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ORIGINAL PAPER

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SPATIAL DIFFERENTIATION OF SOIL MOISTURE IN STRIP-TILL ONE-PASS TECHNOLOGY

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ABSTRACT

Background. As a result of the zonal effect of strip tillage with its simultaneous application of fertilizers and the sowing of seeds, and depending on the presence of post-harvest residues, there may be variations in soil properties including that of moisture content. The aim of this study was to assess the spatial diversity of moisture in soil cultivated or prepared for cultivation according to the strip-till one-pass technology, as well as the dynamics of its changes.
Material and methods. In field experiments and laboratory tests the diversity of soil moisture was assessed depending on the actual or simulated impact zone of the working parts of hybrid strip tilling and sowing machines and the distribution of post-harvest residues on the soil surface.
Results. During the period of intensive growth of plants the water content in the loosened strips of the plant rows was lower than in the uncultivated inter-rows. In these strips there was a rapid infiltration of water after precipitation and a faster decrease in moisture content than there was in the inter-rows. The loosened soil moved away at the time of sowing into the inter-row, or its surface layer, in rainless periods contained less water than the lower layers. Plant mulch on the surface also led to soil having a higher water content.
Conclusion. The zonal effect of the working parts of a strip-till and sowing machine causes spatial differentiation of soil moisture. Non-loosened soil zones, especially in rainless periods, contain more water than the cultivated strips in rows of plants. Higher soil moisture is encouraged by covering the soil with a layer of mulch or a layer of loosened soil.

Key words: plant cultivation, post-harvest residues, soil moisture, strip-till, zonal tillage

INTRODUCTION

An important element of conservation and sustainable agriculture, in addition to tillage, is the handling of plant residues (Wacławowicz, 2013). Reduced, non-inverse tillage and especially direct sowing results in post-harvest residues and catch crop biomass remain on the soil surface. This protects the soil from erosion, surface runoff, degradation of the crumble structure, crusting and high amplitudes of moisture and temperature change. Zero tillage, however, does not loosen the soil sufficiently and that is in many cases a prerequisite for proper plant root growth (Peigne *et al*., 2007; Derpsch *et al*., 2010). For this reason, zone tillage, including strip-till, is increasingly used (Williams *et al*., 2016). This method combines the advantages of deep classical cultivation with the benefits of direct sowing. Currently, strip-till is divided into two-pass and one-pass systems, depending on the timing of the consecutive tillage and sowing (Morrison and Sanabria, 2002). Strip-till one-pass is in fact a technology of soil cultivation

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with simultaneous fertilization and sowing of seeds and it even has the possibility to perform additional cultivation measures, e.g. application of plant protection products. The width of the cultivated soil strips can range from a few to several dozen centimeters, which together make up about 1/3 of the field area. The strips depth can range from a few to 30–35 cm or can covers the full depth of the topsoil (Morris *et al*., 2010; Townsend *et al*., 2016). More than 50%, or even 75% of plant residues remain on the uncultivated surface, which now constitutes the inter-rows after sowing, where they form mulch and perform many agricultural and environmental tasks (Mitchell *et al*., 2009; Lekavičienė *et al*., 2019). The environmental, organizational and economic values of this technology with deep strip cultivation connected to rows of plants means that it is currently used not only in the cultivation of plants sown with a wide row spacing (Morris *et al*., 2007; Jackson *et al*., 2011; Piechota *et al*., 2014), but also in oilseed rape (Schwabe *et al*., 2016) and cereals (Jaskulska *et al*., 2019).

Deep soil loosening, strongly aerating the soil, causes large water losses (Guan *et al*., 2015). However, loosening only soil strips has a positive effect on water management (Jabro *et al*., 2014). Soil water storage and its efficient use is also favored by conservation tillage with a large amount of mulch on the soil surface (Choudhary and Singh, 2002; Busari *et al*., 2015). Mulch reduces surface runoff and increases water infiltration, reduces temperature amplitude and evaporation and increases water retention in the soil. It also has a positive effect on soil properties, both in conditions of rainfall deficiency and large amounts of rainfall (Pramanik *et al*., 2015; Kader *et al*., 2017). Simplified tillage has a similar effect on soil water properties. Alvarez and Steinbach (2009) showed that the water content in critical periods for plant growth in soil cultivated under this system was higher in comparison to that for plowing, and the difference was sufficient to cover evapotranspiration for 1–3 days during the flowering period. According to Pabin *et al*. (2003), the higher moisture of soil cultivated in accordance with the assumptions of reduced and zero tillage in comparison with the plowing system occurred immediately after rainfall. Later evaporation increased despite the presence of straw mulch.

