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Abstract

The aim of the study was to evaluate the effect of winter rape sowing method on plant overwintering. Field study was conducted in 2011-2014 at the Research Station near Bydgoszcz. Strict, two-factorial field experiments were conducted in *Alfisol*. Winter rape 'Californium' was sown from 25 August – 03 September. Three methods were tested (factor I): A – traditional sowing with a drill (Control); B- sowing in 6-8 cm deep furrows with a drill, according to patent PL215714; C – furrow sowing, directly in stubble (seeder with disk coulters). These methods were assessed in 5 variants of sowing density (factor II): 40, 60, 80, 100 and 120 seeds·m^{-2}.

Sowing method had no significant effect on the mean rape density before winter. Plants from furrow sowing formed thicker root necks than in traditional sowing. Plants obtained from sowing directly in stubble were worst developed before winter. They had the thinnest root necks and the fewest leaves in rosettes. In the first year (2011/2012) with frosty winter (minimal temperature -22^{o}C) the number of plants from furrow sowing in spring was significantly higher than those sown with traditional method. In the second year, with mild winter (minimal temperature -13.5^{o}C), better effects were obtained using traditional and direct sowings. Effect of sowing method on rape overwintering depended on sowing density. After sowing of 40, 100 and 120 seeds per m^2 the plants obtained from direct sowing overwintered best. At 60 seeds per m^2 plants from furrow sowing overwintered best, and those from traditional sowing significantly worse.

Keywords: Oilseed Rape, Sowing Method, Furrow Sowing, Direct Sowing, Overwintering, Plant Density.

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Introduction

Winter oilseed rape (Brassica napus L.) is the most important commodity crop in Poland [Central Statistical Office, 2013] and one of the most essential oil crops in the Word [Bartkowiak-Broda et al., 2005; Qiu et al., 2005]. A crucial problem in this crop cultivation is its unreliable overwintering in Northern Europe [Lääniste et al., 2008; Zając et al., 2011; Paulauskas, 2013]. Individual cultivars are characterized by a varied frost resistance, and the cultivar ‘Californium’ cultivated in this experiment has average winter hardiness typical of the species [Heimann 2009]. Currently grown cultivars of winter oilseed rape survive decreases of air temperatures reaching -15^{o}C in conditions of snowless winters. Snow cover enables survival of plants even at -25^{o}C. In the northern part of Europe every few years occur conditions resulting in freezing of winter oilseed rape. Therefore it is necessary to produce cultivars that are better adapted to the prevailing weather conditions. According to Bartkowiak-Broda [2009], breeding work on creating new winter oilseed rape cultivars aims at obtaining plants with a smaller sensitivity to unfavorable abiotic factors, including rainfall deficit and low temperatures and other factors that cause plant losses during winter rest. Also cultivation technology is of great importance in shaping traits that affect plant overwintering. It should enable fast growth in autumn and result in obtaining plants with rosettes composing of 6-8 leaves and well developed root necks 8-10mm trick [Velička et al., 2010]. Due to the insulating properties of snow cover, affecting the soil temperature in the area of oilseed rape root neck, it is recommended to look for such elements of cultivation technology which reduce blowing snow off the plant neighborhood. Methods of furrow sowing of seeds tested in this study can support keeping snow cover on oilseed rape plantations and consequently, limit damage resulted from the action of frost.

The aim of this study was to evaluate the effect of winter oilseed rape sowing technology on the rosette development during autumn and plant overwintering.

Materials and Methods

The field study was carried out at the Research Station of the Faculty of Agriculture and Biotechnology UTP in Mochełek near Bydgoszcz (53°12'N and 17°51'E) in 2011-2014, in the soil classified as *Alfisols* [Soil Survey Staff, 2010].

The two-factorial experiment was conducted with the randomized split-plot design in four replications. The plot area was 60 m^2.

Three sowing methods of winter oilseed rape seeds were evaluated (factor I): A – traditional, with a drill with the classic (ploughing) tillage; B – sowing in furrows with a depth of about 8 cm with classic (ploughing) tillage – according to the patent PL215714 [Wilczewski and Harasimowicz-Hermann, 2014]; C – sowing in furrows with a depth of about 6 cm, directly into stubble

– using a seeder with disk coulters. Each of the mentioned sowing methods was assessed for 5 sowing densities (factor II): 40, 60, 80, 100 and 120 germinating seeds per m^2;

Rape was cultivated after the harvest of winter wheat. In treatments A and B a set of post-harvest cultivating measures was performed each year (skimming at a depth of about 12 cm and harrowing). Pre-sow ploughing was made in about 2-3 weeks before sowing at a depth of 20 cm. Prior to oilseed rape sowing the soil was cultivated with a combined tillage unit composed of a crumbler roller and a cultivator.

