Agronomy Research **18**(2), 628–639, 2020
https://doi.org/10.15159/AR.20.034

Effect of sowing method and density on the physical properties of the seed bed and oilseed rape yield

E. Wilczewski*, G. Harasimowicz-Hermann and G. Lemańczyk

UTP - University of Science and Technology, Al. prof. S. Kaliskiego 7, PL85-796 Bydgoszcz, Poland
*Correspondence: edward@utp.edu.pl

Abstract. Oilseed rape (*Brassica napus* L. var. *napus*), as a plant requiring shallow sowing, is sensitive to water deficiency in the soil during germination. The lack of rainfall results in the delay of emergence and a reduction in plant density before winter. The aim of the present study was to assess the effect of various sowing methods (sowing with the furrow method – in furrows 6–8 cm deep; direct sowing into non-cultivated soil using disc coulters and conventional sowing) on the physical properties of the seed bed and winter oilseed rape yield depending on the sowing density (40, 60, 80, 100 and 120 seeds per m^2). The field study was carried out in 2011–2014, in *Albic Luvisols* with fine sandy loam texture. Furrow sowing and direct sowing provided higher seed bed moisture than conventional sowing. The use of furrow sowing resulted in the formation of a greater number of siliques per plant than in other sowing methods. Furrow sowing made it possible to produce a higher seed yield than direct sowing, however the oilseed rape yield did not increase significantly in relation to conventional sowing. The winter rapeseed yield after sowing 80–120 seeds per m^2 was significantly higher than after sowing 40 and 60 seeds per m^2. When using low sowing densities (40 seeds per m^2), furrow sowing made it possible to produce a higher seed yield than conventional sowing. The possibility of improving oilseed rape yield by differentiating sowing methods at a density of 60–120 seeds per m^2 was not demonstrated.

Key words: direct sowing, furrow sowing, plant density, seed bed moisture, sowing method.

INTRODUCTION

Oilseed rape is a plant of growing economic importance. It is now one of the most important oil crops in the World (Abbasian & Rad, 2011; Szczepaniak, 2014; Wollmer et al., 2018). This plant acts as profitable break crop in cereal crop rotations breaking the life-cycle of common cereal pathogens and pests and also improving the structural properties of the soil (Lääniste et al., 2016). In Poland, the area of oilseed rape cultivation has increased more than 3 times over the past 50 years, and the increase in seed yield has been on average 29 kg ha^{-1} $year^{-1}$ (Central Statistical Office, 2003 & 2017; Zając et al., 2016). One of the major problems in oilseed rape cultivation is a relatively high yield variability, resulting from the sensitivity of this plant to weather conditions (Dzieżyc et al., 2013; Mirzaei et al., 2013). Winter oilseed rape is sensitive to water deficiency in the soil during germination and emergence (Aboutalebian et al., 2012; Harker et al., 2012a), as well as during intensive plant growth in spring (Mirzaei et al., 2013). Plants underdeveloped before winter are not very resistant to low temperatures in winter

(Velička et al., 2010 and 2012; Waalen et al., 2013; Martinez-Feria, 2015). The high sensitivity of winter rape seeds to soil moisture during germination is associated with a large proportion of seed cover in relation to seed weight and their small size, forcing the use of shallow sowing, from 1 cm to 2 cm (Martinez-Feria, 2015). According to Harker et al. (2012a), seeding at a depth of 1 cm will not only improve winter oilseed rape emergence density, but will also decrease days to emergence, increase ground cover by plants, decrease days to flowering and days to maturity and tend to decrease green seed levels compared to sowing at a depth of 4 cm. On the other hand, droughts occurring in some years in Eastern Europe during the sowing period prevent the seeds from collecting water from such a shallow soil layer. As a result, plant emergence is delayed and uneven (Wilczewski et al., 2014). The improvement of germination conditions of plants can be achieved by the application of furrow sowing, according to Patent PL215714 B1 (Wilczewski & Harasimowicz-Hermann, 2014). Furrow sowing allows the seeds to be placed in a deeper, more humid soil layer, while maintaining their shallow cover. Also, the abandonment of pre-sow ploughing and the use of direct sowing ensures a higher moisture of the seed bed (Wilczewski et al., 2014). Ensuring higher moisture of the seed bed can be particularly important when using a low sowing density (40–80 seeds per m^2), where incomplete germination results in too few plants being produced per area unit (Kazemeini et al., 2010; Balodis & Gaile, 2015).

The aim of this study was to assess the effect of different sowing methods (sowing with the furrow method - in furrows 6–8 cm deep, in accordance with Patent PL215714 B1; direct sowing into non-cultivated soil using disc coulters and conventional sowing) on the physical properties of the seed bed and the yield of winter oilseed rape depending on the sowing density (40, 60, 80, 100 and 120 seeds per m^2).

