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Effect of surface-applied compost on soil properties

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Abstract: The positive influence of surface compost application without incorporation on soil physical properties is known but remains underexplored. This study evaluated the effects of surface-applied stable and mature compost on basic soil physical and chemical properties, including saturated hydraulic conductivity, aggregate stability, and penetration resistance. Conducted as a semi-operational field experiment in two Czech agricultural sites (A: Blatnice at Jaroměřice and B: Jevíčko; Cambisols with loam and silty clay loam textures, respectively), the plots were treated with compost (SCA) at rates of 4 × 30 t/ha (A) and 1 × 200 t/ha (B) or left untreated as controls (CON). The crops were wheat (A), maize (A, B) and intercrops. Surface compost application began in 2022, and soil sampling and field measurements were conducted during the 2023 and 2024 growing seasons. Results showed significant positive changes (P < 0.05 or lower) in SCA plots compared to CON. Soil organic matter content increased by 27.8% at locality A and by 58.1% at locality B, while saturated water content increased by 5.3% (A) and 11.0% (B) in the latter season. Similarly, pH and electrical conductivity showed increases. Water-stable aggregate ratios increased by 6% to 30% at both localities. Dry bulk density decreased by 10.5% (A) and 15.7% (B). Improvements in saturated hydraulic conductivity (by 28.6%) and penetration resistance were observed only at locality B. These findings show the potential of surface-applied stable and mature compost to enhance soil properties effectively.

Keywords: compost maturity; compost stability; conservation agriculture; erosion control; water stable aggregates

Land degradation is a critical global issue, affecting approximately 24% of the world's productive lands and leading to significant ecological and economic consequences (FAO 2019). This challenge is exacerbated by intensive agricultural practices that disrupt natural soil functions, reduce biodiversity, and ac-

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celerate erosion. Unsustainable land management practices, such as excessive tillage and monocropping, deplete soil organic matter and leave soils vulnerable to degradation (Lal 2006).

Efforts to address land degradation often focus on sustainable land management (SLM), which aims to balance agricultural productivity with environmental conservation. Among the numerous strategies under SLM, compost is recognized as a traditional yet effective approach. Compost enhances soil structure, boosts biological activity, and improves water retention, providing a sustainable pathway to restore degraded soils (Cogger et al. 2008; Adugna 2016). However, traditional compost incorporation methods often involve tillage, which can disrupt soil structure and partially offset the benefits of compost application. This has led to growing interest in alternative approaches, such as surface application, which aligns well with conservation agriculture practices (Logsdon & Malone 2015).

The Common Agricultural Policy (CAP) emphasizes principles of conservation agriculture, including minimizing soil disturbance, maintaining continuous soil cover, and using crop rotations or intercropping to improve soil health (European Commission 2023). Surface-applied compost aligns with these principles by preserving soil structure, reducing the need for tillage, and acting as a protective mulch. It mitigates erosion, limits evaporation, and supports microbial activity and bioturbation, which are essential for stabilizing soil aggregates and integrating organic matter into deeper layers over time (Bresson et al. 2001; Lapied et al. 2009). These processes help prevent key degradation issues, such as compaction and reduced water infiltration, while promoting long-term soil productivity and resilience. This practice also directly supports the objectives of the United Nations Sustainable Development Goal 15 (Life on Land), which focuses on SLM and reversing land degradation.

Composting plays a vital role in recycling organic waste and improving soil health. Its benefits are amplified when using stable and mature compost, which is rich in humic substances. Unlike fresh organic inputs, which may lead to initial nutrient leaching, mature compost stabilizes aggregates, increases interparticle cohesion, and ensures a gradual release of nutrients, thereby reducing environmental risks (Annabi et al. 2011; Paradelo et al. 2019; Sayara et al. 2020).

Compost stability and maturity are essential parameters for assessing its readiness and safety as a soil amendment. Stability reflects the extent of decomposition of labile organic matter, indicated by low microbial activity (Estrella-González et al. 2020), while maturity ensures the absence of phytotoxic compounds and the presence of stable organic fractions beneficial for plant growth (Siddiqui et al. 2020). Key indicators of mature compost include a carbon-to-nitrogen (C/N) ratio below 20 : 1 and a neutral to slightly alkaline pH (6.0–8.0) (Bernal et al. 2009; Azim et al. 2018). A low ammonium-to-nitrate ratio, reduced electrical conductivity reflecting low soluble salt levels, and a germination index exceeding 80% also confirm compost suitability and safety for plants (Azim et al. 2018).

Research on surface-applied compost remains relatively limited compared to conventional tillage-based methods, even though studies show its unique advantages. The benefits of surface-applied compost take time to fully develop, as they depend on biological activity and the gradual integration of organic matter by soil biota, highlighting its cumulative impact on soil health (Cogger et al. 2008; Lapied et al. 2009).

Recent studies emphasize the role of surface-applied compost in improving soil hydrophysical properties. For example, Cox et al. (2021) found that compost used as a surface mulch performed comparably to traditional incorporation methods. Similarly, in strip-tillage systems, surface compost application has been shown to improve water retention, reduce erosion, and align with sustainable agricultural practices (Logsdon & Malone 2015).

In contrast to sustainable methods, contemporary agricultural practices often create a self-reinforcing vicious circle that accelerates soil degradation and disrupts ecosystem services. This cycle includes the depletion of soil organic matter (SOM), loss of soil structure, increased compaction, disrupted water infiltration and intensified surface runoff, ultimately leading to water erosion and further degradation. These processes diminish soil fertility and resilience, undermining long-term agricultural productivity and sustainability. Surface compost application presents a potential intervention to break this cycle. This study operates on the hypothesis that surface-applied stable and mature compost can enhance soil physical and chemical properties, particularly in conservation-oriented agricultural systems.