Oilseed rape seeds were sown at the time 25th August – 3rd September in the amount resulting from the experimental scheme, at a depth of 1-2 cm from the flat surface of the field in treatments A and at the bottom of the furrow in treatments B and C, at a row spacing of 20 cm. The cultivar 'Californium' which was used in the study is average in respect of yielding, fat content and winter hardiness. It is characterized by good earliness [Broniarz and Stroiwąs, 2013]. Oilseed rape fertilization with phosphorus (70 $kg \cdot ha^{-1}$ P_2O_5) and potassium (140 $kg \cdot ha^{-1}$ K_2O) was applied after the harvest of previous crop (on stubble). Nitrogen (210 $kg \cdot ha^{-1}$ N) was applied in three rates: 40 $kg \cdot ha^{-1}$ N – on stubble (together with phosphorus and potassium); 100 $kg \cdot ha^{-1}$ N – top-dressing in the early spring and 70 $kg \cdot ha^{-1}$ N – at BBCH 55-57 stage.

In the autumn 2011, 2012 and 2013 the plant density of oilseed rape was determined [$no. \cdot m^{-2}$], as well as the thickness of the root neck and the number of leaves in the rosette. Plant density was calculated in randomly selected fragments of rows with a length of 5 meters from each plot. The thickness of the root neck and the number of leaves in the rosette was determined based on 20 plants from each plot.

The weather conditions during the winter were worked out based on the measurements conducted at the meteorological station at Mochełek. The assessment of the weather conditions included: measurement of the total precipitation and mean air temperatures throughout the plant growth period; measurement of minimal temperatures during the winter; measurement of the thickness and lasting time of snow cover.

After starting the growth in spring 2012, 2013 and 2014, the live plant density was determined [$no. \cdot m^{-2}$]. Based on the plant density in autumn and spring, the proportion of plants which overwintered was calculated.

The results obtained were subjected to the analysis of variance. The significance of differences between the means was determined using Tukey's confidence half-interval at the significance level $P \leq 0.05$ for the randomized split-plot design. Correlation coefficients between the structure traits of oilseed rosettes and its overwintering were calculated using the Statistica software.

Results and Discussion

Weather Conditions in the Area of the Study

Weather conditions were considerably varied in individual years (Table 1). They were the most unfavorable for winter oilseed rape in the season 2011/2012. The minimal temperature reaching -22^{o}C occurred on 5th February at not very thick snow cover. In the period from 1st to 12th February 2012 there were 11 days with the minimal temperature below -15^{o}C, which is potentially dangerous for oilseed rape. The plants were in that period covered with a not very trick snow layer (4-6 cm). After melting of the snow, stagnant water was observed in furrows in treatments B and C for 2-3 days. Water percolation in treatments A occurred within 1-2 days. In the season 2012/2013 only 10 days with temperatures below -10^{o}C were found. The most frosty month was December, where the lowest temperature for that season occurred (-13.5^{o}C). Moreover very low temperatures occurred in March 2013 (-13^{o}C on 17.03 and -11.5^{o}C on 14 and 23.03). Snow covered the plants for a total of 59 days. Snow melting proceeded slowly and stagnant water was not observed on the soil surface. In the third year of the study, the weather conditions were favorable for winter oilseed rape. The minimal temperature amounted to -17^{o}C, but it occurred only on one day (25.01), and the plants were covered with 3-5 cm layer of snow at that time. In that season there were only 7 days with the minimal temperature below -10^{o}C. Snow cover lasted for a short period, and after melting snow no stagnant water was observed in the field.

Growth of Oilseed Rape Plants before winter

The sowing method significantly affected the plant growth in autumn. The number of leaves in the rosette of rape sown with the traditional method and the furrow method, into the soil cultivated traditionally, was significantly higher than after the use of furrow sowing directly into the stubble (Table 2). Weaker development of rape rosettes from direct sowing was observed for all the studied sowing rates. Moreover, in rape sown at the density of 80 seeds per m^2, significantly more leaves were found in a rosette from furrow sowing (B) than from traditional sowing (A). Along with increasing sowing rate in the range from 40 to 100 seeds per m^2, the number of leaves in the rosette decreased significantly. Oilseed rape plants from direct sowing to a lesser extent responded to an increase in sowing rate. Only a decrease in the number of leaves in the rosette was observed in them after sowing 100 or 120 seeds per m^2, as compared with 40, 60 or 80. According to Velička et al. [2010], the plants which formed rosettes which consisted of 6-8 leaves before winter overwinter best. Therefore the plants obtained in the present study in treatments with classic tillage achieved the optimal state of rosette development. After the use of direct sowing and the sowing rates of 100 and 120 seeds per m^2 the number of leaves was below the value regarded as the optimal.

