the use of rain simulator). Bebej et al. (2017) studied a 90-year old forest and used brilliant blue solution (10 g L^{-1}); the authors removed the litter layer and the solution was applied by a sprinkler (100 mm h^{-1}) over a 1 m x 1 m plot. Zumr and Císlerová (2007) stated a short description of laboratory and field experiments performed with the use of brilliant blue; the authors, for example, stated a figure with the results of laboratory experiment (a large undisturbed soil sample) and the experiment was performed with the use of 1.5 mg brilliant blue L^{-1}. Some other experiments with the use of brilliant blue are presented in the publications by Jiang et al. (2012), Zhang et al. (2015) or Kan et al. (2020).

In this study, we attempted to determine the effect of subsoiling (realized before the use of compactor plus sowing) on the flow paths of water (the method of blue colour infiltration), bulk density (at depths of 15 cm and 35 cm) and some other physical soil properties determined using laboratory methods as well as its duration. The effect of subsoiling may depend on soil properties (soil type) as stated by Badalíková et al. (2008), Pulkrábek et al. (2015) etc. We hypothesized a positive effect of subsoiling on physical soil properties may be short-term (Evans et al., 1996 etc.).

MATERIALS AND METHODS

In the year 2019, an experimental plot (six experimental parcels, 3 m x 50 m with 1-m space between the parcels, the homogeneity of slope as well as soil) was established near the Hovorčovice village (the cadastral area of Hovorčovice) north of Prague in the Czech Republic (Prague-East District). In the case of all parcels, the soil type is Haplic Chernozem on loess (IUSS Working Group WRB, 2015). This area is characterised by a mean annual air temperature of 8–9 °C, by a mean annual precipitation of 500–600 mm and a sum of air temperatures above 10 °C between 2,600 and 2,800 – warm, mildly dry region of the Czech Republic as described by Vopravil et al. (2021a). All climatic regions of the Czech Republic are described by Podhrázská et al. (2013). Approx. 900 m from the experimental plot, the instalation of ombrometer EMS SR03 (500 cm^2, accuracy 0.1 mm, datalogger MicroLog ER) was performed at the end of March 2020. The survey of soil was realized in 2019, the slope (of the plots) $\leq 3°$ was found out.

In 2019, different variants of this experiment were established (for the period 2019–2023). These variants are three crop rotations commonly used in the Czech Republic (without soil improving ways – no intercrops, with intercrops or with intercrops plus one unproductive year – *Trifolium incarnatum* in the year 2022); in 2019, all mentioned variants were established conventionally (the use of compactor plus sowing) and with the use of subsoiling (40 cm) plus the mentioned conventional way. The used agrotechnology was not different between the variants in the period 2020–2021; the agrotechnology will not be different between the variants in the period 2022–2023 (it was or it will be adapted to the used or planned crops and intercrops).

In 2019, winter crop (*Brassica napus*) was sown in the case of all variants. In 2020, winter wheat (*Triticum aestivum*) was cultivated (all variants); the intercrops were *Sinapis alba* for the variant with intercrops or *Sinapis alba* plus *Phacelia tanacetifolia* in the case of the variant with intercrops plus one unproductive year. In the next crop year, barley (*Hordeum vulgare*) was cultivated in the case of all variants (the variants without soil improving or with intercrops = winter barley, the variant with intercrops plus one unproductive year = spring barley). The intercrops are *Phacelia tanacetifolia* (the variant with intercrops) or *Sinapis alba* (the variant with intercrops plus one unproductive year). Then, spring barley (all experimental parcels with the exception of the variant without soil improving ways) and *Brassica napus* will be cultivated.

Two infiltration tests with the use of brilliant blue (E133) were performed in October 2019, April 2020 (the variant with intercrops) and September 2020 (the variant with intercrops plus one unproductive year). In April 2021, five infiltration tests with the use of brilliant blue were performed (the variant with intercrops). The infiltration tests were realized to compare the use of subsoiling (plus conventional way) and conventional way at the beginning of this experiment. The tests were performed using a field rain simulator with jets (30 WSQ) – they were ca. 0.8 m above the surface of terrain and on stable holder (the distance between them was 0.8 m). Totally, 200 L of brilliant blue (3 g L^{-1}) were applied (working pressure – 3 bars); after 24 hours, the excavation of soil pit was realized. All vertical profiles were photographed (a width of approx. 1 m, a depth of 0.7–0.8 m); consequently, the photographs were used to evaluate the infiltration tests. Individual photographs were combined (Agisoft Photoscan 1.4.5); from the given picture were extracted (the use of GIMP Program) not evaluated areas (stones, different marks in the profiles etc.) and the areas coloured by brilliant blue (GIMP). All profiles were cutted (0.8 m x 0.7 m) and the evaluation was performed using RStudio.

