Soil & Tillage Research 154 (2015) 91–102

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

The influence of free-living nitrogen-fixing bacteria on the mechanical characteristics of different plant residues under no-till and strip-till conditions

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A R T I C L E I N F O

Article history:
Received 14 September 2014
Received in revised form 20 May 2015
Accepted 11 June 2015

Keywords:
Plant residues
Free-living nitrogen-fixing bacteria (FLNFB)
Mechanical characteristics
No-till
Strip-till

A B S T R A C T

In applying no-tillage and strip-tillage technologies, one of the main problems is that the post-harvest plant residues remain on the soil surface and hamper the cultivation, tillage and drilling operations. The experimental researches of this work were established biological preparation and it operation period effect the mechanical breaking and cutting different knives characteristics of winter wheat (*Triticum aestivum* L.) cv. 'Ada' winter rapeseed (*Brassica napus* L. ssp. *Oleifera biennis* Metzq.) cv. 'Sunday' and spring rapeseed (*B. napus* L. ssp. *Oleifera annua* Metzq.) cv. 'Fenja' residues in interaction with the soil. The research was carried out in 2012–2014 in Lithuania. Plant residues were left on the untilled soil surface upon by natural climatic conditions. One part of plant residues were treated with biological preparation and other part untreated. Breaking and cutting researches were carried out weekly for three weeks. The research found that biological preparation consist of free-living nitrogen-fixing bacteria weakened the forces required for the cutting and breaking of all researched plant residues. Prolonging the biological preparation effect period, need substantially less force required for the cutting and breaking of plant residues. After the first week, the force required to break winter wheat residues without node decreased by 38%, after two weeks it decreased by 50%, and after three weeks it decreased by 73%, winter rapeseed—78%, 85%, 90%, spring rapeseed 57%, 77% and 82%, respectively. The forces required for cutting plant residues with the vertical knife need about 1.7–2.5 greater compared with the cutting when the angled knife was used.

1. Introduction

Theoretical and experimental research on the physico-mechanical characteristics of plant residues is relevant for quality tillage and drilling technological processes, manufacturing of agricultural machinery and the selection of working parts (Hemmatian et al., 2012). With the increasing popularity of no-till agriculture throughout the world as well as in Baltic countries, an increasing number of problems arise with plant residues are left on the soil surface. Because of their physico-mechanical, biological and other characteristics, plant residues interfere with the tillage and drilling machinery. When soils are heavily covered with plant residues, tillage and drilling machinery with regular coulters clogs up, and therefore, the quality of seedbed preparation decreases (Arvidsson et al., 2004; Arvidsson, 2010; Šarauskis et al., 2012). Because of the abundant plant residues on the surface in no-till, machinery with disc working parts is commonly used (Magalhaes et al., 2007; Šarauskis et al., 2013b). Disc coulters with serrated cutting edges can cut plant residues better than disc coulters with smooth cutting edges (Bianchini and Magalhaes, 2008; Šarauskis et al., 2013a).

The operation of disc coulters depends highly on good interaction between coulters, plant residues and soils. If the characteristics of at least one of the components in this process change, the tillage and drilling process can improve or worsen dramatically. Previous research (Šarauskis et al., 2005) established that both single-disc and double-disc coulters can cut or press plant residues into the notches made by the coulter while penetrating the soil. However, it is worth noting that the coulters consist of two discs that cut the soil and plant residues left on the soil surface at the same time in two different sections. Under certain climatic conditions, when the penetration resistance of the upper soil layer is not sufficient to ensure cutting through plant

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http://dx.doi.org/10.1016/j.still.2015.06.007
0167-1987/

residues, residues are pressed into the soil in two sections and dragged along the soil surface curved outwards between the discs. Therefore, the plant residues interacting with the soil can be both cut and broken. The soil resists the penetration of disc coulters and plant residues, and therefore, residues can be broken if the stress on the plant residues is exceeded. To cut through the plant residues on the soil surface, the penetration resistance has to be higher than the normal stress of the plant residues ([Šarauskis et al., 2005,Š arauskis et al., 2013b]Šarauskis et al., 2005, 2013b).

Researchers from different countries (Linke, 1998; Tavakoli et al., 2009a,b; Hemmatian et al., 2012) have conducted investigations and observed that the force required to cut or break plant residues depended on the plant species, stem diameter, plant length, moisture, cell structure and elasticity. The design and technological parameters of working parts have great importance for the ability to cut or break through plant residues (Liu et al., 2007a, 2010). Canadian researchers (Kushwaha et al., 1983, 1986) investigated the cutting of unchopped straw (5 t ha^{-1}) with coulters with disks of different diameters. They found that a coulter with disks of 360 mm diameter and 2 mm thickness, while penetrating 60 or 70 mm into the soil, cut approximately 80% of the straw on the soil surface, and the remaining 20% of the straw was pressed into the soil. A disc coulter with 460 mm diameter and 4 mm thickness disks cut approximately 95% of straw while penetrating 60 or 70 mm into the soil. A disc coulter with even larger disks (600 mm diameter and 4.5 mm thickness) cut only approximately 20% of straw while penetrating 55 mm into the soil. The investigations established that more straw was cut with an increase of penetration depth.