Plants obtained from furrow sowing formed thicker root necks than those obtained from traditional sowing (Table 3). However, the effect of the sowing method on this trait was dependent on sowing density. Oilseed rape which was sown with the furrow method in densities of 40, 60 and 80 seeds per m^2 had significantly thicker root necks than plants obtained from seeds sown with the other methods. The thickness of the root neck of plants sown at densities 100 and 120 seeds per m^2 in treatments A and B was similar. The plants which were the least developed before winter were obtained from furrow sowing directly into stubble. Irrespectively of the applied sowing density, they had the thinnest root necks and the least leaves in the rosettes. According to Velička et al. [2010], the optimal thickness of oilseed rape root neck is 8-10 mm. Therefore in the present study the mean value of this trait of oilseed rape sown traditionally and in furrows with the classic tillage was optimal. Oilseed rape sown directly into stubble, irrespective of the sowing density, formed root necks thinner than the optimal.

Oilseed Rape Plant Density

Sowing method did not have a significant effect on the mean from the years plant density in autumn and spring (Table 4). Therefore data concerning this trait were presented only in the form of means from the applied sowing methods. Each increase in sowing rate caused a significant increase in plant density in the autumn and spring. The effect of the sowing method on the number of plants after the winter was different in the study years (Table 5). In the first year of the study (2011/2012), which was characterized by frosty winter (the minimal temperature -22^{o}C), the number of plants in spring in the treatment with furrow sowing was significantly larger than in rape sown with the traditional method. In the second study, in conditions of mild winter (the minimal temperature -13.5^{o}C), better results were obtained using the traditional sowing and direct sowing, whereas in the third year no significant effect of the sowing method on oilseed rape density in spring was observed.

Overwintering of Winter Oilseed Rape

The effect of the sowing method in oilseed rape overwintering depended on sowing density. After sowing 40, 100 and 120 seeds per m^2 plants obtained from direct sowing overwintered best (Table 6). Overwintering of oilseed rape sown in amounts of 40 and 60 seeds per m^2 was significantly better than after sowing 80 and 100 seeds per m^2. Oilseed rape sown in an amount of 120 seeds per m^2 showed the worst overwintering. At a density of 60 seeds per m^2 the best results of overwintering were observed in plants from furrow sowing and significantly worse in those from traditional sowing. Plants from direct sowing, with poorer shaped rosettes (5.5-6.3 leaves and the root neck with a thickness of 5.96-7.45 mm) overwintered better than plants in the treatments with the classic tillage, with more developed rosettes (6.34-7.19 leaves and the root neck with a thickness of 7.73-9.26 mm). This may result from favorable course of the weather during the winter in 2 out of 3 years of the study. Formation of the root neck is of greater importance in seasons where the aboveground parts of plants are damaged in winter and in spring plants need elements accumulated in the root neck to build leave rosettes. In the study by Budzyński et al. [2000], conducted in less favorable conditions for rosette development during the autumn, replacing the classic tillage by direct sowing into standing stubble resulted in a significant decrease in the root neck thickness (from 5.0-5.1 to 4.4-4.5 mm) and the weight of rosettes and poorer overwintering of oilseed rape sown in amounts of 110 and 130 germinating seeds per m^2.

In all the years of the study oilseed rape overwintering was negatively correlated with the number of plants per m^2 in the autumn (Table 7). The results of the study concerning relationship between overwintering and sowing density are ambiguous. According to Bartkowiak-Broda (2002), sparse sowing has a favorable effect on plant health and ensures better winter hardiness. In the study by Lääniste et al. (2008), no effect of sowing density in the range from 100 to 200 seeds per m^2 on plant overwintering was observed.

The correlation analysis did not show relationship between oilseed rape overwintering and the thickness of the root neck, whereas the number of leaves in the oilseed rape rosette significantly determined overwintering only in the first year of the study, which was characterized by low temperatures during the winter (Table 7).

Table 1. *Weather Conditions in the Study Area*

Parameter	Season		
	2011/2012	**2012/2013**	**2013/2014**
Minimal temperature [^oC]	-22	-13.5	-17
Number of days with minimal temperature below -10^oC	16	10	7
Time of temperatures below -10^oC	28.01-12.02	14.12.-25.03	23.01-31.01
Number of days with minimal temperature below -15^oC	11	0	1
Time of temperatures below -15^oC	01.02-12.02	-	25.01
Number of days with minimal temperature below -20^oC	2	0	0
Time of temperatures below -20^oC	05.02-06.02	-	-
Time of snow cover lying [days]	15	59	17
Snow cover thickness during minimal temperatures [cm]	4-6	8-10	3-5

Table 2. *The Number of Leaves in Rosettes of Winter Oilseed Rape Before the Winter – Means for 2011-2013*

