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Influence of soil tillage technology on tillage erosion

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Abstract: Tillage-induced erosion has negative impacts on the soil environment and production of the soil under intensive farming. Tillage erosion was evaluated during soil tillage performed by two technologies, i.e. conventional tillage and reduced tillage, commonly used in the Czech Republic. A field experiment was aimed at evaluating the soil particle translocation and magnitude of the vector angle. Aluminium cubes with an edge length of 16 mm were used as tracers. After each soil tillage operation, a metal detector searched these tracers in the topsoil. During the experiment, agricultural practices were always carried out on their respective dates for the whole season. The experiment results show that conventional tillage had a more adverse effect on tillage erosion than reduced tillage. This was confirmed on three experimental parcels with different slope gradients of 2, 6 and 11°. The largest translocation of soil tracers was observed on a parcel with the highest slope of 11°. There, the length of the translocation of tracers reached up to almost 10 m. The average length of soil tracer translocation in reduced tillage and conventional tillage ranged between 0.86 and 3.69 m. The largest average vector angle of tracer locations was recorded on a parcel with a slope of 6° for reduced tillage. In the treatment with the slope of 2° and conventional tillage used, the direction vector indicated upslope translocation of soil tracers. It was caused by soil tillage with a mouldboard plough turning over the topsoil layer upslope. In a treatment with a slope of 2° and reduced tillage used, no influence of the crosswise slope gradient of the plot on the direction vector was observed. The acquired knowledge will be used in further study of soil erosion processes.

Keywords: cultivators; soil erosion; mouldboard plough; soil tracer translocation, soil sustainability

The translocation of soil particles due to soil tillage is called tillage erosion. In the territory of the Czech Republic, there are about 3.5 million ha of arable land, while a significant portion of this arable land is on sloping lands. An extensive erosion study in conditions of the Czech Republic was published by Novák (2019), which was followed by partial research carried out by Brož and Hůla (2023). Morgan (2009) stated that the slope of arable land has a great potential for the occurrence of erosion, both in water and in tillage. According to Novara et al. (2019), tillage erosion also causes problems in vineyards. Although soil erosion is basically a natural process, it is accelerated by anthropogenic activities, mainly

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by intensive conventional soil cultivation (Van Oost et al. 2000; Young et al. 2014). There is a mutual relationship between the processes of water erosion and tillage erosion, but in many cases, these processes are studied separately (Van Oost et al. 2011; Wang et al. 2016). Generally, the differences between these processes are notable (Lobb 2001). In his studies, Govers concluded that at least 70% of slope erosion may be caused by soil cultivation techniques (Govers et al. 1994, 1999). The translocation of soil particles following the fall line is the most severe threat to convex parts of sloping lands with unequal gradients while the earth accumulates in the concave parts of plots (Heckrath et al. 2006; Li et al. 2009). Consequently, the topsoil depth is diminished in the upper part of plots and on tops of elevations. Besides the translocation of soil particles, nutrients are transported to lower-lying sloping plots due to soil tillage, adversely affecting soil productivity (Lobb and Kachanoski 1999; Quine and Zhang 2002; Zhao et al. 2018). A combination of the influence of the travel direction during soil tillage and slope gradient on undesirable topsoil translocation was studied by Xu et al. (2019). Interactions between the movements of soil components during soil tillage on slopes with a focus on vertical and lateral translocation were investigated by Zhang et al. (2017). More authors accentuated the need for intensive investigation of these processes (Quine and Zhang 2004; Jia et al. 2017).