Disturbed and undisturbed (using a Kopecky cylinder core) soil samples were taken at depths of 15 cm and 35 cm for the determination of selected physical properties (particle and bulk density, total porosity, maximum capillary water capacity and volumetric water content). The mentioned physical soil properties were measured according to Valla et al. (2008). Maximum capillary water capacity was obtained after 2 h suction (on filter paper) of fully saturated soil samples (e.g., Vopravil et al., 2021b). The measurement of particle density and total porosity are described in the works by Flint and Flint (2002a,b) or Duffková and Kvítek (2009). To compare the use of subsoiling (plus conventional way) versus conventional way, 3 versus 3 undisturbed (and disturbed) soil samples per each of the studied depths were taken in April 2020 (the variant with intercrops) and September 2020 (the variant with intercrops plus one unproductive year); in May 2020 (the variant with intercrops plus one unproductive year), the soil samples were taken only from a depth of 15 cm. Soil samples were also taken at the beginning of this experiment (2019). In this publication, the values of bulk density are also compared between the years 2019 versus 2020; the values of particle density, total porosity, maximum capillary water capacity and volumetric water content obtained in the year 2020 (April and September) are presented in this publication. The textural class (Soil Science Division Staff, 2017) is silty clay loam; the values of pH_{H2O} and pH_{KCl} were 7.72 and 6.89 (at a depth of 15 cm) and 7.89 and 7.08 (at a depth of 35 cm) at the beginning of this experiment.

The differences in the values of studied properties were submitted by testing using a oneway ANOVA and Tukey HSD test. All statistical analyses were performed with STATISTICA Cz, v. 10 software (StatSoft, Inc. 2011).

RESULTS AND DISCUSSION

In the variant with intercrops (April 2020), the use of subsoiling plus conventional way at the beginning of this experiment (2019) led to significantly ($P<0.05$) lower bulk density in April 2020 (at a depth of 15 cm) compared with the use of conventional way and the same soil depth (15 cm) as shown in Table 1. In the case of the use of subsoiling plus convential way, not significantly ($P>0.05$) lower value of bulk density was also found out at a depth of 35 cm compared with the use of conventional way (and the same soil depth = 35 cm). In April 2020, the bulk density was significantly ($P<0.05$) lower at a depth of 15 cm compared with a depth of 35 cm in the variant with the use of subsoiling plus conventional way; it was not significantly ($P>0.05$) lower at a depth of 15 cm compared with a depth of 35 cm in the variant with only conventional way (Table 1). The use of subsoiling plus conventional way at the beginning of this experiment (2019) had no significant ($P>0.05$) effect on volumetric water content in soil (= volume water/bulk volume soil) compared with the use of conventional way (April 2020) in the case of both studied depths (Table 1); the values of volumetric soil water content at depths of 15 cm versus 35 cm were not significantly ($P>0.05$) different in the variants with subsoiling plus conventional way and with only conventional way.

Table 1: Selected physical soil properties (the variant with intercrops, April 2020; mean ± standard error)

Soil property	Subsoiling plus conventional way		Conventional way	
	15 cm	35 cm	15 cm	35 cm
Bulk density (g cm^{-3})	1.09 ± 0.05^a	1.41 ± 0.05^b	1.32 ± 0.05^b	1.51 ± 0.04^b
Volumetric water content (% vol.)	17.52 ± 0.90^a	21.76 ± 0.60^a	19.38 ± 0.91^a	22.33 ± 0.41^a

Different letters mark significant ($P < 0.05$) differences between subsoiling plus conventional way versus conventional way (depths 15 cm and 35 cm)

In the variant with intercrops (April 2020), the values of particle density were 2.63 g cm^{-3} (at a depth of 15 cm) and 2.63 g cm^{-3} (at a depth of 35 cm) in the case of conventional way or 2.62 g cm^{-3} (15 cm) and 2.59 g cm^{-3} (35 cm) in the case of subsoiling plus conventional way. The values of total porosity were 45.5 vol. % (15 cm) and 44.3 vol. % (35 cm) in the case of conventional way or 50.9 vol. % (15 cm) and 45.5 vol. % (35 cm) in the case of subsoiling plus conventional way. In the case of maximum capillary water capacity, the values were 36.0 vol. % at a depth of 15 cm and 32.5 vol. % at a depth of 35 cm (the use of conventional way) or 35.9 vol. % at a depth of 15 cm and 32.7 vol. % at a depth of 35 cm (the use of subsoiling plus conventional way in 2019 – the beginning of this experiment).

