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YIELD OF WHITE MUSTARD GROWN AS STUBBLE CROP DEPENDING ON THE METHODS OF FIELD PREPARATION AND SEED SOWING

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ABSTRACT

Background. In order to sustain agrocenosis biodiversity and high soil richness, under the conditions of production intensification and specialisation, it is justified to search for simplified technologies of stubble crop cultivation that would make it possible to grow it on a wider scale. The aim of the work was to determine the possibility to simplify the technology of white mustard cultivation as a stubble crop and to evaluate the effect of possible simplifications on plant yield.
Material and methods. Field experiment was carried out at the Research Station in Mochełek near Bydgoszcz in the years 2010–2012, on lessive soil of very good rye complex. The experimental factors were soil cultivation and seed sowing methods: A – traditional ploughing with seed drilling, B – simplified: stubble discing, broadcast sowing, C – simplified: stubble discing, broadcast sowing with a 20% increase in the sowing amount, D – broadcast sowing before winter wheat harvest, E – broadcast sowing before winter wheat harvest with a 20% increase in the sowing amount. Seed sowing on plots A, B, and C was carried out between August 16^{th} and 18^{th}, and on plots D and E on July 20^{th}.
Results. In the study period, very high precipitation occurred in July and August. In the conditions of excessive soil moisture, the yield from white mustard was relatively low: from 1.18 $Mg \cdot ha^{-1}$ on plots with simplified cultivation to 1.56 $Mg \cdot ha^{-1}$ on plots with traditional cultivation. The highest dynamics of the yield increase was found in the period between the 4th and 6th week after emergence of plants cultivated traditionally and between the 4^{th} and 8^{th} week after emergence in the simplified soil tillage option. Simplified soil cultivation resulted in a significant decrease in the yield of white mustard green and dry matter in comparison with traditional cultivation.
Conclusion. Simplification of soil cultivation for white mustard grown as stubble crop is possible, although it affects negatively green and dry matter yield. Replacing traditional ploughing and seed drilling with stubble discing and broadcast sowing caused a very significant decrease in the yield of white mustard green and dry matter. White mustard responded relatively well to broadcast sowing carried out before winter wheat harvest.

Key words: broadcast sowing, simplified cultivation, stubble crop, white mustard, zero cultivation

INTRODUCTION

In the present conditions of agricultural practice, characterized by the dominance of cereals in the sowing structure, stubble crop is a significant element that makes it possible to sustain agrocenosis biodiversity. Due to production intensification and specialization, the growth of catch crops can be limited

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by problems resulting from the accumulation of tasks during harvest, especially if there is a delayed cereal harvest or if cereals are cultivated with intensive technology. It seems justified to search for simplified cultivation technologies that would make it possible to lower the costs and increase the acreage of stubble crops. In such cultivations, established in order to help protect soil and water from agricultural pollution, mineral fertilizers should not be applied. In addition to the cost of the soil cultivation technique used a further significant element of stubble crop cultivation is the purchase of sowing material. Currently the cost of 1 kg of sowing material ranges from 2.1 PLN for pea, 3–5 PLN for yellow lupine and white mustard, 10–20 PLN for blue tansy, and up to 40 PLN in the case of rapeseed (ODR Minikowo, 2018). Taking into account recommended sowing rates, the cost of sowing material for 1 ha of cultivation amounts to 50–70 PLN for white mustard and up to 600–700 PLN in the case of yellow lupine.

White mustard, in addition to low costs, is also characterized by high tolerance to a delayed sowing date (Kisielewska and Harasimowicz-Hermann, 2008a), high yield stability, and resistance to various weather conditions (Muśnicki *et al*., 1997; Toboła and Muśnicki, 1999; Jankowski and Budzyński, 2003; Paszkiewicz-Jasińska, 2005; Davis *et al*., 2010, Handlířová *et al*., 2016). Davis *et al.* (2010) demonstrated that white mustard is a plant of high resistance to high temperature and precipitation shortage in the summer, which is of particular importance to its cultivation as a stubble crop. According to Taherkhani *et al*., (2013), drought in the period of mustard sowing may, however, significantly affect the germination percentage, seedling vigour index, length of radicles, coleoptile length and dry weight of a seedling.

Due to low cultivation costs and environmental requirements, white mustard is, at present, the most widespread species for stubble crop growth. It was assumed in the study hypothesis that white mustard cultivated as a stubble crop with the use of simplified soil cultivation or with no cultivation would make it possible to produce satisfactory biomass yield by the plants, which could be used as green manure.

The aim of the present study was to determine the possibility of simplifying the technology of white mustard cultivation as a stubble crop and make an evaluation of the effect of the applied simplifications on plant growth and yield.

