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Depth and Sowing Rate as Factors Affecting the Development, Plant Density, Height and Yielding for Two Faba Bean (*Vicia faba* L. Var. *Minor*) Cultivars

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Abstract: Sowing depth and density are factors which affect development and yielding due to their influence on plants' competition for water, light and nutrients. The aim of the present research was to evaluate the effect of sowing depth (5 and 8 cm) and density (45, 60, 75 seeds m²) on the development and yield of two morphotypes of faba bean. Higher plants were found at 8 cm sowing depth in 2011 and 2013, in turn, plant density before harvest, at 5 cm in 2011 and 8 cm in 2013. The greatest seed yield was observed while sowing shallower in 2011 (4.50 t ha^{−1}) and 2012 (6.62 t ha^{−1}), and deeper in 2013 (3.53 t ha^{−1}). Cultivar played an important role in shaping plant height and seed yield in all years of the experiment, as well as in straw yield in 2012. Bobas characterized by the greatest seed productivity in all years of experiment compared to Granit, as well as quantity of straw yield in 2011 and 2012 (3.51 and 4.88 t ha^{−1}, respectively) and therefore can be recommended for cultivation. Taking into account plant density before harvest in 2011–2013 as well as straw yield in 2011 and 2013, the most favorable sowing density is 75 seeds per m².

Keywords: sowing depth; sowing density; determinate and indeterminate cultivar; development; seed yield; straw yield; plant height; plant density before harvest

1. Introduction

Faba bean (*V. faba* L.) is the fourth most important pulse crop in the world used for grain, vegetables, animal feed, and green manure cultivated in 58 countries over a large area [1,2].

The genotypes of *V. faba* are classified into three main botanical varieties according to seed size: *V. faba* var. *major* with large seeds, *V. faba* var. *minor* with small seeds, and *V. faba* var. *equina* with medium seeds [3]. The first two varieties are relevant in European agriculture. Faba bean seed size is an important trait in determining market and consumption forms. *V. faba* var. *major* is commonly used for food (either as fresh green vegetable or dry seeds). *V. faba* var. *minor* and var. *equina* are mostly used for animal feed [3]. Seeds of the faba bean are regarded as a valuable protein crop, which ranks seventh in terms of protein source found in legumes [4].

Faba bean is adapted to various habitat conditions. This crop contributes to yield improvement, reduction of pest and diseases, and weed control in cereal production. Moreover, it enriches the soil with organic compounds and nutrients. According to Landry et al. [5] and Jensen et al. [6], the average N fixation globally can gain 153 kg shoot N ha^{−1}, while Galloway et al. [7] concluded that faba bean can fix 50–330 kg N hm^{−2}.

Study by Neugschwandtner et al. [8] showed that faba bean can fix up to 200 kg N ha^{-1} and legume residues into the soil, improving soil properties, such as organic matter content, density, porosity, and water capacity [2,9]. The ability to fix atmospheric nitrogen allows to reduce the use of mineral fertilisers by as much as 20–25% [10]. The amount of nutrients in legume crop residues is around 35 kg ha^{-1} K and 25 kg ha^{-1} P, and therefore its use in crop rotation is highly desirable [11].

One of the factors affecting economics (cost of material seed), biomass, yield and its components is sowing density. It determines the number of seeds per square meter, which in turn is responsible for the area available for each future plant [12]. There are divergences in the available literature in the determination of optimal faba bean sowing density [1,13]. The available literature related to the response of faba beans to sowing density presents a wide range of densities [14,15]. Optimum sowing density as a result of the correct sowing rate for various faba bean varieties can range from 10 to $100 \text{ plants m}^{-2}$. However, Mwanamwenge et al. [16] claimed that the optimal sowing densities for faba beans have not been yet determined. There is a need to determine the sowing seed rate depending on seed size and different legume morphotypes (determinate and indeterminate) under different sowing conditions.