By contributing stable organic matter to the soil surface, compost can counteract SOM depletion through increased biotic activity, without the need for mechanical incorporation. Based on this hypothesis,

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the primary objective of this study was to evaluate the effect of surface-applied stable and mature compost on selected soil physical and chemical properties in semi-operational field experiments conducted over three years. By comparing soils treated by surface compost application (SCA) to untreated controls (CON), the study focused on assessing changes in soil structure, water content, saturated hydraulic conductivity and penetration resistance, among others, during the latter two growing seasons in two agricultural fields in the Czech Republic.

MATERIAL AND METHODS

Study area. The semi-operational experiments were conducted at two localities: (A) Blatnice in the Třebíč district (49.0739847N, 15.8827081E; 445 m a.s.l.) and (B) Jevíčko in the Svitavy district (49.6211317N, 16.7440606E; 385 m a.s.l.) in the Czech Republic (Figure 1). Both sites are situated in a mildly warm, mildly humid climatic region, with average annual temperatures ranging from 7 to 8 °C and average annual precipitation between 550 and 650 mm. The land use at both locations is classified as rainfed arable land. The soil type at both localities is Cambisol modal, with a carbonate variety in Blatnice and a eubasic variety in Jevíčko (RISWC 2022). The terrain is flat in Blatnice and mildly sloped (10%) in Jevíčko.

Experimental design. The experiment ran for three years, from 2022 to 2024. At each locality, two experimental parcels measuring 30 × 120 m were established on homogeneous soil blocks. Standard farming machinery and practices were employed across the entire field, without exception for the experiment. One parcel at each locality was treated with compost (SCA), while the other parcel served as a control without compost application (CON). Importantly, the experimental parcels were not isolated from the rest of the field. Farm management practices, including crop production operations, were consistent across the entire field, with the only distinction being the application of compost to the designated experimental parcel.

The composts used in the experiments were sourced from local composting plants (see their properties in Table 1) and applied according to the following scheme.

At the Blatnice locality, compost was applied in total four times during the experiment in doses of about 30 t/ha, a standard rate typically used when compost is incorporated into the soil. In contrast, at the Jevíčko locality, compost was applied only once, in February 2022, at an extreme dose of 200 t/ha. This unusually high application rate was intended to observe potential negative effects of surface application, such as nutrient leaching, which were outside the scope of this study. Soil cultivation varied by location and crop. At the Blatnice site, the crop rotation included winter rapeseed (2022), winter wheat (2023), and grain maize (2024). At the Jevíčko site, silage maize was cultivated continuously from 2022 to 2024, following winter wheat (2021).

A detailed description of the farming practices follows:

(A) Blatnice (2022–2024):

– 2022: Winter rapeseed harvested on July 26, followed by compost application (30 t/ha) on Au-

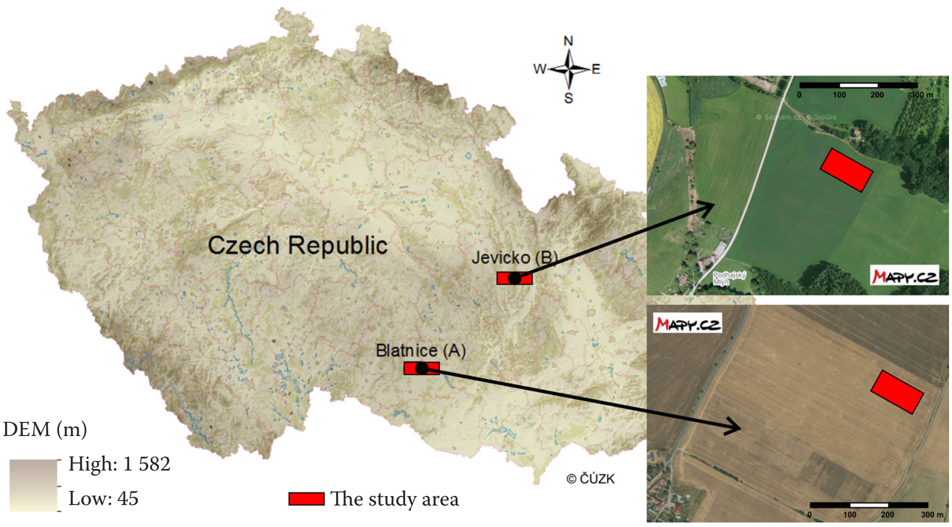

Figure 1. Schematic map with the location of the study areas

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gust 12 to rapeseed residues, along with glyphosate application.
- 2023: Winter wheat direct-seeded at 180 kg/ha (depth 0.03 m), compost applied (30 t/ha) at BBCH 27, harvested on July 27. Catch crops (winter rye, broad beans, vetch) no-till seeded on September 3, compost applied (30 t/ha) to the catch crop on October 14.
- 2024: Spring treatment included glyphosate application and compost application (30 t/ha) on April 10, with strip loosening (depth 0.22 m). Maize (FAO 270) no-till seeded on April 24, harvested on September 23.

(B) Jevíčko (2022–2024):
- Preceded by winter wheat (2020/21) and compost applied (174 t/ha) to catch crops on February 28, 2022.
- Annual sequence (2022–2024): Glyphosate application, strip loosening (depth 0.22 m) with fertilizer (10-26-26) application, no-till seeding of silage maize (FAO 300), maize harvest, followed by catch crop no-till seeding (forage pea and *Phacelia tanacetifolia*).

Weather conditions throughout the experimental period were monitored using portable weather stations integrated into the Agdata.ag smart agriculture system.

