DEEP, SHALLOW AND NO-TILLAGE EFFECTS ON SOIL COMPACTION PARAMETERS

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Abstract. As one of the key physical-mechanical properties of soil, soil compaction is used to assess resistance of the soil to penetration of a solid body. Soil compaction also determines the actual service life of the tillage machine working parts, quality of technological processes, energy consumption and other parameters. It also affects seed incorporation and germination, crop growth and the yield. Technological processes of soil loosening or compaction depend on the intensity of application of tillage machines, working depth and soil properties. This paper aims at determining the effects of deep, shallow and no-tillage technologies on soil compaction parameters of different soil layers. Experimental studies on five different tillage technologies (deep ploughing, shallow ploughing, deep cultivation, shallow cultivation and no-tillage) have been conducted on medium heavy soils at the Experimental Station of Aleksandras Stulginskis University. The studies have shown that in case of prolonged application of the same tillage technologies, no-tillage soils demonstrate the highest degree of soil compaction in the upper layer. Autumn soil tillage by shallow cultivation has the least effect on soil compaction of the upper layer, while the greatest effect on the soil compaction has been demonstrated by deep ploughing. Deeper soil layers have shown increase in soil compaction in case of years-long soil cultivation at the same depth using the same tillage technology.

Keywords: deep tillage, shallow tillage, no-tillage, soil compaction.

Introduction

Soil compaction is a very important indicator for estimation of the quality of the technological process of soil cultivation, seedbed preparation and crop germination conditions, as plants must use their energy reserves at the beginning of growth in order to overcome soil resistance. The more compact the soil, the worse germination and growth of plants and the weaker their root system, which might lead to future decrease in the crop yield [1; 2]. Soil compaction is also an important criterion in design and manufacturing of tillage machines and attachments.

Soil compaction varies depending on the depth. Different technological operations of soil tillage demonstrate different effects on soil compaction of middle and deep layers. Soil compaction of the middle layer only can be altered using conventional tillage methods such as ploughing, disking, and loosening by shallow cultivators. On the other hand, same machines cannot be used to reduce soil compaction of the deeper layers. To the contrary, deep ploughing or disking might even lead to more compact soil of the deeper layers [3].

The more intensive soil tillage, cutting, turning, crumbling and mixing, the less compact the soil is in the cultivated layer. It should be noted, however, that intensive tillage is energy consuming and requires significant labour force and energy resources. Hence, the choice over the soil tillage technologies is a highly important and responsible task. Very intensive soil mixing and loosening does not always result in the expected positive outcomes. The quality of soil tillage depends on the granulometric composition, structure, density, moisture content and other soil properties [4]. Moreover, these soil properties are usually closely interrelated, and changes in one of them are often – either directly or indirectly – accompanied by changes in other properties. Scientists in other countries who have studied the effects of no-tillage technology have determined that resistance of no-tillage soil to penetration of a solid body is not as noticeably proportional to the soil density and its moisture as in soil cultivated using other tillage technologies. They argue that no-tillage technology preserves stable soil pores that have formed under the influence of plant root channels and soil organisms and that contribute to stabilization of the soil structure [5]. Lapen et al. [6] have assessed the effect of the moisture content in soil on the degree of its compaction. The study results have demonstrated inverse relationship between the moisture content and resistance of soil to penetration of a solid body after application of no-tillage technology. A similar study has shown that relationship between the moisture content and soil compaction exists in conventional tillage technologies as well; however, it depends heavily on the crop species and seasonality. Other scientists [7] consider the moisture content in soil to have different effects on the degree of soil compaction in different tillage technologies. Soil compaction is increased primarily by the pressure applied to the soil. The higher the moisture content in soil, the greater the effect of the applied pressure on the degree of soil compaction. Chung et al. [8] have provided scientific evidence that the degree of soil compaction is higher with higher soil density and lower moisture content in soil.