The results of the studies cited above and those carried out by Yang *et al*. (2018) enable us to assume that the spatial diversity of soil moisture is a result of the interactive zonal impact of the working parts of hybrid strip-till machines on soil and plant residues. The aim of this study was to assess the spatial, zonal diversity of moisture in soil cultivated or prepared for cultivation according to the strip-till one-pass technology, as well as to determine soil moisture changes over time.

MATERIAL AND METHODS

In the years 2017–2019, 6 series of field tests and a laboratory experiment were performed. Experimental units in the field experiments were located on plantations of winter wheat, winter oilseed rape and maize cultivated with the strip-till one-pass technology using a MZURI Pro-Till 4T hybrid machine, which enables simultaneous cultivation of soil strips, application of mineral fertilizers and the sowing of seeds. The cultivated soil strips were 12 cm wide and 20 cm deep. The row spacing of wheat during sowing was 36.3 cm and maize 72.6 cm. Between these strips were non-cultivated inter-rows (Fig. 1). The sowing coulter was equipped with side wings that result in the seeds being sown and then the plants growing in small furrows, while in the inter-rows a ridge with a height of several centimeters is formed. With narrow inter-rows – wheat and oilseed rape cultivation - this ridge occupies the full width of the inter-row (Fig. 2). In maize cultivation with a row spacing of 72.6 cm and with an inter-row width of approximately 60 cm, ridges are formed in the immediate vicinity of the till-sowing strips, and in the central part of the inter-row there remains mulch from the post-harvest residues of the previous crop (Fig. 3).

The field experiments were carried out on a farm, cooperating with the Department of Agronomy of the University of Technology and Life Sciences in Bydgoszcz, located in Śmielin (53°09′04″ N; 17°29′11″ E, 92 m a.s.l.), the Kuyavian-Pomeranian Voivodeship, Poland. They were carried out on brown specific soil with an average content of sand fraction 44.8%, silt 50.1%, clay 5.1% and assimilable forms of macronutrients (in 1 kg of soil DM): 90 mg P, 221 mg K, 74 mg Mg. The pHKCl index was 6.2.

The pluviothermal conditions during the study period (months, years) and on average for the multiannual period are presented in Table 1.

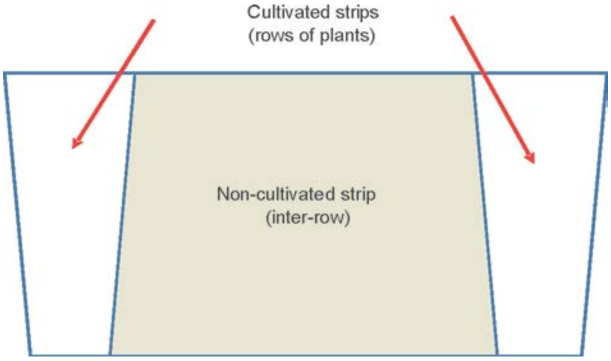

Fig. 1. Arrangement of till-sowing strips in strip-till one-pass technology

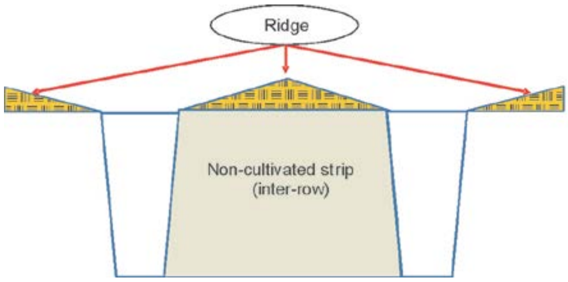

Fig. 2. Diagram of spatial differentiation of the topsoil layer in strip-till one-pass technology with till-sowing strip spacing of 36.3 cm