Soil sampling and analysis. Soil samples were taken from the surface layer (0–10 cm) two or three times during each vegetation season. Samples from the two latter seasons (2023–2024) were analysed within this study. At each sampling, five disturbed and five undisturbed (250 cm^3) samples were taken from each parcel, altogether 40 sets of samples from Blatnice and 50 sets of samples from Jevíčko. They were always collected in a representative transect along the experimental parcel, ensuring a uniform amount of compost distributed by a standard field compost spreader machine (parallelly with its wheel marks).

The undisturbed samples were used to determine saturated hydraulic conductivity (*Ks*; falling head technique (Kutílek & Nielsen 1994) on KSAT device, METER Group Inc., USA), volumetric water content (VWC) both in the field conditions and saturated (gravimetric method) and dry bulk density (BD; gravimetric method) according to Blake and Hartge (1986). The air-dried disturbed samples were used for determination of soil particle size distribution (hydrometer method by Gee and Bauder (1986)) followed by the soil texture classification (Soil Survey Staff 1999), soil organic matter content (SOM; Nelson & Sommers 1996), electrical conductivity (EC) and pH (both measured in a 1 : 2.5 H_2O solution according to Rayment and Higgenson (1992)) and water stable aggregates index (WSA; wet sieving method employing the wet sieving apparatus manufactured by Eijkelkamp described in details by Rohošková and Valla (2004)).

In addition, penetration resistance (PR) was measured during the sampling periods along with detailed soil sampling for water content determination by gravimetric method (GWC) from three depths using soil auger. Measurements were conducted till maximum depth of 45 cm, in 12 repetitions from

Table 1. Selected properties of the applied composts (Badalíková et al. 2023)

Compost property	Blatnice				Jevíčko 2022
	2022	2023 spring	2023 autumn	2024	
Application rate (t/ha)	31	30	30	30	200
C/N ratio	12	11	11	10	13
OM (%)	33	27	23	22	42
pH	8.5	8.4	8.6	8.0	9
EC (mS/cm)	1.22	1.15	na	1.03	1.08
Moisture (%)	33.9	43.8	28.2	32.5	51.5
N_{min}/N_{tot} (% in dry matter)	20.6	2.4	7.8	7.5	2.9
N-NH_4 (mg/kg in dry matter)	398	202	506	204	304
N-NO_3 (mg/kg in dry matter)	2 910	134	427	743	239
Stability index	6.9	8.2	7.5	7.5	4.1

C/N – carbon/nitrogen; OM – organic matter content; EC – electric conductivity; N_{min} – mineral nitrogen; N_{tot} – total nitrogen; N-NH_4 – ammonium nitrogen; N-NO_3 – nitrate nitrogen; na – not available

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each treatment using the device Field ScoutTM SC 900 Soil Compaction Meter (Spectrum Technologies, Inc., USA). The sets of 12 repeated PR measurements were carried out on both localities two times a year (in 2023 and 2024), in May and in September.

Obtained data were statistically evaluated using the TIBCO Statistica v13 (Statsoft Inc., USA) and STATGRAPHICS Centurion XV (Statgraphics Technologies, Inc., VA). The data were tested for normal distribution by Shapiro-Wilk test ($P < 0.05$) prior to further evaluation. Hydraulic conductivity values were log-transformed.

RESULTS AND DISCUSSION

Weather conditions. During the experimental period, the air temperature and precipitation directly in the experimental fields were recorded and used e.g. for optimization of the soil sampling. Monthly averages of the air temperatures and monthly sums of the precipitation are presented in Figure 2. Temperatures in both localities had similar trends, except for the spring months in 2023, which were consistently higher than the long-term average from the period 1991–2020 provided by the Czech Hydrometeorological Institute (https://www.chmi.cz/). In terms of precipitation, the year 2023 was drier than the long-term average on both localities (702 mm compared to the long-term average of 750 mm in A and 568 mm compared to 702 mm in B), while 2024 tends to have higher precipitation in total. Notable is extremely high precipitation in Blatnice in September 2024, where during the weekend of 13th–14th September the precipitation of about 280 mm was recorded,