MATERIAL AND METHODS

The field experiment was carried out at the Experimental Station of the Faculty of Agriculture and Biotechnology of UTP University of Science and Technology in Bydgoszcz, Poland, located in Mochełek near Bydgoszcz. A strict field experiment was set up as a randomized block design in the years 2010-2012, with 4 repetitions, on lessive soil, very good rye complex, formed from sandy clay. The soil was characterized by a very high content of assimilable phosphorus and high concentration of potassium and magnesium. Organic carbon content in the soil amounted to 0.73%, and its pH was slightly acidic. Chemical analyses were carried out in the laboratories of the Faculty of Agriculture and Biotechnology, UTP in Bydgoszcz. Determination of assimilable phosphorus and potassium was made using the Egner-Riehm (DL) method and magnesium using the Schachtschabel method. Organic carbon content was determined using the dichromate oxidation procedure (Pansu and Gautheyron, 2006). Plot area was 14 m^2. In the particular study years, in July and August, white mustard ‘Bamberka’ was sown as a stubble crop. The experimental factors were the method of field cultivation after winter wheat harvest and the sowing method: A – traditional: ploughing, soil preparation with cultivation unit, seed drilling, B – simplified: stubble discing, broadcast sowing, harrowing, C – simplified+: stubble discing, broadcast sowing with a 20% increase in the sowing amount, harrowing, and before winter wheat harvest, D – broadcast sowing (zero cultivation), E – broadcast sowing with a 20% increase in the sowing amount (zero+). Seed sowing on plots A, B, and C was carried out between August 16th and 18th in the form of seed drilling (A) and broadcast sowing (B and C). On plots D and E, broadcast sowing was carried out into maturing winter wheat on July 20th. White mustard was sown in the amount of 15 kg on plots A, B, and D and 18 kg on plots C and E. Planned plant density amounted to 200 and 240 plants·m^{-2}, respectively. No fertilization was applied in the stubble crop cultivation.

In all of the study years observation of the course of plant development was carried out with dates of the initiation of particular developmental stages of mustard being determined, as well as density after emergence [plants·m^{-2}] and plant growth dynamics. To determine plant growth dynamics, plant height measurement and green and dry matter yield determinations were carried out four, six, and eight weeks after full emergence of plants sown after winter wheat harvest. With white mustard sown into maturing wheat the time to the I, II, and III measuring dates were 9–10, 11–12, and 13–14 weeks, respectively. Dry matter yield was determined through the collection of green matter samples during each measuring period and was harvested from 2 m^2 lots on every plot. Samples were weighed, dried at the temperature of 50^{o}C, and then weighed again. Calculations of accumulation pace (AP) of white mustard green matter yield were done according to the equations:

$AP_I = GMY_I : ND_I$

$AP_{II} = GMY_{II} : ND_{II}$

$AP_{III} = GMY_{III} : ND_{III}$

where:

AP_I, AP_{II}, AP_{III} – accumulation pace in first, second and third measurement date respectively;

GMY_I, GMY_{II}, GMY_{III} – green matter yield [kg·ha^{-1}] in first, second and third measurement date respectively;

ND_I, – number of days between sowing and first measurement date (40 days for A, B and C, whereas 68 days for D and E;

ND_{II}, ND_{III} – number of days between first and second and between second and third growth period (14 days).

Weather conditions during the stubble crop growth are described on the basis of the measurements carried out at the meteorological station in Mochełek, and processed by the Department of Melioration and Agrometeorology of the Faculty of Agriculture and Biotechnology of UTP University of Science and Technology in Bydgoszcz (Table 1).

Results of the field experiment were statistically processed with the analysis of variance using the two-way ANOVA. Significance of the differences was determined with the Tukey's confidence half-intervals, for the significance level of $P < 0.05$.

RESULTS

Weather conditions in the three-year study period were unfavourable for stubble crop cultivation due to very high precipitation in July and in the first ten days of August (Table 1). The above weather course caused a delay in winter wheat harvest, and, therefore, a delay in white mustard sowing on plots with traditional and simplified cultivation (A, B, and C), which was carried out between August 16th and 18th. Due to the delayed harvests the plants from plots with no soil cultivation (D and E), where broadcast sowing was carried out into maturing wheat (July 20th), also developed poorly. As a consequence, white mustard density was 30.2–58.6% lower than predicted.

Results of the conducted research indicate unambiguously that field preparation and sowing method diversified plant number per area unit. On average for the three years of the study the highest white mustard plant density was obtained in the variant with simplified soil cultivation and broadcast sowing with a 20% increase in the sowing amount (Table 2). Significantly lower plant numbers were found after the application of traditional cultivation with seed drilling (A) and in simplified cultivation with broadcast sowing (B). The lowest plant density occurred on plots with zero cultivation and broadcast sowing into maturing winter wheat (D). Increasing the sowing amount by 20% contributed to a significant increase in white mustard density both on plots with zero cultivation (E) and with simplified cultivation (C).

An interaction was found between the study factors and the study years, in relation to plant density after emergence. In the years 2011 and 2012, the use of broadcast sowing before wheat harvest resulted in a significantly lower white mustard density than in traditional cultivation or even in simplified cultivation, whereas in 2010 the density of plants after emergence was at a similar level on those plots as it was in traditional and simplified cultivation (Table 2). In 2010, plant density diversification resulted mainly from seed sowing amount.

