Agronomy Research **16**(4), 1607–1613, 2018
https://doi.org/10.15159/AR.18.150

Effect of PTO- driven tillage machines on soil particles transfer

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Abstract. Displacement of soil particles by erosion can be seen as a major threat to the quality of agricultural land in the conditions of Czech Republic. While the effects of water and wind erosion have long been investigated and reported, the effect of soil tillage technology on soil particles translocation are relatively new area of agriculture research. Soil tillage may contribute to the undesirable translocation of soil particles towards lower-lying parts of fields especially on slopes. The effect of soil tillage implements on soil particle translocation has not been sufficiently explained yet. The object of this research was to assess the influence of PTO (power takeoff)-driven tillage machines on soil particle translocation during secondary tillage (soil preparation). Measurements to determine the displacement of soil particles were performed in location Nesperská Lhota in the Central Bohemia Region. Measurements were performed on a sandy loam cambisol after harvest winter cereals (winter wheat). To indicate displacement of soil particles was used grit of white limestone (size 10–16 mm). Limestone was put down into the trench with known position orthogonal to the direction of working operations. Subsequently were performed working operations in the specified sequence. Limestone particles were counted and weighed in each section. It was detected by measuring the different nature of displacement for each machine. Statistical significance of differences in the weight of translocated particles was evaluated for different type of machines.

Key words: tillage erosion, soil tillage, seedbed preparation.

INTRODUCTION

Tillage erosion is presently regarded as a serious phenomenon that contributes to the degradation of soil fertility (Govers et al., 1999; Logsdon, 2013). In some areas, tillage erosion can be a greater risk than water erosion. Van Oost et al. (2006) report that about half of the arable land in Canada is damaged by tillage soil erosion (soil translocation more than 6 Mg ha^{-1} yr^{-1}), while only 15% of arable land is damaged by water erosion. Due to repeated soil tillage operations, soil particles gradually move in downslope direction. Soil particles are removed from areas where slope is increasing (convex) to areas where slope is decreasing – concave (Papiernik, 2009). Machines for soil tillage are characterized by different intensity on the soil and their undesirable displacement. The literature gives as more aggressive and potentially erosive effects of mouldboard ploughs and chisel tillers. Van Muysen & Govers (2002), Van Muysen et al. (2006) and Li et al. (2007) reported that in general there was considerably more information about the effects of primary soil tillage on soil particle translocation than in secondary soil tillage. Soil tillage machines are characterized by varying intensity on the soil and their undesirable displacement.

Serious displacement of soil particles can also be caused by secondary soil tillage. Tiessen et al. (2007) found that secondary tillage can be equally as erosive as conventional primary tillage with use the mouldboard plough. The authors emphasize the importance of tillage speed and depth. Soil damage is increasing when the secondary soil tillage is repeated during the seedbed preparation.

Displacement of soil particles by machines with active powered working tools has been relatively little studied. Van Muysen & Govers (2002) investigated the displacement of soil particles using rotary harrow and seeder combination. The relativery high value of transport coefficient *k* was rather surprising (123 kg m^{-1} per tillage operation). Tillage depth is relatively low for cultivation with the harrow-seeder combination. Tillage at shallow depth of an unconsolidated soil causes not only large displacement of soil particles, but high variation in displacement distances of soil particles too. The analysis indicates that powered tools move quantities of soil particles, resulting in tillage erosion.

MATERIALS AND METHODS

An experiment was established at the location of Nesperská Lhota in Central Bohemia for the purpose of assessment of soil particles translocation. The experiment was focused on measurement of the influence of PTO- driven tillage machines on the translocation of soil particles during seedbed preparation (secondary soil tillage). On the experimental field was sandy-loam cambisol.

At the beginning of August 2017 winter wheat was harvested (yield 5.8 t ha^{-1}) and the straw was crushed. Subsequently, the field was cultivated by a disc harrow. After emergence of shattered seeds, the field was ploughed to a depth of 0.22 m paralleled to the contours at the beginning of September. After the soil subsided, measurements were carried out during the second half of September. Firstly, soil tillage was conducted by a levelling bars and harrow. Three grooves (each for one machine tested) were then created (see Fig. 1).