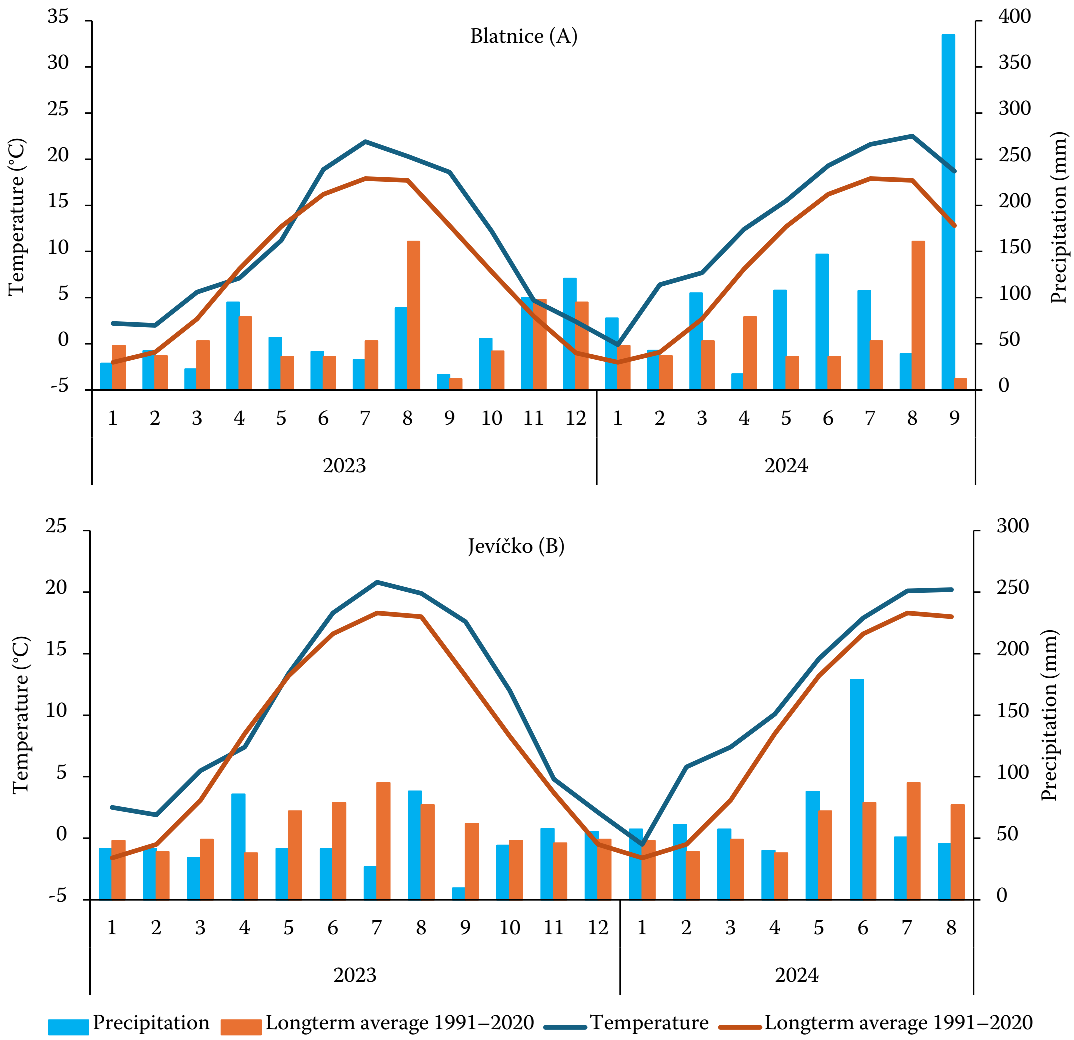

Figure 2. Monthly average air temperatures and monthly sums of precipitation in experimental localities

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increasing the total amount for the time period from January till September to 1029 mm, which is double than the long-term average for the given period (515 mm). The last sampling in this locality was thus postponed to the 25th of September.

Soil physical and chemical properties. Prior to the first compost treatment, representative soil samples were taken to characterize the experimental parcels and ensure homogeneity. Particle size distribution analysis classified the soil in Blatnice as loam, with 15% clay (< 0.002 mm), 37% silt (0.002–0.05 mm), and 48% sand (0.05–2.0 mm), while the soil in Jevíčko is classified as silty clay loam, containing 28% clay, 64% silt, and 8% sand. On average based on 10 samples from each locality, initial SOM, pH, and EC in Blatnice were 2.69%, 6.60, and 221 μS/cm, respectively, while in Jevíčko, these values were 2.72%, 6.65, and 173 μS/cm, respectively. Initial WSA (2–5 mm) in Jevíčko was 0.533.

The analyses of the undisturbed samples, together with the tested chemical soil properties, are summarised in Table 2. In the Blatnice locality, the one-way ANOVA revealed a significant increase in SOM content. While there is no significant change in the CON soil in both seasons, in the SCA soil is significant increase already in 2023 compared to the CON ($P < 0.005$) and even in both seasons of SCA ($P < 0.05$), as revealed by the Duncan's post hoc test. However, analysis of the undisturbed soil samples in field VWC revealed no significant differences between the two treatments. However, saturated VWC was found to be significantly higher in the SCA treatment ($P = 0.0052$), with a notable increase observed in 2024. This is significantly correlated ($R = -0.88$) with the observed decline in BD values in the SCA soil. Although there is a significant correlation between the BD and *Ks* ($R = -0.64$), there is no statistical improvement in *Ks*. Nevertheless, the *Ks* values in the CON soil were already near the optimal range, which, combined with the loamy soil at Blatnice facilitating rapid infiltration and leading to more transient water retention in the surface layers, likely reduced the observable short-term effects of compost application on *Ks*. This limited response may also be attributed to the moderate compost dose and the fact that compost's primary influence on soil hydraulic properties, such as macroporosity and BD, requires extended timeframes or higher application rates to manifest significant improvements (Logsdon & Malone 2015; Toková et al. 2020).

Table 2. Mean values of the observed soil properties at surface compost treated plots (SCA) and control plots (CON)

Location		A				B			
Season		2023		2024		2023		2024	
Treatment		SCA	CON	SCA	CON	SCA	CON	SCA	CON
N		10	10	10	10	15	15	10	10
Field VWC	mean	16.14	16.98	27.29	25.60	31.58	24.16	31.08	25.86
(% v/v)	*CV* (%)	65	59	27	35	30	25	26	33
Saturated VWC	mean	53.53	52.26	55.44	52.51	51.28	44.92	51.60	45.92
(% v/v)	*CV* (%)	4	4	4	5	8	5	6	5
Dry bulk density	Mean	1.131	1.151	1.001	1.118	1.128	1.374	1.136	1.347
(g/cm^3)	*CV* (%)	7	5	9	6	15	7	10	5
Ks	mean	1 241.1	844.3	1 325.9	1 222.2	965.6	178.8	182.6	381.1
(cm/d)	*CV* (%)	93.1	96.2	82.8	63.4	120.1	152.7	253.9	103.5
Ks	mean	2.920	2.928	2.945	2.771	2.267	1.490	2.597	1.854
(log cm/d)	*CV* (%)	19	17	13	14	29	51	28	34
pH	mean	7.06	6.59	6.96	6.53	6.95	6.27	7.36	6.40
	CV (%)	1	2	3	5	2	2	2	3
EC	mean	323.8	197.3	362.6	225.4	301.8	171.9	308.8	147.6
(mS/cm)	*CV* (%)	47	50	25	33	30	25	19	29
SOM	mean	3.77	2.91	4.37	3.15	4.50	2.70	6.91	2.89
(%)	*CV* (%)	16	17	9	8	18	8	20	12