MATERIALS AND METHODS

Experimental design and conditions

The field study was conducted in 2011–2014 at the Research Station in Mochełek (53°13' N; 17°52' E) near Bydgoszcz, Poland. Three sowing methods were tested (factor I): A – conventional row sowing (control), B – sowing in furrows 6–8 cm deep, using a row drill, according to patent PL215714 (Wilczewski & Harasimowicz-Hermann, 2014); C – furrow sowing directly in the stubble (using a drill with disc coulters). These methods were assessed in 5 variants of sowing density (factor II): 40, 60, 80, 100 and 120 seeds m^{-2}. The split-plot experimental design with four repetitions was used. Field experiments were performed on *Albic Luvisols* (*LVab*) with a fine sandy loam texture (WRB, 2014). Furrow sowing involves placing seeds in a seed bed at the bottom of a furrow formed to a depth of 6–8 cm from the flat surface of the field. For sowing, a seeder equipped with coulters which have a larger wing opening angle (10–20 degrees) is used. During operation, the coulter wings make a furrow 6–10 cm wide and 6–8 cm deep, depending on the coulter setting. Seeds falling from the seeder to the bottom of the furrows are covered by a 1 cm layer of soil sliding by gravity from the ridges.

The soil was characterized by a high content of available forms of phosphorus and potassium (70.6 and 194.2 mg of P and K in kg of dry soil, respectively), a very high magnesium concentration (98.7 mg of Mg in kg of dry soil) and a neutral (first and third year of the study) or slightly acidic reaction (second year of the study).

The total rainfall in August was high in the first year of the study and average in the second and third years of the study (Table 1). In the first year of the study, there were quite low precipitation totals in September and October, very low in November and in the March-May period, and excessively high in June and July, when they exceeded the long-term averages by 147.3 and 55.6% respectively. In the second year of the study, the precipitation totals occurring in autumn and spring were well matched to the needs of winter oilseed rape. The precipitation in May was higher than the average multi-year total for this month by as much as 107.9%. Only in April 2013 there was a shortage of precipitation (-50.0%, compared to average for 1949–2019). In the third year of the study, the precipitation total and distribution were the closest to the long-term averages for the study area.

Table 1. Weather conditions at the experiment site

Months	2011–2012	2012–2013	2013–2014	1949–2019	2011–2012	2012–2013	2013–2014
Total precipitation (mm)					Deviations from the total precipitation of 1949–2019 (%)		
August	67.7	51.8	56.6	53.2	27.3	-2.6	6.4
September	37	25.1	64.1	42.1	-12.1	-40.4	52.3
October	13.2	40.3	18.6	34.3	-61.5	17.5	-45.8
November	9	53.7	28.5	33.1	-72.8	62.2	-13.9
December	46.2	27.2	19.1	32.6	41.7	-16.6	-41.4
January	62.9	44	23.5	25.6	145.7	71.9	-8.2
February	29.6	31.3	18	19.1	55.0	63.9	-5.8
March	15.4	14.7	49.7	24.7	-37.7	-40.5	101.2
April	26.5	13.6	40.7	27.2	-2.6	-50.0	49.6
May	25.4	91.7	65.7	44.1	-42.4	107.9	49.0
June	133.8	49.3	44.9	54.1	147.3	-8.9	-17.0
July	115.6	79	55.4	74.3	55.6	6.3	-25.4
August–July	582.3	521.7	484.8	464.4	25.4	12.3	4.4
Average air temperature (°C)					Deviations from the average air temperature of 1949–2019 (°C)		
August	17.7	17.6	18.1	17.6	0.1	0.0	0.5
September	14.3	13.3	10.7	13.3	1.0	0.0	-2.6
October	8.4	7.4	8.2	8.2	0.2	-0.8	0.0
November	2.7	4.5	4.9	3.3	-0.6	1.2	1.6
December	2.7	-2.5	1.8	-0.4	3.1	-2.1	2.2
January	-0.3	-3.5	-3.2	-2.2	1.9	-1.3	-1.0
February	-5.4	-0.9	2	-1.4	-4.0	0.5	3.4
March	4.6	-3	5.6	2	2.6	-5	3.6
April	8.4	7	9.9	7.6	0.8	-0.6	2.3
May	14.5	14.2	13.3	12.9	1.6	1.3	0.4
June	15.2	17.4	16	16.4	-1.2	1.0	-0.4
July	18.8	18.9	21.5	18.1	0.7	0.8	3.4
August–July	8.5	7.5	9.1	7.9	0.6	-0.4	1.2

The air temperature in autumn was relatively high in the first and second year of the study, which favoured the intensive development of plants and the formation of a thicker root neck than in the third year of the study, characterized by cool September, when the temperature was lower by 2.6 °C compared to average for 1949−2019. Thermal conditions in winter were considerably different in individual years of the study. They were the most unfavourable for winter oilseed rape in the 2011–2012 season, in which the minimum temperature reaching -22 °C occurred on February 5, with not very thick snow cover. In the second and third years of the study, thermal conditions in winter were favourable for winter oilseed rape. Although the average temperatures in March 2013 were as much as 5°C lower than the long-term average, but they were not harmful to this plant.

