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Translocation of soil particles during primary soil tillage

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Abstract. The loss of soil particles due to water erosion is a crucial problem of current farming on the soil. 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. Three basic machines for soil tillage were used for measurements: disc tiller, tine cultivator and five-share plough. Measurements were performed on sandy-loamy Cambisol after 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 tine cultivator and mouldboard plough - the average translocation rates ranged between 0 and 0.9 m. Disc tiller displaced the soil particles into smaller distance (into 0.3–0.45 m). The dependence of tracer weight on a distance from the original location could be described for disc tiller and tine cultivator by an exponential function. The type of soil particle translocation by a mouldboard plough was completely different from the translocation by a disc tiller and tine cultivator. Topsoil turning over by a plough showed the lengthwise and crosswise movement of tracers with a typical dependence of their weight on a distance from the original location. The dependence of tracer weight on a distance from the original location could be described for mouldboard ploug by an quadratic function. Individual machines for primary tillage have a different character of translocation of soil particles.

Key words: soil particles transport; soil erosion; machines for soil tillage.

INTRODUCTION

Different soil tillage and sowing methods have a significant effect on soil structure, soil bulk density, soil penetration resistance, total and air-filled porosity, soil moisture and yield (Šimanskaitė, 2008). Another effect of soil tillage is the influence on soil erosion conditions. Of the factors influencing soil erosion are distinguished erosivity: action of the eroding agent (rainfall, but also the action of tillage) and erodibility: the resistance of the soil to detachment and transport. Soil resistance to erosion (erodibility) depends on slope steepness and on intensity of disturbance during soil tillage. Soil erodibility is impacted by soil texture, aggregate stability, plant cover, infiltration capacity, organic and chemical content and other soil properties (bulk density, moisture content) – Morgan (2005). Effects of soil erosion are particularly important on agricultural land where it causes the redistribution of soil within a field, the loss of soil from field and the breakdown of soil structure. Another serious consequence of soil erosion is the decline in organic matter and nutrient result in a reduction of soil cultivable depth and a decline of soil fertility. Tillage erosion is the net downslope movement of soil brought about by tillage operations. Soil tillage erosion and the related study of soil particle translocation by working operations and machines during soil tillage belong to the little examined area of soil erosion research (Govers et al., 1999). Based on findings from Ontario, Canada, Lobb et al. (1995) stated that tillage erosion accounts for at least 70% of the total loss of soil on hilltops. There is not a sufficient description of the influence of particular groups of machines and their implements on soil with regard to the translocation of soil particles – it is mainly applicable to secondary soil tillage and sowing. More information is available about the movement of soil particles by operations and machines for primary soil tillage (ploughing with mouldboard ploughs, loosening with chisel ploughs). There is also a lack of data on the translocation of soil particles when the sequences of working operations of soil tillage are applied for cultural practices (Tiessen et al., 2007). The extent of tillage erosion depends on the erosivity of tillage operations and erodibility of the landscape (Lobb et Kachanoski, 1999). Tillage erosion is largely influenced by the design of a tillage implement (type of equipment, the geometry and arrangement of the cutting tools) and how the tillage is operated – frequency of tillage operations, tillage speed and depth, the behavior of the operator (Li et al., 2007). Tiessen et al. (2007) concluded that the erosivity of a pneumatic seed drill was comparable with the erosivity of a cultivator during primary soil tillage if the sowing was performed shortly after seedbed preparation.

To measure the translocation of soil particles during soil tillage is not easy. Logsdon (2013) presented an overview of tracers that were incorporated into the soil by some authors in order to indicate the topsoil translocation during soil tillage (Al cubes, dyed limestone, steel nuts, Cs^{137}).

The objective for the study was to evaluate the displacement of soil particles in the primary tillage with the use of three machines: disc tiller, tine cultivator and mouldboard plough. White limestone grit was used to indicate the soil particles translocation.