Table 1. Weather conditions in the study region

Years	July	August	September	October	Mean/Total VII-X
Average air temperature, °C					
2010	21.6	18.4	12.2	5.5	14.4
2011	17.5	17.7	14.3	8.4	14.5
2012	18.8	17.6	13.3	7.4	14.3
Mean 2010–2012	19.3	17.9	13.3	7.1	14.4
Mean 1949–2015	18.1	17.5	13.2	8.1	14.2
Total monthly precipitation, mm					
2010	107.4	150.7	74.7	2.3	335.1
2011	132.5	67.7	37.0	13.2	250.4
2012	115.6	51.8	25.1	40.3	232.8
Mean 2010–2012	118.5	90.1	45.6	18.6	272.8
Mean 1949–2015	73.3	52.8	41.4	32.0	199.5

Table 2. White mustard plant density after emergence [pcs.$\cdot$m^{-2}]

Soil cultivation and sowing variant	2010	2011	2012	Mean 2010–2012
A – traditional, ploughing, soil enriching with cultivation unit, seed drilling	101.0b*	134.0a	139.5a	124.8b
B – simplified, stubble discing, broadcast sowing, harrowing	111.0b	101.0b	106.5b	106.2c
C – simplified+, stubble discing, broadcast sowing with a 20% increase in the sowing amount, harrowing	150.0a	127.0a	113.5b	130.2a
D – zero cultivation: broadcast sowing before winter wheat harvest	110.0b	72.30c	68.0c	83.4e
E – zero cultivation+: broadcast sowing before winter wheat harvest with a 20% increase in the sowing amount	126.0ab	90.0b	82.0c	99.3d
Mean	119.6	104.9	101.9	108.8

* mean values in the columns marked with the same letters do not significantly differ statistically for $P < 0.05$

Plants reached different heights in every year of investigation (Table 3). They were the tallest in 2011 and the shortest in 2010. A significant effect of soil cultivation and sowing methods on white mustard plant height was found. In all study years, on the first measurement date, the tallest plants were found on plots with white mustard sown into maturing winter wheat (variants D and E). Significantly smaller plants were obtained in simplified cultivation. On average, over the three years of research, traditional cultivation resulted in significantly shorter plants in the period of the first measurement than those found in sowing carried out before wheat harvest, but they were significantly taller than those in the variants with simplified cultivation. On the second measurement date (six weeks after emergence), white mustard with seed drilling in traditional soil cultivation (A variant) on average for all years of the research was of similar height to the plants from plots with broadcast sowing before winter wheat harvest (D and E variants). Significantly shorter plants were obtained on plots with simplified cultivation.

Table 3. White mustard plant height after emergence [cm]

Soil cultivation and sowing variant**	2010	2011	2012	2010–2012
First measurement date***				
A – traditional	16.73b*	25.93b	50.95a	31.20b
B – simplified	14.50b	26.75b	27.60b	22.95c
C – simplified+	16.05b	22.43b	25.65b	21.38c
D – zero	42.88a	48.10a	48.00a	46.33a
E – zero+	39.80a	50.70a	49.85a	46.78a
Mean	25.99	34.78	40.41	33.73
Second measurement date				
A – traditional	39.75b	63.58ab	63.15a	55.50a
B – simplified	34.85b	67.45a	41.35cd	47.88b
C – simplified+	39.75b	60.20bc	37.90d	45.95b
D – zero	57.13a	56.33c	50.70bc	54.72a
E – zero+	53.50a	63.28ab	52.00b	56.26a
Mean	45.00	62.17	49.02	52.06
Third measurement date				
A – traditional	47.25b	86.35a	76.25a	69.95a
B – simplified	39.80b	81.25ab	47.90c	56.32c
C – simplified+	45.20b	76.00ab	43.35c	54.85c
D – zero	58.70a	72.60b	58.00b	63.10b
E – zero+	62.45a	73.35b	59.55b	65.12b
Mean	50.68	77.91	57.01	61.87

*** first, second, and third measurement dates were 4, 6, and 8 weeks after full emergence of plants sown after winter wheat harvest (A, B and C variants), whereas they were 9–10, 11–12, and 13–14 weeks, respectively, after sowing of white mustard into maturing winter wheat (D and E variants)
** denotations as in Table 2
* mean values marked with the same letters within a given measurement date do not significantly differ statistically for $P < 0.05$

On the last measurement date, the best results were found for plants in traditional cultivation. Soil cultivation and sowing methods diversified unequally white mustard plant height in the study years. In 2010, regardless of the measurement date, white mustard after traditional and simplified soil cultivation was significantly shorter than after broadcast sowing into maturing winter wheat. Similar results were obtained in 2011, but only on the first measurement date. In 2012, traditional cultivation was favourable to stem elongation to the most significant degree and, on the second and third measurement dates, these white mustard plants were the tallest.

