INFLUENCE OF DISC CULTIVATOR DESIGN ON SOIL PARTICLE DISPLACEMENT

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Abstract. The aim of this research is to assess the influence of the design of disc cultivators on the displacement of soil particles. A disc cultivator with X-shaped rows of working tools and a disc cultivator with parallel rows of working tools are evaluated. Both of these machines are evaluated when working at three different slope levels of 2º,6º,11º. The method used for detection of particle displacement was a modification of the tracer method. Tracers used for this experiment were aluminium cubes with an edge length of 16 mm. Forty cubes were used for one measurement, they were placed in two layers, with the cubes placed perpendicular to the soil processing direction at intervals of 0.1 m. Their original position is therefore precisely known for the subsequent determination of their displacement in both axes. The measured data were processed and evaluated in terms of the displacement of soil particles in the longitudinal and transverse direction perpendicular to the soil processing and the size of the vector angle. The vector then determines the size and direction in which the tracer was displaced. When comparing the values of the vector angles, it is evident that when using a cultivator with an X-shaped disc row design, higher average values were achieved for 4 of the 6 measurements than with a cultivator with parallel disc rows. The effect of the design on the average length of the vectors is not clear, as the design with X-shaped disc rows achieves higher values in the topsoil when comparing the average displacement length. In contrast, the average vector length values measured in the subsurface layer are higher, with the design with parallel rows of disc tools achieving higher average values.

Keywords: tillage, erosion, tracers, working tools.

Introduction

Soil is currently an irreplaceable and very valuable resource for us, there are approximately 4.2 million hectares of agricultural land in the Czech Republic and over 1.6 million of hectares are endangered by water erosion. Research on tillage erosion has been underdeveloped and not given much attention in the past. However, according to [1], the impact of this type of erosion on agricultural land degradation is in most cases equal, if not higher, compared to that of water erosion.

For this type of erosion, soil particles are moved by agrotechnical operations. The most influential are tillage operations. They actively cause erosion, transporting particles in both horizontal and vertical directions, and we describe erosion primarily as transport in the horizontal direction, but unlike other types of erosion, this type is always confined to a specific parcel of land. It then modifies land attributes (soil texture, vegetation cover, soil moisture) through passive influence, resulting in greater vulnerability to other types of erosion [2; 3].

There are several parameters affecting tillage erosion. The first is the speed of tillage, which has been studied by [5] and shown that as the speed increases, the displacement of soil particles increases. In the same publication and by analogy, it is confirmed that soil particle displacement increases with deeper soil tillage. From the point of view of soil properties, it appears to be important whether the soil is primarily cultivated or whether it is already undergoing secondary cultivation, in which case the soil particles are more transported.

However, by far the greatest influence on tillage erosion is by the topography, the shape of the land and especially the direction of tillage. As many studies, such as [6-8], point out certain patterns, showing that soil particles are displaced further when working the soil in the downslope direction than in the upslope direction. However, a similar phenomenon can be observed in contour tillage, where soil particles are carried further down the slope by gravity.

The objective of this study is to compare the influence of a disk cultivator with X-shaped rows of working tools and a disc cultivator with parallel rows type construction on soil displacement working in different levels of slope.

Materials and methods

The experiments took place in the area of Nesperská Lhota near Vlašim. The land is located at an average altitude of 462 m above the sea level and its average slope is 7.85º, the type of soil on the location is sandy loam Cambisol. Before the experiment, winter wheat was grown on the parcel, which was harvested, and the plant residues were crushed and spread on the parcel. For the experiment, areas with the required slopes (2º, 6º, 11º) were found on the parcel, marked and prepared for measurement. Afterwards, the soil in the identified areas was cultivated with the given types of machines. Soil properties were determined by taking unaffected soil samples using the Kopecky cylinder method, the values of which are shown in Table 1.

Table 1

Soil properties

Property	Unit	Average of 10 samples
Weight	g	296.69
Initial moisture content	% Vol.	20.81
Dry weight	g	142.21
Bulk density	$g \cdot cm^{-3}$	1.42
Total porosity	% Vol.	46.33
Capillary porosity	% Vol	21.33
Non-capillary porosity	% Vol	10.38

A modification of the tracer method was used to detect the soil particle displacement. These were aluminium cubes with an edge length of 16 mm used for this experiment. The reason for choosing aluminium as a material was that its density is similar to mineral particles in the soil and so it approximates their behaviour as closely as possible. Forty cubes were used for a single measurement, they were placed in two layers, with the cubes placed perpendicular to the soil processing direction at 0.1 m intervals, Figure 1. Their original position for the subsequent determination of their displacement in both axes is therefore precisely known. The first layer of tracers was placed at a depth of 0.05 m and the second at the surface.

