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Influence of primary tillage on the displacement of soil particles

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Abstract: The loss of soil particles due to erosion is one of the main problems of current agriculture. However, soil tillage may also contribute to the undesirable transport of soil particles. It is to note that the effects of particular working elements used on implements for soil tillage have not been described in a sufficient way. To determine the translocation of soil particles, measurements were done in the Central Bohemian region. Two basic machines for soil tillage were used for measurements: a disc harrow and a tine cultivator. Measurements were performed on sandy-loamy Cambisol after the harvest of a spring cereal crop. White limestone grit was used for the indication of soil particle translocation. Great translocation of soil particles was observed after soil tillage with a tine cultivator − the most distant particles were found out at a distance of more than 1.50 m from the original location. After soil tillage with disc harrows, the most distant particles were found out at a distance of 0.90 m. The dependence of tracer weight on a distance from the original location could be described for disc harrows and tine cultivator by an exponential function.

Keywords: field; soil particles transfer; tillage erosion

The erosion process is the main risk for agricultural soils in the Czech Republic. Together with technogenic compaction and the lack of high-quality organic matter in the soil, erosion reduces soil quality in the long-term effect (Novák and Hůla 2017). Tillage erosion is an undesirable phenomenon that occurs on intensively managed plots. With the advancement of innovative cultivation technologies, the importance of undesirable soil particle transfer is increasing (Wysocka-Czubaszek and Czubaszek 2014).

Research into this undesirable phenomenon is very difficult. It is, therefore, an effort to create model situations in interactive forms (models). However, predicting the actual displacement of soil particles on land in models is very demanding on accurate input data (Ucgul et al. 2015). The results of previous research show that the displacement of soil particles is significantly influenced by the tools of machines and by the kind of working operation (Novák and Hůla 2017). There are large differences between the individual tillage machines, especially in the design

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of the working tools, working speed, and moisture conditions. Probably, therefore, there is a significant difference in the measured values of soil displacement by individual machines (Logsdon 2013). The average slope of the cultivated land also has a significant effect on the amount of soil particle displacement.

Van Muysen et al. (2006) and Logsdon (2013) report that the soil does not move the same throughout all tilled profiles during tillage with the tine cultivator. The particles on the soil surface can move over long distances because their displacement is not restricted by any particles above them. On the contrary, the deeper particles move only at small distances due to the pressure exerted by the soil's own weight.

The aim of the work was to evaluate the displacement of soil particles by working tools of the tine cultivator and disc cultivator at three working speeds and to assess the relation with tillage erosion.

MATERIAL AND METHODS

The field experiment was carried out in the locality Nesperská Lhota (49°41'34.8''N and 14°49'46.2''E) on a plot with an altitude of 420 m. The content of particles smaller than 0.01 mm in the topsoil was 29%. The soil on the plot is shallow, slightly rocky Cambisol, and the plot was after the oat harvest (haylage harvest).

The soil moisture at the time of measurement was 12.2% volume. The average slope of the plot was 1.7°. Tillage of the soil was carried in a downslope orientation. Tractor Zetor 12045 (Zetor, Czech Republic), with a nominal power of 90 kW, was used as the pulling vehicle, which allowed the highest required working speed of 14 km·h^{-1} with both machines. The disc cultivator Akpil X 3.0 (Kromexin, Czech Republic) with a working width of 3 m was used for the measurement. The 500 mm diameter disc is always mounted on a common shaft, and the arrangement of the four-disc units is X-shaped. The working depth was 0.08 m.

The second machine was a Lemken Smaragd 80/220 tine cultivator (Lemken, Germany) with a working width of 2.2 m. The machine has five tines, which were equipped with chisels with wings for full-surface tillage. Next come levelling discs, where two pairs of soil-sweeping discs are fitted in the middle as standard. In addition, the machine was equipped with two separate plates on the outside of the machine, as is currently common with share cultivators. The back roller was not installed.