White mustard growth dynamics depended on the cultivation method (Fig. 1). In traditional cultivation with ploughing, white mustard stem elongation pace was not too high in the period between the sowing and four weeks after emergence (7.8 mm·day^{-1}), very high in the period between the first and second measurement date (17.36 mm·day^{-1}), and rather high in the period between the second and third measurement date (10.3 mm·day^{-1}). After simplified soil cultivation and broadcast sowing, initial growth was slow (5.74 mm·day^{-1}), and in the period between the first and second measurement date, the pace of growth was even slightly higher than after traditional cultivation, whilst between the second and third measurement date essentially a slowdown in growth occurred. The pace of white mustard growth with broadcast sowing into maturing winter wheat was low throughout the entire period from sowing to the final harvest. However, due to the white mustard growth period being longer by 28 days in these variants, the plants were taller before the final harvest than were those in simplified cultivation with sowing after winter wheat harvest.

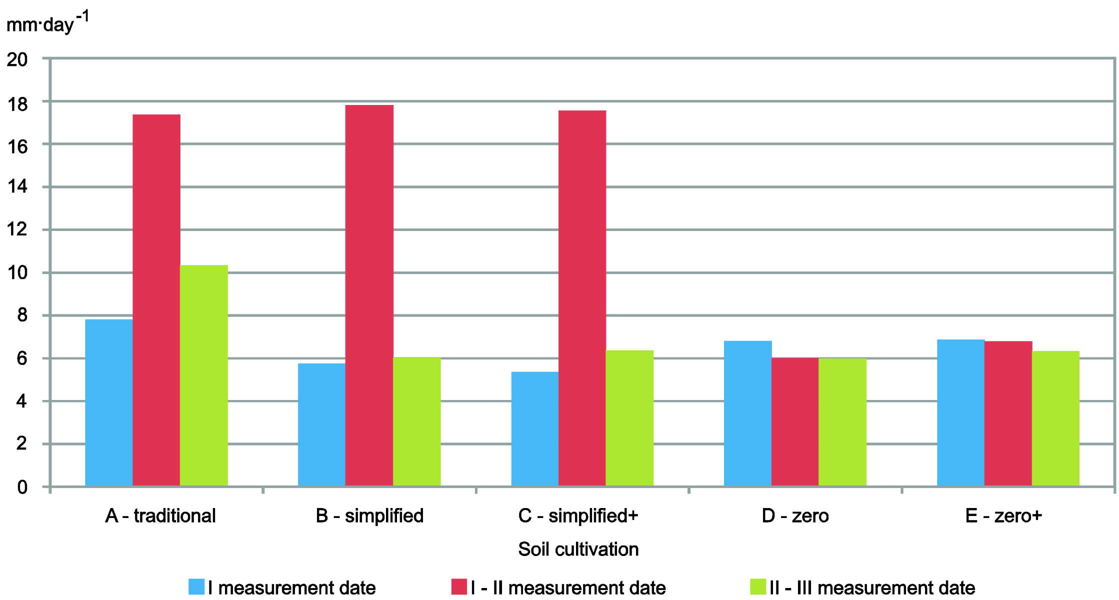

Fig. 1. White mustard plant growth dynamics in the particular periods – mean values for the years 2010–2012

The study results show that particular soil cultivation and sowing methods, in the three-year-long study period, significantly diversified the yield of white mustard green matter (Table 4). Only in 2010 did it not significantly depend on the studied factors. Simplification of soil cultivation and the application of broadcast sowing usually affected unfavourably the yield of white mustard biomass. However, in the second study year, six weeks after white mustard emergence, green matter yield did not statistically differ between the particular methods of soil cultivation or sowing. On average for the three years, the most satisfactory results for final green matter yield were obtained from the plot with traditional cultivation (A). Only in the second study year, four weeks after emergence, were the results after the application of traditional ploughing significantly poorer than on the plot with sowing into maturing winter wheat. The application of simplified cultivation with broadcast sowing between August 16th and 18th resulted in a significantly lower yield of white mustard green matter on the first and second measurement date in comparison with broadcast sowing before wheat harvest. However, final yield did not differ significantly on those plots.

Table 4. Green matter yield of white mustard grown as stubble crop [$Mg \cdot ha^{-1}$]

Soil cultivation and sowing variant**	2010	2011	2012	2010–2012
First measurement date***				
A – traditional	1.85a*	3.67b	7.25a	4.26a
B – simplified	1.43a	2.08b	1.88c	1.80c
C – simplified+	2.20a	2.94b	1.24c	2.13c
D – zero	2.45a	3.98ab	3.55b	3.32b
E – zero+	2.71a	5.77a	4.29b	4.26a
Mean	2.13	3.69	3.64	3.15
Second measurement date				
A – traditional	3.38a	7.38a	10.57a	7.11a
B – simplified	3.44a	5.57a	4.57c	4.52c
C – simplified+	3.99a	6.34a	4.50c	4.94bc
D – zero	5.48a	5.36a	7.53b	6.12ab
E – zero+	4.85a	5.95a	7.58b	6.13ab
Mean	4.23	6.12	6.95	5.76
Third measurement date				
A – traditional	5.28a	8.78a	12.16a	8.74a
B – simplified	5.95a	6.95ab	7.53b	6.81b
C – simplified+	6.12a	7.02ab	6.26b	6.47b
D – zero	6.15a	5.40b	7.84b	6.46b
E – zero+	6.01a	6.15b	7.73b	6.63b
Mean	5.90	6.86	8.30	7.02