Another factor effect on yield is sowing depth, something which has a significant effect on the ability of plants to emerge and allows to create an appropriate environmental place for the plant [17]. It is an essential issue to plant at the appropriate depth to receive good percentage germination, satisfying emergence and high plant population [17]. Emergence of faba beans is hypogeal, meaning that the cotyledons are in the soil while only the shoot emerges from the soil surface [16,18]. Therefore, hypogeal germinating plants, compared to epigeal, may be sown both shallower and deeper. are sown deeper. Sowing too shallow can affect poor germination due to unsuitable soil moisture in the top soil layer. Deep placement of seeds in the soil contributes to better rooting of the plant, which decreases lodging susceptibility [19]. Deeper sown plants are able for more efficient use of available soil water. Conversely, the energy needed for emergence is greater for deep-sown compared to shallow-sown seeds [20]. According to Siddique and Loss [18] the recommended faba bean sowing depth is 5–8 cm. Germination starts in 4–12 days after sowing with an optimum temperature around 20°C [13,15]. According to Baye et al. [17], sowing Faba beans with a depth 8 cm positively impacted germination and growth, including height, compared to deeper depth of 12 cm.

It was hypothesized that the depth of sowing and density (pcs m^{-2}) as the main factor against the background of the weather conditions would significantly affect plant height, length of vegetative and generative period, as well as yield of seed and straw in faba bean cultivation. It would be assumed that the cultivars of faba bean would differ, taking into account the duration of length of vegetative and generative period and selected traits against different weather course. It is also supposed that the depth of sowing and sowing density would be different for determinate and indeterminate cultivar in different years of experiment.

Information regarding sowing depth and density on the development and yielding of faba bean morphotypes (determinate and indeterminate) is scant. Thus, the objective of the field study was to determine the effect of two sowing depths and three sowing densities on the growth and yielding of Bobas (indeterminate growth habit) and Granit (determinate growth habit) cultivars.

2. Materials and Methods

2.1. Experiment Design and Conditions (Weather, Soil) of Experiment

A field experiment was established in the field belonging to the Institute of Agroecology and Plant Production of the Wrocław University of Life Sciences in Poland ($51^\circ 11' \text{ N}$, $17^\circ 08' \text{ E}$).

The field experiment was carried out in the years 2011–2013 in a split-plot design. Sowing depth (5, 8 cm) was allocated in the main plots, faba bean cultivars (Bobas—

indeterminate growth habit, and Granit—determinate growth habit) were placed in the sub-plots and the sowing density (45, 60, 75 pc m⁻²) in the sub-sub-plots. The experiment consisted of 12 combinations. Size of the single sub-sub-plot was 15.0 m² (10 m × 1.5 m).

Wrocław and adjacent areas are one of the warmest parts of Lower Silesia in the temperate climate of Poland. In 2011 and 2012, the average temperatures for the vegetation period were higher than the multiannual mean for 1981–2010 and reached 13.7 and 13.8 °C, respectively. In both years, the average monthly temperatures were higher than the multiannual mean. In 2013, March was frosty. That caused the moving of the sowing date to the second half of April. However, other months of the vegetation period were characterized by average temperatures higher than the multiannual mean. The average temperature of the vegetation period in 2013 was 12.2 °C, which was lower than the multiannual mean for the vegetation period by 1.4 °C.

The sum of precipitation during the vegetation period in the years 2011–2013 was changeable. The third year of the experiment was characterized by the highest sum of precipitation (499 mm), lesser in the first year (467 mm), and the least in the second year (380 mm). However, these values were higher compared to the multiannual mean sum of precipitation (314 mm) during the vegetation season.

The experiment was established on typical brown Luvisols developed from light loam underlain by medium loam, suitable for wheat production [21]. Macronutrients availability (P and K—the Egner-Riehm method, Mg—Schachtschabel method) and soil pH (potentiometrically) in the years of the experiment are presented in Table 1 and are as follows: high to very high P content, from medium to high K content, high Mg content and slightly acidic pH of soil [22].