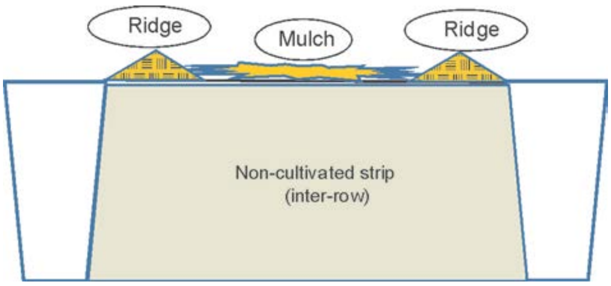

Fig. 3. Diagram of spatial differentiation of the topsoil layer in strip-till one-pass technology with till-sowing strip spacing of 72.6 cm

In the first series of field experiments the diversity of soil moisture in the 0–20 cm layer was assessed during the period of intensive growth of winter wheat (BBCH 37–39) after 14 days with no rainfall. Soil samples were taken from rows of winter wheat (removing plant roots) and from the middle of the inter-rows from the uncultivated layer, which constituted two levels of the experimental factor.

The second and third series of experiments consisted of determining the soil moisture content, respectively, immediately after precipitation of at least 20 mm and then at least 5 days after that precipitation. The places of soil moisture assessment (the factor levels) were: winter wheat plants row (cultivated strip), non-cultivated inter-row (between the rows) and the ridge in the inter-row. Soil samples from rows and inter-rows were taken from the 0–20 cm layer, and from the ridge formed in the inter-row from the 0–5 cm layer.

In the fourth series of experiments the soil moisture content of the seedbed up to a depth of 5 cm was estimated during maize emergence (BBCH 11) in loosened rows, in non-loosened inter-rows under the ridge formed by the soil, under the layer of mulch of maize straw – the previous crop, as well as the moisture content of the soil forming the ridge.

The fifth series consisted of estimation of the 0–20 cm layer soil moisture after winter wheat harvest depending on straw management and post-harvest tillage. The four levels of the factor were straw harvest followed by: a 5 cm shallow loosening cultivation, a 15 cm deep loosening cultivation, no tillage, mulching with fragmented straw without tillage. Soil moisture assessment was carried out after a 10-day rainless period.

The sixth series of experiments compared the soil moisture content of the seedbed in the six consecutive days preceding sowing of winter oilseed rape, prepared classically (pre-sow plowing 14 days before sowing, a combined tillage unit – 10 days before sowing) and soil mulched with straw before sowing the oilseed rape with the strip-till technology.

In all field experiments, repeated three times during the study period, soil samples were taken from 10 locations of each factor level into 100 cm^3 cylinders using an Eijkelkamp sampler. Soil moisture (W) was determined by means of the oven-drying method by determining its value according to the formula:

$$W = (c - e) / (e - a) \cdot 100 \text{ [wt\%]} \quad (1)$$

where:
a – weight of the weighing vessel,
c – soil mass with the vessel before drying,
e – soil mass with the vessel after drying.

Table 1. Mean monthly air temperature and total rainfall during the study period

Month	Year							
	2017	2018	2019	Multiannual	2017	2018	2019	Multiannual
	Temperature, °C				Rainfall, mm			
March	5.4	-0.2	5.4	2.5	27.5	16.6	28.8	31.9
April	6.8	12.0	9.3	7.9	40.8	40.4	1.5	27.0
May	13.4	16.9	12.1	13.3	56.3	14.2	89.2	49.3
June	16.8	18.4	21.9	16.1	54.3	26.4	17.7	52.8
July	17.7	20.5	18.6	18.6	118.9	86.0	22.4	69.8
August	17.7	19.9	19.7	17.9	126.1	23.7	37.7	62.6

Laboratory experiment: In each tared pot with a diameter of 12 cm and 15 cm in height 3.5 kg DM soil was placed, which was compacted to 1.5 $g \cdot cm^{-3}$ and moistened 25% by weight. The substrate prepared in this way was subjected to the action of an experimental factor – surface measures imitating post-harvest cultivation: 5 cm loosening, mulch made of straw fragmented to 2 cm, no loosening and mulch. Each level of the factor consisted of 5 pots distributed in full random order. The pots were placed in the vegetative laboratory of the Department of Agronomy at 20–24°C. The weight of each soil pot was measured every day for 21 days, which allowed its moisture content to be determined.