In May 2020 (the variant with intercrops plus one unproductive year), the bulk density was not significantly (P>0.05) lower in the case of subsoiling plus conventional way (a depth of 15 cm) compared with the use of conventional way (the same depth = 15 cm) as shown in Table 2.

Table 2: Selected physical soil properties (the variant with intercrops plus one unproductive year, May 2020; mean ± standard error)

Soil property	Subsoiling plus conventional way	Conventional way
	15 cm	15 cm
Bulk density (g cm^{-3})	1.11±0.01^{a}	1.27±0.02^{a}
Volumetric water content (% vol.)	n.d.	n.d.

n.d. – not determined

In September 2020 (the variant with intercrops plus one unproductive year), the values of bulk density or volumetric water content at a depth of 15 cm (or at a depth of 35 cm) were similar when the variants (subsoiling plus conventional way versus conventional way) were compared (Table 3). The bulk density at a depth of 15 cm was not significantly (P>0.05) lower compared with the bulk density at a depth of 35 cm in the case of both variants (subsoiling plus conventional way or conventional way); the values of bulk density measured in September 2020 were similar to the values (from the year 2019) obtained before the variants of this experiment were established (1.25 g cm^{-3} at a depth of 15 cm, 1.44 g cm^{-3} at a depth of 35 cm). The volumetric water content was significantly (P<0.05) higher at a depth of 35 cm compared with a depth of 15 cm (both variants - subsoiling plus conventional way as well as conventional way).

Table 3: Selected physical soil properties (the variant with intercrops plus one unproductive year, September 2020; mean ± standard error)

Soil property	Subsoiling plus conventional way		Conventional way	
	15 cm	35 cm	15 cm	35 cm
Bulk density (g cm^{-3})	1.26±0.07^{a,b}	1.47±0.02^{b}	1.23±0.05^{a}	1.40±0.02^{a,b}
Volumetric water content (% vol.)	21.60±1.20^{a}	27.83±0.50^{b}	21.65±1.98^{a}	26.98±0.57^{b}

Different letters mark significant (P < 0.05) differences between subsoiling plus conventional way versus conventional way (depths 15 cm and 35 cm)

In the variant with intercrops plus one unproductive year (September 2020), the values of particle density were 2.57 g cm^{-3} (15 cm) and 2.60 g cm^{-3} (35 cm) in the case of conventional way or 2.63 g cm^{-3} (15 cm) and 2.51 g cm^{-3} (35 cm) in the case of subsoiling plus conventional way. The values of total porosity were 52.2 vol. % (15 cm) and 46.4 vol. % (35 cm) in the case of conventional way or 55.6 vol. % (15 cm) and 45.2 vol. % (35 cm) in the case of subsoiling plus conventional way. In September 2020, the values of maximum capillary water capacity were 32.8 vol. % at a depth of 15 cm and 32. vol. % at a depth of 35 cm (the use of conventional way) or 33.3 vol. % at a depth of 15 cm and 31.5 vol. % at a depth of 35 cm (the use of subsoiling plus conventional way in 2019 – the beginning of this experiment).

In the case of subsoiling plus conventional way (compared with the use of conventional way), the dye coverage was increased only in October 2019 (see Fig. 1). In April 2020 or September 2020, the effect of subsoiling on the dye coverage was not visible (see Fig. 2–4). In April 2021, the average values of dye coverage were almost the same (42.2 % = the use of conventional way; 42.4 % = the use of subsoiling plus conventional way) in the case of both variants (Fig. 5).