Fig. 1. **Placement of tracers in the soil**

The following phase of the experiment was the soil tillage together with the tracers, during which they were displaced together with the soil particles. The position of each tracer was then located, the first to record the lateral and longitudinal positions of those lying visibly on the surface. The M6 metal detector from Whites Devices was used to locate the cubes lying below the surface, and the approximate position of the tracer was found using this detector. However, further specification of the position required careful manual removal of the soil to prevent further displacement of the cube before the displacement values were noted. Once the values were found and noted, a vector angle was determined to indicate in which direction and by what distance the tracer was displaced.

The experiment was done in three variations for each machine tested (disc cultivator with X-shaped placement of disc rows and disc cultivator with parallel placement of disc rows), with the variations varying in the size of the slope of the plot. The slope levels were measured using a digital inclinometer from BMI Germany and the values were 2º, 6º and 11º.These levels were chosen because the average slope of arable land in Czech Republic is 6.3° [9] and the remaining two were selected as the closest multiples of this average with location with suitable conditions for the experiment.

For the experiment, a Zetor Forterra 130 HSX tractor was used as a pulling vehicle. Two types of disc cultivators were used for tillage. The first was a 3 m Akpil disc cultivator, which uses two rows of 500 mm diameter discs in an X-shaped configuration. The second was a disc cultivator from AGRO-MASZ, also 3 m in width, which uses two rows of parallel discs with a diameter of 460 mm. These cultivators were used because both of them were machines owned by the company farming on the testing field. Both cultivators cultivated the soil to a depth of 0.08 m at a speed of 9 $km \cdot h^{-1}$.

Results and discussion

The measured data were processed and evaluated in terms of the displacement of soil particles in the longitudinal and transverse direction perpendicular to the soil processing and the vector angle. The vector then determines the size and direction (angle plotted from the soil tillage direction and the original position of the tracer) in which the tracer was displaced. Boxplot graphs are constructed as arithmetic mean, standard deviation and 0.95-confidence interval.

It is evident from Figure 2 that with increasing slope there is a significant change in the vector angle, which reaches its highest values at a slope of 11°. This is true for both the measurement of the vector angle of the markers on the surface and those located under the surface. The average values of the angle are the same for the surface at slopes of 2° and 6°, namely 9.97°. For a slope of 11°, the angle value reached the highest average, namely 36.28°. The values of the angles measured for the tracers located under the surface are then 15.26° for a slope of 2°, 18.29° for a slope of 6° and 24.4° for a slope of 11°.

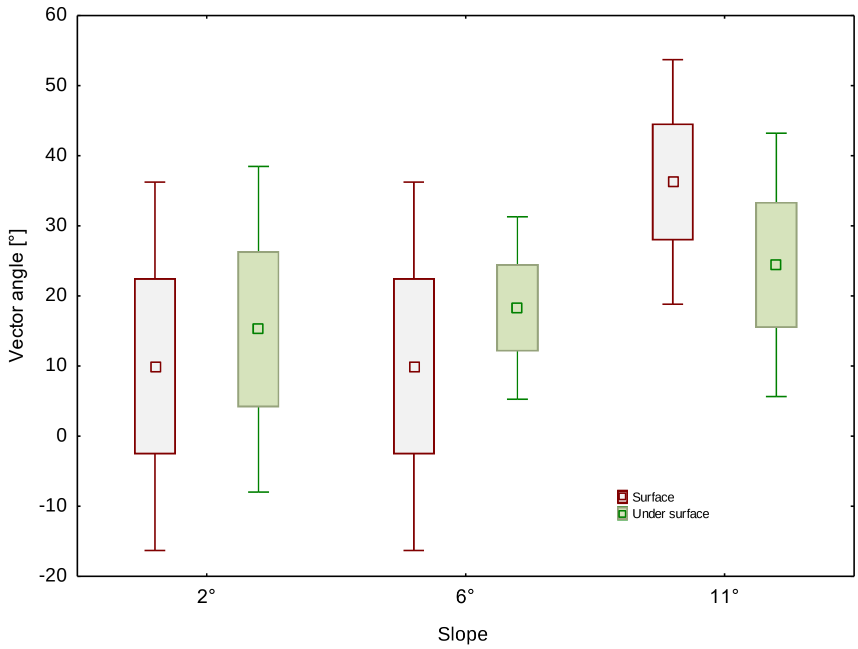

Fig. 2. **Dependence of the vector angle on slope for a disc cultivator with parallel rows**

From Figure 3, it is evident that the length of the vector increases as a function of the slope of the land. Similar to Figure 2, the surface tracer values for slopes of 2° and 6° are the same with an average length of 0.22 m. The remaining vector length for the surface values is the highest within this graph, reaching an average value of 0.36 m. The average length of the subsurface tracer displacement at 2° slope reached the lowest average value within this graph, specifically a value of 0.11 m. Higher average values were achieved by the subsurface tracer measurements at 6° slope, with a value of 0.29 m, and at 11° slope, with a value of 0.32 m.