N – number of samples; VWC – volumetric water content; *Ks* – saturated hydraulic conductivity; EC – electrical conductivity; SOM – soil organic matter; *CV* – coefficient of variation

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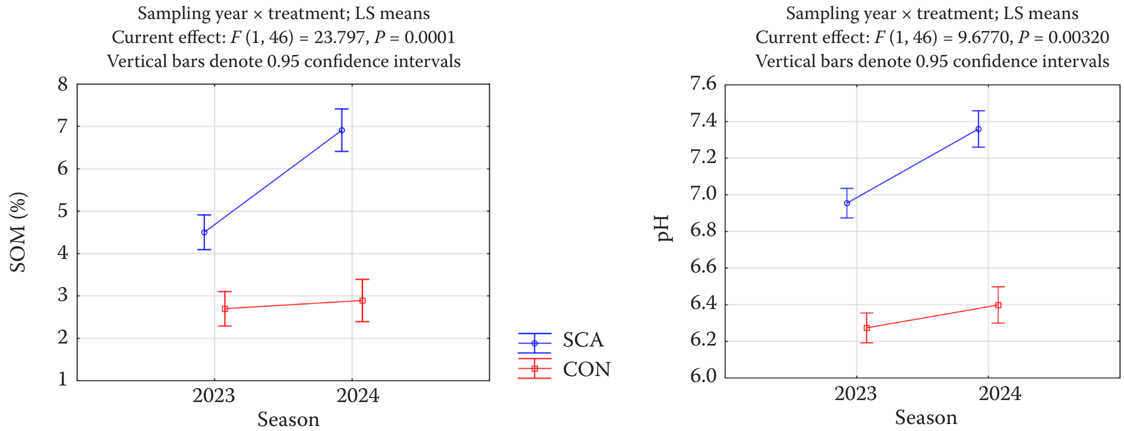

Figure 3. Factorial ANOVA for the Jevíčko locality (B) revealing the effect of the compost amendment (SCA) and its persistence into the subsequent season on soil organic matter (SOM) and pH, compared to the control soil (CON)

Both the values of pH and EC slightly increased after the compost application ($P < 0.000$) and this effect was persistent in both seasons, as revealed by the Duncan's post hoc test.

For the Jevíčko locality, the effects were more significant, which is based mainly on the high dose of the compost used. The factorial ANOVA revealed a highly significant increase in SOM for the SCA treatment compared to the CON ($P < 0.0000$) in 2023, and a further significant increase in the following season ($P < 0.0000$), see Figure 3. These findings demonstrate the enhancing effect of the surface-applied compost as will be further discussed. The field VWC exhibited an average increase of approximately 6% (v/v) in the SCA relative to the CON, with a near-identical trend observed in both years ($P < 0.01$). The observed increase in water content can likely be attributed to the effects of the organic matter in the compost, as well as its application as a surface mulch, which acts as a physical barrier reducing water evaporation from the soil surface. A comparable pattern was evident in the saturated VWC, displaying a more pronounced disparity between the SCA and CON ($P < 0.000$). The decline in BD within the SCA plot, accompanied by an enhancement in porosity, aligns with these observations ($P < 0.0000$). This effect was projected into the increase of *Ks* at SCA plot of about 30% compared to the CON plot ($P < 0.001$ in 2023 and $P < 0.01$ in 2024). These findings are consistent with studies showing that surface compost application improves soil structure by reducing the dry bulk density and increasing macroporosity, thereby enhancing water movement and hydraulic conductivity (Logsdon & Malone 2015; Toková et al. 2020).

Furthermore, the observed changes in pH and EC are in accordance with these findings ($P < 0.0000$).

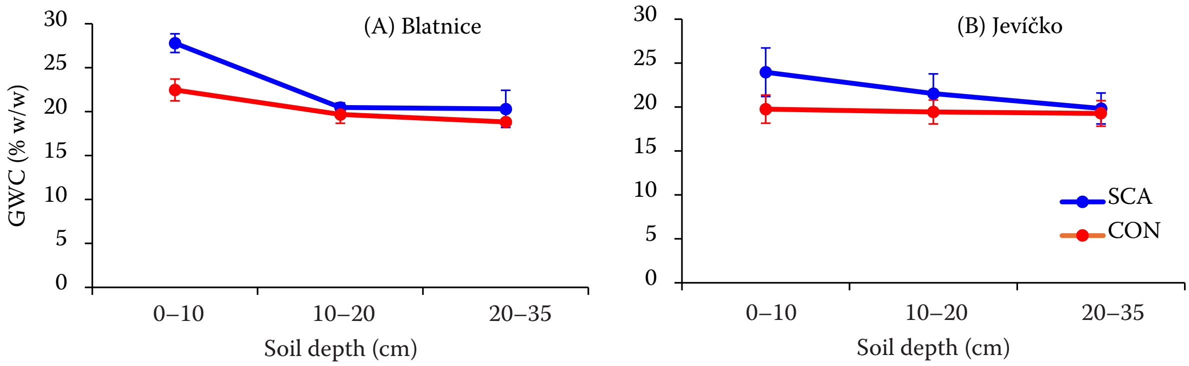

Figure 4. Change in the gravimetric water content (GWC) within the depth for compost application (SCA) compared to control soil (CON)

Bars are standard errors of the mean

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Spearman correlation coefficients between SOM and pH and EC are 0.83 and 0.82, respectively. The increase in SOM following the compost treatment contributed to a rise in soluble salts in the soil, subsequently resulting in higher EC. Similarly to the observed change in SOM, the pH value in SCA increased between seasons (Figure 3) from slightly acidic to neutral or even slightly alkaline. Stable and mature composts contribute to increased soil pH through their high content of humic acids and calcium carbonate, which act as natural pH buffers, gradually neutralizing soil acidity. Over time, the decomposition of organic acids within the compost declines, resulting in the accumulation of stable alkaline residues that further enhance soil pH stability and buffering capacity (Haynes & Naidu 1998; Campitelli & Ceppi 2008).