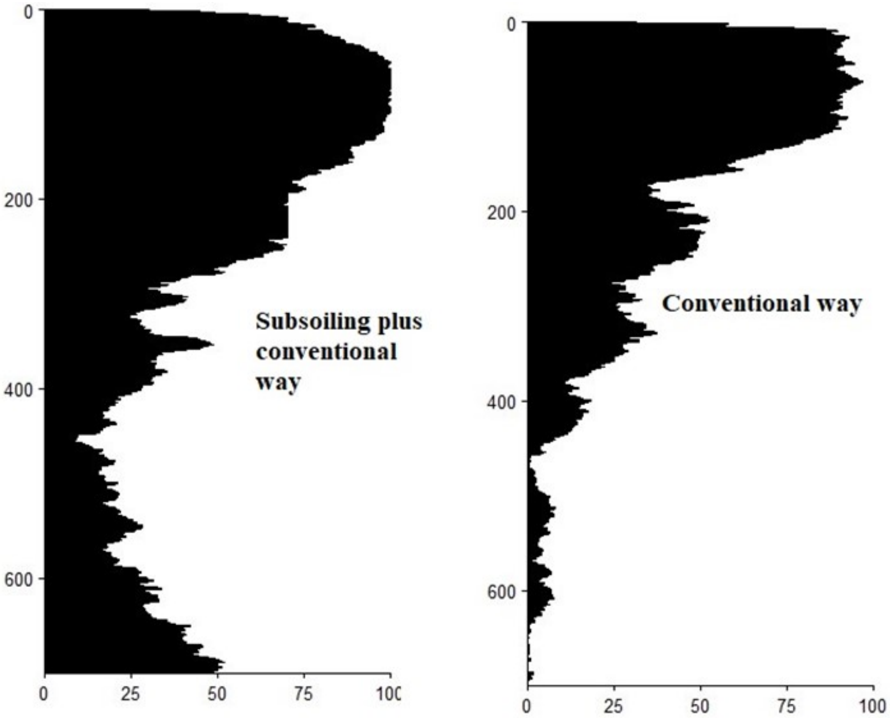

Fig 1: The values of dye coverage vs. depth (October 2019). In the case of subsoiling plus conventional way versus conventional way, the dye coverage was 49 % versus 32 %.

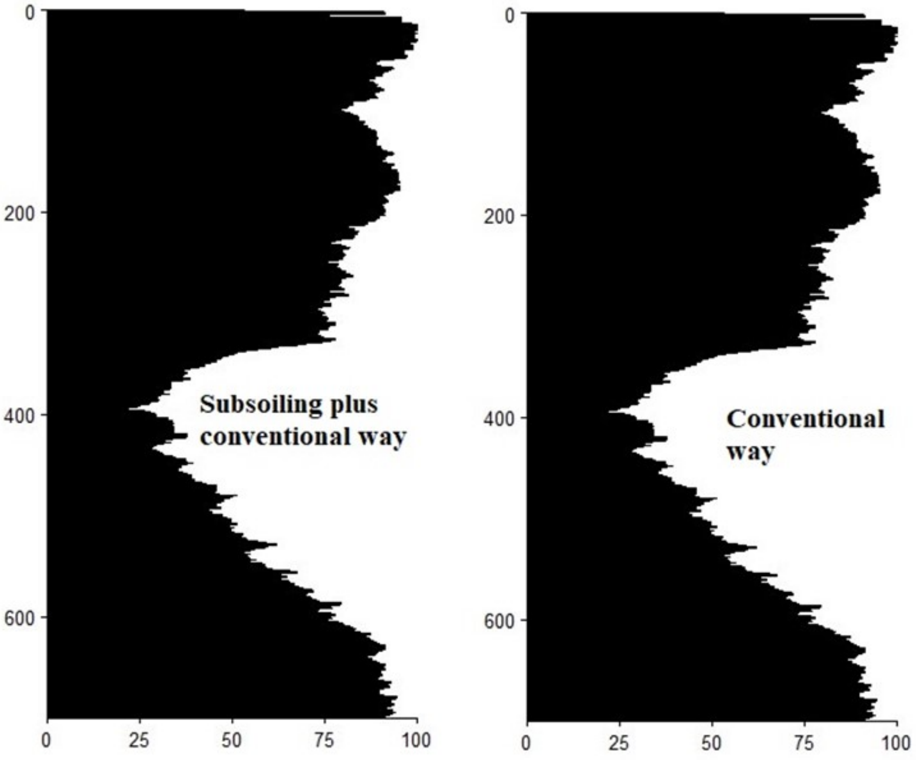

Fig 2: The values of dye coverage vs. depth (April 2020) - the variant with intercrops. In the case of subsoiling plus conventional way versus conventional way, the dye coverage was 71 % versus 79 %