According to Figure 4, it is clear that the highest average vector angle values were obtained by both measurements at a slope of 6° (surface 35.86° and under surface 30.75°), but if we take into account the variance, we obtain higher values measured at a slope of 11°. The lowest average values are found for the subsurface tracers at a slope of 2°, when the value reaches 6.52°. The surface tracers have a higher value at a slope of 2º, which reaches 22.56º. According to these values, no trend can be accurately predicted for the dependence of the vector angle on the slope, or no mechanics are known to explain it.

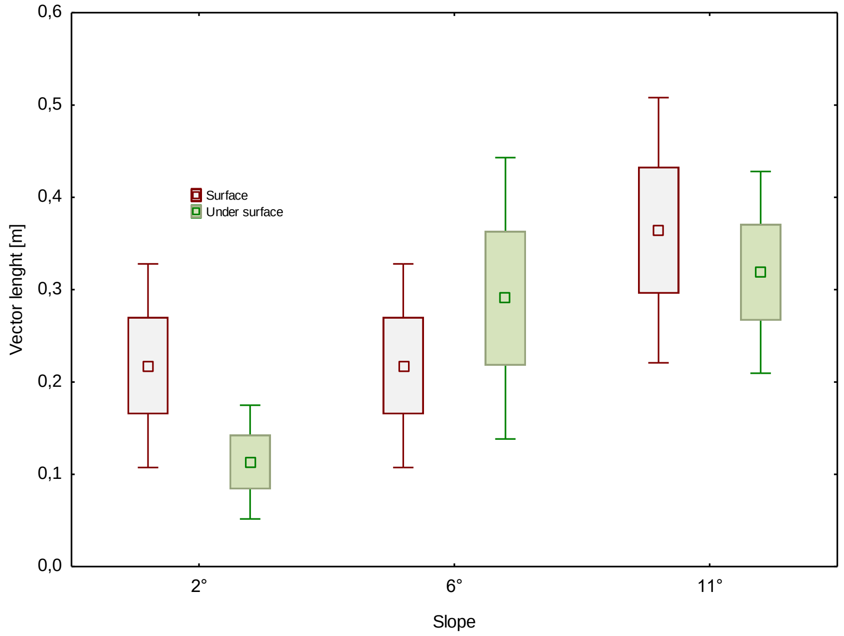

Fig. 3. **Dependence of the vector length on slope for a disc cultivator with parallel rows**

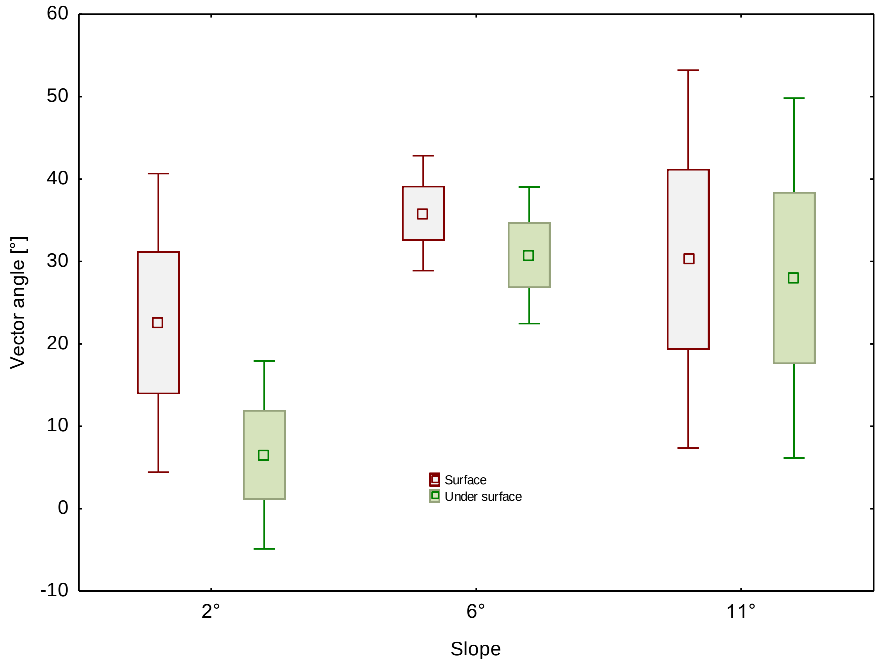

Fig. 4. **Dependence of the vector angle on slope for a disc cultivator with X-shaped rows**

From Figure 5, it is evident that the highest values of the vector length are achieved by the measurements at a slope of 6º, specifically the tracers located under the surface had an average value of 0.39 m and the tracers located on the surface had an average value of 0.36 m. The remaining measurements for the surface variant are very similar in terms of average values, namely 0.28 m for a slope of 2º and 0.29 m for a slope of 11º. A similar but not so narrow difference is for the similar results for the subsurface variant, with average results of 0.15 m for the 2º slope and 0.18 m for the 11º slope.