MATERIALS AND METHODS

The translocation of soil particles was measured in June 2015 after harvest of common oat in the green ripeness phase. Basic data on a field where measurements were done: the locality Nesperska Lhota near Vlasim, altitude of 420 m a.s.l., sandy loamy Cambisol. The soil on the plot is shallow, slightly stony. The field was after harvest of common oat (*Avena sativa*) for green forage. Before the translocation of soil particles started to be measured, soil samples (5 pieces at each depth) were taken to determine the basic physical properties of soil at a depth of its tillage. Soil physical properties have been evaluated employing Kopecky's cylinders with volume 100 cm^3 and subsequently analysed in the laboratories of the CULS Prague. Soil moisture content was measured with a ThetaProbe sensor (Delta Devices, UK). A digital clinometer (BMI, Germany) was used to measure the angle of slope of a part of the field where measurements were performed. The average slope of area is 2.7°. The content of particles < 0.01 mm: 29% weight. Soil moisture in the soil tillage depth: 10.7% vol. Soil bulk density and porosity before tillage is given in Table 1. The table shows the average values. Colected samples are showing a high content of macropores in the soil. Macropores are evident even at a depth from 0.15 to 0.20 m. It cannot therefore demonstrate the influence of oat plants to physical properties of soil.

Table 1. Soil bulk density before tillage

Depth (m)	Bulk density (g cm^{-3})	Porosity (%)
0.05–0.10	1.49	43.8
0.10–0.15	1.52	43.3
0.15–0.20	1.51	43.2

For tillage passes the chosen direction was 'downslope orientation'. The machines that were chosen to measure the translocation of soil particles in the operations of primary soil tillage:

Akpil X 3.0 disc tiller of working width 3 m, Ross Kon-375 tine cultivator of working width 3.5 m and Ross PH-1-535 five-share plough of working width 1.75 m.

To indicate the translocation of soil particles white limestone grit (particle size 10–16 mm) was used. Grits were incorporated into grooves 0.20 m in width and 1 m in length. The longer side of the grooves was oriented perpendicularly to the direction of subsequent passes of tillage machines. The groove depth was chosen to match the working depth of tools of tillage machines. Soil tillage depth: disc tiller – 0.08–0.10 m, tine cultivator – 0.15 m, mouldboard plough – 0.20 m. The travel speed of machines in the field was chosen according to the manufacturers' recommendations: disc tiller 10 km.h^{-1}, tine cultivator 5.5 km h^{-1}, mouldboard plough 4.5 km h^{-1}.

After the tractor with a respective implement passed across the field, the tracers were picked by hand from the soil in segments of 0.30 m (tine cultivator, mouldboard plough) or 0.15 m (disc tiller), in the direction of machine movement. After the machines passed across the field, the segments were divided into three segments of 0.33 m also in a crosswise direction. By weighing the tracers their weight was determined in each segment as an indicator of soil particle translocation by soil tillage. Data were processed by the programmes MS Excel (Microsoft Corp., USA) and Statistica 12 (Statsoft Inc., USA). From the statistical methods regression and the average evaluation were used.

RESULTS AND DISCUSSION

The first evaluated machine was an Akpil disc tiller of the working width 3 m. The machine had a conventional 'X'-shaped design with discs on a common shaft with working tools. A groove of 0.12 cm in depth was made and it contained 25 kg of crushed limestone. Subsequently, the tractor with the disc tiller passed the groove while the groove centre was in the middle of the working width of the machine.

After the tillage operation the segment was divided by 0.15 m. In a crosswise direction the groove width (1 m) was always divided into three segments (of 0.33 m). The evaluation of acquired data shows a noticeable translocation of particles in the direction of the machine movement. Fig. 1 shows the curve representing the average values of translocation in the particular segments. There is a steep fall in the weight of translocated particles at a longer distance from the original location. The relationship of the tracer weight to a distance from the original location can be described by an exponential function. The graph shows that the particles are translocated by the discs of the cultivator only to short distances. The mechanism of the translocation is the movement of soil particles bouncing off from the cultivator discs as a result of the angle of their slant. So the disc geometry influences also the translocation of particles.