*** denotations as in Table 3
** denotations as in Table 2
* mean values marked with the same letters within a given measurement date do not significantly differ statistically for $P < 0.05$

Dynamics of white mustard green matter yield accumulation depended on the soil cultivation method (Fig. 2). After the application of traditional ploughing, it was of medium height in the period between the sowing and four weeks after emergence (107 kg·ha^{-1}·day^{-1}), very high in the period between the first and second measurement date (204 kg·ha^{-1}·day^{-1}), and of medium height in the period between the second and third measurement date (116 kg·ha^{-1}·day^{-1}). After the application of simplified soil cultivation and broadcast sowing the initial increase in green matter yield was very low (45-53 kg·ha^{-1}·day^{-1}), while in the period between the first and second measurement date the pace of green matter yield formation was very high (194-201 kg·ha^{-1}·day^{-1}). In the period between the second and third measurement date a slowdown in yield formation occurred, although it was still very high (164 kg·ha^{-1}·day^{-1}) on plot B and medium high (109 kg·ha^{-1}·day^{-1}) on plot C. Dynamics of the accumulation of white mustard green matter yield from broadcast sowing into maturing winter wheat was very low in the period between the sowing and the first measurement date, very high in the period between the first and second measurement date, and very low in the period between the second and third measurement date.

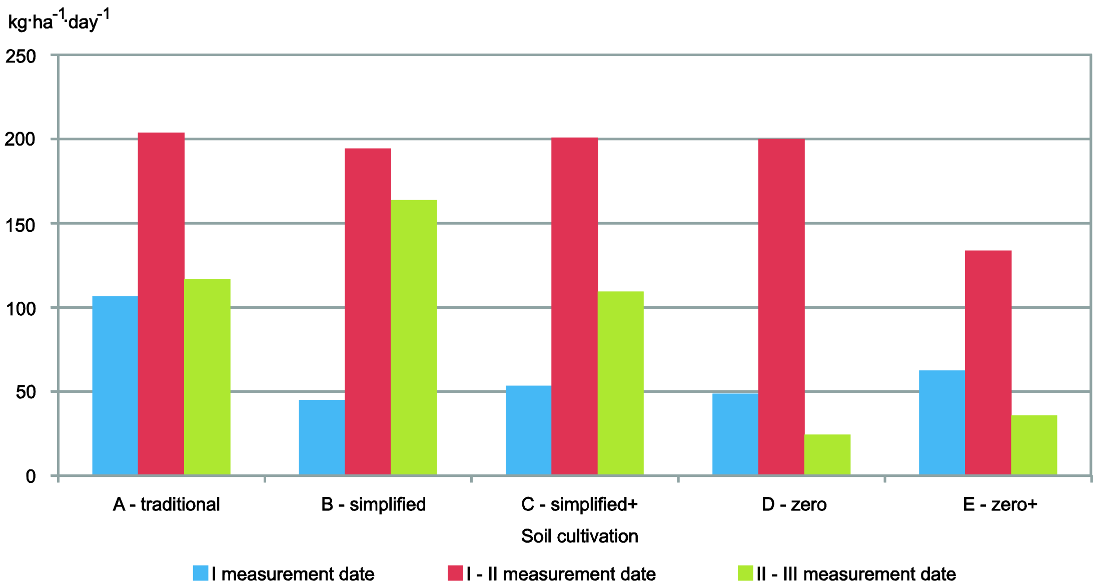

Fig. 2. Pace of white mustard green matter yield accumulation in stubble crop – mean values for the years 2010–2012

White mustard dry matter yield on the first measurement date (four weeks after emergence) in all the study years depended on the methods of soil cultivation and sowing (Table 5). On average from the study years, the highest yield on the first measurement date was obtained with zero cultivation and broadcast sowing into maturing winter wheat in an increased sowing amount (E). Significantly lower yield was collected after the application of traditional cultivation with sowing after the winter wheat harvest (A) and from the plot with zero cultivation and broadcast sowing into wheat in a regular amount (D). The lowest yield at the first measurement date came from white mustard after the application of simplified soil cultivation and broadcast sowing after winter wheat harvest (B and C). In particular years the effect of the study factor on dry matter yield at the first measurement date was diversified. In 2010, the highest yield was obtained from plot E, whereas the lowest yield was characteristic for plot B. In 2011, zero cultivation with broadcast sowing led to the production of higher yield than that for mustard seed sown after wheat harvest and the application of traditional or simplified soil cultivation. On the second and third measurement dates (six and eight weeks after emergence), the yield of white mustard dry matter on the plots with traditional cultivation (A) and with no cultivation and sowing into maturing wheat (D, and E) was significantly higher than on the plots with simplified cultivation. The study factor diversified dry matter yield on the second measurement date in 2011 and 2012, whereas on the third measurement date only in 2012 was dry matter yield diversified. In 2010 and 2011, no significant effect of the methods of soil cultivation and sowing on the final yield of white mustard dry matter was found. On average for the three study years, yields were the highest after the application of traditional ploughing and after zero cultivation with sowing in an increased amount into maturing winter wheat, whereas it was significantly lower in simplified cultivation.