Soil compaction is a very important indicator in assessment of the soil quality and estimation of the crop yield. Studies carried out in the Central Lithuania have demonstrated that soil compaction affects the crop yield directly, whereas soil density and soil air permeability affect the crop yield indirectly, i.e., by affecting soil compaction. The studies have determined that in the case of deep ploughing, shallow ploughing and no-tillage technologies, the highest degree of soil compaction is achieved by no-tillage mode. Feiza et al. [9] have determined that the degree of soil compaction after harvesting was the lowest in deep plough soil, ca. 12-30 % higher in shallow plough soil, and even 52–71% higher in no-tillage soil compared to deep plough soil. Horn [10] argues that, compared to conventional tillage, prolonged application of conservation tillage technologies has positive effect on the physical properties of soil, as soil becomes more resistant to physical impact and deformation. A similar position has been expressed by Veiga et al. [11] who have determined in their studies that no-tillage soil is more resistant to deformation compared to soils cultivated using plough and other tillage machines. Soil compaction measurements with account for tyre tracks left by agricultural machines and structural particle sizes of soil can also be used for identification of the total soil strength profile and assessment of soil structure degradation [12].

Conventional tillage technologies involve multiple technological operations involving multiple passages over the soil. The soil is affected by each passage that increases its compaction. Kroulik et al. [13] have carried out studies on the intensity of soil trafficking by agricultural machines using different tillage technologies. They have determined that the entire soil surface is run over by agricultural machinery tyres at least once using conventional tillage technology for cereals, when liquid organic fertilisers are spread before the main tillage and straw bales are pressed and disposed after cereal harvesting. Considering that the effective width of agricultural machinery tyres on soil is slightly wider than the working width of the tyres, 87.5 to 95.3 % of the entire soil surface is run over in case of conventional tillage. In case of minimum tillage technology, about 72.8 % of soil surface is run over by machinery tyres, and about 55.7 % in case of no-tillage. It should be noted, however, that certain soil areas are run over 2 or more times. Application of different tillage technologies is believed to result in 18.4 to 44.8 % of the entire soil area being run over [13].

Although analysis of soil compaction seems to be rather common, it usually comes in the form of an addition to other analysis and characterises the possible effects on crop yield and its qualitative parameters. There is lack of studies assessing soil compaction in various soil layers in a long-term perspective, when the same tillage is applied to the same area for years.

The aim of this paper is to determine the effects of various deep, shallow and no-tillage effects on soil compaction of different soil layers.

Materials and methods

Experimental studies on the effects of tillage on soil compaction were conducted at meteorological conditions of the Central Lithuania at the Experimental Station of Aleksandras Stulginskis University. The Station has the history of over 20 years of various experimental studies conducted using uniform and consistent tillage systems. Soil – *Endohypogleyic-Eutric Planosols – PLe-gln-w*.

Experimental study on the effects of tillage on soil compaction was carried out in five repetitions using five different tillage technologies (Table 1). The control tillage technology (DP) usually referred to as conventional was chosen to compare the effects of 4 other reduced tillage technologies on soil compaction properties.

Arrangement of the experimental research plots was random. Initial plot area – 126 m^2 (14×9 m), recorded area – 84 m^2 (12×7 m). Soil compaction was measured using the electronic meter of compaction (Penetrologger) by the company "Eijkelkamp". The penetrologger consists of a housing with GPS antenna, screen, control panel, level, impact absorber and other components. The data logger is installed in a water-resistant housing with insulated handles. The penetrologger is powered by rechargeable AA NiMH batteries. Prior to measurements, a cone is screwed onto a probing rod. 4 different cones can be used depending on the degree of soil resistance to penetration. The probing pole is attached to the impact absorber on the bottom of the penetrologger. During measurement, the integral ultrasonic sensor registers the correct depth up to 80 cm using the depth reference plate. The plate is placed on the soil surface with the raised edges pointing downwards. The penetrologger cone is placed vertically into the hole in the plate. It is recommended to maintain the speed of penetration into soil at 2 $cm \cdot s^{-1}$. The penetrologger must be pre-programmed by setting the initial parameters (company, number of plots and penetrations per plot, penetration speed, cone type etc.) via the control panel.