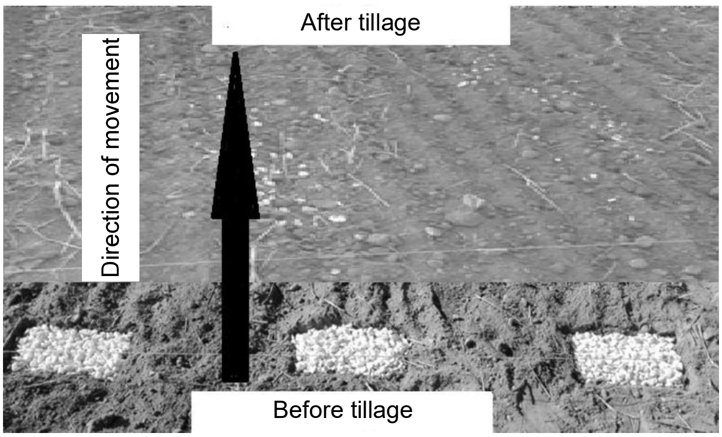

Figure 1. Experimental scheme.

Topsoil displacement of limestone grit with the fraction size of 12–16 mm was the indicator. Grits were placed into 3 created grooves of 0.33 m in length, 0.10 m in depth (soil tillage depth) and 0.20 m in width. The longer side of all grooves was perpendicular to the direction of the all machines movement. After the grooves had been created and filled with limestone grit, the measured place was passed through by individually machines for secondary soil tillage.

The machines that were chosen to measure the translocation of soil particles in the operations of secondary soil tillage:Vitkovice H 180 rotary cultivator of working width 1.8 m, Amazone Re Vario 401 oscillating harrows of working width 4 m and Rabe Werk 250 power harrows of working width 2.5 m. Working speeds were chosen according to typical speeds for a given machine design: 4 km h^{-1} (rotary cultivator), 6.5 km h^{-1} (oscillating harrows), 6.5 km h^{-1} (power harrows).

Individual grits (tracers) were picked by hand in 0.3 m sections. In a crosswise direction each section was divided into 3 parts (3 grooves in one line- 3 repeats). All grits from the given section were weighed. Kopecky cylinders with the volume of 100 cm^3 were taken to determine the basic physical properties of soil. Soil moisture was measured with a Theta Probe sensor (Delta Devices) in a layer of tilled soil. Data were processed using the programmes MS Excel (Microsoft Corp., USA) and Statistica 12 (Statsoft Inc., USA). It was used descriptive statistics and anova.

Table 1 shows the basic physical soil properties. The values of reduced bulk density and porosity are typical for soil kind in the experimental field. The values of porosity indicate a higher content of macro pores, which is a result of recent soil tillage (ploughing).

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Table 1. Soil bulk density and total porosity before secondary tillage

Depth, m	Bulk density, g cm^{-3}	Porosity, % vol.
0.05–0.10	1.34	47.2
0.10–0.15	1.37	46.1

RESULTS AND DISCUSSION

The first evaluated machine was an Amazone oscillating harrows of the working width 4 m. The machine had a conventional 2 rows design. A groove of 0.10 m in depth was made and it contained crushed limestone. Subsequently, the tractor with the harrows passed the groove while the groove centre was in the middle of the working width of the machine. 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 (per 0.3 m). 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 a power function. The graph shows that the particles are translocated by the spikes of the harrows to short and middle distances. The most distant tracers were found out at a distance of more than 4.50 m. Novák & Hůla (2017a) found power functions for moving the particles during secondary tillage. In their research they used combinator to secondary soil tillage on a slope. They found a very strong relationship.

Further measurements were done after the soil tillage operation with a power harrows cultivator of the working width 2.5 m. Fig. 2 shows a relation of the weight of translocated tracers to a distance from the original location. To express this relation a power model of the function was used again. For this machine the most distant tracers were found at a distance 5.27 m. The weight of displaced particles again drops rapidly with the distance from the original site Character of the movement can also be affected by plant residues in the subsurface layer of soil.