Table 4. Dry matter yield of white mustard grown as stubble crop [Mg·ha^{-1}]

Soil cultivation and sowing variant**	2010	2011	2012	2010–2012
First measurement date***				
A – traditional	0.28ab*	0.47c	0.86a	0.53b
B – simplified	0.24b	0.30c	0.26c	0.27c
C – simplified+	0.36ab	0.38c	0.18c	0.31c
D – zero	0.44ab	0.80b	0.52b	0.58b
E – zero+	0.46a	1.08a	0.61ab	0.72a
Mean	0.36	0.61	0.49	0.48
Second measurement date				
A – traditional	0.57a	1.21ab	1.70a	1.16a
B – simplified	0.58a	0.79b	0.59c	0.65b
C – simplified+	0.67a	0.93ab	0.68c	0.76b
D – zero	1.08a	1.21ab	1.32b	1.20a
E – zero+	0.99a	1.37a	1.36b	1.24a
Mean	0.78	1.10	1.13	1.00
Third measurement date				
A – traditional	1.06a	1.77a	1.84a	1.56a
B – simplified	1.17a	1.44a	0.97c	1.19b
C – simplified+	1.25a	1.41a	0.86c	1.17b
D – zero	1.49a	1.24a	1.41b	1.38ab
E – zero+	1.40a	1.49a	1.45b	1.45a
Mean	1.27	1.47	1.31	1.35

*** denotations as in Table 3
** denotations as in Table 2
* mean values marked with the same letters within a given measurement date do not significantly differ statistically for $P < 0.05$

Dynamics of white mustard dry matter yield accumulation depended on the study factor (Fig. 3). In the period between the sowing and the first measurement date, dry matter yield increase was low in all the soil cultivation variants and varied from 7 kg·ha^{-1}·day^{-1} in simplified cultivation with a regular sowing amount to 13 kg·ha^{-1}·day^{-1} after traditional ploughing. Dynamics of dry matter yield formation was very high in the period between the first and second measurement date on the plots with traditional and zero cultivation (45 and 44 kg·ha^{-1}·day^{-1}, respectively) and with zero+ cultivation (37 kg·ha^{-1}·day^{-1}). In this period a significant increase in white mustard dry matter yield was also found after the application of simplified soil cultivation with broadcast sowing. In the period between the second and third measurement date, dry matter yield increase was high after the application of traditional and simplified+ cultivation, and very high on the plot with simplified cultivation. After the application of zero and zero+ cultivation with broadcast sowing into maturing wheat, dry matter yield increase was very low in this period (13 and 15 kg·ha^{-1}·day^{-1}, respectively).

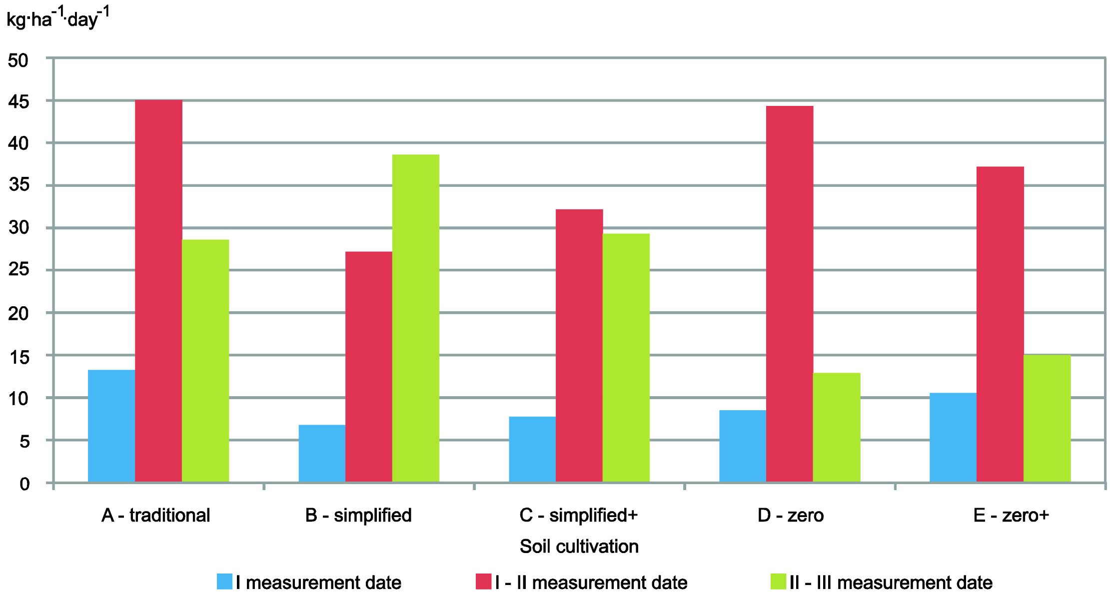

Fig. 3. Dynamics of white mustard dry matter yield accumulation in stubble crop – mean values for the years 2010–2012