The results of field experiments were statistically evaluated. The significance of the influence of experimental factors was assessed by the F test. The differences between the mean values of the characteristics and the groups of homogeneous results were determined based on Tukey’s test at $P<0.05$. The significance of soil moisture diversity in the seedbed prepared classically and according to strip-till technology was estimated using the Student's t test. In the laboratory tests, F and Tukey's tests were also used to assess differences in soil moisture at the time of seedbed preparation, and then after 3, 7, 10, 14 and 21 days, depending on the measures performed on its surface. Excel Microsoft 2016, Statistica 12 and FR-ANALWAR-5.2 were used to develop the results.

RESULTS AND DISCUSSION

An analysis of the rainfall needs of arable crops and the amount and distribution of precipitation indicates that in Poland there is often a shortage of water in the soil in critical periods for plants, including for winter wheat (Dzieżyc *et al*., 1987; Samborski, 2007). During the intensive growth period of winter wheat biomass, when there had been no rainfall for a minimum of 14 days, the soil moisture level in the present study did not exceed 10%. At the same time the water content in the rows of plants was significantly, by 3.0 percentage points, lower than in the inter-rows (Fig. 4). This indicates, on the one hand, a large water uptake by plants, and on the other hand, a sure supply of water in the non-cultivated inter-rows, which confirms the results of the study by Tabatabaeekoloor (2011) on zonal differentiation of water-thermal conditions after strip soil cultivation.

Immediately after rainfall soil moisture in the winter wheat crop increased by the greatest extent in the cultivated soil zone. The soil in the rows of plants was moister at this time than in the ridge formed in the inter-row, and especially in its non-loosened lower zone (Fig. 5). This was probably the result of a greater infiltration of water into the soil in a loosened strip, as well as the likely runoff of some water during rainfall down the sloping surfaces of the ridge located in the inter-row. Matula (2003) draws attention to the relationship between water infiltration into the soil and the soil cultivation system. According to this author, reduced tillage and no tillage limit water infiltration into the soil. By contrast, in loose soil with high non-capillary porosity – ridge in the inter-row – rapid gravitational water displacement occurs along with evaporation (Lipiec *et al*., 2006). After at least 5 days with no rainfall there were rapid changes in spatial soil moisture levels. Then the highest moisture level was in the area of the non-cultivated inter-row, significantly lower in the rows of plants, and the lowest in the ridge in the inter-row (Fig. 6). Thus, the compacted, non-loosened soil zone plays an important role in water storage. Similar results were indicated in the study by Wang *et al*. (2018) regarding variable tillage methods, including zero tillage and the presence of straw mulch.

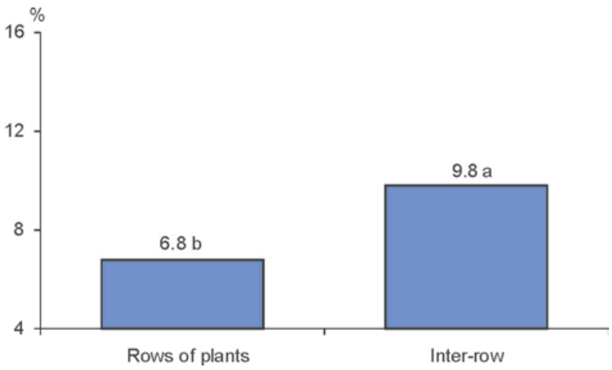

Fig. 4. Soil moisture in rows and inter-rows of winter wheat (BBCH 37-39)