Table 1

Technologies of different tillage systems

Technologies	Tillage operation	Tillage machine	Tillage depth, mm
DP (control)	Deep ploughing	Plough	23-25
SP	Shallow ploughing	Plough	12-15
DC	Deep cultivation	Cultivator	25-27
SC	Shallow cultivation	Disc harrow	12-15
NT	No-tillage	-	-

Soil compaction may be very different in different locations. Hence, measurements must be repeated to obtain an average reliable value. Soil compaction was measured five times. The registered data on resistance of soil to penetration are stored in the data logger of the electronic penetrologger. The soil compaction readings are displayed in MPa. The data stored in the data logger can be uploaded to a computer after connecting the penetrologger to the computer, and then statistically processed by the program ANOVA [14]. The scientists [3; 15] classify the soil according to its degree of compaction into the following groups: highly compact (homogeneous) > 10 MPa, very compact – 5-10 MPa, compact – 3-5 MPa, partly compact – 2-3 MPa, partly loose – 1-2 MPa, loose – <1 MPa.

Results and discussion

The experimental study has shown that the degree of soil compaction reduced significantly during autumn tillage in the upper layer (at the depth of 0-4 cm) using DP and SP as well as DC technologies (Fig. 1). In case of the SC technology, the effect of tillage on soil compaction was less noticeable.

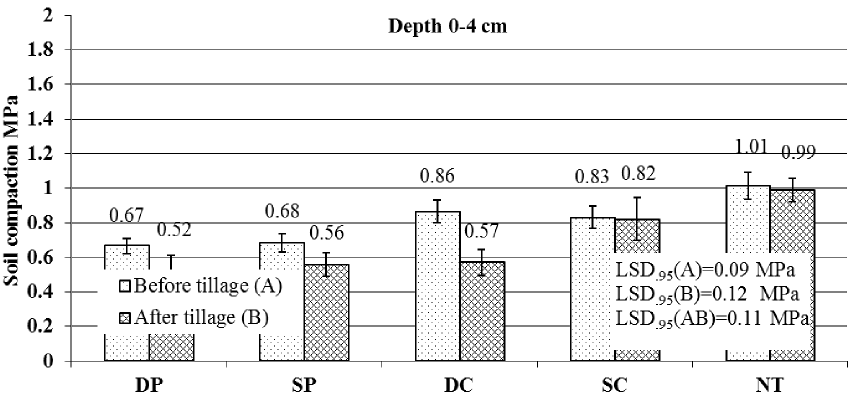

Fig. 1. **Soil compaction (in the depth of 0-4 cm) before and after autumn soil tillage**

Autumn soil tillage at the depth of 5-9 cm led to significant reduction of soil compaction using all tillage technologies, except for shallow loosening. The lowest average soil compaction after autumn tillage was registered in DP soil – about 0.69 MPa. The least significant effect of tillage on soil compaction was registered using the SC technology. Same soil compaction tendencies were determined at the depth of 10-14 cm as well. Prior to autumn tillage, the lowest soil compaction at the depth of 10-14 cm was registered in the case of deep ploughing technology – 1.42 MPa (Fig. 2). Autumn tillage had significant effect on soil compaction using DP, SP and DC technologies, whereas no significant difference was noticed in SC and NT.

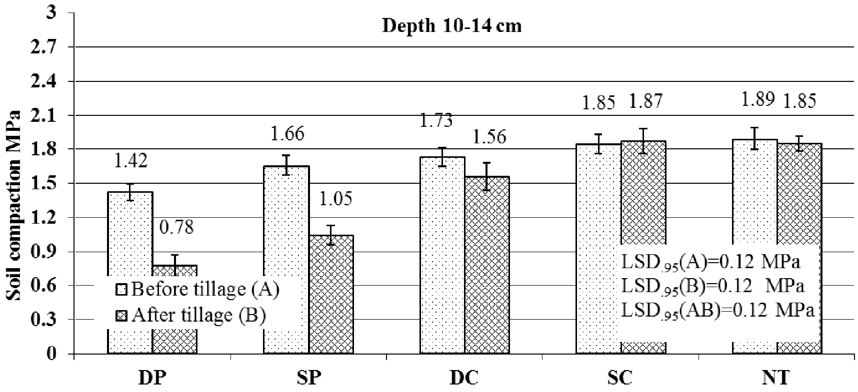

Fig. 2. **Soil compaction (in the depth of 10-14 cm) before and after autumn soil tillage**