Crop management

Seeds of winter oilseed rape (*Brassica napus* L. var. *napus*) were sown after the harvest of winter wheat in the period of 25 August – 3 September. Open pollinated cultivar 'Californium' was used in the research. The weight of 1,000 seeds used for sowing was 4.25, 4.60 and 4.31 g, respectively, in 2011, 2012 and 2013. Fertilization of oilseed rape with phosphorus (70 kg ha^{-1} P_2O_5) and potassium (140 kg ha^{-1} K_2O) was applied directly after the harvest of the previous crop (on stubble). Nitrogen (210 kg ha^{-1} N) was applied at three rates. The first rate (40 kg ha^{-1} N) was spread on stubble (together with phosphorus and potassium); the second rate (100 kg ha^{-1} N) was spread in early spring (for starting growth). The last rate (70 kg ha^{-1} N) was applied at BBCH 55–57 stage (Böttcher et al., 2016).

The control of dicot and monocot weeds was carried out immediately after sowing seeds with the preparation Butisan Star 416 SC (a.i. metazachlor + qinomerak) at a dose of 2.5 dm^3 ha^{-1}. In addition, in the first and third years of the study, an additional treatment was applied to control monocot weeds. This treatment in the first year of the study was carried out at the stage of 4–6 oilseed rape leaves using Fusilade Forte 150 EC (a.i. fluazifop-P-butyl), at a dose of 1.5 dm^3 ha^{-1}, and in the third year of the study in the early spring, at the stem formation stage, with Elegant 0.5 EC (a.i. qizalofop-P-ethyl) at a dose 1 dm^3 ha^{-1}. The control of pests of winter oilseed rape was carried out by performing two or three chemical treatments in individual years of conducting the field study. The first treatment was performed using Proteus 110 OD (a.i. thiacloprid + deltamethrin) at a dose of 0.6 dm^3 ha^{-1}, in the early spring, after observing the appearance of ceutorrhynchid beetles. The second treatment was carried out during the oilseed rape budding season, mainly to control rape blossom beetle. In the first year, Mospilan 20 SP (a.i. acetamiprid) was used for this purpose, in a dose of 0.1 kg ha^{-1}, and in subsequent years, Fastac 100 EC (a.i. alpha-cypermethrin) in a dose 0.1 dm^3 ha^{-1}. In the first year of the study, the treatment was also applied during the fall of flower petals with Fastac 100 EC (a.i. alpha- cypermethrin) in a dose of 0.1 dm^3 ha^{-1}, in order to control the silique-damaging pests. To reduce seed shedding, Nu Film 96 EC (a.i. di-1-p-menthene) was used in a dose of 0.7 dm^3 ha^{-1}, during the technical maturity stage. Plant harvesting was carried out within 23–30 July, in one step with a Wintersteiger plot combine, harvesting crops from an area of 26 m^2. Seed moisture at harvest was 6.95, 10.69 and 7.31% in 2012, 2013 and 2014, respectively. Seed yield and 1,000 seed weight from individual plots have been calculated into 7% water content.

Measurements and observations made during oilseed rape growth

In the period from rape sowing to emergence, measurements of soil moisture and temperature in the vicinity of sown seeds were carried out. The measurement was carried out every second day with the TDR WET-2/d-02 probe, equipped with the HH2 reader. Based on the measurements made, the average moisture and temperature of the seed bed was calculated during oilseed rape germination and emergence. In the spring each year, the plant density was determined (No. m^{-2}). On each plot, plants were counted on a randomly chosen row with a length of 5 meters. Prior to the harvest of winter oilseed rape, on each plot, the number of siliques per plant (on 20 randomly chosen plants) and the number of seeds per silique (on 20 randomly collected siliques) were determined. After the harvest of rapeseed, the seed crop from each plot was weighed and seed samples were collected in which the 1,000 seed weight was determined. The measurement was performed in the seed laboratory of the Department of Agronomy. 500 seeds were counted from each sample and weighed on the analytical balance to the nearest 0.01 g, and the results were multiplied by two.

Statistical analysis

Statistical treatment of the data were performed using analyses of variance mixed model. When significant effects of the studied factor were found, Tukey's test at the significance level $P < 0.05$ was used to compare treatment means. Regression equations for the relationship between the sowing density and the seed yield for individual sowing methods were developed using the software *Statistica* for Windows.

RESULTS

The effect of a sowing method on winter oilseed rape yield and its structure

The sowing method significantly affected the moisture in the sowing bed space during plant germination and emergence (Table 2). It was the highest in treatments with direct sowing, significantly lower after the application of furrow sowing and the lowest in the vicinity of seeds sown with the conventional method. The soil surrounding seeds sown with the conventional method was characterized by a significantly higher temperature in this period than after the application of other methods of cultivation and sowing. A better moisture of the seed bed resulted in the acceleration of oilseed rape emergence, however, it did not affect the plant density after the end of emergence.