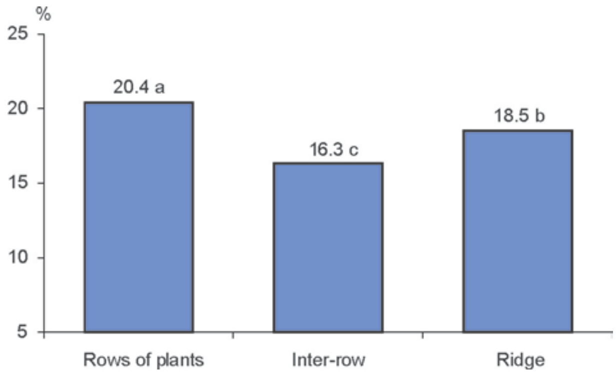

Fig. 5. Spatial diversity of soil moisture in the topsoil layer immediately after rainfall

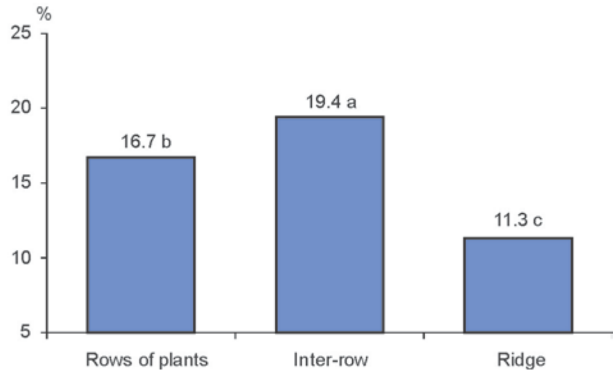

Fig. 6. Spatial diversity of soil moisture in the topsoil layer after 5 non-rainy day

Differences in the moisture of the topsoil layer (0–5 cm) during the emergence of maize depended on the previous interaction of the working parts of a hybrid strip-till and sowing machine. The most desiccated was the soil moved away by the coulter wings of the sowing machine- the ridge (Fig. 7). Significantly more water was found in the deeply loosened sowing strip, but also compacted by the consolidation wheels – rows of plants. The most water, however, was found in the soil directly below the loosely formed ridge. Its moisture was, by 0.7 percentage point, higher than the moisture of soil under the layer of maize straw mulch, but this difference was not statistically significant. Thus, both a thin, superficial, loosened soil layer and the mulch effectively protected the water in the non-loosened soil layer. In light of these results, the soil surface condition that remains after the passing of a strip-till and sowing machine appears to be important for subsequent crop growth conditions, including the redistribution of post-harvest residues, as is the case with other soil simplified cultivation methods (Schneider *et al*., 2006).

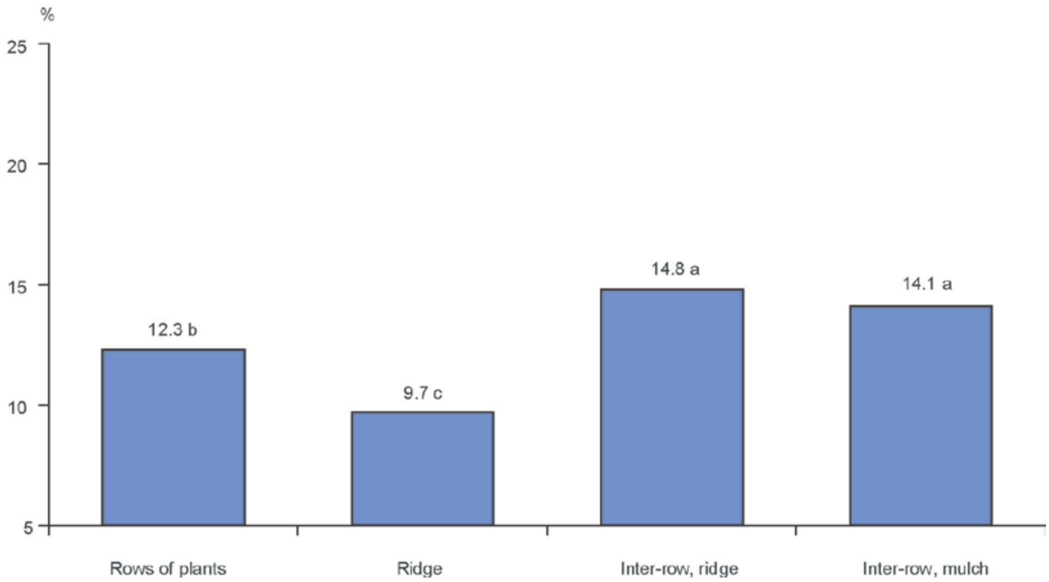

Fig. 7. Diversity of soil moisture of the topsoil layer (0-5 cm) during the emergence of maize