The method described by Logsdon (2013) was used to assess soil displacement. The method consists of the use of tracers inserted into the topsoil at a depth that corresponds to the required depth of subsequent soil treatment. The marking tracers were used to indicate the displacement of a part of topsoil during its processing. Crushed white limestone (particle size 10–16 mm) was used.

The groove dimension of 0.20 m width was chosen for both cases. The length of the groove (perpendicular to the direction of travel) was 1 m for both machines. The depth of the groove was 0.10 m for the disc cultivator and 0.20 m for the tine cultivator. 25 kg of crushed white limestone was placed in the groove for the disc cultivator and 50 kg of crushed stone was placed in the groove for the tine cultivator. Variants of three working speeds (4.5, 9.0, and 14 km·h^{-1}) were measured for both machines. After tillage, white limestone grit was manually picked from the soil in marked sections. For the disc cultivator, the sections had a sampling interval of 0.30 m; for the tine cultivator, the first four sections had a sampling interval of 0.30 m; for the other sections, the sampling interval was extended to 0.60 m. Each section was divided into three sub-sections (left, middle, and right). The weight of the crushed stone selected from individual sections was determined.

The sum curve can be used to evaluate soil displacement (Lobb and Kachanoski 1999). Figure 1 shows the distance from the beginning of the groove on the x-axis and the relative concentration (frequency) of the marker tracers on the y-axis. The groove, the place in which the marking medium at the beginning of the experiment is located, creates the basis for hypothetical distribution functions with its width. The frequencies at the individual distances are added together to give a summing curve that takes a value from zero to one. The area above the curve represents the relative amount of soil moved from the area above the curve (Lobb and Kachanoski 1999), the second integral considers the displacement of the soil against the direction of travel, for example, on a slope.

Kruskal-Wallis test and Tukey's honestly significant difference (HSD) test were used to evaluate statistical hypotheses. According to Lobb and Kachanoski (1999), a summation curve was created, which was calculated for each speed and each machine from the average value at each distance (interval). The λ50,

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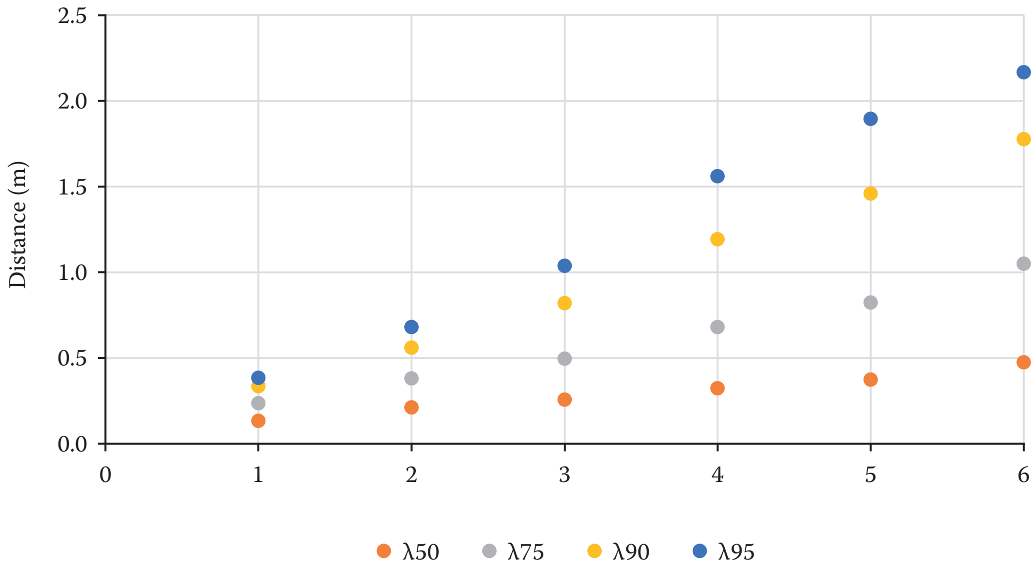

Figure 1. Graph of percentiles distance

λ75, λ90, and λ95 percentiles were used to evaluate the variability of tracer displacement. These determine the distance at which 50, 75, 90, and 95% of the tracer mass has already been moved (for example, 50% of the particles have been moved λ50 and less) (Lobb et al. 2001).