Table 2. Properties of the winter oilseed rape seed bed during germination and after emergence depending on the sowing method (means for 2012–2014)*

Trait	Control	Furrow sowing	Direct sowing	Mean	$HSD_{0.05}$
Moisture of the seed bed, %	6.33	8.97	10.85	8.72	1.06
Temperature of the seed bed, °C	21.63	21.17	21.07	21.29	0.23
Plant density in the autumn, No. m^{-2}	62.3	62.5	61.8	62.2	ns

* – the results presented in the table are averages of all sowing rates (40, 60, 80, 100 and 120 seeds per m^2); ns – non-significant differences.

The number of plants in spring was on average by 14% smaller than in autumn. No significant effect of the sowing method on the winter oilseed rape plant density after winter was found (Table 3). Furrow sowing has contributed to formation of a significantly larger number of siliques per plant and per m^2 than in treatments with the conventional and direct sowings. However, no effect of this factor on the number of seeds per silique and on the weight of 1,000 oilseed rape seeds was found. Oilseed rape yield was dependent on the sowing method. Furrow sowing resulted in a significantly higher seed yield than that obtained after direct sowing. The seed yield obtained after conventional sowing was not significantly different from that obtained in other treatments.

Table 3. Yielding and yield components of winter oilseed rape depending on the sowing method (means for 2012–2014)*

Trait	Control	Furrow sowing	Direct sowing	Mean	$HSD_{0.05}$
Plant density in the spring, No. m^{-2}	53.2	53.5	54.1	53.6	ns
Number of siliques per plant	117	133	115	122	12.9
Number of siliques per m^2	5711	6582	5829	6040	680
Number of seeds per silique	22.4	23.5	23.7	23.2	ns
1000 seeds weight, g	5.39	5.31	5.46	5.39	ns
Seed yield, Mg ha^{-1}	3.42	3.58	3.34	3.45	0.213

* – the results presented in the table are averages of all sowing rates (40, 60, 80, 100 and 120 seeds per m^2); ns – non-significant differences.

The effect of sowing density on the winter oilseed rape yield and its structure

Most yield components were dependent on the sowing density (Table 4). Each increase in sowing density within the range of 40 to 120 seeds per m^2 resulted in a significant increase in the number of plants per m^2. Along with increasing the sowing rate and thus significantly increasing the plant density, the number of siliques per plant decreased. It was the largest after sowing 40 seeds per m^2, significantly smaller after sowing 60 or 80 seeds per m^2 and the smallest at the two highest sowing densities. The number of siliques per m^2 was the largest after sowing 80, 100 or 120, and the smallest after sowing 40 seeds per m^2. In contrast to the plant density and the number of siliques per plant, the number of seeds per silique, although depending on the sowing density, was not subject to unidirectional changes. It was the largest after sowing 60 and the smallest after sowing 100 rape seeds per m^2. There was no significant variation in this characteristic for other sowing densities. The weight of 1,000 rape seeds was an average of 5.39 g and it was not dependent on the sowing rate.

Table 4. Yield components of winter oilseed rape depending on the sowing density (means for 2012–2014)

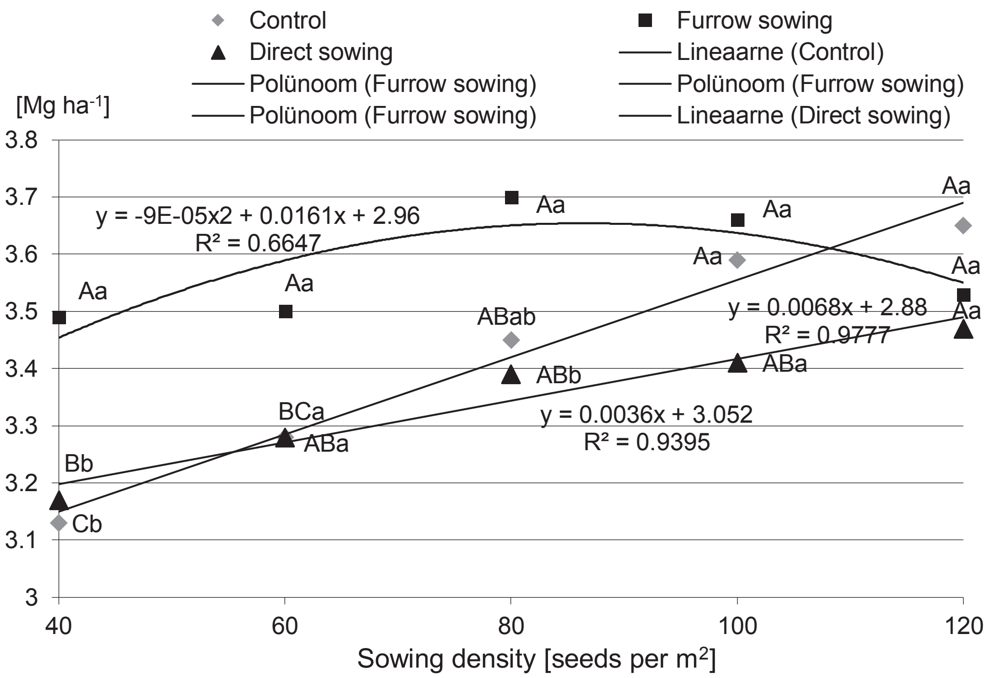
Trait	Sowing density (seeds m^{-2})						
	40	60	80	100	120	Mean	$HSD_{0.05}$
Plant density in the autumn, No. m^{-2}	35.0	49.4	63.8	75.2	87.6	62.2	3.46
Plant density in the spring, No. m^{-2}	31.8	44.2	55.5	64.3	72.2	53.6	2.69
Number of siliques per plant	149	134	123	105	97	122	11.8
Number of siliques per m^2	4554	5748	6628	6518	6756	6040	876
Number of seeds per silique	23.5	23.8	23.2	22.4	23.1	23.2	1.24
1000 seeds weight, g	5.53	5.43	5.29	5.38	5.30	5.39	ns
Seed yield, Mg ha^{-1}	3.27	3.35	3.51	3.55	3.55	3.45	0.149