The field experiments during the post-harvest period clearly show that the method of topsoil layer management after winter wheat harvest significantly affected its moisture (Fig. 8). The mean water content in the 0–20 cm layer after at least 10 days without rainfall was the highest under crushed straw mulch. This soil contained 2.4 percentage points more water than shallowly loosened soil immediately after harvest. Significantly less water was found in unmulched soil that had not been loosened on the surface. The most desiccated was the soil loosened to a depth of 15 cm. It contained 1.4 percentage points less water than in uncultivated soil and up to 6.6 percentage points less water than under mulch. Therefore, mulch is a good way to protect soil from water loss when the soil is "waiting" for the sowing of the successive crop with the strip-till technology. Similar conclusions can be drawn from previous studies on the role of mulch in zero tillage and direct sowing (Zamir *et al*., 2013). In the absence of mulch, however, the topsoil should be loosened.

The beneficial effect of winter wheat straw mulch on the soil moisture of the seedbed was confirmed by the study comparing the water content in this layer before sowing winter oilseed rape. Six days before sowing, the plowed soil and the seedbed surface prepared with a cultivation unit contained, in the 0–5 cm layer, 3.9 percentage points less water than soil mulched with crushed straw and prepared for strip cultivation and simultaneous sowing (Fig. 9). This difference increased each day for the first 3 days, however, after rainfall three days before sowing the difference became insignificant. In the following rainless days the water content in the soil under the mulch was again significantly higher than in the loosened layer. Dynamic changes in soil moisture, both loosened and mulched, being largely dependent on the amount and distribution of precipitation has also been documented by Wuest and Schillinger (2011).

The results of the field experiments were confirmed in the laboratory experiment that assessed the dynamics of subsoil moisture differentiation by imitating field changes in soil moisture during the post-harvest period depending on surface cultivation measures. It was found that throughout the entire study period the smallest losses of water from the subsoil took place when it was covered with crushed straw and the largest losses were from compacted subsoil without any treatment (Fig. 10). After only three days the moisture content of the mulched subsoil was significantly higher than that without the crushed straw layer and non-loosened. Shallow loosening limited water losses, as compared with non-loosened subsoil, to a small extent initially as well as after 3 weeks of testing, while between the 7th and 14th days the effect was significant. These results confirm the very beneficial effect of mulch on reducing soil water loss. At the same time they indicate that soil without shredded plant residues should be shallowly loosened.