In the Czech Republic, several soil tillage technologies are used. Among them (Brant et al. 2016), two particular technologies are significant, i.e. ploughing (conventional tillage), and technology without ploughing (reduced tillage, referred to also as minimum tillage). Evidence on the influence of particular agricultural practices on tillage erosion was confirmed by Lindstrom et al. (1992) or Quine et al. (1999). However, those authors did not evaluate the influence of complete soil tillage technologies in one plot during the entire cultivation season. In primary soil tillage, more data on the translocation of soil particles are available, particularly for cultivation with a mould-board plough (Tiessen et al. 2007). Fewer experimental results on the translocation of soil particles by farm machines were published for secondary soil tillage (Li et al. 2007). The undesirable movement of soil particles is related to the intensity of soil tillage. Minimum topsoil translocation occurs when no-tillage technology is used.

Lobb and Kachanoski (1999) summarise that tillage erosion is determined by two factors – the erosivity of the tillage operation and the erodibility of the landscape. The tillage equipment and operational parameters (tillage depth and speed) affect erosivity. The erodibility is affected by the topographic properties of the landscape – slope gradient and slope curvature, and soil condition, such as soil texture, structure of soil and moisture content.

Zheng et al. (2021) present an interesting study on forming channels such as rills and gullies in water erosion processes. These channels also affect tillage erosion.

The field experiment in this study aimed to evaluate the displacement of soil particles of two tillage technologies on the translocation of soil particles during tillage operations at three different slopes throughout the growing season. Conventional tillage technology and reduced tillage technology were chosen for the evaluation. The partial aim was to obtain data for sustainable land management in conditions where the soil is threatened by compaction and erosion.

MATERIAL AND METHODS

The area where an experiment was conducted was in the cadastre of Nesperská Lhota municipality in Central Bohemia. A field experiment was aimed at evaluating soil particle translocation and the magnitude of the vector angle in conventional tillage and the technology of reduced soil tillage.

The experiment focused on determining the crosswise and lengthwise translocation of soil particles during soil tillage on the plot with different slope gradients. Six experimental parcels were surveyed on the plot using a digital clinometer. Three parcels on slopes of 2, 6 and 11° were surveyed for conventional tillage, while the other three parcels with the same respective inclinations were surveyed for reduced tillage. Parcels with a slope of 11° were considered the ultimate ones given labour safety in conditions of the CZE. The parcels were surveyed at the beginning of the experiment during primary soil tillage (stubble field skimming), and their demarcation on the plot was left unaltered until the last measurement after seedbed preparation was terminated.

Metal tracers were used as indicators of the translocation of soil particles (Li et al 2009). These were aluminium cubes with an edge length of 16 mm. An advantage of aluminium is that its density is similar to the density of mineral particles in soil (Van

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Muysen and Govers 2002; Zhang and Li 2011). The experiment contained a total of 120 tracers divided evenly between reduction technology (60 tracers) and conventional technology (again 60 tracers). At the beginning of the experiment, the aluminium cubes were incorporated into the soil in a row at a fixed spacing of 0.2 m. The direction of the travel of a farm machine (tractor with tillage implement) was perpendicular to this row of indicators. The tracers were numbered and had different colours.

The reason for tracer numbering was the identification for surveying and determination of their translocation during soil tillage. Their initial (primary) location was recorded. After the given agricultural practice was performed, the translocation of aluminium tracers was recorded. The aluminium cubes were retrieved using an M6 metal detector (Whites Devices, United Kingdom), their position was recorded, and the cubes were returned to the same place where they had been found after the agricultural operation. Therefore, an assessment of their further translocation after a subsequent tillage operation was enabled. The measurement method is shown in Figure 1.

The farm machines (tractors with tillage implements) always passed along the contours on the experimental parcels. From point zero of the respective parcel, the farm machine (tractor with tillage implement) travelled in the same direction each time. The tractor's travel speed with tillage implemented during cultivation corresponded with the instructions of the implement manufacturer. The operating speed of the disc harrow was 10 km·h^{-1}, the operating speed of the plough was 7 km·h^{-1}, the operating speed of the cultivator for reduced tillage was 10 km·h^{-1}, and the operating speed of the combined cultivator for seedbed preparation in the conventional tillage system was 12 km·h^{-1}.