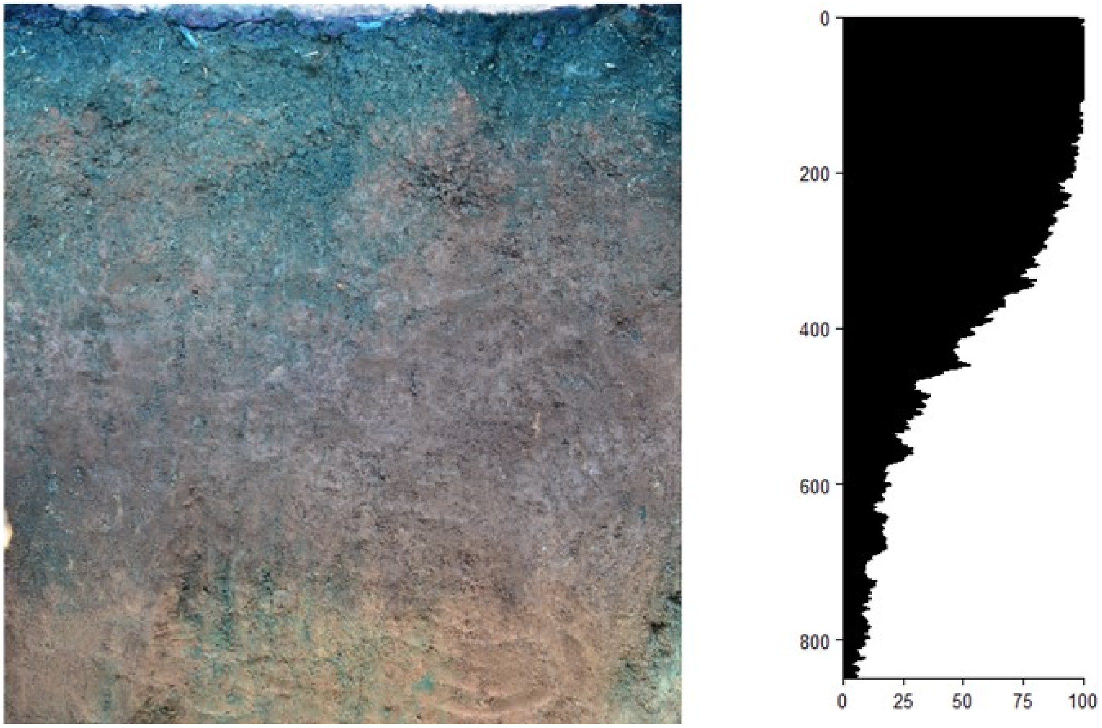

Fig 3: Illustration of Brilliant blue movement and the values of dye coverage vs. depth; the use of subsoiling plus conventional way (the variant with intercrops plus one unproductive year, September 2020); the dye coverage = 52.9 %