ns – non-significant differences.

The sowing density significantly influenced the size of the seed yield. It was significantly higher after sowing 80, 100 and 120 seeds per m^2 than after sowing 40 and 60 seeds per m^2 (Table 4).

Interaction of the sowing method and sowing density in shaping winter oilseed rape yield and its structure

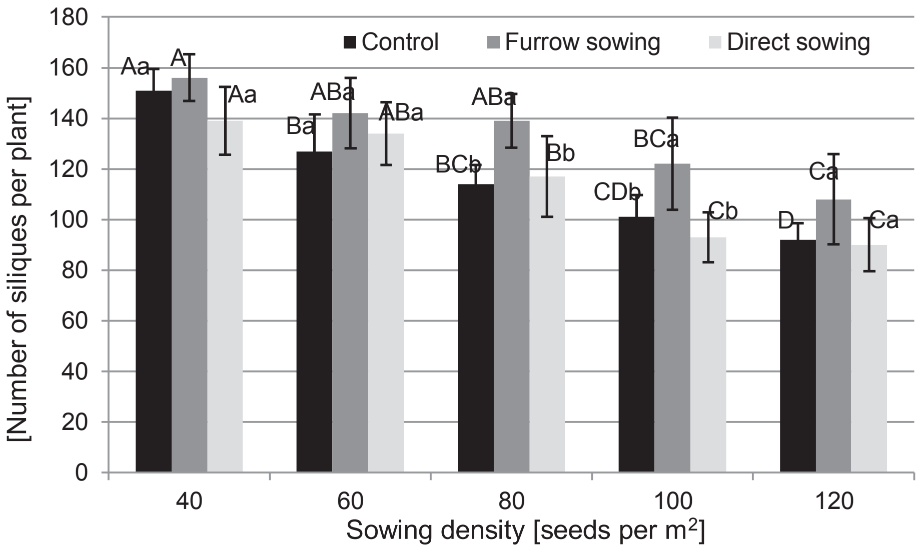
An interaction between the study factors in shaping the seed yield and the number of siliques per rapeseed plant has been demonstrated (Figs 1 and 2). After applying conventional sowing, increasing the sowing density from 40 to 80 and from 60 to 100 seeds per m^2 resulted in a significant increase in the seed yield (Fig. 1). Also, after direct sowing, an increase in seed yield was found as a result of the increased sowing rate from 40 to 120 seeds per m^2. However, no significant effect of sowing density on the yield of oilseed rape seeds sown with the furrow method was found, for which a curvilinear relation was found between the sowing density and the rapeseed yield. There was a tendency to increase the yield as the sowing rate with the furrow method increased from 40 to 80 seeds per m^2. After increasing the sowing density from 80 to 100 and 120 seeds per m^2 there was a tendency for the seed yield to decrease. In the case of conventional and direct sowings, this relationship was linear in the entire range of applied sowing densities.



Note. a, b, c – data marked with various small letters within particular sowing density differ significantly as a result of sowing method influence, at $P < 0.05$; A, B, C – data marked with various capital letters within particular sowing method differ significantly as a result of sowing density influence, at $P < 0.05$.

Figure 1. Interaction of sowing method with the sowing density for the seed yield of winter oilseed rape (means for 2012–2014).

Regardless of the sowing method, increasing the sowing density resulted in a reduction in the number of siliques per plant (Fig. 2).



Note. a, b, c – data marked with various small letters within particular sowing density differ significantly as a result of sowing method influence, at $P < 0.05$; A, B, C – data marked with various capital letters within particular sowing method differ significantly as a result of sowing density influence, at $P < 0.05$.

Figure 2. Interaction of sowing method with the sowing density for the number of siliques per plant of winter oilseed rape (means for 2012–2014).

The sowing method did not affect the number of siliques per plant of oilseed rape sown in the amount of 40, 60 and 120 seeds per m^2. After applying 80 and 100 seeds per m^2, the number of siliques per plant of oilseed rape sown with the furrow method was significantly higher than after using the conventional or direct sowings.