Soil water content. Gravimetric water content (GWC) observations across three sampled soil depths at both localities are summarized in Figure 4. A clear trend can be seen, with the SCA soil showing significantly higher GWC in the 0–10 cm surface layer compared to the control (CON) at both sites ($P < 0.01$). This effect is especially pronounced in Blatnice, where the GWC in the surface layer of SCA exceeds 30% (w/w), while the CON remains below 25%. This can be attributed to the high sand content in Blatnice compared to Jevíčko, making the effect more significant.

Similarly, at Jevíčko, SCA consistently outperforms CON in surface GWC, reflecting the enhanced water retention properties provided by compost. The differences decrease with depth, particularly in the 20–35 cm layer, where GWC values converge between SCA and CON. This trend suggests that the influence of surface-applied compost on water retention is most pronounced in the near-surface layers due to its mulching effect, which reduces evaporation and enhances water infiltration. Deeper layers are likely less affected due to the limited organic matter migration or incorporation by soil biota over the time frame of the study. These results align with findings that surface-applied organic amendments improve near-surface hydrology while their effects on deeper layers require longer timeframes or specific bioturbation activity (Gülser 2006; Lal 2006; Logsdon & Malone 2015).

Aggregate stability analysis. The evaluation of the soil aggregate stability expressed by the ratio of water-stable aggregates (WSA) revealed significant improvements in soil structure with the SCA compared to CON soils. This aligns with findings that surface-applied organic amendments enhance soil structure through the integration of organic matter and stimulation of microbial activity, which are critical for aggregate stability (Novotná & Badalíková 2018). The SCA treatments consistently showed higher percentages of WSA (Table 3). However, responce of the soil is different at each locality. In Blatnice is, the initial WSA ratio for the aggregates between 2 and 5 mm rather high (0.65 on average), showing

Table 3. Results of water stable aggregates (WSA) ratio analysis with descriptive statistics for surface compost treated plots (SCA) and control plots (CON)

Locality	Season	Aggreg. size (mm)	Treatment	*N*	Mean	SD	*CV*	Min.	Max.	Skewness	Kurtosis
Blatnice	2023	2–5	SCA	40	0.752	0.204	27.152	0.448	0.981	–0.115	–1.914
	2023	2–5	CON	40	0.663	0.232	35.041	0.239	0.982	–0.502	–1.254
	2024	2–5	SCA	20	0.680	0.057	8.407	0.602	0.807	0.655	–0.222
	2024	2–5	CON	20	0.638	0.018	2.840	0.606	0.675	0.315	0.202
Jevíčko	2023	2–5	SCA	60	0.626	0.081	12.942	0.467	0.834	0.599	–0.044
	2023	2–5	CON	60	0.488	0.108	22.209	0.331	0.806	0.691	–0.124
	2024	2–5	SCA	20	0.631	0.039	6.174	0.557	0.692	–0.605	–0.628
	2024	2–5	CON	20	0.512	0.101	19.672	0.203	0.593	–2.195	4.662
	2023	1–2	SCA	20	0.455	0.075	16.388	0.371	0.598	0.518	–1.023
	2023	1–2	CON	20	0.429	0.044	10.321	0.355	0.531	0.172	–0.009
	2024	1–2	SCA	20	0.586	0.071	12.107	0.450	0.690	–0.886	–0.326
	2024	1–2	CON	20	0.413	0.052	12.664	0.343	0.487	0.033	–1.611

N – number of samples, SD – standard deviation, *CV* – coefficient of variation

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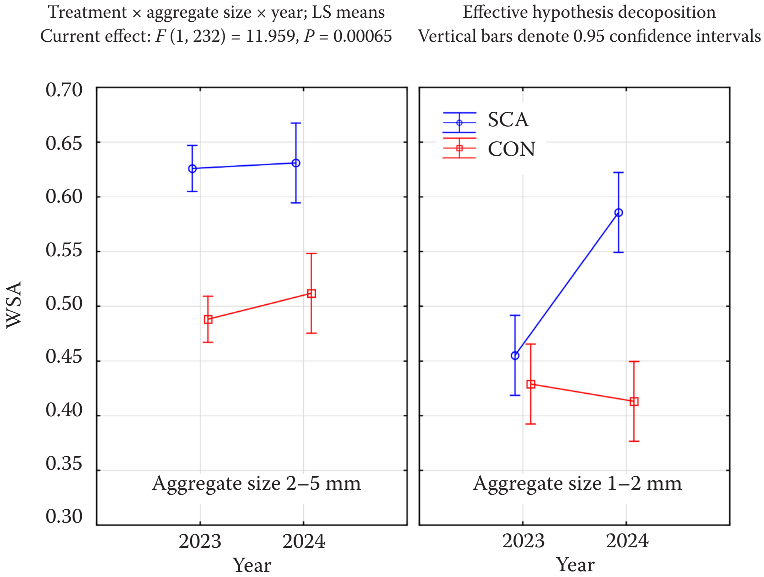

Figure 5. Changes in soil structure in Jevíčko demonstrated by water stable aggregates ratio (WSA) changes in 2nd and 3rd year from the compost application (SCA) compared to control soil (CON)

a good level of soil structure; thus, the improving effect of standard compost dose is not that notable. Comparison between CSA and CON, however, still shows a statistically significant improvement after the application (P < 0.05, one-way ANOVA) in general. Further refinement between seasons is not significant.