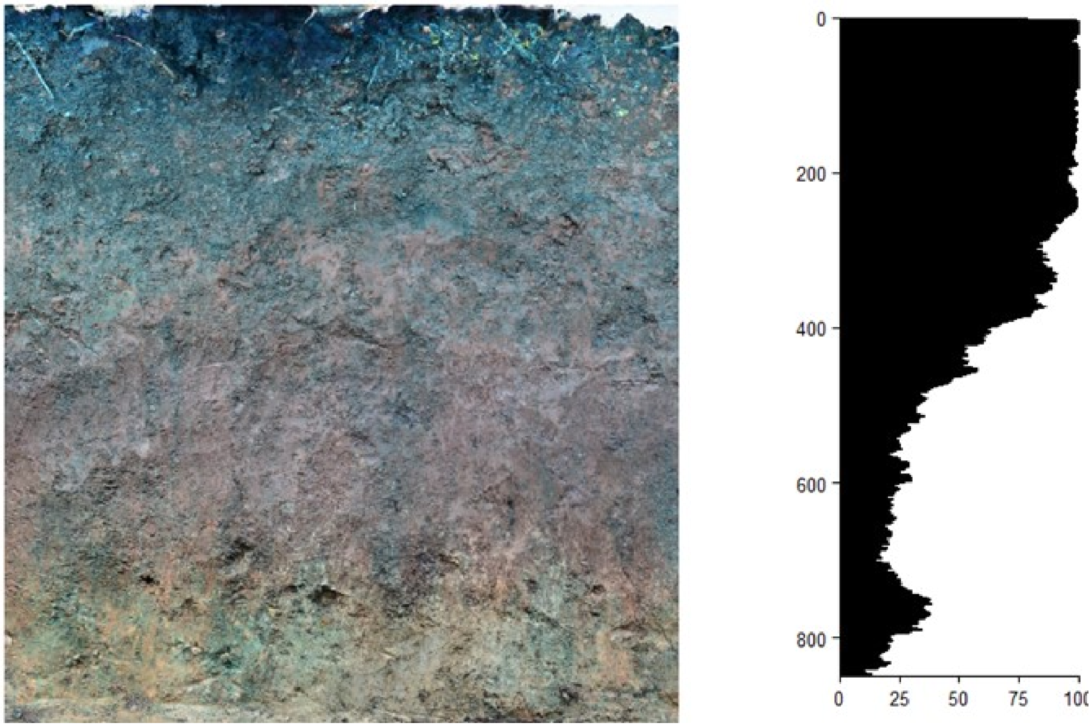

Fig 4: Illustration of Brilliant blue movement and the values of dye coverage vs. depth; the use of conventional way (the variant with intercrops plus one unproductive year; September 2020); the dye coverage = 59.7 %

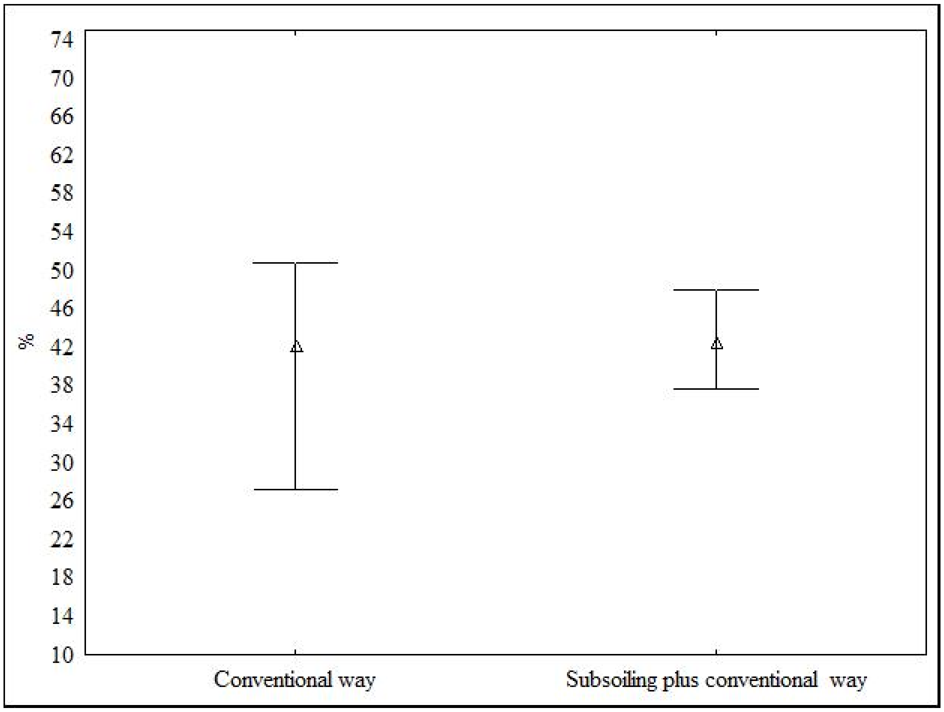

Fig 5: The dye coverage in April 2021 (the variant with intercrops, mean and minimum – maximum)