Table 1. Soil pH and abundance in macronutrients (mg kg⁻¹).

Years	pH in 1 M KCl	P	K	Mg
2011	5.8	74	179	72
2012	6.2	73	133	96
2013	5.9	62	116	87
Average (2011–2013)	6.0	70	143	85

The experimental field was cultivated according to standard plot management techniques and standard agronomic practices. Winter wheat (*Triticum aestivum* L.) was the preceding crop in each year of the experiment. Directly before faba bean sowing, the soil was cultivated, and fertilization was carried out. Fertilizers were applied in the following doses (kg ha⁻¹): 30 N (ammonium nitrate), 60 P₂O₅ (triple superphosphate), and 100 K₂O.

The seeds were inoculated with Nitragina (Institute of Soil Science and Plant Cultivation State Research Institute, Puławy, Poland) (an inoculant containing *Rhizobium leguminosarum* bv. *viciae* bacteria) directly before sowing. For the experiment, certified seed material has been used with 100% purity and germination capacity as presented in Table 2.

Table 2. Characterization of seeds material.

Specification	Cultivars					
	Bobas			Granit		
	2011	2012	2013	2011	2012	2013
Germination capacity (%)	95	98	94	80	94	80
Purity (%)	100	100	100	100	100	100
Mass of 1000 seeds (g)	500	667	612	466	510	554

Sowing and harvesting dates in the years of research and plant protection treatment are presented in Table 3. Plant protection was carried out in accordance with the assumptions of integrated pest management.

Table 3. Sowing and harvesting date and plant protection of faba bean in years 2011–2013.

Specification		Years		
		2011	2012	2013
Sowing Date		31/03	26/03	16/04
Plant Protection Products	Active Substances			
Linurex 500 SC-1.5 dm ³ ha ⁻¹	Linuron	02/04	26/03	17/04
Basagran 480 SL-2 dm ³ ha ⁻¹	Bentazone	02/05	07/05	10/05
Alert 375-1.3 dm ³ ha ⁻¹	Flusilazole and carbendazim	19/05	18/06	-
Karate Zeon 050 SC-0.1 dm ³ ha ⁻¹	Lambda-cyhalothrin	-	29/05	-
Bi 58 Nowy 400 EC-0.5 dm ³ ha ⁻¹	Dimethoate	-	22/05	22/05
Mospilan 20 SP-1 dm ³ ha ⁻¹	Acetamipride	-	31/05	-
Fastac 0.1 dm ³ ha ⁻¹	Alpha-cypermethrin	22/06	18/06	-
Harvesting date		11/08	16/08	14/08

2.2. Measurements

The field observations were done each year of the study during the vegetation period of faba bean plants. Growing stages in BBCH scale and the development of plants were noted [23]. Before harvest, plant density was determined at 2 RMT (running metres) of the middle row and then the results were converted to 1 m⁻². The plant height to the top of the main shoot (cm) was measured on 10 randomly selected plants from each plot before harvest. After harvest, the yield of seeds and straw from each sub-sub-plot was determined (t ha⁻¹) at moisture level at 15%. The moisture of faba bean seeds has been converted to a constant moisture content using the following formula:

$$x = P \cdot \frac{100 - W1}{100 - W2}$$

x—yield after being converted to the assumed moisture content (t ha⁻¹)

P—yield (t ha⁻¹)

W1—seed moisture at harvest (%)

W2—seed moisture content determined, assumed (%)

2.3. Statistical Analyses

The analysis of variance (ANOVA) was done at the significance level $p < 0.05$ using Statistica program 13.1 (StatSoft, Kraków, Poland). The experiment included four factors: two sowing depths, two cultivars, three sowing densities, three years, and four randomized replicates arranged in a split-plot design. For the resulting data (plant development) presented in the Table 4, standard deviations (SD) were calculated. Homogeneous groups were determined by Tukey's multiple range test using consecutive letters starting from "a"—the most beneficial value—to "f"—the least beneficial in terms of analysed traits. Figures were prepared in Excel 2010.