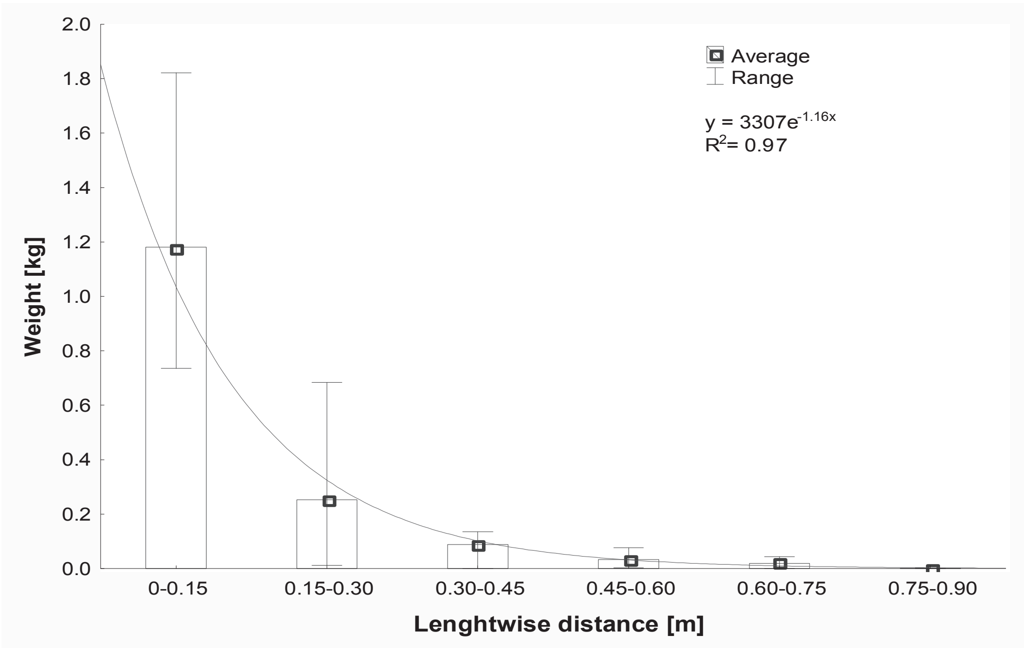

Figure 1. Average values of translocated particles in a lengthwise direction for a disc tiller. Lenghtwise segment: 0.15 m, average values from 3 crosswise segments Interpolation: exponencial function.

Fig. 2 illustrates the translocation of particles in partial segments. Obviously, the highest translocation of particles was measured in the central segment. It is most likely a result of the cultivator design, where the 'X' type design creates a slightly crest profile of the tilled soil after the tillage operations, leading to the more intense translocation.

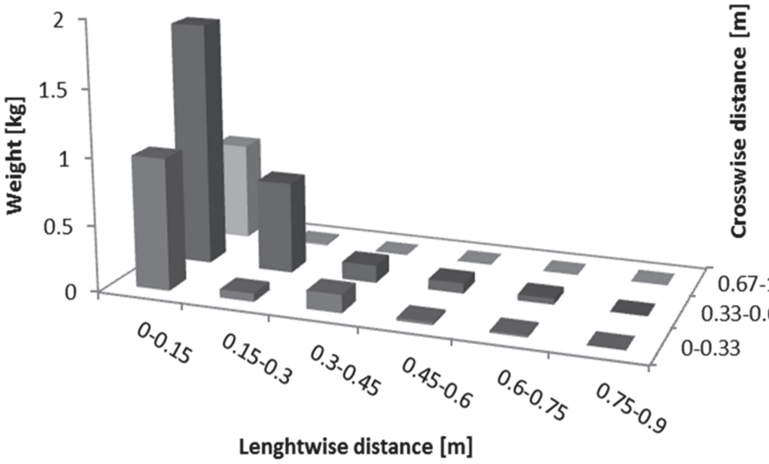

Figure 2. Translocation of particles in the particular segments for a disc tiller. Lenghtwise segment 0.15 m, crosswise segments 0.33 m.