DISCUSSION

Sowing technology is a factor of great importance in shaping the habit of plants and their yield (Jambor, 2007; Wielebski, 2007; Lääniste et al., 2008; Kazemeini et al., 2010; French et al., 2016; Harker et al., 2017). In the scientific literature, there are no results regarding the effect of furrow sowing on the yield of winter oilseed rape. Numerous studies have been conducted regarding the possibilities of using direct sowing in oilseed rape cultivation, which has been shown by Harker et al. (2012b) to provide better rainwater retention and availability for plants. The present study confirmed the beneficial effect of this sowing method on the seed bed moisture during the oilseed rape germination period. Despite this, the favourable effect of direct sowing on the plant density after emergence was not obtained. Also in the spring season, the density was not dependent on the sowing method, and the plants from direct sowing produced significantly smaller seed yields than after the application of furrow sowing. The disadvantage of this method of cultivation and sowing is a large resistance to soil penetration (Celik, 2011; Oduma et al., 2017), which puts more resistance to the developing roots, which generally has a negative effect on plant yields (Chiriac et al., 2013). In our studies it has been found, that plants in furrow sowing were stronger before the winter, compared to direct sowing treatment. This was seen through greater number of leaves per plant and thicker root neck (Wilczewski et al., 2015). As a result, in spring the plants started growing faster and produced a greater number of siliques per plant (Table 3).

According to Wielebski (2007), the plant density prior to harvest should not be lower than 50 plants per m^2, for which 80 seeds per m^2 should be sown. The author, conducting research in unfavourable moisture and thermal conditions (drought during sowing), did not show the relationship between the type of cultivar (composite hybrids, restored hybrids and open pollinated) and their reaction to the sowing density. The opposite results were obtained by Vujaković et al. (2014), who did not show the relationship between the oilseed rape seed yield and the plant density in the range of 20 to 80 seeds per m^2. Also in the study by Jambor (2007) the amount of seeding rate in the range of 30 to 80 of germinable seeds per m^2, had only a little influence on yield. The author stated significant interaction between seeding rate and variety in yield forming effect. For Artus variety 80 germinable seeds per m^2 gave best yield whereas for Fanal variety the lowest seeding rate used was the most favourable. According to French et al. (2016), the optimal oilseed rape plant density in low and medium rainfall zones is 30 plants per m^2 for hybrid cultivars and 75 plants per m^2 for population cultivars. The present study generally confirms the results presented by these authors. However, the optimal plant density for the studied population cultivar 'Californium' was dependent on the sowing method. After application of furrow sowing, the optimal sowing density was 80 seeds per m^2, for which the spring oilseed rape density was 55 plants per m^2. For the other sowing methods, a tendency to increase the yield was observed as the sowing density increased to 120 seeds per m^2, with 72 plants per m^2 found in spring. In the study by Harker et al. (2017), the effect of increasing the sowing density (from 50 to 150 seeds per m^2) on rapeseed yield was dependent on the size of seeds sown. After sowing small seeds (the weight of 1,000 seeds 3.32–3.44 g) the authors found that the seed yield increased as the sowing density increased, while no such an effect was found after sowing large seeds (the weight of 1,000 seeds 4.96–5.40 g). The seed material used in the present study was characterized by an average 1,000 seed weight (4.25–4.60 g), and the oilseed rape response to increasing the sowing density was similar to that for small seeds in the study by Harker et al. (2017), but only in the case of conventional and direct sowings. However, in the present study this tendency was only tested in the range of sowing density from 40 to 120 seeds per m^2. According to Harker et al. (2017), increasing the sowing density increases the loss of plants during the growing season, especially when small seeds are used for sowing. In the present study, this relationship was confirmed. Plant loss in the autumn and winter period increased from 9.1% after applying the sowing density of 40 seeds per m^2 to 17.6% after sowing 120 seeds per m^2.

The relationship between sowing density and winter rape seed yield depended on the method of sowing. For furrow sowing it was curvilinear, while for other sowing methods it was rectilinear within the tested sowing densities (Fig. 1). This variation in the relationship between the method of sowing and the sowing density in shaping the seed yield may be due to the fact that in the case of furrow sowing a relatively high yield was found after applying 40 seeds per m^2. In this variant it was significantly higher than in traditional or direct sowing. This was related to the positive effect of furrow sowing on the number of siliques per plant. However, increasing the sowing density to 100 and 120 seeds per m^2 in a furrow sowing method resulted in a tendency to reduce rapeseed yield. Meanwhile, in the treatment with traditional or direct sowing, none of the tested sowing densities were excessive and this relationship was straight-line.

CONCLUSION

A significant effect of the studied factors on the yield of winter oilseed rape was demonstrated. The highest seed yields were harvested from oilseed rape sown using the furrow method, and significantly lower after direct sowing. When using a low sowing density (40 seeds per m^2), furrow sowing allowed for a higher seed yield than conventional sowing. The sowing method has not been found to significantly affect the yield of winter oilseed rape sown in the amount of 60–120 seeds per m^2. Increasing the sowing density from 40 to 80 seeds per m^2 most often led to an increase in yield of winter oilseed rape. There was no significant increase in seed yield as a result of increased sowing density in the range from 80 to 120 seeds per m^2.