Sowing method	Sowing density [seeds per m^2]					
	40	**60**	**80**	**100**	**120**	**Mean**
A–control	7.21 Aa	6.86 Ba	6.49 Cb	6.52 Ca	6.34 Ca	6.68 a^
B–furrow sowing	7.19 Aa	7.20 Aa	6.98 ABa	6.82 BCa	6.58 Ca	6.95 a
C–direct sowing	6.30 Ab	6.05 Ab	6.02 Ac	5.53 Bb	5.68 Bb	5.92 b
Mean	6.90 A*	6.70 B	6.50 C	6.29D	6.20 D	6.52

*Values followed by different capital letter within a line differ significantly at $P\leq0.05$.
^Values followed by different small letter within each column differ significantly at $P\leq0.05$.

Table 3. *The Thickness of the Root Neck of Winter Oilseed Rape Before Winter [mm] – Means for 2011-2013*

Sowing method	Sowing density [seeds per m^2]					
	40	60	80	100	120	Mean
A–control	8.54 Ab	8.58 Ab	8.38 Bb	8.13 Ca	7.73 Da	8.27 b^
B–furrow sowing	9.26 Aa	9.21 ABa	9.12 Ba	8.63 Ca	7.90 Da	8.82 a
C–direct sowing	7.45 Ac	7.24 Bc	6.79Cc	5.96 Eb	6.17 Db	6.72 c
Mean	8.42 A*	8.34 B	8.10 C	7.57 D	7.27 E	7.94

*Values followed by different capital letter within a line differ significantly at $P \leq 0.05$. ^Values followed by different small letter within each column differ significantly at $P \leq 0.05$.

Table 4. *Number of Winter Oilseed Rape Plants Before and After the Winter [No m^{-2}] – Means for 2011-2014*

Measurement time	Sowing density [seeds per m^2]					
	40	60	80	100	120	Mean
Autumn 2011-2013	35.0 E*	49.4 D	63.8 C	75.2 B	87.6 A	62.2
Spring 2012-2014	31.8 E	44.2 D	55.4 C	64.2 B	72.2 A	53.6

*Values followed by different capital letter within a line differ significantly at $P \leq 0.05$.

Table 5. *Number of Winter Oilseed Rape Plants After the Winter [No m^{-2}]*

Sowing method	Year		
	2012	2013	2014
A–control	39.4 b^	49.9 a	70.2 a
B–furrow sowing	48.2 a	44.6 b	67.5 a
C–direct sowing	42.8 ab	52.9 a	66.5 a
Mean	43.5	49.2	68.1

^Values followed by different small letter within each column differ significantly at $P \leq 0.05$.

Table 6. *Overwintering of Winter Oilseed Rape [%]– Means for 2012-2014*

Sowing method	Sowing density [seeds per m^2]					
	40	60	80	100	120	Mean
A–control	90.9 Aab	87.5 Bb	85.6 Ca	83.5 Db	81.1 Eb	85.7 a^
B–furrow sowing	89.1 Ab	90.2 Aa	85.8 Ba	84.3 Bb	81.0 Cb	86.1 a
C–direct sowing	92.8 Aa	88.8 Bab	87.2 Ba	87.4 Ba	83.8 Ca	88.0 a
Mean	90.9 A*	88.8 A	86.2 B	85.1 B	81.9 C	86.6

*Values followed by different capital letter within a line differ significantly at $P \leq 0.05$. ^Values followed by different small letter within each column differ significantly at $P \leq 0.05$

Table 7. *Simple Correlation Coefficients for the Relationship between Overwintering and Botanical Traits of Winter Oilseed Rape in Autumn (n=15)*

Variables	**Overwintering**		
	2011/2012	**2012/2013**	**2013/2014**
Plant density in the autumn	-0.85*	-0.73*	-0.61*
Thickness of root neck	0.29	-0.31	0.39
Number of leaves in rosettes	0.64*	-0.01	0.36

*– significant at P≤0.05;

Conclusions

The effect of winter oilseed rape ‘Californium’ sowing method on overwintering was dependent on the sowing density. After sowing 100 and 120 seeds per m^2, the plants from direct furrow sowing overwintered most successfully. After sowing 60 seeds per m^2, the best overwintering was shown in oilseed rape from furrow sowing with classic tillage significantly worse in that sown traditionally.

Overwintering of oilseed rape was negatively correlated with the number of plants during autumn.

No effect of the thickness of oilseed rape root neck in the autumn period within the range 6.2-9.3 mm on its winter hardiness was found. Relationship between the number of leaves in the oilseed rape rosette and overwintering was different in the years of the study. In the season that was characterized by the frosty winter, there was a positive relationship between those variables, whereas in the other seasons, no relationships were observed.

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