Further measurements were done after the soil tillage operation with a Ross tine cultivator of the working width 3.5 m. Fig. 3 shows a relation of the weight of translocated tracers to a distance from the original location. To express this relation an exponential model of the function was used again. Tracers were translocated to a much longer distance from the original location than in soil tillage with a disc tiller. For the tine cultivator the most distant tracers were found at a distance of more than 1.50 m while after soil tillage with a disc tiller they were at a distance of 0.90 m.

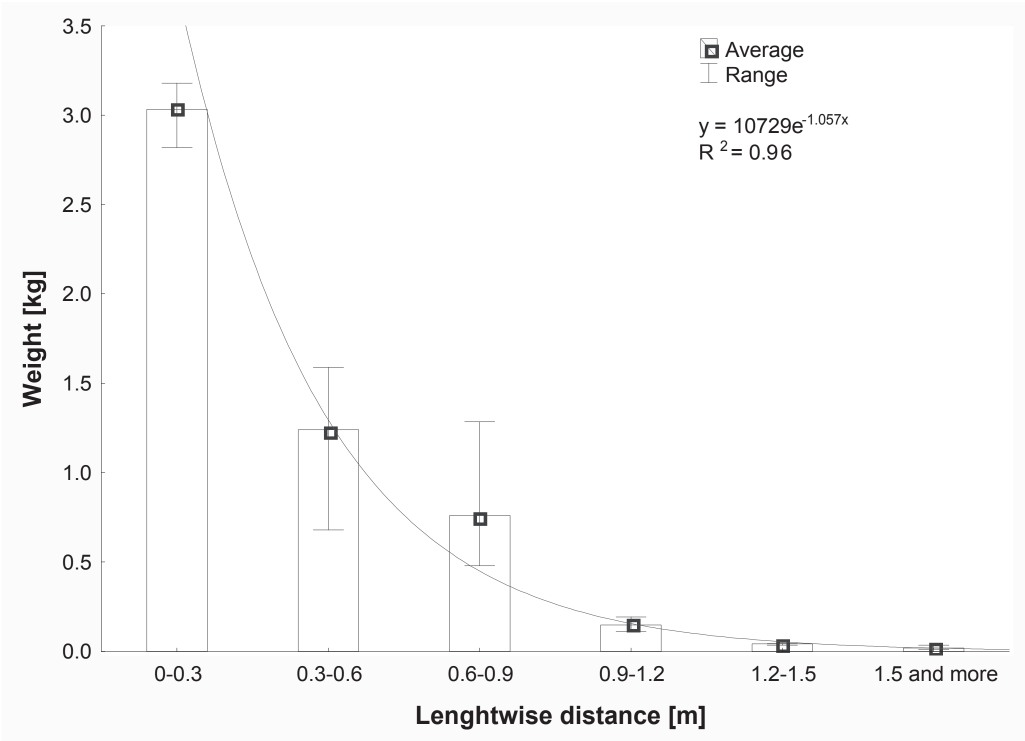

Figure 3. Average values of particle translocation in a lengthwise direction for a tine cultivator. Lenghtwise segment: 0.3 m, average values from 3 crosswise segments. Interpolation: exponencial function.

Fig. 4 illustrates the translocation of particles in the particular segments. After soil tillage with a tine cultivator no greater crosswise translocation of particles was observed. However, among all the evaluated machines, the lengthwise translocation was unambiguously the greatest.

The third machine evaluated with regard to the translocation of soil particles was a Ross five-share plough. The type of particle translocation was completely different from preceding measurements (Fig. 5). The reason is the turning over of a part of the soil profile by the bottoms. The turning over operation causes both the lengthwise and crosswise translocation, which can be seen in Fig. 6. Especially the evaluation of the particular segments (Fig. 6) reveals a crosswise translocation, when all tracers from a part of the groove were displaced both in lengthwise and crosswise direction from the original location.