Table 4. Effect of weather conditions on faba bean development stages in the years 2011–2013.

Specification	Development Stages								
	Vegetative (V)		Average for Years	Generative (G)		Average for Years	Vegetation Period (V + G)		Average for Years
	Bobas	Granit		Bobas	Granit		Bobas	Granit	
2011									
Length of stages [days]	46.0	46.0	46.0 ± 0.0	86	81	83.5 ± 3.5	132	127	130 ± 3.5
Average temperature [°C]	12.0	12.0	12.0	18.7	18.6	18.7	16.4	16.2	16.4
Total sum of precipitation [mm]	61.5	61.5	61.05	296.0	284.8	290.4	357.5	346.3	351.9

Table 4. Cont.

Specification	Development Stages								
	Vegetative (V)		Average for Years	Generative (G)		Average for Years	Vegetation Period (V + G)		Average for Years
	Bobas	Granit		Bobas	Granit		Bobas	Granit	
2012									
Length of stages [days]	45	45	45 ± 0.0	96	91	93.5 ± 3.5	141	136	138.5 ± 3.5
Average temperature [°C]	10.7	10.7	10.7	18.1	18.2	18.2	15.7	15.8	15.8
Total sum of precipitation [mm]	111.8	111.8	111.8	202.6	239.3	220.9	314.4	351.1	332.75
2013									
Length of stages [days]	39	39	39 ± 0.0	77	75	76 ± 1.4	116	114	115 ± 1.4
Average temperature [°C]	14.6	14.6	14.6	19.1	18.6	18.6	17.6	17.2	17.4
Total sum of precipitation [mm]	116.4	116.4	116.4	302.5	280.9	291.7	418.9	397.3	408.1
Average for the years 2011–2013									
Length of stages [days]	43 ±	43 ±	43 ± 0.0	86 ±	82 ±	84 ± 13.3	130 ±	126 ±	128.0 ± 11.9
(average for cultivars)	3.8	3.8		9.5	8.1		12.7	11.1	
Average temperature [°C]	12.3	12.3	12.3	18.6	18.5	18.6	16.5	16.4	16.5
Total sum of precipitation [mm]	96.6	96.6	96.6	267.0	268.3	267.6	363.6	364.9	364.3

± means SD for average for length of stages in the years of research.

3. Results

3.1. Effect of Weather Conditions in Years of Research on the Plant Development of Faba Bean

The greatest precipitation before sowing was noted in the first year of the experiment, less in 2013 and the least in 2012. In the same year, the least amount rainfall was found in the flowering stage. The most favourable precipitation during harvest (II decade of August) was stated in the second year of field study (Figures 1–3). Faba bean sowing in 2011–2012 was performed in the third decade of March in a range of minimum (0–4 °C) and maximum (13–14 °C) temperature (Figures 1 and 2). In 2013 there was observed low temperature in third decade of March. Sowing faba bean in this year was conducted in the second decade of April at a minimum temperature about 6 °C and maximum of about 17 °C (Figure 3).

Figure 1. Decade weather condition in 2011 with marking minimum and maximum temperature.

Figure 2. Decade weather condition in 2012 with marking minimum and maximum temperature.

Figure 3. Decade weather condition in 2013 marking minimum and maximum temperature and precipitation in decades.