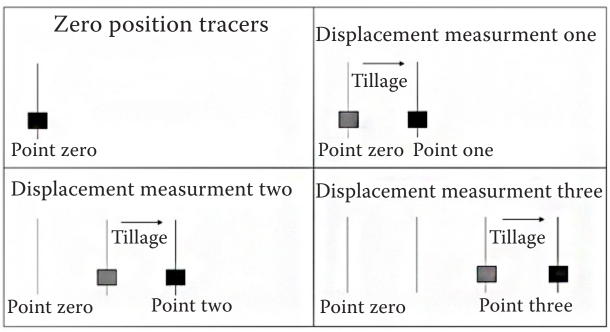

Figure 1. Translocation of tracers during measurements throughout the season

The soil on the experimental plot chosen was arenic Cambisol. Texture class: sandy loam (content of particles < 0.01 mm: 29% by weight). Cox – 1.32%; pH_{H_2O} – 6.15 (Table 1 and Table 2). Soil samples had 5 repeats (Kopecky cylinders). A register penetrometer measured the cone index in 10 repetitions. Oilseed rape was grown on the plot before the start of the experiment. Rapeseed was harvested at the end of July with straw chopped and evenly spread out by a combine harvester. Still, at the end of July, the field stubble was skimmed using a disc harrow. The specific date of the operation was the July 29th, 2022. Skimming with a disc harrow was done on the parcels intended for conventional tillage and on the parcels intended for reduced tillage. The depth of soil tillage was 0.08 m. At the beginning of September, ploughing to a depth of 0.22 m was done on the parcels where conventional tillage was used, while soil loosening to a depth of 0.15 m was performed on the parcels with reduced tillage. The direction of ploughing was down the slope. The specific date of the operation was the September 5th, 2022. At the beginning of October, on the parcels destined for conventional tillage, a combined cultivator performed seedbed preparation to a depth of 0.08 m. The specific date of the operation was October 3, 2022. No soil tillage was carried out on the parcels, with reduced tillage at the time. A total of 5 repetitions were performed.

Farm machines used in experiment. The Zetor 130 HSX tractor (Zetor, Czech Republic) with an engine power of 93.2 kW was used as a traction vehicle. This power corresponded to the requirements posed by the draft of the soil tillage implements used in the field experiment. The Zetor 130 HSX tractor was used for all the tillage operations during the experiment. The Akpil disc harrow with a working width of 3 m was used for primary tillage. The discs were arranged in sections in a conventional X-form. The diameter of the discs of the harrow was 500 mm. A PH5-35 one-sided plough was used on the parcels with conventional tillage. The overall working width of this five-furrow plough was 1.75 m. A coulter was mounted in front of each ploughshare. The Kromexim tine cultivator with seven tines and six levelling discs was chosen for reduced technology. The working width of this cultivator was 3 m. The Saturn combined cultivator was used for seedbed preparation on the parcels with conventional tillage. The working width of the cultivator was 6 m. This working width was divided into four sections. Each

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Table 1. Characteristics of the soil before soil tillage

Depth (m)	Bulk density (g·cm^{-1})	Porosity (% vol.)	C_{ox} (%)	Moisture (% vol.)
0.05–0.10	1.54	39.4	1.37	10.6
0.10–0.15	1.66	36.1	1.32	13.4

C_{ox} – oxidizable carbon

Table 2. Cone index before soil tillage

Depth (m)	Cone index (MPa)
0.04	1.5
0.08	1.8
0.12	1.7
0.16	2.1
0.20	2.2
0.24	2.6

section contained 2 rollers and 6 duckfoot shares. At the end of the cultivator, a roller of the crosskill type was mounted.

Data evaluation. Data were processed by the software MS Excel (software version 2021) and Statistica 12 (software version 12).