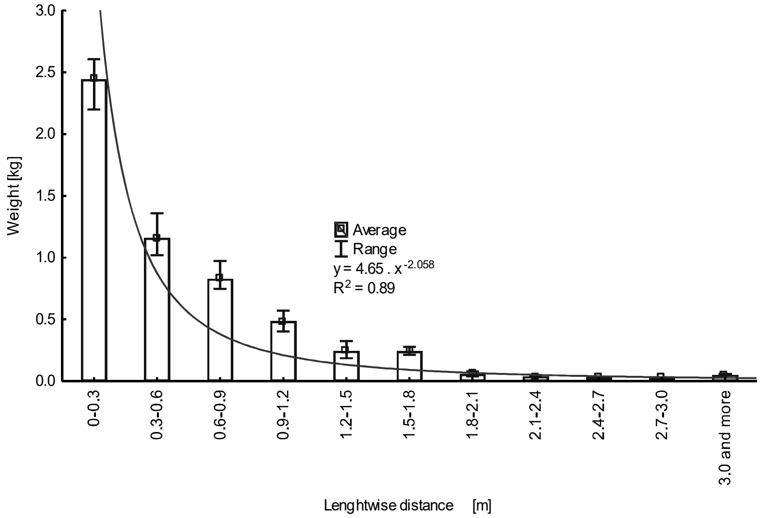

Figure 2. Translocation of tracers – oscillating harrows.

Table 2 contains a comparison of both machines. For comparison, the Tukey HSD test was used at a significance level of 0.05. The table shows average values, homogeneous groups are indexed. It can be seen from the table that in most sections a statistically significant difference was recorded. It is true that the oscillating harrows have less effect on the longitudinal movement of the particles than the power harrows. This is due to the smaller effect of working tools. Comparison took place at the same work speed, depth and soil conditions.

The third machine evaluated with regard to the translocation of soil particles was a Vitkovice rotary cultivator (see Fig. 4). The type of particle translocation

Table 2. Average translocation of particles (g) with a power harrows in a lengthwise direction and marked out homogeneous groups (Tukey's HSD test)

Distance, m	Power harrows	Oscillating harrows
0–0.3	3.24^a	2.48^b
0.3–0.6	0.95^a	1.19^a
0.6–0.9	0.49^a	0.88^b
0.9–1.2	0.95^a	0.51^b
1.2–1.5	0.89^a	0.32^b
1.5–1.8	0.46^a	0.33^a
1.8–2.1	0.41^a	0.11^b
2.1–2.4	0.23^a	0.09^b
2.4–2.7	0.19^a	0.08^b
2.7–3.0	0.16^a	0.06^b
3.0 and more	0.24^a	0.03^b

Homogeneous groups are marked by letters a, b.

was completely different from preceding measurements (Fig. 3). The reason is the turning of working tools. The rotating knives throw the parts of the soil backwards. The displacement of the particles is thus not deducted in the direction of movement but against it. Rotary cultivators are the only soil cultivation machines with this ability. The particle translocation can be successfully described by the quadratic function. The quadratic function was used by the Hůla et al. (2015) to describe the movement of soil particles when using the plow for primary soil cultivation. Character of the movement was in this case due to the reversal of the soil layer by the plow working tools. In this case, it is caused by throwing the particles through the rotor of the machine. Particles most likely hit the machine cover and then down to the ground. This is the most probable distance of about 0.6 m. Less particles then remain in their original location, or they reach a greater distance.

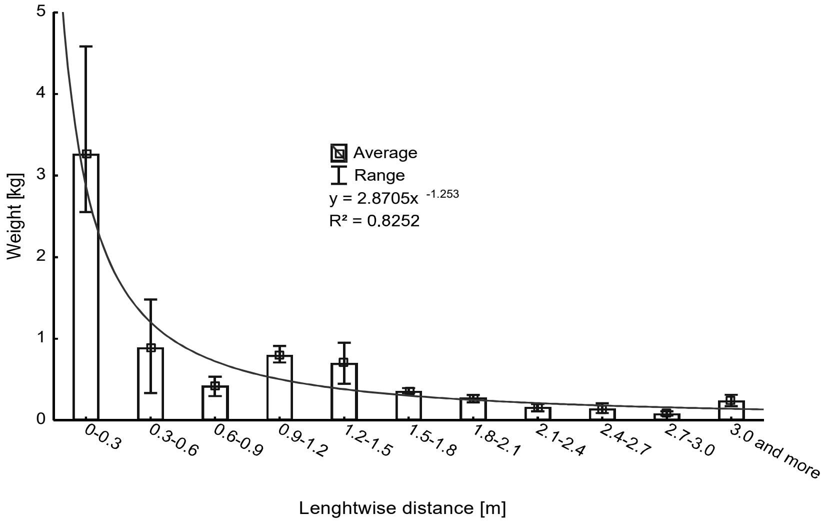

Figure 3. Translocation of tracers – power harrows.

