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Influence of Combined Drill Coulters on Seedbed Compaction under Conservation Tillage Technologies

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***Abstract*—**All over the world, including the Middle and East European countries, sustainable tillage and sowing technologies are applied increasingly broadly with a view to optimising soil resources, mitigating soil degradation processes, saving energy resources, preserving biological diversity, etc. As a result, altered conditions of tillage and sowing technological processes are faced inevitably. The purpose of this study is to determine the seedbed topsoil hardness when using a combined sowing coulter in different sustainable tillage technologies. The research involved a combined coulter consisting of two dissected blade discs and a shoe coulter. In order to determine soil hardness at the seedbed area, a multipenetrometer was used. It was found by experimental studies that in loosened soil, a combined sowing coulter equally suppresses the furrow bottom, walls and soil near the furrow; therefore, here, soil hardness was similar at all researched depths and no significant differences were established. In loosened and compacted (double-rolled) soil, the impact of a combined coulter on the hardness of seedbed soil surface was more considerable at a depth of 2 mm. Soil hardness at the furrow bottom and walls to a distance of up to 26 mm was 1.1 MPa. At a depth of 10 mm, the greatest hardness was established at the furrow bottom. In loosened and heavily compacted (rolled for 6 times) soil, at a depth of 2 and 10 mm a combined coulter most of all compacted the furrow bottom, which has a hardness of 1.8 MPa. At a depth of 20 mm, soil hardness within the whole investigated area varied insignificantly and fluctuated by around 2.0 MPa. The hardness of furrow walls and soil near the furrow was by approximately 1.0 MPa lower than that at the furrow bottom.

***Keywords*—**Coulters design, seedbed, soil hardness, combined coulters, soil compaction.

I. INTRODUCTION

TO protect environment, to save labour and energy costs, to accelerate tillage and sowing operations, and to reduce the self-cost of cultivated agricultural produce are the main goals to be achieved by implementing new no-till farming and sowing technologies. Currently, the most advanced agricultural technologies that ensure greatest economic, energy and environmental benefits are implemented in the production of agricultural produce in Europe very rapidly. The basis of these technologies is to limit the intensive mechanical impact on soil and plants, to ensure the renewal of soil productivity, to protect environment, to rationally use material, energy and labour resources, to produce health products and to guaranteethe economic efficiency of the production of agricultural produce [7], [5]. Improper and ill-timed selection of a tillage method changes the main object of agricultural production – soil, the potential of which is closely associated with the organic material contained in it [8]-[10], [4]. The sustainability of soil depends on the genetic properties of soil, local environmental conditions and method of the use of soil [6]. Regular deep ploughing affects many properties of soil and promotes the compaction of the subsoil layer [2]. In search of alternative options of reducing intensive tillage, soil-saving, minimum-tillage technologies are applied more and more broadly. This allows reducing the impact of tillage machines on wind and water erosion and soil properties, easing compaction of soil layers and, consequently, preserving more natural water filtration and plant root penetration into various soil layers [3].

The purpose of the technological processes of tillage and seeding machines is to form a seedbed with suitable properties because it preconditions proper contact between seed and soil aggregates. Seeding machines intended for sowing into untilled soils should be designed so that sowing coulters, irrespective of changing soil properties and plant residues on the soil surface, could evenly draw a furrow in soil at the set depth and insert seeds at required intervals [11]. If a proper seedbed is prepared, seeds and, later on, plant roots can be optimally provided with soil water, nutrients and oxygen. It is greatly influenced by the physical and mechanical properties of the seedbed such as soil density, hardness and moisture content [13]. If the topsoil is loosened excessively, soil respiration processes and capillary water equilibrium are disturbed, which affects water filtration and, in the event of heavier precipitation, a compacted layer may form on the soil surface. Excessively strong seedbed compaction has exactly opposite effect – soil pores are contracted and their efficiency in providing plant roots with moisture and oxygen decreases remarkably [12], [1].

In ploughless tillage and direct sowing technologies, the design of seeding-machine coulters has the greatest impact on seedbed compaction. Some coulters are able to form furrows of proper depth but fail to ensure good contact between seeds

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and soil aggregates. Other coulters form seedbeds insufficiently uniformly under difficult conditions of untilled soil. This is why ploughless and direct-seeding technologies often involve the application of combined seeding coulters that are able to evenly draw sowing furrows in soil and to form a seedbed of the optimal hardness [1].