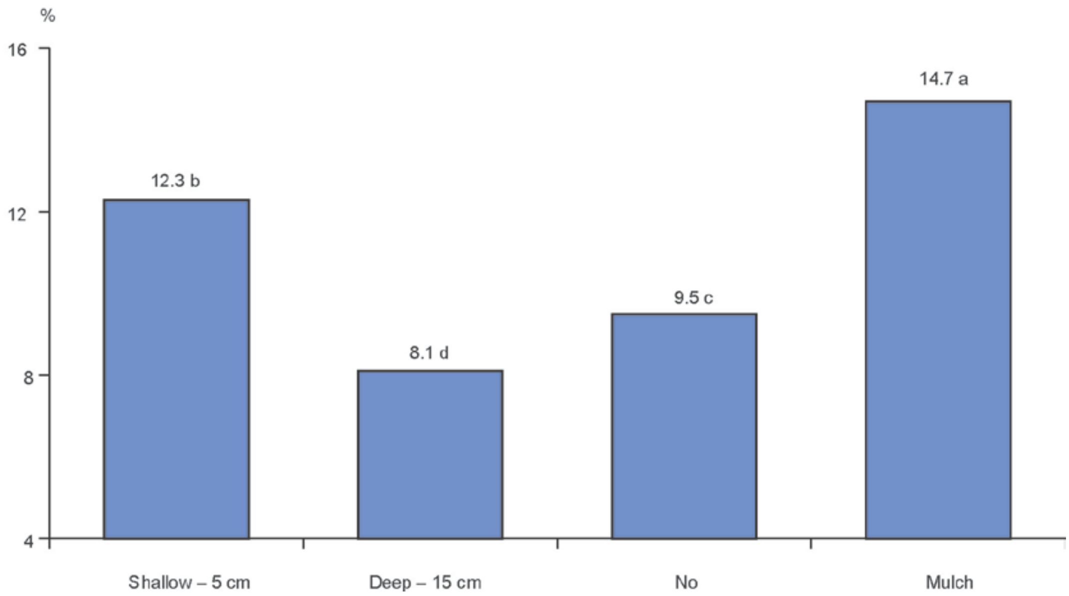

Fig. 8. Soil moisture (0-20 cm) depending on how the surface is managed

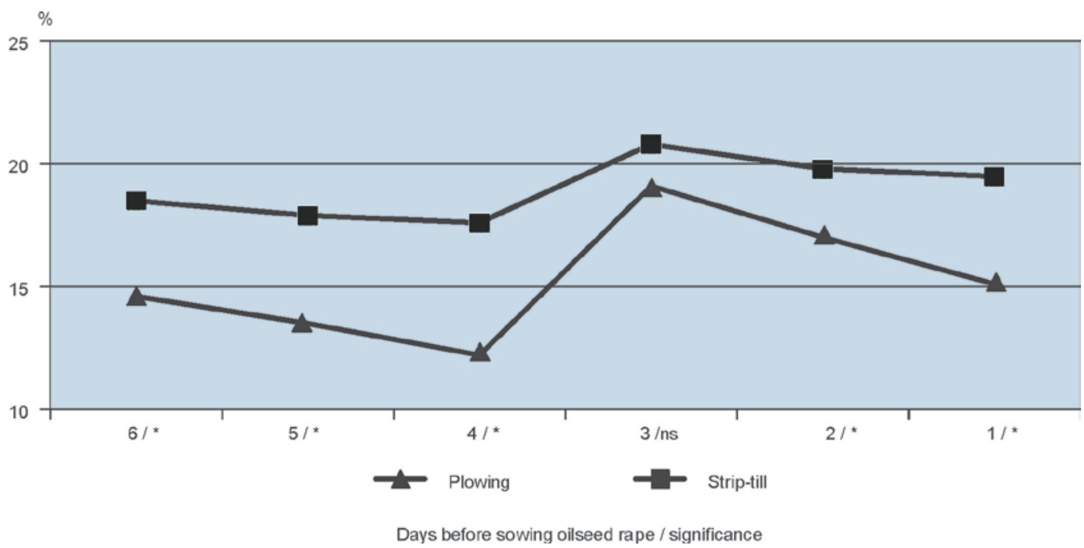

Fig. 9. Difference in soil moisture of seedbed cultivated by plowing and prepared for strip sowing