RESULTS AND DISCUSSION

Selected descriptive characteristics for machine and speed groups are shown in Table 1. It can be seen from the table that the weight of the tracers displaced outside the groove increased with the working speed of the disc cultivator. This may be due to the fact that at low velocities, part of the tracers moved only inside the groove. On the contrary, with the tine cultivator, the number of displaced tracers was similar in the first two speeds and was significantly lower at the highest speed. As can be seen from the median values, in all cases outside of the highest working speeds of the tine cultivator, more than half of all particles were moved only to the first interval with a median value of 0.15 m. Furthermore, it can be seen that with increasing working speed, the arithmetic mean and the standard deviation are higher. The distance of the most distant tracer found from the end of the groove was also recorded.

Tables 2 and 3 contain the primary displacement data for both machines. The longitudinal displacement was divided into several sections. Data are also expressed using homogeneous groups. The data shows the influence of machine speed as well as the much more intensive work of the tine cultivator. A statistically significant difference was noted in only a few cases.

Table 1. Descriptive statistics of tracers displaced outside the groove

Machine/ speed	Mass of tracers displaced from the groove (kg)	Arithmetic mean (m)	Standard deviation (m)	Median (m)	Maximum distance (m)	Lower quartile (m)	Upper quartile (m)
T1	20.99	0.46	0.50	0.15	3.45	0.15	0.45
T2	20.96	0.51	0.60	0.15	3.45	0.15	0.75
T3	16.62	0.65	0.72	0.45	3.45	0.15	0.75
D1	2.32	0.18	0.11	0.15	1.35	0.15	0.15
D2	3.99	0.31	0.23	0.15	1.35	0.15	0.45
D3	6.21	0.37	0.34	0.15	1.65	0.15	0.45

T – tine cultivator; D – disc cultivator; speeds: 1 – 4.5 km·h^{-1}, 2 – 9 km·h^{-1}, 3 – 14 km·h^{-1}

https://doi.org/10.17221/76/2022-RAE

Table 2. Longitudinal displacement for a disc cultivator in weight

Distance (m)	Weight (kg) at a different working speed		
	D1	D2	D3
0–0.3	0.690[a]	0.823[a]	1.267[a]
0.3–0.6	0.078[a]	0.353[b]	0.391[b]
0.6–0.9	0.002[a]	0.124[a]	0.212[a]
0.9–1.2	0.001[a]	0.024[a]	0.110[b]
1.2–1.5	0.001[a]	0.004[a]	0.088[a]
up to 1.5	0[a]	0[a]	0.003[a]

[a,b] homogeneous groups (P = 0.95); D – disc cultivator; speeds: 1 – 4.5 km·h^{-1}, 2 – 9 km·h^{-1}, 3 – 14 km·h^{-1}

Table 3. Longitudinal displacement for a tine cultivator in weight

Distance (m)	Weight (kg) at a different working speed		
	T1	T2	T3
0–0.3	3.963[a]	3.887[a]	2.477[a]
0.3–0.6	1.393[a]	1.257[a]	1.367[a]
0.6–0.9	0.667[a]	0.630[a]	0.377[a]
0.9–1.2	0.370[a]	0.390[a]	0.440[a]
1.2–1.8	0.415[a]	0.439[a]	0.374[a]
1.8–2.4	0.120[a]	0.168[a,b]	0.329[b]
2.4–3	0.050[a]	0.122[a,b]	0.171[b]
up to 3	0.016[a]	0.044[a]	0.056[a]

[a,b] homogeneous groups (P = 0.95); T – tine cultivator; speeds: 1 – 4.5 km·h^{-1}, 2 – 9 km·h^{-1}, 3 – 14 km·h^{-1}

Table 4 shows the values obtained using the sum curve method. According to Lobb and Kachanoski (1999), a summation curve was created, which was calculated for each speed and each machine from the average value at each distance. The values show a lower effect of the disc cultivator. The influence of speed is also much more pronounced with a disc cultivator.