The main problem of sowing into untilled soil is to insert seeds into straw-covered, hard soil surface. During the recent decade, effort was made to resolve the following topical technical issues in different countries of the world: how to insert seeds into untilled soil so that to ensure the required insertion depth, good contact between soil and seeds, proper granulometric composition of soil layers above seeds, etc. When the soil surface if free of straw, seeds can be inserted by coulters of conventional seeding machines which plant seeds into soil at an acute angle. However, when soil surface contains plant residues (e.g. straw), seeding machine coulters clog up.

The objective of this study is to determine the hardness of the seedbed topsoil when using a combined coulter and applying different soil-conserving tillage technologies.

II. MATERIALS AND METHODS

Experimental studies of combined coulter on the hardness of seedbed were carried out for three different options in soils of various physical and mechanical properties of the seedbed (Table I). After tilling soil with a vertical-rotor cultivator and rolling it with a plain roller, the physical and mechanical properties of the initial seedbed soil were determined: soil hardness, shear stress and moisture content.

TABLE I
TECHNOLOGICAL OPERATIONS AND SOIL PROPERTIES OF THE EXPERIMENTAL STUDIES

Technological operations and soil properties	Option I	Option II	Option III
Tillage	Vertical-rotor cultivator (working width – 1.5 m; working depth – 0.1 m)		
Rolling	Non-rolled	Rolled twice with a plain roller with a weight of 1000 kg	Rolled six times with a plain roller with a weight of 1000 kg
Soil hardness at a depth of 25 mm	0.02 MPa	0.40 MPa	0.90 MPa
Soil shear stress at 0-30 mm	0.002 MPa	0.017 MPa	0.044 MPa
Soil moisture content at 0-50 mm	4.5 %Vol.	10.9 %Vol.	11.1 %Vol.

Measurements were performed in nine different places of the field. Soil hardness was measured with a manual multipenetrometer with a clock-type indicator, shear stress – with a special device with an impeller-type head (diameter – 19 mm; length – 28 mm), and moisture content – with the volumetric moisture meter.

Seed insertion furrows were formed by a combined precise seeding coulter by two 380 mm diameter dissected blade disc coulters and a shoe coulter installed between them. The insertion depth of the shoe coulter was set at 30 mm, and that of the disc coulter was slightly shallower at 25 mm. During the experimental studies, the combined coulter moved at a speed of 5.0 km h^{-1}. Thereafter, the hardness of the seedbed topsoil was measured with the manual multipenetrometer (Fig. 1) at depths of 2 mm, 10 mm and 20 mm. The device was comprised of 11 steel needles with a diameter of 2 mm. The intervals between the needles were 13 mm.

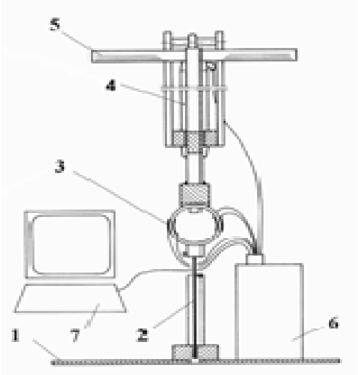


Fig. 1 Multipenetrometer: 1 – support; 2 – steel needles; 3 – sensors; 4 – depth sensor; 5 – handle; 6 – amplifier; 7 – computer

The multipenetrometer was designed so that the needles would rest against rings, to each of which two pairs of sensors were attached. The rings themselves were fastened to a frame and pushed with a handle. When the needles of the device were pressed into soil, separate sensors recorded soil hardness and penetration depth. Amplified pulses of all the sensors were stored in the computer memory. During the studies, the hardness measuring device was placed so that the middle sixth needle would be against the centre of the furrow. Ten measurements per second were recorded. Measurements were performed with three replications. The soil hardness of the furrow drawn by the combined coulter was calculated according to the following formula:

$$K = \frac{x_m g}{1000 \pi R_a^{\ 2}} \qquad (1)$$

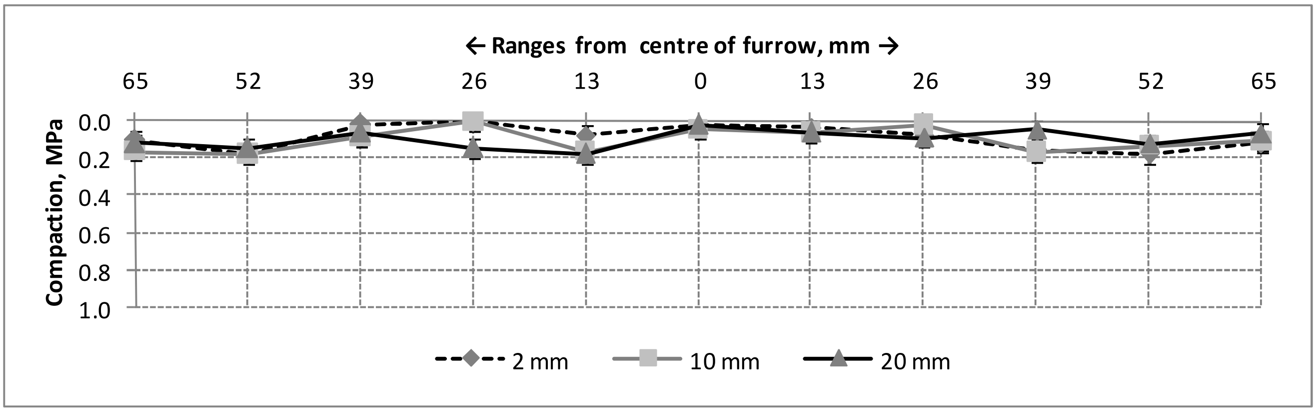
where: K – soil hardness, MPa; X_m – multipenetrometer readings, g; g – free-fall acceleration, m s^{-2}; R_a – needle head radius, mm.

The data of the experiments was analyzed by statistical-mathematical methods assessing the least significant difference LSD_{05} at 95% probability level [14].

III. RESULTS AND DISCUSSION

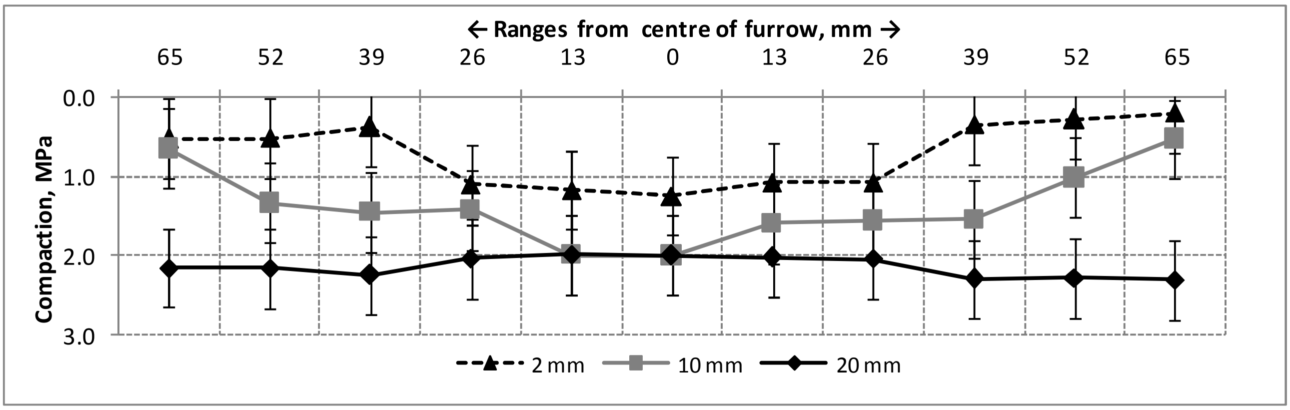
On the basis of the experimental studies of the hardness of seedbed topsoil conducted with the use of a multipenetrometer, it was established that the hardness of the furrow bottom, walls and soil near the furrow in the case of loosened soil (Option I) was the same (Fig. 2) .It could be preconditioned by the fact that the soil prepared for the studies was very loose and, therefore, the impact of the combined coulter on the hardness of the furrow soil at different soil depths was insignificant. The impact of the combined coulter on the hardness of the furrow topsoil in Option II, where soil was rolled twice, was considerably higher (Fig. 3). At a depth of 2 mm, the combined coulter compacted the seedbed bottom and its walls at a distance of 26 mm from the furrow centre almost equally (around 1.1 MPa). At a depth of 10 mm, the greatest hardness was determined at the furrow bottom, and soil hardness varied insignificantly throughout the whole studied area at a depth of 20 mm (around 2.0 MPa). In heavily compacted soil (rolled six times), at a depth of 2 mm the combined coulter compacted the seedbed bottom most of all and its hardness was 1.8 MPa (Fig. 4). The hardness of walls and soil near the furrow was by 1.0 MPa lower than that of the bottom of the seedbed being formed. At a depth of 10 mm, trends similar to those in the studied top layer were determined. At a depth of 20 mm, soil hardness was approximately 2.0 MPa and varied insignificantly throughout the whole investigated area.