In the case of the SC technology, the opposite effect of tillage on soil compaction was noticed at the same depth. Namely, there was significant increase in soil compaction after shallow loosening using a disc harrow compared to soil compaction before autumn tillage. Similar variation in soil compaction, but at different depth, was registered in the cases of SP and DC tillage technologies. Deeper soil layers became more compact after autumn tillage. The evidence has supported other authors' [16] observations that autumn tillage reduces soil compaction at the depth that is subjected to tillage, whereas deeper layers of soil tend to become more compact.

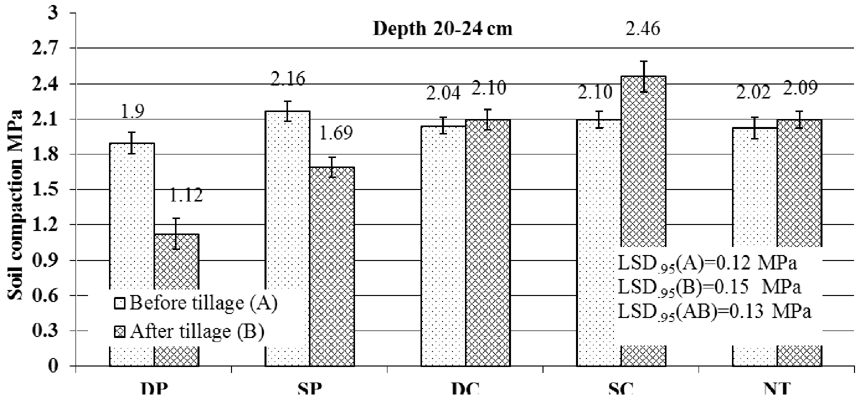

Fig. 3. **Soil compaction (in the depth of 20-24cm) before and after autumn soil tillage**

No significant changes were identified at the depth of 25-29 cm before autumn tillage in the case of all tillage modes (Fig. 4). Autumn tillage using DP and SP technologies led to significant reduction of soil compaction, whereas other tillage technologies led to increase of soil compaction after soil tillage, while significant increase was registered in the SC mode only.

After ploughing at the depth of 30-34 cm during autumn tillage, soil compaction reduced significantly using the DP technology only (Fig. 5). However, the difference in the soil compaction started reducing with each deeper layer of soil. In the case of the SP technology, soil compaction after autumn tillage reached the degree of compaction before tillage (ca. 2.0-2.1 MPa). In the case of other conserving tillage technologies, soil at this depth was more compact after autumn tillage than before tillage. Significant increase in soil compaction was registered in the case of SC and DC technologies.

Compared to the research results published by other authors [17], this study suggests that the obtained soil compaction data in Lithuanian weather conditions are adequate to the results of studies of similar nature in other countries. The degree of NT soil compaction before tillage was noticed to be the highest compared to other tillage modes. Studies have also shown that precipitations in the period between two measurements (measurement before tillage to measurement after tillage) affect NT soil compaction in the upper layer. Such tendency was not registered in SC soil. Even to the contrary, SC soil compaction increased after tillage at the depth of 0.7 to 5.0 cm. Scientists in other countries who have conducted similar studies [7; 18] have also noted that, besides tillage, the moisture content in soil also has strong influence on soil compaction. Hence, less intensive tillage may produce very different results of soil compaction.