ACKNOWLEDGEMENTS. This scientific study was financed from the funds for science by the National Science Centre of Poland, in the years 2011–2014, as research project No. N N310 731040.
Weather data was developed in the Melioration and Agrometeorology Laboratory at the Faculty of Agriculture and Biotechnology, UTP in Bydgoszcz.

REFERENCES

Abbasian, A. & Rad, A.H.S. 2011. Investigation the response of rapeseed cultivars to moisture regimes in different growth stages. *Journal of Central European Agriculture* **12**(2), 353–366. https://doi.org/10.5513/JCEA/12.2.923

Aboutalebian, M.A., Mohagheghi, A., Niaz, S.A. & Rouhi, H.R. 2012. Influence of hydropriming on seed germination behaviour of canola cultivars as affected by saline and drought stresses. *Annals of Biological Research* **3**(11), 5216–5222. https://www.scholarsresearchlibrary.com

Balodis, O. & Gaile, Z. 2015. Changes of winter oilseed rape plant survival during vegetation. *Proceedings of the Latvia University of Agriculture* **33**(1), 35–45. https://doi.org/10.1515/plua-2015-0005

Böttcher, U., Rampin, E., Hartmann, K., Zanetti, F., Flenet, F., Morison, M. & Kage, H. 2016. A phenological model of winter oilseed rape according to the BBCH scale. *Crop and Pasture Science* **67**(3-4), 345–358. https://doi.org/10.1071/CP15321

Celik, I. 2011. Effects of tillage methods on penetration resistance, bulk density and saturated hydraulic conductivity in a clayey soil conditions. *Journal of Agricultural Sciences* **17**(2), 143–156. https://doi.org/10.1501/Tarimbil_0000001166

Central Statistical Office 2003. Statistical yearbook of the Republik of Poland, Warsaw, pp. 362–392 (in Polish).

Central Statistical Office 2017. Branch yearbooks. Statistical yearbook of agriculture. Warsaw, Poland, pp. 160–162 (in Polish).

Chiriac, G., Raus, L., Coroi, I.G., Gales, D.C. & Jitareanu, G. 2013. Effect of tillage and cultivar on winter oilseed rape (*Brassica napus* L.) yield and economic efficiency in Suceava Plateau. *ProEnvironment* **6**, 130–135. http://journals.usamvcluj.ro/index.php

Dzieżyc, H., Chmura, K. & Piotrowski, M. 2013. Influence of meteorological conditions on the yield of winter oilseed rape in Lower Silesia. Annals of Warsaw University of Life Sciences – SGGW, *Land Reclamation* **45**(2), 235–242. http://ann_landreclam.sggw.pl/Zeszyt452.html

French, R.J., Seymour, M. & Malik, R.S. 2016. Plant density response and optimum crop densities for canola (*Brassica napus* L.) in Western Australia. *Crop and Pasture Science* **67**(3–4), 397–408. https://doi.org/10.1071/CP15373

Harker, K.N., O'Donovan, J.T., Blackshaw, R.E., Johnson, E.N., Lafond, G.P. & May, W.E. 2012a. Seeding depth and seeding speed effects on no-till canola emergence, maturity, yield and seed quality. *Canadian Journal of Plant Science* **92**, 795–802. https://doi.org/10.4141/cjps2011-189

Harker, K.N., O'Donovan, J.T., Turkington, T.K., Blackshaw, R.E., Lupwayi, N.Z., Smith, E.G., Klein-Gebbinck, H., Dosdall, L.M., Hall, L.M., Willenborg, C.J., Kutcher, H.R., Malhi, S.S., Vera, C.L., Gan, Y., Lafond, G.P., May, W.E., Grant, C.A. & McLaren, D.L. 2012b. High-yield no-till canola production on the Canadian prairies. *Canadian Journal of Plant Science* **92**, 221–233. https://doi.org/10.4141/cjps2011-125

Harker, K.N., O'Donovan, J.T., Smith, E.G., Johnson, E.N., Peng, G., Willenborg, C.J., Gulden, R.H., Mohr, R.M., Gill, K.S., Weber, J.D. & Issah, G. 2017. Canola growth, production, and quality are influenced by seed size and seeding rate. *Canadian Journal of Plant Science* **97**(3), 438–448. https://doi.org/10.1139/cjps-2016-0215

Jambor, M. 2007. Effect of seeding rate and seeding date on creation of yield of selected winter oilseed rape varieties and hybrids. *Agriculture (Poľnohospodárstvo)* **53**(1), 49–57.