By comparing the impact of the combined coulter on the preparation of seedbed in soils with different degree of compaction, it was established that it changes most significantly at the upper layer at a depth of 2 mm. At deeper soil layers (10 mm and 20 mm), the impact of the coulter on soil hardness was less significant.



LSD$_{05}$ = 0.039

Fig. 2 The impact of the combined coulter on the hardness of the furrow at depths of 2 mm, 10 mm and 20 mm in loosened soil (Option I)



LSD$_{05}$ = 0.501

Fig. 3 The impact of the combined coulter on the hardness of the furrow at depths of 2 mm, 10 mm and 20 mm in double-rolled soil (Option II)

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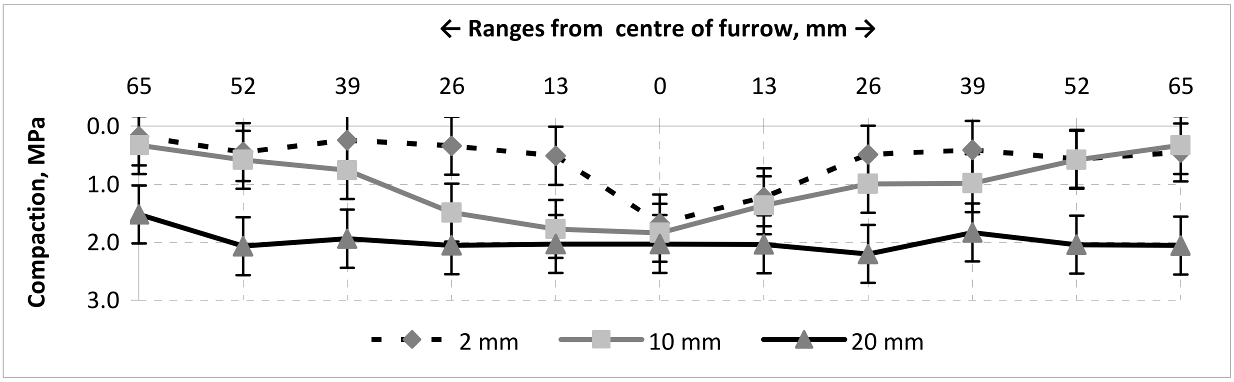

LSD$_{05}$ = 0.426

Fig. 4 The impact of the combined coulter on the hardness of the furrow at depths of 2 mm, 10 mm and 20 mm in six times-rolled soil (Option III)

To summarise, we can state that in soil artificially compacted by rolling twice and six times, the combined coulter compacted the furrow bottom most of all. The main cause of this fact is that the shoe coulter, by penetrating slightly deeper than the disc coulter, forms not only the furrow but also compacts its bottom. The importance of the impact of pre-sowing tillage and seeding machines on the dynamics of soil hardness in the seedbed area lays in the fact that in the excessively compacted or excessively loose furrow bottom, contact of seeds with soil worsens and conditions for germination and nutrient supply deteriorate.

IV. CONCLUSIONS

1. In soil loosened with a vertical-rotor cultivator, the combined seeding coulter equally compacted the furrow bottom, walls and soil near the furrow; therefore, soil hardness was similar at all the studied depths and no significant differences were established.
2. In loosened and compacted (double-rolled) soil, the combined coulter compacted the furrow bottom at the seedbed topsoil (at a depth of 2 mm) and its walls at a distance of 26 mm from the furrow centre to a greater extent and soil hardness was around 1.1 MPa. At a depth of 10 mm, the greatest hardness was determined at the furrow bottom, and soil hardness varied insignificantly at a depth of 20 mm.
3. In heavily compacted soil (rolled 6 times), at a depth of 2 mm and 10 mm, the combined coulter pressed the furrow bottom most of all – 1.8 MPa. The hardness of furrow walls and soil near the furrow was by 1.0 MPa lower than that of the bottom of the furrow being formed. At a depth of 20 mm, soil hardness was approximately 2.0 MPa and varied insignificantly throughout the whole studied area.

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