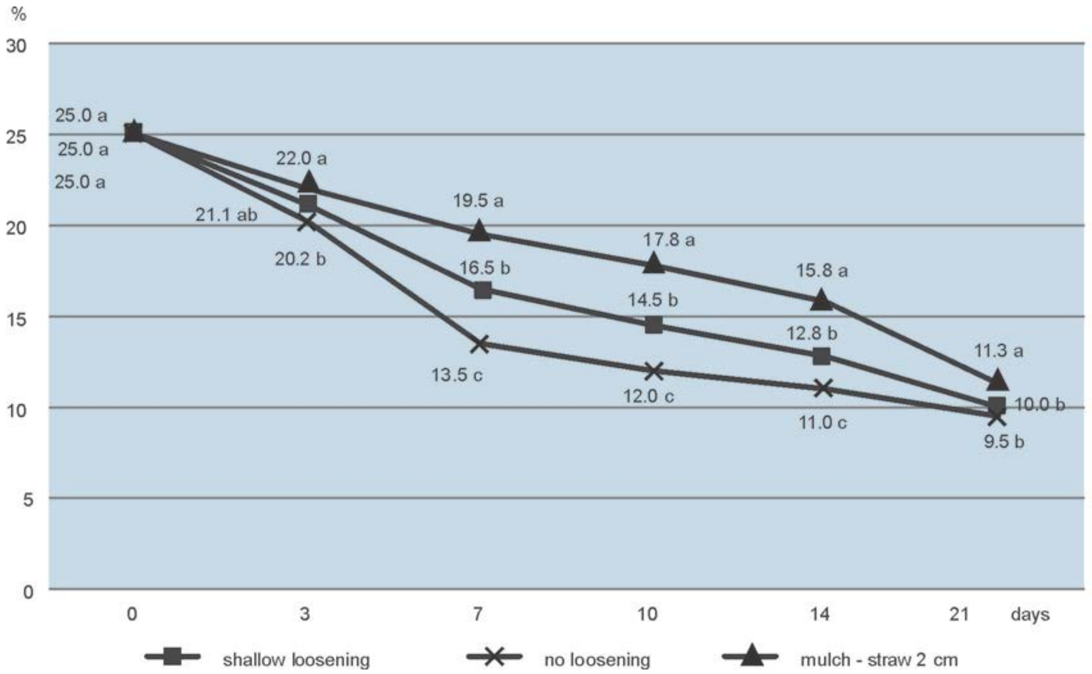

Fig. 10. Dynamics of substrate moisture changes depending on treatments on its surface

CONCLUSIONS

Seedbed soil, especially mulched or shallowly loosened, prepared for growing plants with strip-till technology contained more water than soil after classical plowing cultivation. The zonal interaction of the working parts of a strip tillage and sowing machine caused a spatial differentiation in soil moisture. In loosened strips and rows of plants there was a rapid increase in soil moisture immediately after rainfall, but also a rapid loss of water in the absence of rain. Non-loosened soil zones in inter-rows, especially in periods without rainfall, contained more water than the cultivated strips. The higher moisture of inter-row soil is helped by covering it with a layer of mulch or a layer of loosened soil. Non-cultivated soil without a covering layer quickly loses water.

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PRZESTRZENNE ZRÓŻNICOWANIE WILGOTNOŚCI GLEBY W TECHNOLOGII STRIP-TILL ONE-PASS

Streszczenie

W wyniku strefowego oddziaływania pasowej uprawy roli z jednoczesną aplikacją nawozów i siewem nasion na glebę i resztki pożniwne może występować zróżnicowanie jej właściwości, w tym wilgotności. Celem badań była ocena przestrzennego zróżnicowania wilgotności gleby uprawianej lub przygotowanej do uprawy według technologii strip-till one-pass, a także dynamiki jej zmian. W badaniach polowych i laboratoryjnych oceniono zróżnicowanie wilgotności gleby w zależności od rzeczywistej lub symulowanej strefy oddziaływania elementów roboczych hybrydowej maszyny do uprawy roli i siewu pasowego oraz rozmieszczenia resztek pożniwnych na powierzchni gleby. W okresie intensywnej wegetacji roślin zawartość wody w spulchnionych pasach i jednocześnie rzędach roślin była mniejsza niż w nieuprawianych międzyrzędziach. W strefie tej występowała szybka infiltracja wody po opadach i szybsze niż w międzyrzędziach zmniejszenie wilgotności po ich ustąpieniu. Gleba spulchniona, odsunięta w momencie siewu w międzyrzędzie lub jej warstwa powierzchniowa, w okresie bezopadowym zawierała mniej wody niż warstwy niżej położone. Większej zawartości wody w glebie sprzyjał również mulcz roślinny na jej powierzchni. Strefowe oddziaływanie elementów roboczych maszyny do pasowej uprawy roli i siewu powoduje przestrzenne zróżnicowanie wilgotności gleby. Strefy gleby niespulchnionej, zwłaszcza w okresach bezopadowych, zawierają więcej wody niż pasy uprawione w rzędach roślin. Większej wilgotności gleby sprzyja jej przykrycie warstwą mulczu lub warstwą gleby spulchnionej.

Słowa kluczowe: resztki pożniwne, uprawa roślin, uprawa strefowa roli, właściwości gleby