DISCUSSION

The research was carried out in the conditions of excessively high precipitation in July and, in 2010, in August. This resulted in stubble crop sowing being delayed, which made it impossible to attain high dry matter yield. Plants were relatively short (55–70 cm) during the final harvest. In the studies by Kisielewska (2010), conducted in the same soil conditions in the years 2005–2007, white mustard sown in the second ten days of July attained a height of between 91 cm and 102 cm, and those sown in the second ten days of August reached between 101 cm and 108 cm. The poor plant growth in the present study might have been a result of the lack of white mustard fertilization with nitrogen, which in the studies cited above was applied in the amount of 34.5 kg·ha^{-1}. According to the studies by Kisielewska and Harasimowicz--Hermann (2008 a, b), the highest white mustard dry matter yield in stubble crop may be obtained when the sowing takes place in the first half of August. However, the highest green matter yield was obtained by them when the sowing was performed in the second half of that month. Therefore, sowing carried out in the present research between August 16^{th} and 18^{th} on plots A, B, and C may be considered as nearly optimum, whereas broadcast sowing on plots D and E on July 20^{th} was definitely too early. The present study indicates, however, the dominant effect of soil cultivation technology on white mustard yield as a stubble crop. The lowest white mustard green and dry matter yield was obtained from simplified soil cultivation and sowing after wheat harvest. A better solution for white mustard yield was demonstrated to be broadcast sowing before wheat harvest. This is a favourable technology due to the low costs of this kind of cultivation, and the produced biomass may be considered sufficient if intended for green manure. White mustard dry matter yield obtained in the present study on the plot with traditional ploughing and seed drilling varied from 1.06 $Mg \cdot ha^{-1}$ to 1.84 $Mg \cdot ha^{-1}$ and amounted to, respectively, 25.38% and 44.9% of the yield obtained in the same soil conditions and on similar sowing dates in the years 2005–2006 by Kisielewska and Harasimowicz-Hermann (2008a,b). However, in this cited research, mineral fertilization was applied at the doses of 34.5 $kg \cdot ha^{-1}$ N, 50 $kg \cdot ha^{-1}$ P, and 70 $kg \cdot ha^{-1}$ K, whereas in the present study no fertilizers were applied. On the other hand, in the research by Wojciechowski and Wermińska (2016), white mustard cultivated with no mineral fertilization produced dry matter yield higher by 1.2 $Mg \cdot ha^{-1}$ than that found in the present research, which indicates the significant effect of weather conditions. In the present study the lowest yield was obtained in 2010, a year in which extremely high precipitation occurred in July and August that was followed by low temperatures in September and October. The optimum precipitation total for white mustard grown as stubble crop between the beginning of July and the end of August is about 170 mm (Wilczewski *et al*., 2018). In the present study it was near this value only in 2012. In the years 2010 and 2011 the precipitation was higher than the optimum by 88.1 mm and 30.2 mm, respectively. However, even in the year 2012, which was characterized by an optimum precipitation total, dry matter yield was low. In that particular year a very strong effect of the cultivation technology on white mustard yield was found. Biomass of white mustard cultivated with the application of traditional ploughing was nearly twice as high as in simplified cultivation.

Simplifications in soil cultivation and sowing significantly decreased white mustard green matter yield. An increase by 20% in the amount of seeds that were sown did not compensate for the poorer conditions for mustard growth and yield that were the consequence of simplified or zero cultivation. However, white mustard dry matter yield on the plot with broadcast sowing into maturing wheat was nearly the same as with traditional ploughing with seed drilling. This is a result of the different mustard growth period length on particular plots. Plants from broadcast sowing into maturing winter wheat were collected at full flowering: BBA 64 (Gąsowski and Ostrowska, 1993), whereas in traditional cultivation they were collected during siliques forming, when the first fruits with seeds on the main shoot reached normal size: BBA 71. This is in line with the studies by Sowiński *et al.* (1995) that showed that white mustard sown as stubble crop in the first ten days of August forms siliques in October. Therefore, the white mustard development course in the present research was correct. Diversification in development advancement under the effect of differing soil cultivation and sowing methods resulted in differences in dry matter content during harvest. On the plot with traditional cultivation, dry matter amounted to 17.8% on average, whereas on the plots with zero cultivation and broadcast sowing into maturing winter wheat it amounted to 21.4% and 21.8%, respectively, on plots D and E. The dry matter content found in the above-ground biomass of white mustard was relatively high. Numerous studies indicate that it most often is between 13% and 16% (Nowakowski *et al*., 1996; Nowakowski and Kostka-Gościniak, 1997; Nowakowski and Szymczak-Nowak, 1998). In the research by Kisielewska and Harasimowicz-Hermann (2008b), carried out in the same soil conditions, delaying sowing from July 19^{th}-20^{th} to August 16^{th}–17^{th} resulted in a decrease in the dry matter content from 26.9% to 16.6%. According to Kisielewska (2010), dry matter content in the above-ground biomass is significantly negatively correlated with the sowing date (r = -0845). In the research by this author, delaying sowing by one day resulted in a decrease in white mustard dry matter content by 0.4 percentage points. In the present research this value decreased on average by 0.14 percentage points. This lower pace of decrease in dry matter content, together with the delay in the sowing date, might have resulted from the high precipitation totals in July and August and from a slow initial growth and development of white mustard sown on July 20th into maturing winter wheat.