Another situation is in Jevíčko, where the initial WSA ratio for the aggregates between 2 and 5 mm is significantly lower compared to Blatnice (0.49 on average). Two aggregate sizes were compared for better insight into the soil structure, aggregates between 2 and 5 mm and aggregates between 1 and 2 mm. For both sizes, there is no significant difference between the experimental seasons on CON plots, showing no other influencing factor on the soil structure (Figure 5). There is no significant difference in WSA between seasons 2023 and 2024 in both CON and SCA in 2–5 mm size. That means, the positive effect of compost was already significant in 2023 and continued to 2024. There is notable progress in the smaller aggregates between 1 and 2 mm. The WSA index rapidly increased from the season 2023 to 2024 (P < 0.0000). Compost application improves WSA by increasing SOM content, which acts as a binding agent, particularly in finer-textured soils like the silty clay loam of Jevíčko. The type and maturity of compost also play a role, with mature composts rich in humic substances having a stronger effect on long-term stabilization by enhancing interparticle cohesion (Annabi et al. 2011). This may explain the pronounced improvement in macroaggregate stability observed at Jevíčko. Compost is especially effective in stabilizing aggregates in high-clay soils, where clay particles aid in forming stable micro- and

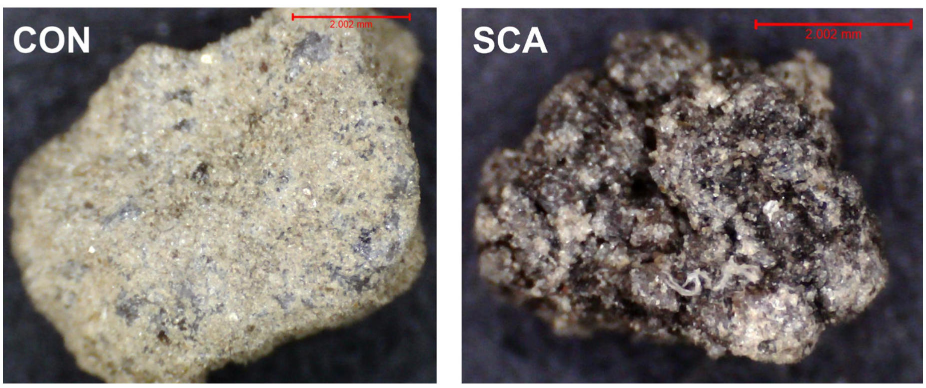

Figure 6. Soil structure aggregates under the microscope from the Jevíčko locality; the aggregates in compost-treated soil (SCA) exhibit dark colouration due to the incorporation of organic matter, highlighting the effect of compost on soil aggregation compared to untreated (CON) soil

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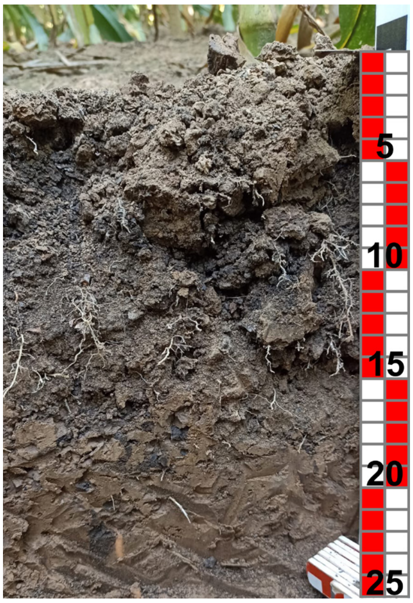

Figure 7. Soil profile at the Jevíčko locality on 14th August 2024, after 2.5 years of surface compost application; the initial compost layer was fully integrated into the soil to depths exceeding 25 cm by biological activity, despite minimal disturbance

macroaggregates (Bresson et al. 2001; Wortmann & Shapiro 2008).

At the Jevíčko locality, the surface application of a high compost dose appeared to result in the incorporation of organic matter into soil aggregates and the deeper soil profile. Microscopic analysis revealed darkened aggregates in the SCA soil, indicating the integration of compost-derived organic matter compared to untreated CON soil (Figure 6). Over 2.5 years, spanning two winters and three growing seasons, the initially thick compost layer on the surface was fully incorporated to a depth exceeding 25 cm by soil biota, with minimal soil disturbance and only strip-till used for maize sowing (Figure 7). This aligns with studies showing that compost enhances soil structure and microbial activity, promoting the humification of organic matter and the incorporation of aromatic and functional carbon groups into the soil matrix (Jindo et al. 2016; Sharma et al. 2017; Fuentes et al. 2020).

Penetration resistance. The soil penetration resistance (PR) has been one of the most used parameters in the evaluation of its physical structure (Bartzen et al. 2019). PR is reflecting the amount of soil pores in the soil and indicating the level of soil compaction. PR helps to identify areas with restrictions due to compaction, which may result in reduced root growth and reduced crop yield.

The PR measurements were carried out on both localities two times in each season. Different meteorological conditions leading to different soil moisture conditions within the profiles have led to different outcomes of the measurement. The hypothesis assuming a decrease in PR for treatments with SCA due to improved structure and due to increased soil moisture content has been tested. Multifactor ANOVA with three factors (treatment, depth and date) and their interactions was carried out. The variability of the soil conditions, as documented in Table 2 and Figure 4, is reflected in the variable outcomes of PR. Figure 8 shows the comparison of the PR data measured for Blatnice and Jevíčko for both treatments within the whole experimental period.

