



Design, development and field evaluation of row-cleaners for strip tillage in conservation farming



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ABSTRACT

Given the drawbacks of conventional soil tillage and direct drilling, an environmentally friendly technology of strip-tillage has been gaining increasing popularity worldwide because it allows the employment of full tillage and direct drilling advantages. Strip-tillage compared to the direct drilling is a good option for proper seedbed preparation because it ensures favourable conditions for seed germination; in comparison with full tillage it reduces working time, fuel and production costs, protects soil, and is environmentally friendly. To remove plant residues from a tilled soil strip row, cleaners of different shapes are used. There is a lack of knowledge regarding which design and technological parameters of the row cleaners of strip-tillage equipment are best suited for interaction with soil and plant residues. Therefore, theoretical research of 340 mm serrated disc row cleaners was carried out, which substantiated the strip width while assessing the disc rake angle, gap between the centres of row cleaner disc fixing holders (gap B_{lc}) and working speed. The experimental research was carried out in the Trial Station of Aleksandras Stulginskis University; it established the influence of different technological parameters of row cleaners on the distance of wheat residue removal. The experimental research established that the serrated disc row cleaners of a strip-tillage machine cleans the greatest amount of plant residues; when the rake angle of the cleaner discs varies from 10° to 15°, gap B_{lc} is 165–180 mm, and the working speed ranges from 1.3 m s⁻¹ to 2.5 m s⁻¹.

1. Introduction

Soil tillage is one of the most important technological operations in agriculture (Abbaspour-Gilandeh and Sedghi, 2015; Hamzei and Seyyedi, 2016; Romaneckas et al., 2015). During tillage, the main changes of the upper soil layer take place: soil is mixed with mineral or organic fertilizer and plant residues, and a proper seedbed is prepared (Rasmussen, 1999).

According to the performance, soil tillage is divided into conventional and zero tillage (Morris et al., 2010). Zero tillage (minimum tillage, direct drilling) has some advantages compared with conventional tillage: it is soil- and environment-friendly, and saves working time and energy resources (Šarauskis et al., 2014). However, zero tillage reveals disadvantages as well because the seedbed is not optimal conditions. Therefore, research on a new type of zero tillage, strip-tillage, has been started globally. This technology includes the advantage of full soil tillage inasmuch as narrow soil strips can be tilled rather deeply (down to 250 mm). Having sown plants into the strips of tilled soil, seeds and subsequent plants can grow under conditions similar to

those of the fully tilled soil. Moreover, strip-tillage combines the advantage of direct drilling that untilled soil is left between strips, which facilitates the reduction of soil degradation processes and nutrient leaching, increases soil biological activity, improves composition, conserves water, etc., owing to the plant residues present on the surface (Bilen et al., 2010; Celik et al., 2013; Jabro et al., 2011; Morris et al., 2010).

In terms of environmental, agronomic and economic aspects, strip-tillage has many advantages. Currently, there is no properly established design of strip-tillage equipment and its working parts worldwide. Some agricultural machinery manufacturers seeking to design the most appropriate option for a strip-tillage machinery are developing conventional tillage implements—cultivators; others continue to develop direct drilling machinery. Depending on the plants to be cultivated or the prevailing soil properties, different designs are appropriate in different countries (Atif Munir et al., 2012; Celik and Raper, 2012; Fallahi and Raoufat, 2008; Raoufat and Matbooei, 2007; Karayel and Özmerzi, 2007; Vaitauskienė et al., 2015). Both in the Baltic countries and in the rest of Europe, there has been practically no experimental research on

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Nomenclature

$R = C_1F_1$	Disc radius of row cleaner (mm)
CD	Disc penetration depth (mm)
O	Disc centre; A and B—points at which disc serration ends meet soil surface
$HI = b_j$	Total strip width (mm)
HF	Soil disturbance width of a strip cleaned by one row

	cleaner disc (mm)
$FG = B_1$	Gap between discs, front (mm)
α	Disc rake angle (degree)
$EC = EC_1$	Length of disc fixing holder (mm)
$E_1E_2 = B_{1c}$	Gap between the centres of row cleaner disc fixing holders (mm)
D_1	Diameter of row cleaner disc (mm)
g	Standard acceleration of free fall ($m\ s^{-2}$)

strip-tillage technological processes and related machinery parts.

Major uncertainties arise while analysing row cleaners designed for cleaning post-harvest plant residues from the tilled soil strip; for example, if plant residues are not cleaned, other equipment parts (e.g., coulters) will become clogged and interfere with the technological process. Many scientists noted that post-harvest plant residues left on the soil surface represent one of the main sources of interference in ensuring the proper technological process of strip-tillage and direct drilling (Korucu and Arslan, 2009; Siemens et al., 2004; Tourn et al., 2003; Vaitauskienė et al., 2015).