Positive effects of subsoiling on physical soil properties can be short-term or their duration is approximately three years (or > three years) as stated by Twomlow et al. (1994), Evans et al. (1996), Willis et al. (1997), Pulkrábek et al. (2015), Hůla et al. (2017) etc. Soltanabadi et al. (2008) studied the effect of subsoiling plus conventional tillage plus flat planting (compared with conventional tillage plus flat planting) on different soil properties (clay loam); contrary to our results, the authors reported no significant effect of the used subsoiling on the values of bulk density (depths of 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm or 40–50 cm). On the other hand, Soltanabadi et al. (2008) stated the used subsoiling significantly improved the values of infiltration rate. Evans et al. (1996) studied the effect of different primary tillage systems plus a one-time subsoiling on selected physical soil properties (the study was performed from the fall of 1988 to the fall of 1991) – all wheel traffic (the tillage secondary operations etc.) in the same tracks. The authors reported the subsoiling led to more favourable bulk density in the spring of 1989; in the fall of 1989 (and in the next years), the bulk density was more favourable only in the case of no wheel traffic (the upper 30 cm). Evans et al. (1996) also reported reduced volumetric soil water content in the variants with subsoiling in the spring of 1989. Twomlow et al. (1994) studied the effect of soil loosening (to a depth of 40 cm) on different soil properties. The authors, for example, reported the loosened soil was wetter than the unloosened soil. The loosening led to more favourable bulk density; within 3 years, the bulk density returned to the pre-loosening values. Pulkrábek et al. (2015) reported the effect of subsoiling may weaken one year after the subsoiling. Hůla et al. (2017) stated one-time loosening of compacted layer in soil profile (sandy loam) led to more favourable total porosity (2.5 months and 9 months after the loosening) or penetrometer resistance (at a depth >20 cm) measured 9 months after the loosening. The effect of the mentioned loosening on total porosity was low (or very low) 20 (or 32) months after the loosening. Ten months after the loosening, the authors used the method of blue colour infiltration and found out the dye penetrated deeper into the soil in the case of loosening compared with control. Willis et al. (1997) stated the use of deep ripping (or deep mouldboard ploughing) significantly reduced the values of bulk density (compared with the use of disc ploughing); this reduction in the values of bulk density persisted > 18 months. In this study, the values of bulk density at a depth of 15 cm were similar when the variant with intercrops (April 2020) and the variant with intercrops plus one unproductive year (May 2020) were compared (Table 1 versus Table 2). Nevertheless, the variants did not differ at the beginning of this experiment (2019) or in April 2020 and May 2020.

CONCLUSIONS

The effect of subsoiling realized before the use of compactor plus sowing (winter crop = *Brassica napus*; this sowing was realized in 2019) on bulk density (compared with the variant with compactor plus sowing = conventional way) was found out in April 2020 (or May 2020) at depths 15 cm and 35 cm – the effect was significant ($P<0.05$) at a depth of 15 cm (April 2020). In September 2020, the values of bulk density in both variants were similar to the values obtained before the variants of this experiment were established. The effect of subsoiling and subsequent conventional way (compared with the use of conventional way) on volumetric soil water content (at depths of 15 cm and 35 cm) was not significant ($P > 0.05$). The dye coverage (the use of blue colour infiltration method) was higher because of subsoiling only in October 2019 (not in the years 2020 and 2021).

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Abstrakt

Zhutnění půdy se může nepříznivě projevit na výnosu plodin a významné mohou být i jeho další vlivy. V rámci této studie jsme zkoumali vliv zařazení podrývání před zpracování půdy kompaktorem plus setí ozimé řepky (*Brassica napus*) v roce 2019 na objemovou hmotnost půdy redukovanou, objemovou vlhkost půdy, infiltraci modré barvy (brilantní modř = potravinářské barvivo E133) do půdy a další fyzikální půdní vlastnosti. Zařazení podrývání s následným využitím kompaktoru plus setím vedlo v porovnání s variantou bez zařazení podrývání (pouze využití kompaktoru plus setí) ke zlepšení objemové hmotnosti redukované v hloubce 15 cm i 35 cm, která byla stanovena v dubnu roku 2020 (průkazné zlepšení bylo zjištěno pouze v případě hloubky 15 cm). Hodnoty objemové hmotnosti redukované, stanovené v září roku 2020, byly podobné hodnotám stanoveným před zahájením tohoto experimentu v roce 2019 (i v případě zařazení podrývání). Objemová vlhkost půdy nebyla průkazně ovlivněna zařazením podrývání. Využití metody infiltrace modré barvy ukázalo, že zařazení podrývání vedlo ke zvýšení podílu plochy obarvené brilantní modří pouze v říjnu roku 2019 (nikoliv v letech 2020 a 2021).

Klíčová slova: agrotechnika, brilantní modř, černozem, osevní postup, pórovitost půdy

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