The results of the measurement of soil particles displacement by machines with powered working tools confirmed the findings of other authors partly. Novák & Hůla (2017b) found a significant displacement during repeated secondary soil tillage. They also confirmed the conclusions of their earlier study (Hůla & Novák, 2016) .Rotary harrow and driven oscillating harrow moved the soil particles in the driving direction similar to the pre-sowing machines with non-powered working tools. These results are basically consistent with findings reported by Van Muysen & Govers (2002). Also, the results of Tiessen et al. (2007) were confirmed: secondary tillage implements can be equally as erosive as conventional primary tillage implements, for example mouldboard plough. A totally different character of the soil particles displacement was found when working with the horizontal rotary blade tiller. Translocation of soil particles was in a direction opposite to the machine movement direction. It can be a positive effect in driving in downslope direction. However, it is not possible to assume the use of the horizontal rotary blade tiller as a corrective measure on soils with symptoms of tillage erosion.

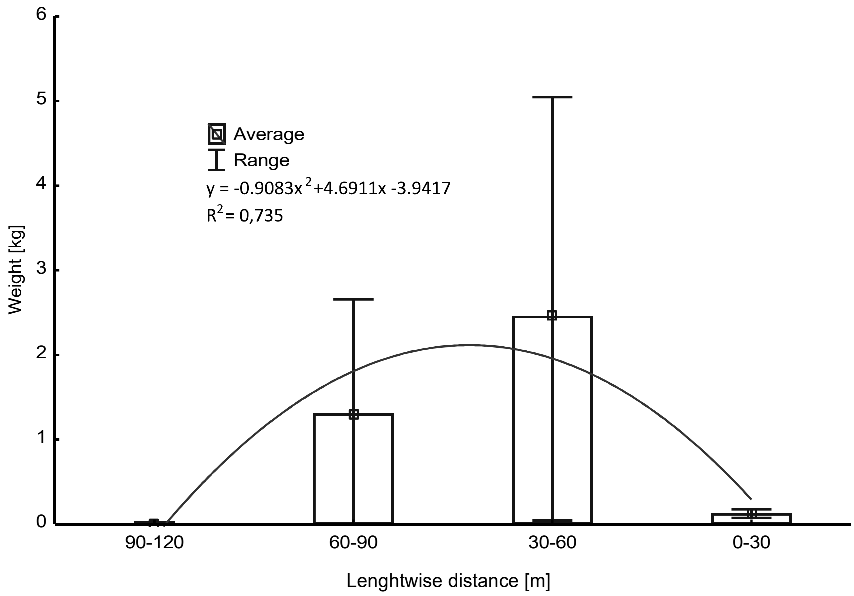

Figure 4. Translocation of tracers –rotary cultivator.

Overall, it is possible to agree with Van Muysen & Govers (2002) conclusions: powered tools move quantities of soil material. Therefore it is necessary to obtain further results of research on the erosivity of powered tools.

In practise, powered harrows and oscillating harrows are in combination with seeder machines, which further increases the erosive effect of these machines sets.

CONCLUSIONS

The results of measuring the translocation of soil particles document the fact that soil tillage may translocate soil particles to a different extent both in the direction of the machine movement and in a crosswise direction. Tillage erosion can thus contribute to soil erosion as well as water or wind. The selection of machines (not only PTO driven) for soil tillage can substantially influence the intensity of soil translocation. The results of the experiment demonstrate the significant effect of PTO driven machinery on the translocation of soil particles. It was recorded entirely different character of translocations when using a rotary cultivator. For two other tested machines, the character of the soil particles translocation was similar.

ACKNOWLEDGEMENTS. Supported by the Ministry of Agriculture of the Czech Republic – Project No. QJ1520028 and by the Czech University of Life Sciences Prague, Project No. IGA 31160/1312/3117.

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