Penetrometers are devices used for PR measurement. The force used to push a probe with a specified cone through the soil at a constant speed over a distance is determined, and the resulting

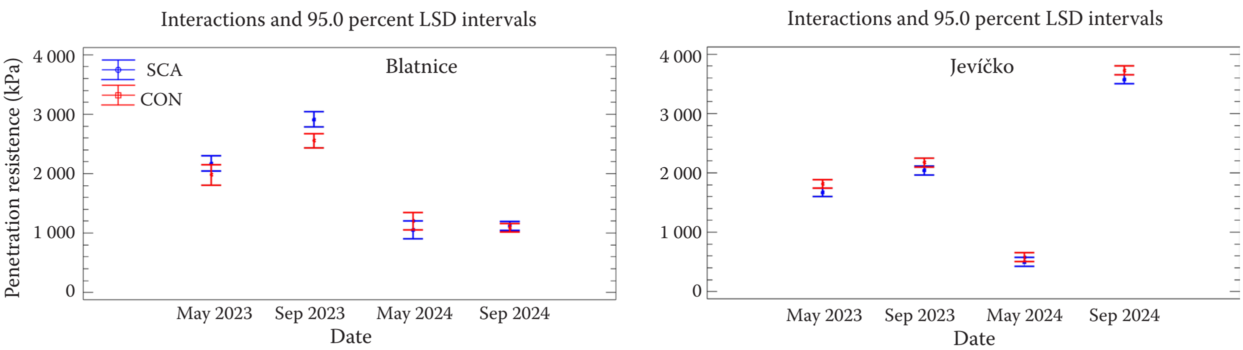

Figure 8. Penetration resistance (PR) comparison across all measured depths for Blatnice and Jevíčko for each experimental date, including compost-treated soil (SCA) and untreated control (CON)

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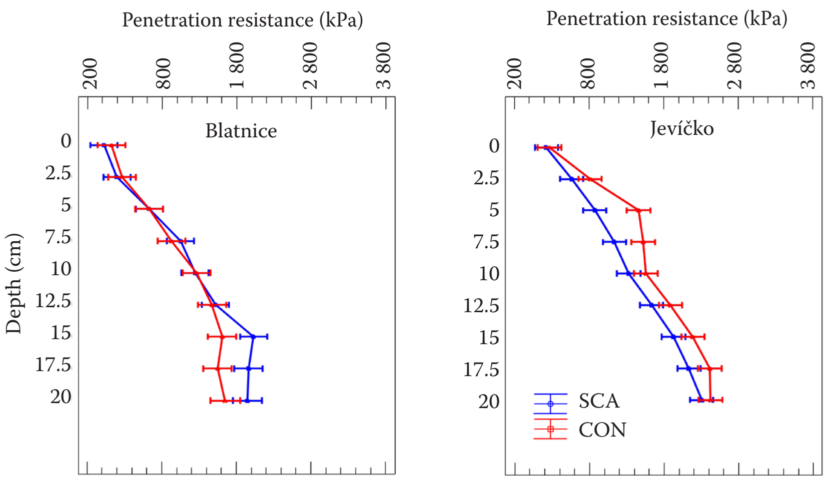

Figure 9. Comparison of the PR data measured for Blatnice and Jevíčko to the depth of 20 cm within the whole experimental period; the interaction plots show the differences between the compost-treated soil (SCA) compared to the untreated control (CON) for the individual depths in 2.5 cm intervals for which the PR data were measured by the penetrometer

PR is expressed as pressure with kPa or MPa as its unit. PR measurement in the field is relatively fast and easy; however, its interpretation is not that simple since the PR naturally increases with increasing depth and decreases with increasing BD and soil moisture content level. The effect of SCA can be easily observed in Jevíčko for the depth up to 20 cm (Figure 9). The differences between the treatments were statistically significant ($P < 0.0000$ with 95% least significant difference LSD). On the other hand, in the Blatnice locality, the treatments did not vary. In general, the differences are less significant when the soil is moist and getting more pronounced when the soil is dry, showing the positive effect of surface compost application on the porosity and water retention values.

The effects of different factors affecting the PR data have been widely studied. The effect of different soil tillage treatments, especially evaluation of conservation tillage, was recently researched by e.g. Bogunovic et al. (2019), Duchene et al. (2023) and Wilczewski et al. (2023). Compost and biochar application with incorporation into the soil has also been widely studied e.g. Stock and Downes (2008), Xin et al. (2016) and Negiş et al. (2020). Not many studies can be found to be referred to discuss the effect of surface compost application. The observations of this study show the natural effect of the soil biota to incorporate the applied compost into the depth of 20–25 cm (Figures 6 and 7). This is in agreement with a study by Cogger et al. (2008), who reported increased porosity and biological mixing in the top 24–30 cm of soil. The observations of this study are promising, the long-term observations might be leading to more statistically significant effects.

CONCLUSION

The results of this study demonstrate that the surface application of stable and mature compost has significant potential to enhance soil properties. Instead of merely mixing organic matter with soil, it facilitates its incorporation into soil aggregates through the activity of soil biota, preserving the soil as a living, dynamic system – the Earth's vital crust. Maintaining soil structure is critical, as it prevents compaction, improves water infiltration, reduces surface runoff, and enhances erosion control.

While positive effects were evident shortly after compost application, primarily due to the physical presence of the compost, the medium-term benefits were particularly pronounced. Over time, compost-supported biological activity emerged as a key driver in the formation of water-stable aggregates, a critical factor in improving soil structure. At both experimental sites, this was reflected in a significant increase in aggregate stability, reduction in dry bulk density and penetration resistance, improvement in water retention within the soil profile, and enhanced water infiltration. Further observation of the experimental parcels is highly recommended, as the medium-term and long-term effects are anticipated. Additionally, a comparison of the surface-applied compost with the traditionally incorporated compost can be recommended, too, but it is essential to consider the differing field management practices required for each approach.

In conclusion, surface-applied compost not only improves soil physical properties but also directly contributes to the global agenda for SLM and climate-resilient agriculture. This approach aligns with the CAP, emphasizing reduced tillage, continuous soil

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cover, and improved soil carbon sequestration, shortly, supporting long-term agricultural productivity.

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