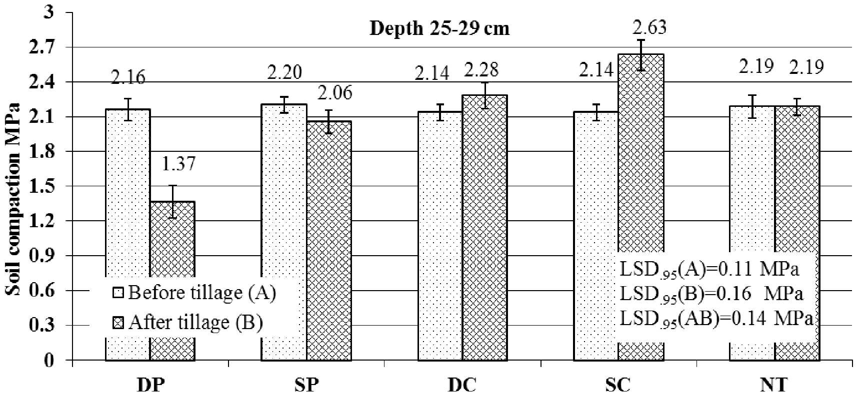

Fig. 4. **Soil compaction (in the depth of 25-29 cm) before and after autumn soil tillage**

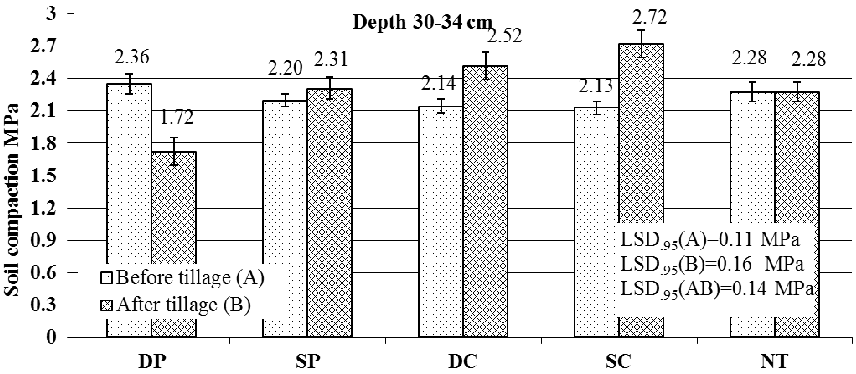

Fig. 5. **Soil compaction (in the depth of 30-34 cm) before and after autumn soil tillage**

The analysis of soil compaction before autumn tillage has shown increase of soil compaction using all tillage technologies at deeper layers of soil. However, it has been found that increase of soil compaction with increase of the depth is not uniform in all tillage technologies. In the case of the DP technology, soil compaction increased consistently throughout the analysed soil layer. In the case of the SP technology, soil compaction before autumn tillage was found to be increasing down to the depth of 18 cm, but did not increase significantly at greater depth. In the case of other conserving tillage technologies, tendencies of change in soil compaction before tillage were found to be very similar to the SP technology, although not as noticeable in other soil layers. In the case of the DC technology, sudden increase of soil compaction has been determined at the depth up to 20 cm, and in the case of SC – at the depth of up to 14 cm. This could be explained by the fact that autumn tillage is performed at this depth each year using either of these technologies. In the case of the NT technology, autumn tillage is omitted; however, working attachments of sowers also act on the upper layer of soil. In general, autumn tillage could be considered to have the greatest effect on soil compaction by intensive use of DP and SP tillage technologies.

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Conclusions

1. Soil compaction of the upper layer of 0-4 cm before autumn tillage was the highest (1.01 MPa) in NT soil that has not been cultivated for over 20 years. Direct seeding technology was applied in this case.
2. Autumn tillage led to reduction of soil compaction of upper layers (0-14 cm) using either of the technologies, except for shallow harrow loosening under SC and NT technologies, where reduction of soil compaction was minor.
3. Soil compaction at deeper soil layers (24-34 cm) before and after autumn tillage continued to reduce in deep plough soil, while other tillage technologies demonstrated increase in soil

compaction at this depth. This was the result of mass and vibrations of the machine transferred to machine attachments that, in turn, made deeper layers of soil more compact. Moreover, during and immediately after tillage, minor soil particles tend to penetrate or be washed by precipitations into deeper layers of soil, thus, eventually, forming a more compact layer of soil.

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