Table 4 presents the average temperature and total sum of precipitation for the vegetative and generative period for determinate and indeterminate cultivar. On the basis of field observations, it was stated that the sowing depth, density and repetitions did not differentiate the duration of development stages. The length of the development period of faba beans in the experiment varied, on average, from 126 days for Granit cultivar to 130 days for Bobas cultivar. Greater differences in the length of vegetation period was stated in Bobas cultivar ($SD \pm 12.7$) than Granit cultivar ($SD \pm 11.1$). Bobas indeterminate cultivar characterized by longer vegetation period (V + G) compared to Granit determinate cultivar in the years 2011–2013. The length of vegetative development (V) in both cultivars in the years of experiment did not vary and lasted about 43 days. Differences in the number of days were found in the generative development of both cultivars. In the years of experiment, a longer generative development (G) concerned Bobas indeterminate cultivar (Table 4). The average temperature in the years of the experiment ranged from 12.3 °C (2011) to 18.6 °C (2012). Differences were observed in the total sum of precipitation. The longest vegetation period was found in 2012 and the shortest in 2013. The least differences in the length of vegetation period concerned the third year of experiment ($SD \pm 1.4$).

3.2. Effect of Examined Factors on Plant Density, Height of Plants before Harvest and Seed and Straw Yield

Sowing depth played an important role in plant density in 2011 and 2013, while in turn, cultivar only in 2011 and 2012. Plant density before harvest ($pc\ m^{-2}$) in the years experiment was significantly dependent on sowing density. A significant effect was also found for the interaction: sowing depth (SDH) $\times$ sowing density (SDY) and (cultivar) C $\times$

(sowing density) SDY in the first year of experiment. Sowing depth influenced on plant height in 2011 and 2013 while cultivar differentiated significantly this trait in all years of experiment (Table 5). Sowing density only had a significant effect on plant height in 2013. In turn, interaction SDH $\times$ SDY and C $\times$ SDY affected significantly this trait in 2011 (Table 5).

Table 5. Effect of examined factors on plant density and height of plants before harvest.

Specification	Plant Density before Harvest [pc m ⁻²]			Height of Plants [cm]		
	<i>p</i> -Value					
	2011	2012	2013	2011	2012	2013
For factors						
Sowing depth (SDH)	0.0008	0.1645	0.0198	0.0034	0.4845	0.0007
Cultivar (C)	0.0071	0.0114	0.9628	0.0000	0.0000	0.0000
Sowing density (SDY)	0.0000	0.0000	0.0000	0.2818	0.8549	0.0193
For interactions						
SDH × C	0.4175	0.9257	0.8889	0.4816	0.0726	0.2453
SDH × SDY	0.0013	0.7486	0.8163	0.0004	0.5208	0.9371
C × SDY	0.0002	0.6047	0.9254	0.0000	0.8127	0.6391

Sowing depth had a significant effect on seed yield in 2011 and 2013. Cultivar and sowing density played a pivotal role in seed yield shaping in all years of the experiment. There were found also interaction: sowing depth (SDH) $\times$ cultivar (C) and C $\times$ SDY in 2011, 2013, SDH $\times$ SDY in 2013 (Table 6).

Table 6. Effect of examined factors on the seed and straw yield of faba bean [t ha⁻¹].

Specification	Yield [t ha ⁻¹]					
	Seed			Straw		
	<i>p</i> -Value					
	2011	2012	2013	2011	2012	2013
For factors						
Sowing depth (SDH)	0.0020	0.1885	0.0010	0.2841	0.1387	0.0184
Cultivar (C)	0.0000	0.0001	0.0001	0.0857	0.0001	0.1140
Sowing density (SDY)	0.0000	0.0189	0.0000	0.0000	0.0594	0.0000
For interactions						
SDH × C	0.0133	0.5922	0.0255	0.3563	0.2893	0.0285
SDH × SDY	0.0580	0.6407	0.0000	0.0547	0.3123	0.0133
C × SDY	0.0114	0.8561	0.0005	0.0050	0.9779	0.8071

Sowing depth significantly affected plant density in 2011 and 2013. In these years of research, opposite results were obtained: a higher planting density at 5 cm in 2011 (48.7 pcs m²) and in 2013 at 8 cm (53.4 pcs m²). Cultivar had no effect on plant density in all years of experiment. Sowing density affected significantly on plant density in all years of experiment. Plant density values were much higher when using 75 seeds per m² in all years of the experiment, while the lowest used 45 seeds per m² (Table 7).