Kazemeini, S.A., Edalat, M., Shekoofa, A. & Hamidi, R. 2010. Effects of nitrogen and plant density on rapeseed (*Brassica napus* L.) yield and yield components in Southern Iran. *Journal of Applied Sciences* **10**, 1461–1465. https://doi.org/10.3923/jas.2010.1461.1465

Lääniste, P., Joudu, J., Eremeev, V. & Mäeorg, E. 2008. Effect of sowing date and increasing sowing rates on plant density and yield of winter oilseed rape (*Brassica napus* L.) under Nordic climate conditions. *Acta Agriculturae Scandinavica, Section B – Soil and Plant Science* **58**, 330–335. https://doi.org/10.1080/09064710701763821

Lääniste, P., Eremeev, V., Mäeorg, E. & Jõudu, J. 2016.Effect of sowing date on oil, protein and glucosinolate concentration of winter oilseed rape (*Brassica napus* L.). *Agronomy Research* **14**(S2), 1384–1395.

Martinez-Feria, R.A. 2015. Suitability of winter canola (*Brassica napus*) for enhancing summer annual crop rotations in Iowa. *Graduate Theses and Dissertations* **14637**, pp. 149 https://lib.dr.iastate.edu/etd/14637

Mirzaei, A., Naseri, R., Moghadam, A. & Esmailpour-Jahromi, M. 2013. The effects of drought stress on seed yield and some agronomic traits of canola cultivars at different growth stages. *Bulletin of Environment, Pharmacology and Life Sciences* **2**(11), 115–121. http://www.bepls.com/oct_2013

Oduma, O., Nnadi, D.C., Agu, C.S. & Igwe, J.E. 2017. Determination of the effect of tillage on soil resistance to penetration. A study of south-east agricultural soils. *American Journal of Engineering Research* **6**(7), 1–5. http://www.ajer.org/v6(07).html

Szczepaniak, W. 2014. A mineral profile of winter oilseed rape in critical stages of growth – nitrogen. *Journal of Elementology* **19**(3), 759–778. https://doi.org/10.5601/jelem.2014.19.1.600

Velička, R., Anisimovienė, N., Pupalienė, R., Jankauskienė, J., Butkevičienė, L.M. & Kriaučiûnienė, Z. 2010. Preparation of oilseed rape for over-wintering according to autumnal growth and cold acclimation period. *Žemdirbyste = Agriculture* **97**(3), 69–76.
Velička, R., Pupalienė, R., Butkevičienė, L.M. & Kriaučiūnienė, Z. 2012. Peculiarities of overwintering of hybrid and conventional cultivars of winter rapeseed depending on the sowing date. *Acta Scientiarum Polonorum, Agricultura* **11**(1), 53–66. http://agricultura.acta.utp.edu.pl
Vujaković, M., Marjanović-Jeromela, A., Jovičić, D., Lečić, N., Marinković, R., Jakovljević, N. & Mehandžić-Stanišić, S. 2014. Effect of plant density on seed quality and yield of oilseed rape (*Brassica napus* L.). *Journal on Processing and Energy in Agriculture* **18**(2), 73–76. http://scindeks.ceon.rs/issue.aspx?issue=11983&lang=en
Waalen, W., Øvergaard, S.I., Åssveen, M., Eltun, R. & Gusta, L.V. 2013. Winter survival of winter rapeseed and winter turnip rapeseed in field trials, as explained by PPLS regression. *European Journal of Agronomy* **51**, 81–90. http://dx.doi.org/10.1016/j.eja.2013.06.004
Wielebski, F. 2007. Response of different types of winter oilseed rape varieties to various plant density in the field. I. Seed yield and its components. *Rośliny Oleiste – Oilseed Crops*, **28,** 209–226 (in Polish). http://biblioteka.ihar.edu.pl/oilseed_crops
Wilczewski, E. & Harasimowicz-Hermann, G. 2014. Patent No PL215714 B1. Furrow sowing of winter oilseed rape (in Polish).
Wilczewski, E., Harasimowicz-Hermann, G. & Lemańczyk, G. 2015. Effect of sowing technology on winter oilseed rape density in autumn and plant overwintering. In: Emerging Innovations in Agriculture: From Theory to Practice. Rakshit, A. (ed.), Atiner, pp. 57–66.
Wilczewski, E., Harasimowicz-Hermann, G., Szczepanek, M. & Kaszkowiak, J. 2014. Effect of sowing method on soil properties in the surroundings of seeds and emergence dynamics of winter oilseed rape. In Pepó, P.& Csajbók, J.(eds): *Proceedings of 13th Congress of the European Society for Agronomy*, Debrecen, Hungary, pp. 67–68.
Wollmer, A.C., Pitann, B. & Mühling, K.H. 2018. Waterlogging events during stem elongation or flowering affect yield of oilseed rape (*Brassica napus* L.) but not seed quality. *Journal of Agronomy and Crop Sciences* **204**, 165–174. https://doi.org/10.1111/jac.12244
WRB. 2015. World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. *World Soil Resources Reports* No. 106. FAO, Rome.
Zając, T., Klimek-Kopyra, A., Oleksy, A., Lorenc-Kozik, A. & Ratajczak, K. 2016. Analysis of field and plant traits of oilseed rape (*Brassica napus* L.) cultivated in temperate region in light of the possibilities of sowing in arid areas. *Acta Agrobotanica* **69**(4), 1696–1708. https://doi.org/10.5586/aa.1696