Figures 1–3 show the values obtained using the sum curve method. The disc cultivator moved

Table 4. Values obtained using the sum curve method

Parameter	D1	D2	D3	T1	T2	T3
Dp (m)	0.100	0.100	0.100	0.200	0.200	0.200
Dt (m)	0.012	0.018	0.029	0.102	0.101	0.078
Tp (m)	0.026	0.064	0.116	0.232	0.256	0.248
TL (m)	0.222	0.357	0.403	0.455	0.505	0.637
Tm (kg·m^{-1})	3.900	9.650	17.380	69.620	76.740	74.380
λ50 (m)	0.135	0.213	0.258	0.324	0.375	0.476
λ75 (m)	0.238	0.381	0.497	0.681	0.824	1.050
λ90 (m)	0.336	0.562	0.821	1.193	1.459	1.776
λ95 (m)	0.385	0.682	1.039	1.561	1.895	2.167
ε	1.090	0.870	1.350	1.330	1.240	0.490

D – disc cultivator; T – tine cultivator; speeds: 1 – 4.5 km·h^{-1}, 2 – 9 km·h^{-1}, 3 – 14 km·h^{-1}; *Dp* – groove depth; *Dt* – tillage depth; *Tp* – displacement for *Dp*; *TL* – displacement for *Dt*; *Tm* – intensity of soil displacement; λ50, λ75, λ90, λ95 – percentiles; ε – measurement error

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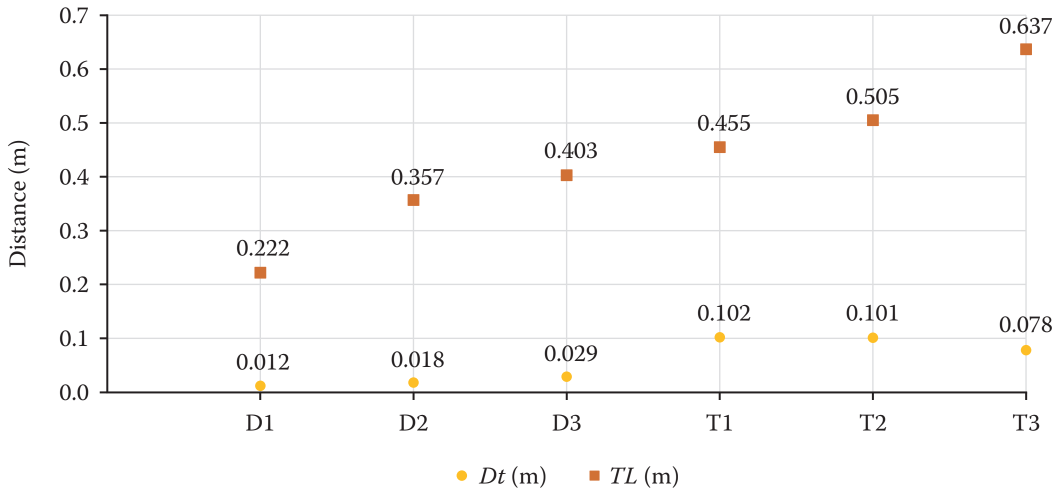

Figure 2. Graph of lengthwise distance

D – disc cultivator; T – tine cultivator; speeds: 1 – 4.5 km·h^{-1}, 2 – 9 km·h^{-1}, 3 – 14 km·h^{-1}; *Dt* – tillage depth; *TL* – displacement for *Dt*

the particles in the treatment depth (*TL*) to a distance of approximately 0.3 m and the tine cultivator to a distance of 0.5 m, as can be seen from Figure 2. Both from the value of the intensity of soil displacement *Tm* and from the displacement distance *Tp* for the depth of the groove *Dp*, it can be seen that the harrow cultivator moved the marking tracers more intensively. This is primarily due to the greater depth of tillage *Dt*, as well as the greater distance of displacement in the depth of tillage *TL*. At the same speed of both machines, the displacement intensity *Tm* of the tine cultivator was about seven times higher than that of the disc cultivator.