RESULTS AND DISCUSSION

The experiment's results, which compared soil particle translocation in conventional and reduced soil tillage systems, demonstrated that reduced tillage is more suitable for protecting soil against tillage erosion. This result was confirmed for all three treatments with different slope gradients. The experiment's results also compare the magnitude of the direction angle in the above-mentioned tillage systems.

After the experiment was terminated, the length of the direction vector was evaluated. The length is represented by the translocation value of particular tracers from the initial position. The direction vector was also evaluated. The direction vector represents the angle of a vector that indicates a difference from the direction of travel of farm machines in the given tillage technology. The positive value of this angle shows a downslope translocation along the fall line (perpendicularly to the direction of the travel of the tractor and tillage implement).

Figure 2 illustrates the translocation of soil tracers. The graph shows that longer translocation was always observed in conventional tillage compared to reduced tillage. The largest translocation occurred on an experimental parcel with a slope of 11°. The average values of translocations for particular tillage technologies on parcels of particular slope gradients are shown in Table 3. In Table 3, variants with a 95% probability of soil particle translocation on the chosen slope of the parcel for the respective tillage technology are also documented. The longitudinal distance differed significantly among conventional technology on a slope of 11° and all the other variants.

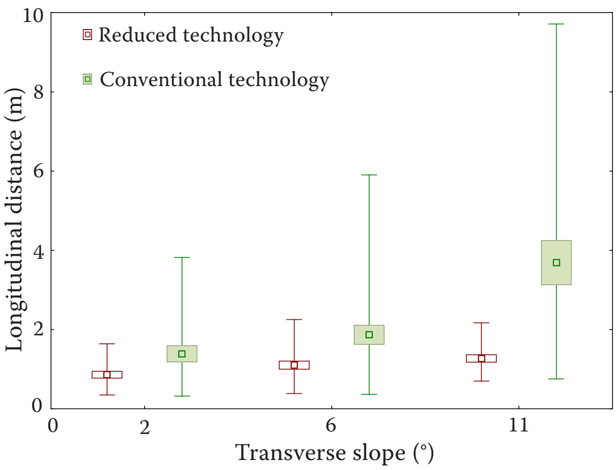

Figure 2. Translocation of soil tracers in reduced tillage and conventional tillage at locations of the plot with different slope gradients (P = 0.95)

Table 3. Translocation of soil tracers for different tillage technologies and slope gradients

Tillage technology and slope gradient	Average (m)	Variance (m)	SD	CV
Reduced technology (2°)	0.86^{a}	0.15	0.88	45.11
Conventional technology (2°)	1.39^{a}	0.85	0.92	66.22
Reduced technology (6°)	1.10^{a}	0.21	0.45	41.15
Conventional technology (6°)	1.87^{a}	1.18	1.09	58.18
Reduced technology (11°)	1.27^{a}	0.18	0.42	33.04
Conventional technology (11°)	3.69^{b}	6.22	2.49	67.61

$^{a, b}$ letters indicate homogeneous groups (Tukey HSD test); SD – standard deviation; CV – coeficient of variation

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The magnitude of vector angles is represented in Figure 3. The graph shows that the direction vector indicated downslope translocation of soil particles on experimental parcels with slopes of 6 and 11°. On a parcel with a slope of 2°, the direction vector showed upslope translocation of soil particles when conventional tillage was used. The assumed cause is the soil tillage with a mouldboard plough when the topsoil layer is turned over upslope during ploughing. On a parcel with a slope of 2° where reduced tillage was used, no influence of the crosswise slope gradient of the plot on the direction vector was observed.

Table 4 documents the magnitudes of vector angles of particular tillage technologies on parcel slope gradients. It also shows the values of the angles with 95% probability. The vector angles differed significantly among conventional technology on a slope of 2° and all the other variants.