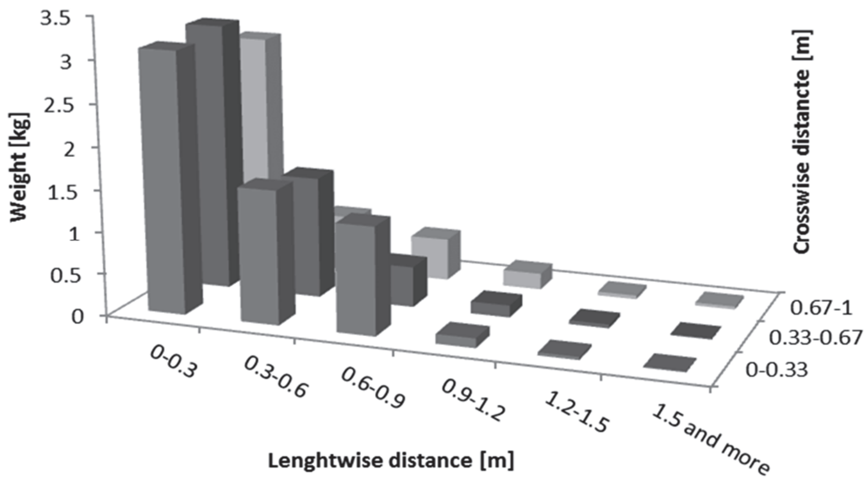

Figure 4. Particle translocation in the particular segments for a tine cultivator. Lenghtwise segment 0.3 m, crosswise segments 0.33 m.

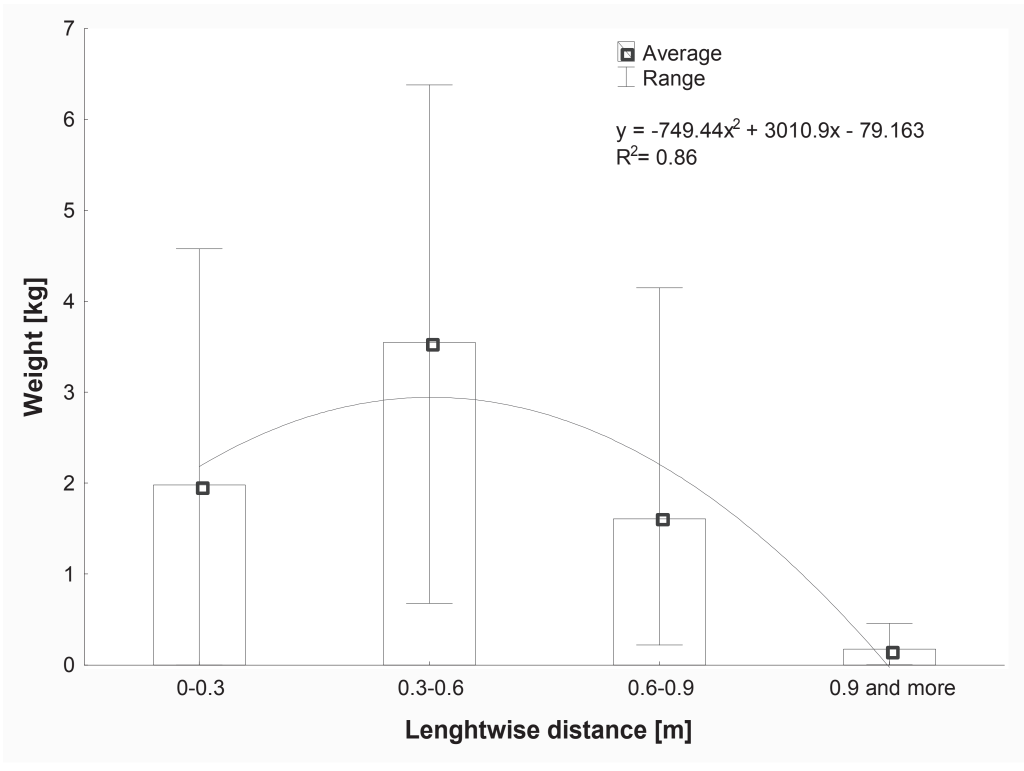

Figure 5. Average values of particle translocation in a lengthwise direction for a mouldboard plough. Lenghtwise segment: 0.3 m, average values from 3 crosswise segments. Interpolation: quadratic function.