From the values of displacement distances *TL*, *Tp*, the intensity of displacement *Tm*, and from the percentile values, it can be seen that the displacement of soil increased with increasing working speed (Tables 1 and 2). The increase is best seen especially in the highest percentiles. The displacement of the tine cultivator increased less with increasing speed than that of the disc cultivator.

Although the issue of soil displacement is not well resolved, it is possible to compare the results of this study with other authors. A methodologically similar measurement using the sum curve was carried out by Tiessen et al. (2007) in the New Brunswick region

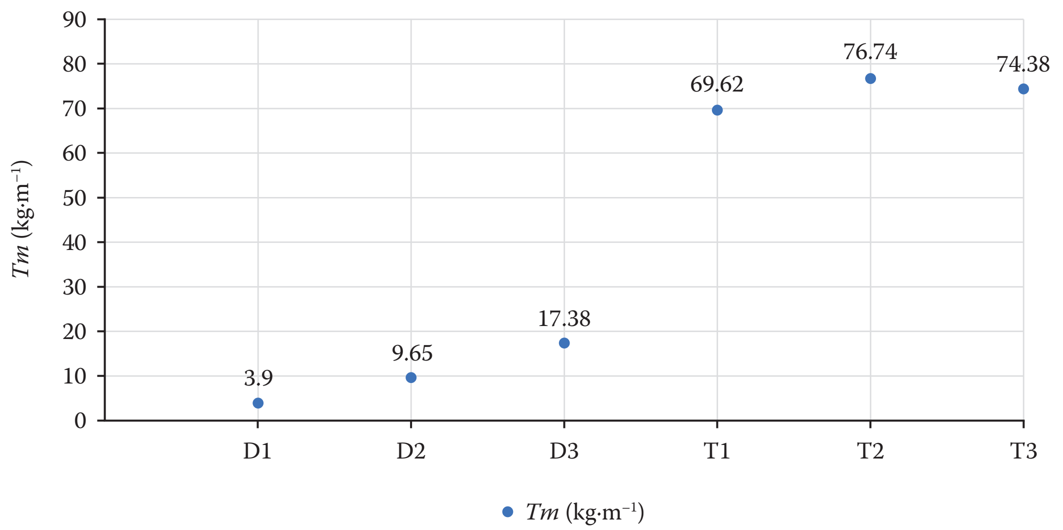

Figure 3. Graph of the intensity of soil displacement (*Tm*)

D – disc cultivator; T – tine cultivator; speeds: 1 – 4.5 km·h^{-1}, 2 – 9 km·h^{-1}, 3 – 14 km·h^{-1}

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of Canada, in a potato-growing area with clay soils. The results of the displacement intensity *Tm* are comparable to our measurement. Percentiles reported by Tiessen et al. (2007) are higher, which applies in percentage terms, especially for λ50. While in our case, the tine cultivator was two-row construction, Tiessen et al. (2007) used a three-row cultivator.

For the disc cultivator, the displacement distance *TL* is comparable to the results obtained by Tiessen et al. (2007), the intensity of mass displacement *Tm* is lower than that of these authors, which is apparently caused by the unequal working depth of loosening. The percentiles calculated in our measurements are lower.

The presented results of soil particle displacement evaluation are comparable to the results obtained by Govers et al. (1999) and Van Muysen et al. (2006).

CONCLUSION

In this research, it was proven that for the disc cultivator, the weight of the tracers displaced outside the groove increased with the working speed. On the contrary, with the tine cultivator, the number of displaced tracers was similar at the lower speeds and was significantly lower at the highest speed. Measured data expressed the influence of machine speed as well as the much more intensive work of the tine cultivator. The sum curve method showed that the influence of speed is much more pronounced with a disc cultivator. Also, the harrow cultivator moved the marking tracers more intensively. The displacement intensity of the tine cultivator was higher than that of the disc cultivator, and the displacement of soil increased with increasing working speed. It turned out that, in the field of tillage erosion, it is necessary to obtain more information about the influence of the working tools of machines on soil particles and their displacement during different ways of applying machines in cultivation technologies.

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