Our results confirm the conclusions of Kouselou et al. that conventional tillage causes greater translocation of soil particles in the direction of the farm machine travel than minimum and reduced tillage

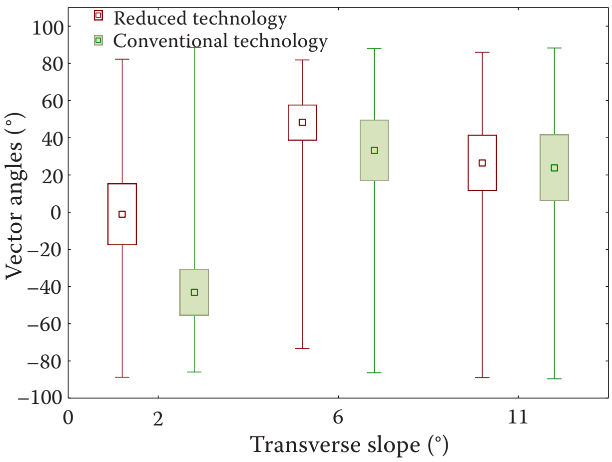

Figure 3. The magnitude of vector angles at locations with different slope gradient of the plot (P = 0.95)

(Kouselou et al. 2018). However, partly different results were obtained in the lateral translocation of soil particles. On the slope of a low gradient (2°) and with the contour travel of farm machines, the upslope turning over of the soil layer by a mouldboard plough was found to be positive. On the slope of higher gradients (6 and 11°), the upslope turning over of the furrow slice was insufficient to prevent soil particles' undesirable lateral downslope translocation during conventional tillage.

The translocation of soil tracers in reduced tillage and conventional tillage at locations of the experimental plot with different slope gradients ranged between 0.86 and 3.69 m. Van Muysen et al. (2006) found that in a typical sequence of soil tillage operations, the translocation of soil particles ranged between 0 and 0.9 m.

The results are consistent with Xu et al. (2019), who accentuated the importance of the choice of the farm machine travel direction during soil tillage on sloping plots with respect to tillage erosion. Zheng et al. (2021) confirmed that contour tillage is a suitable choice for farming on sloping land compared to downslope tillage and upslope tillage. This was also confirmed in previous experiments of Novák and Hůla (2007).

With increased knowledge of the processes involved in soil tillage erosion, it is possible to avoid undesired damage to soil fertility (Li et al. 2009). Zheng et al. (2021) emphasised the importance of gaining new knowledge about tillage erosion for water and tillage erosion modelling.

CONCLUSION

During soil tillage, the soil may be unwillingly damaged by the undesirable translocation of soil particles. An appropriately chosen tillage technology can contribute to a reduction in tillage erosion. Our measurements indicated that reduced tillage

Table 4. The magnitude of vector angles

Technology and slope size	Average (m)	Variance (m)	SD	CV
Reduced technology (2°)	−1.18[b,a]	5 479.09	74.02	−6 289.15
Conventional technology (2°)	−43.02[a]	3 120.95	55.87	−129.86
Reduced technology (6°)	48.21[a]	1 842.47	42.92	89.032
Conventional technology (6°)	33.17[a]	5 429.85	73.69	222.16
Reduced technology (11°)	26.49[a]	4 523.07	67.25	253.86
Conventional technology (11°)	23.88[b]	6 347.84	79.67	333.61

[a, b] letters indicate homogeneous groups (Tukey HSD test); SD – standard deviation; CV – coeficient of variation

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was friendlier during soil tillage on sloping plots than conventional tillage with a mouldboard plough. A lower intensity of the action of tillage tools on the soil is typical of reduced tillage compared to conventional tillage. This distinction can manifest in tillage erosion differences during farming on sloping plots. On a slope of 11°, the tracers' average distance travelled was 3.7 m with conventional technology and 1.3 m for reduced technology. The average displacement distance of the tracers was larger with the conventional technology than with the reduced technology, even on 6 and 2° slopes.

Studies of tillage erosion should continue intensively because this phenomenon is very important for maintaining soil productivity under intensive farming.

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