The measurements related to disc cultivators are largely consistent with the results of [10] confirming the effects of cultivator designs on soil particle displacement. Some differences can be found when comparing with the work of [11], which claims that soil particle displacement after soil processing with disc cultivators reaches values in the range of 0-0.9 m, but the furthest particles can be found at distances of up to 10 m. The upper limit of this interval was not reached, as the maximum value in this case was 0.6 m.

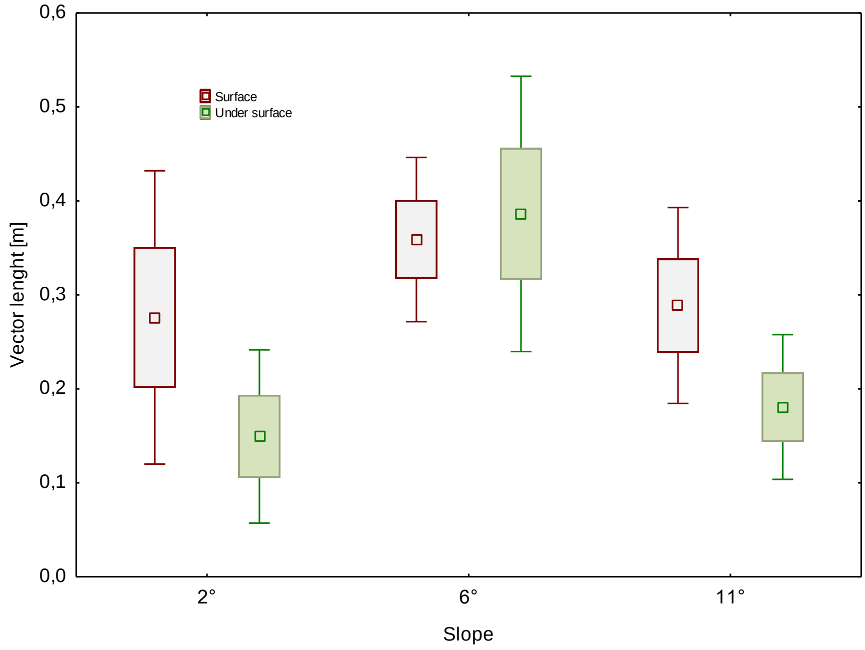

Fig. 5. **Dependence of the vector angle on slope for a disc cultivator with X-shaped rows**

The effect of slope on soil particle displacement has also been evaluated by [3; 12] in their study, which is in agreement with this work, [13] even claim in their study that slope is the main parameter affecting soil erosion by tillage and is demonstrable for all types of tillage. However, they also argue that upslope tillage cannot be seen as a corrective action to downslope tillage.

The results of individual works and research may vary to some extent depending on the method of measurement used and the use of different types of tracers, especially their size and the material from which they are formed. A similar claim has been made in the work [14]. However, the opposite claim that neither the material nor the size of tracers has a significant effect on the measurement results, has been expressed in the work [15]. In the case of this work, aluminium tracers in the form of cubes were used because aluminium is closest in density to mineral particles in the soil. The same material was also used by [11] in their work.

Conclusions

The measurements proved the influence of the construction of disc cultivators on the soil particle displacement. When comparing the vector angle values measured as part of the evaluation of the influence of the disc cultivator design, it is evident that when using a cultivator with an X-shaped disc row design, Figure 4, higher average values were achieved (for 4 out of 6 measurements) than for the cultivator with parallel disc rows, which however achieved the absolute highest average value of 36.28° in the surface layer at a slope of 11°, Figure 2. Despite this value, the phenomenon is most evident when comparing the average values in the surface layer.

The effect of the design on the average length of the vectors, however, is not so clear-cut, since when comparing the lengths on average, they reach larger values in the surface layer of the design with rows of plates in an X-shape, Figure 5. The difference to this, however, is the average vector length values measured in the subsurface layer, with the structure with parallel rows of plates achieving higher values, Figure 3.

The effect of slope on the measured variables is consistent for the plate cultivator with parallel rows of plates, with the premise that as slope increases, so do the values of the measured variables. The difference to this, however, is the values measured after the use of the disc cultivator with an X-shaped design of the disc rows, where the highest average values were obtained with the 6° inclination variant.

Author contributions

The entire author team contributed equally to this research in all its aspects. All authors have read and agreed to the published version of the manuscript.

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