The row cleaner design is important in ensuring that all plant residues are removed from soil strips and that planted seeds are not incorporated into those residues, which would prevent good interaction between the seeds and soil, and germination would be negatively affected (Siemens et al., 2004; Sprague and Triplett, 1986). Siemens et al. (2004), Skeeles and Brandt (1993) and Tourn et al. (2003) proposed that the removal of plant residues from the soil section of plant seed incorporation results in a greater yield compared with the soil section where row cleaners have not been used in front of the drill. Plant residue removal from a seed row facilitates reduced disease spreading as well. The performance of row cleaners depends on the amounts of the preceding crop and plant residues left on the soil surface after harvest. The working depth can be adjusted to increase the operation performance of row cleaners.

Disc row cleaners of different designs can be used for strip-tillage or direct drilling. The most common are one- or two-disc row cleaners. A one-disc row cleaner is positioned at a greater rake angle and removes plant residues to one side only. Two-disc cleaners are positioned at a smaller rake angle in accordance with the driving direction and remove plant residues to both directions. Owing to a smaller positioning angle, two-disc row cleaners are more affected by weaker side forces than one-disc row cleaners. It has not been established which rake angle is the most suited under the climatic conditions of Lithuania or other countries of the Baltic Sea region because this type of research has never been performed. Such research is scarce both in Europe and the rest of the world. Another important aspect is that disc row cleaners can have different numbers of teeth. Either too many or too few teeth can impair the quality of plant residue removal. Disc row cleaners can be manufactured with straight or hooked teeth or pins. In certain cases, a disc knife can be fixed in front of row cleaners or between cleaner discs, which cuts plant residues and soil surface before removing residues to the sides (Fallahi and Raoufat, 2008; Linke, 1998; Raoufat and Matbooei, 2007).

In direct drilling, the purpose of row cleaners is to improve the penetration of drill coulters and reduce clogging of machinery with plant residues, thus improving the quality of sowing. In strip-tillage, the purpose of row cleaners is somewhat different. In case of direct drilling, it is sufficient to remove plant residues only from the soil width of several millimetres for a drill coulter to carve a row, whereas in strip-tillage, the strip width can be several or many times higher, so the technological processes appropriate for direct drilling are not fully suitable for the strip-tillage. The influence of plant residue removal in the strip-tillage has been analysed by researchers from different countries. Siemens et al. (2004), Skeeles and Brandt (1993) and Tourn et al. (2003) proposed that the removal of plant residues from the soil section

for seed incorporation results in a higher yield compared with other soil sections, where row cleaners have not been used in front of the drill.

Linke (1998) investigated two types of row cleaners of different designs intended for direct drilling. He established that a one-disc finger type row cleaner with a diameter of 500 mm and rake angle 10° removed 10 to 15% of cereal residues. A two-disc serrated row cleaner with a diameter of 330 mm and 60° angle between the discs removed 40 to 50% of plant residues. The removal of plant residues by the one-disc finger row cleaner improved marginally by increasing the working speed from 1.4 to $3.3\ m\ s^{-1}$, but this had no effect on the operation of two-disc serrated row cleaners. The two-disc row cleaner removed plant residues from the soil surface in a swath wider by 100 mm compared with the one-disc finger row cleaner.

Iranian researchers (Fallahi and Raoufat, 2008; Raoufat and Matbooei, 2007) carried out a study on plant residue removal and established that row cleaner operation is more efficient; i.e., approximately 25% more plant residues are removed, when the soil area is covered with a greater amount of plant residues— $1050\ kg\ ha^{-1}$ compared with $920\ kg\ ha^{-1}$. They also analysed direct drill designs and established that fixing disc cleaners behind disc coulters resulted in a greater amount of plant residues incorporated (pressed) into soil compared with disc cleaners fixed in front of drill coulters (Fallahi and Raoufat, 2008).

In assessing the working process of two-disc row cleaners, researchers from the USA and Germany proposed that a 10–30 mm gap is required between the disc row cleaners to prevent clogging with plant residues and pushing them upwards (Linke, 1998; ASAE, 1995).

The row cleaner of plant residues is a very important working part of soil tillage equipment because the resulting quality of the tillage technological process depends on it. At present, there is practically no in-depth research establishing which technological parameters (rake angles, distances) of a row cleaner are the most appropriate and which working speeds of the machine should be maintained to ensure the best possible plant residue removal quality in the strip-tillage.

The objective of this work is to establish the influence of the technological parameters of disc row cleaners in strip-tillage on strip formation in soil by theoretical and experimental research.

2. Theoretical consideration

2.1. Theoretical substantiation of strip width

By varying the rake angles of disc row cleaners and the gaps between discs, it is possible to change the width of the soil strip cleaned. For the removal of plant residue from the soil strip surface, row cleaner discs or their teeth must penetrate the soil, thus disturbing the soil surface in the strip inevitably. Let us consider that the row cleaner discs penetrating the soil down to point C (Fig. 1).

According to Fig. 1, the radius of row cleaner disc R can be expressed as:

$$R = OC + CD. \quad (1)$$

In the case where a disc tooth is in the deepest position and its central axis corresponds to the vertical axis of the entire disc, angle γ —which is between this vertical axis and the line joining the disc

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