The straw and stems of different plants have different physical and mechanical characteristics. Investigations into the influence of sunflower (*Helianthus annuus*) stems on the operation of disc coulters demonstrated that, at 80% moisture, the force required for bending a sunflower stem ranged from 34 to 47 N mm^{-2}, and at 55% moisture content, the force required ranged from 41 to 64 N mm^{-2}. The sunflower stem is a fibrous material with a tubular profile. Due to these attributes, first of all a sunflower stem be crushed prior cutting and it do the influence for cutting. The force required to cut through a sunflower stem ranged from 10 to 95 N mm^{-2} at 80% stem moisture content (Ince et al., 2005). Liu et al. (2007a,b) investigated the cutting force required to cut through a sugar cane stem. They found a linear relationship between the cutting force and the cutting speed. With an increase in cutting speed, the cutting force required for cutting through a sugar cane stem increased. Hemmatian et al. (2012) conducted similar cutting force experiments with sugar cane (*Saccharum* spp.) stems and established that the reduction in plant moisture content from 78 to 46% resulted in a decrease in cutting force of approximately 16.3%. A cutting speed increase from 5 to 15 mm min^{-1} increased the cutting force required by approximately 3.2%. Nazari et al. (2008) investigated the physico-mechanical characteristics of alfalfa (*Medicago saliva* L.), and he proposed that a decrease of alfalfa stem moisture content resulted in a reduction in the force required to cut it. The investigations also established that a decrease in plant stem diameter decreased the force required for cutting.

Tavakoli et al. (2009a,b) investigated the influence of barley (*Hordeum vulgare* L.) straw moisture content, the length of an internode and the loading rate on straw bending characteristics. The barley straw was divided into three different groups according to moisture content: 10%, 15% and 20%. Three straw internode sections were distinguished, and three loading rates were chosen: 5, 10 and 15 mm min^{-1}. After investigating the bending characteristics of barley straw under different conditions, it was established that an increase in straw moisture content and bending rate resulted in a decrease in the relative force required for bending in the third section of an internode and that this force varied from 6.32 N mm^{-2} to 12.41 N mm^{-2}. Cakir et al. (1994) proposed that the coulter relative force required to cut through wheat straw ranges from 2.8 to 6.4 N mm^{-2}, a maize (*Zea mays* L.) stem from 0.75 to 1.65 N mm^{-2}, a soya (*Glycine max*) straw from 3.8 to 5.8 N mm^{-2}, and a cotton stem from 6.0 to 10.0 N mm^{-2}. Chen et al. (2004) indicated that to cut through a hemp (*Cannabis*) straw the average force required was approximately 243 N.

The mechanical characteristics of plant residues depend on how long the residues are left on the soil surface. The forces required to cut or break through fresh or overwintered plant residues were very different (Linke, 1998). For instance, the force required to break overwintered winter wheat straw is about 3.2-fold lower than the force required to break the straw of winter wheat harvested fresh in autumn. Investigations with spring barley showed that the breaking force for overwintered spring barley straw decreased approximately 34% compared with the autumn straw (Šarauskis et al., 2013b). Long periods deteriorate the mechanical characteristics of plant residues. However, modern agriculture does not always provide an opportunity for waiting until the plant residue mechanical characteristics, which influence the working parts of tillage and drilling machinery, are weakened under natural conditions. Very often, several weeks after crop harvesting, new plants are already being drilled. The application of no-till and strip-till results in the plant residues from the previous harvest being left on the soil surface, which directly influences drilling coulter operation. Because plant residues left on the surface for a short time can maintain strong mechanical characteristics, disc coulters may fail to cut through or break them, and plant residues will be pressed into the notches. To prevent this, it is necessary to speed up the processes of plant residue mineralization and the associated mechanical weakening. To activate such processes, different biological preparations with free-living nitrogen-fixing bacteria are being introduced rapidly. The functions performed by soil organisms have great direct and indirect impacts on the growth and quality of crops, the spreading of pests in the soil and plant residues, the distribution of diseases, the rates of nutrient circulation in the soil, the receptivity of soil to water and the consistency of its ecological productivity. They also affect the stability of agroecosystems and the resistance to abiotic environmental factors and stress (Brussaard et al., 2007). Biological preparations create a distinctive agricultural culture and ensure long-term and stable fertility of field plants, while maintaining a clean environment and without causing damage to people (Ahmadi, 2010; Brussaard et al., 2007). These biological preparations are most often used as nutrients for the soil and plants. Plants sprayed with the solution of such preparations can assimilate mineral materials better and grow more vigorously, and the productivity of plants increases (Dewar et al., 2003; Jakienė and Liakas, 2013). The recommended rate of spraying during plant growth is 0.5–2.0 l ha^{-1}. The biological preparation consists of nitrogen-fixing stem bacteria *Acotobacter vinelandii* and biologically active materials affecting the structure of plant residues. Therefore, the mineralization of plant residues is activated on the soil surface, and at the same time, the nitrogen-fixing bacteria perform the function of speeding up the processes of plant residue decomposition and the weakening of the mechanical characteristics of the residues (Jakienė, 2011; Holtze et al., 2008; Ahmadi, 2010). Taking account of other scientific researches conducted with wheat straw using various microorganisms combinations together with *Azotobacter*, chemical analysis of the samples showed a significant decrease in cellulose, hemicellulose and lignin contents during pre-decomposition (Singh and Sharma, 2002).

The objectives of this work were to investigate the influence of free-living nitrogen-fixing bacteria on the mechanical characteristics of cutting and breaking of different plant residues over time