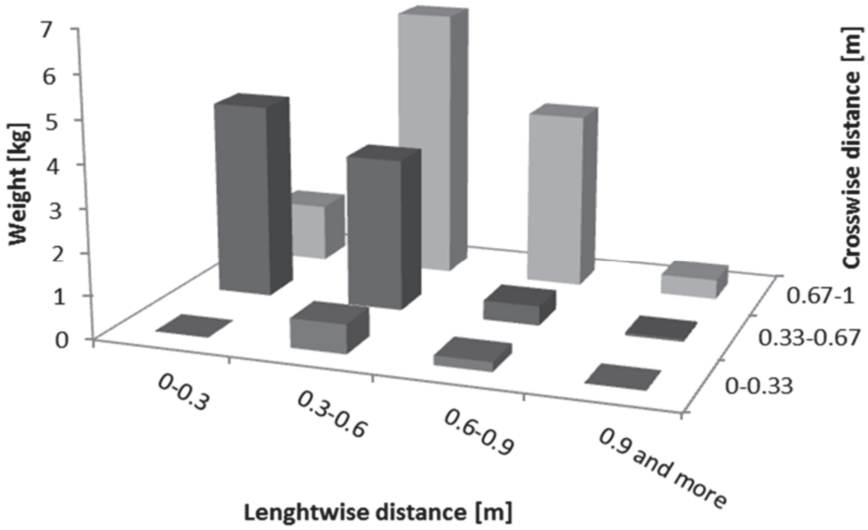

Figure 6. Translocation of particles in the particular segments for a mouldboard plough Lenghtwise segment 0.3 m, crosswise segments 0.33 m.

The performed measurements of the translocation of soil particles by three machines during primary soil tillage showed a considerable translocation of particles in the direction of machine movement and in a crosswise direction. It confirmed the conclusions drawn by Tiessen et al. (2007) about great differences in the translocation of soil particles during soil tillage by machines with different design of working tools. Van Muysen et al. (2006) found out that during a typical tillage including use of multiple of mouldboard plough, chisel tiller and disc tiller the average translocation rates ranged between 0 and 0.9 m. During our research the particles were displaced in this range of distance after tillage by time cultivator and mouldbroad plough. Disc tiller displaced the soil particles into smaller distance (into 0.3–0.45 m). The presented results are consistent with the conclusions of Tiessen et al. (2007) about the crucial influence of the type of working tools acting on the soil, their geometry and adjustment of machines. It is to emphasize the importance of tillage speed and depth and soil tillage frequency. Logsdon (2013) reported the lengthwise translocation of tracers placed on the soil surface to a distance of 2–3 m for soil tillage with a chisel plough – in our measurement the most distant particles at primary soil tillage were found out at a distance of 2.25 m from the location of their incorporation into soil. The 'down slope orientation' direction was chosen for driving the machines.

However, it is actual to evaluate the displacement of soil particles during repeated work operations in the choice of different driving direction (Van Muysen, 2006). It is also necessary to focus on tillage erosion during the secondary tillage and seeding (Li et al., 2007).

CONCLUSIONS

The results of measuring the translocation of soil particles document the fact that has been neglected until now: soil tillage may translocate soil particles to a different extent both in the direction of the machine movement and in a crosswise direction. The choice of machines for soil tillage can substantially influence the intensity of undesirable soil translocation especially in sloping fields. At the same time it is necessary to conduct research on the translocation of soil particles not only by single implements for soil tillage but also by sequences of implements when the particular operations of soil tillage and sowing succeed each other. Furthermore, the intense development in technology and machinery for soil tillage continues. It is therefore current to evaluate the effect on the translocation of soil particles in unconventional tillage. An example is strip tillage.

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