CONCLUSIONS

1. Simplification of soil cultivation for white mustard grown as stubble crop is possible, although substitution of classic ploughing and seed drilling with stubble discing and broadcast sowing caused a very significant decrease in the three years yield average of green and dry matter of white mustard.

2. White mustard responded relatively well to broadcast sowing into the field before winter wheat harvest. Green matter yield on those plots was significantly lower than in the variant with traditional cultivation, although dry matter yield did not differ significantly between these variants.

3. In two out of the three study years, white mustard dry matter yield, collected eight weeks after the emergence of plants sown after winter wheat harvest, did not depend significantly on the methods of soil cultivation and sowing, which indicates a high tolerance of the plant to simplified soil cultivation.

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PLONOWANIE GORCZYCY BIAŁEJ UPRAWIANEJ W MIĘDZYPLONIE ŚCIERNISKOWYM W ZALEŻNOŚCI OD SPOSOBÓW PRZYGOTOWANIA ROLI I WYSIEWU NASION

Streszczenie

Dla podtrzymania bioróżnorodności agrocenoz i wysokiej urodzajności gleby, w warunkach intensyfikacji i specjalizacji produkcji, uzasadnione jest poszukiwanie uproszczonych technologii uprawy międzyplonów ścierniskowych, pozwalających na ich stosowanie na szerszą skalę. Celem badań było określenie możliwości uproszczenia technologii uprawy gorczycy białej w międzyplonie ścierniskowym oraz ocena wpływu tych uproszczeń na plonowanie rośliny. Badania polowe przeprowadzono w Stacji Badawczej w Mochełku koło Bydgoszczy w latach 2010–2012, na glebie płowej, należącej do kompleksu żytniego bardzo dobrego. Czynnikiem doświadczenia był sposób przygotowania roli i siewu: A – tradycyjny orkowy, z siewem rzędowym nasion, B – uproszczony – talerzowanie ścierniska, siew rzutowy nasion, C – uproszczony – talerzowanie ścierniska, siew rzutowy nasion ze zwiększoną o 20% ilością wysiewu, D – siew rzutowy nasion przed zbiorem pszenicy ozimej, E – siew rzutowy nasion przed zbiorem pszenicy ozimej ze zwiększoną o 20% ilością wysiewu. Siew nasion w obiektach A, B i C wykonywano w terminie 16–18 sierpnia, a w obiektach D i E 20 lipca. W okresie badań wystąpiły bardzo wysokie opady w lipcu i sierpniu. W warunkach nadmiaru wilgoci plonowanie gorczycy białej było na relatywnie niskim poziomie – od 1.18 $Mg \cdot ha^{-1}$ w obiektach z uprawą uproszczoną do 1.56 $Mg \cdot ha^{-1}$ po zastosowaniu uprawy tradycyjnej. Uproszczenie uprawy roli skutkowało istotnym zmniejszeniem plonu zielonej i suchej masy gorczycy białej w porównaniu z uprawą tradycyjną. Najwyższą dynamikę gromadzenia plonu stwierdzono w okresie od 4. do 6. tygodnia po wschodach roślin uprawianych w technologii tradycyjnej oraz od 4. do 8. tygodnia po wschodach w wariancie z uproszczoną uprawą gleby. Uproszczenie uprawy roli pod gorczycę białą uprawianą w międzyplonie ścierniskowym jest możliwe, jednak wpływa ono negatywnie na plon zielonej i suchej masy. Zastąpienie klasycznej uprawy orkowej i siewu rzędowego talerzowaniem ścierniska i siewem rzutowym spowodowało bardzo istotne zmniejszenie plonu zielonej i suchej masy gorczycy białej. Gorczyca biała relatywnie dobrze reagowała na siew rzutowy wykonywany przed zbiorem pszenicy ozimej.

Słowa kluczowe: gorczyca biała, międzyplon ścierniskowy, siew rzutowy, uprawa uproszczona, uprawa zerowa