Significantly higher plants were found in 2011 and 2013 at 8 cm sowing depth (65.5 cm and 90.5, respectively). A different reaction in a case of cultivar was found for plant height. In all years of the experiment, higher plants were stated in Bobas cultivar (7.3, 38.3 cm) higher than Granit (Table 7).

Table 7. Table Effect of examined factors on plant density, height and seed and straw yield.

Specification		Plant Density before Harvest [pc m ⁻²]	Plant Height [cm]	Seed Yield [t ha ⁻¹]	Straw Yield [t ha ⁻¹]
2011					
Sowing depth (SDH)	5	48.7a	62.5b	4.50a	3.26a
	8	44.8b	65.5a	4.26b	3.18a
Cultivars (C)	Bobas	47.7a	67.5a	4.75a	3.51a
	Granit	45.8a	60.5b	4.01b	2.93b
Sowing density (SDY)	45	37.5c	64.5a	4.18a	3.00a
	60	48.3b	63.9a	4.42a	3.23ab
	75	54.5a	63.6a	4.55a	3.38b
2012					
Sowing depth (SDH)	5	49.6a	69.8a	6.62a	4.22a
	8	51.1a	68.5a	6.25b	3.89a
Cultivars (C)	Bobas	51.8a	88.0a	7.27a	4.88a
	Granit	48.8a	50.3b	5.60b	3.23b
Sowing density (SDY)	45	38.8c	68.5a	6.20a	3.91a
	60	50.2b	69.7a	6.39a	3.81a
	75	61.9a	69.4a	6.72a	4.44a
2013					
Sowing depth (SDH)	5	48.4b	81.3b	3.32b	1.89b
	8	53.4a	90.5a	3.53a	2.42a
Cultivars (C)	Bobas	51.0a	90.3a	3.61a	2.12a
	Granit	50.9a	81.5b	3.24b	2.19a
Sowing density (SDY)	45	39.6c	83.7a	3.24a	1.92a
	60	51.5b	85.7a	3.50b	2.17ab
	75	61.8a	88.4a	3.54b	2.38b

Means for factors and years. Different letters indicate significant differences between factors (Tukey's multiple range test).

Seed yield was dependent on sowing depth in all years of experiment. In the first two years of the experiment, a significantly higher seed yield was stated at 5 cm sowing depth (4.50 and 6.62 t ha⁻¹ respectively), while in 2013, a significantly higher value at 8 cm of depth (3.53 ha⁻¹) was observed. Higher seed yield was observed in 2012, while the lowest was in 2013. Seed yield also depended on cultivar. Bobas indeterminate cultivar characterized by higher seed yield in all years of experiment. Increase sowing rate to 60 seeds per m² resulted in larger seed yield only in the last year of experiment (Table 7).

The results of the analysis of sowing depth effect showed that deeper sowing in 2013 led to greater straw yield. Cultivar with indeterminate growth type characterized by larger straw yield in two first years of research. In turn, enlargement seed sown per m² contributed to increase straw yield in 2011 and 2013 (Table 7).

Higher plant density was noted by 5 cm of sowing depth using 60 and 75 seeds on m² in 2011. Increasing tendency of plant density per 1 m² both at 5 and 8 cm depth was stated. The greatest plant density was found using 75 seeds per m², while the lowest with 45 seeds per m² (Figure 4).

Higher plant density was stated in Bobas cultivar using 75 seeds on 1 m², while Granit characterized by greater plant density using 60 seeds sown per m² (Figure 5). Change of seed sowing from 45 to 75 seeds per m² in both cultivars caused an increase in plant density before harvest (Figure 5).

Indeed, higher plants were observed at 8 cm sowing depth using only 60 seeds per m² and lower using the same amount of seeds at 5 cm of sowing depth (Figure 6).

Figure 4. Plant density before harvest in 2011 (interaction SDH × SDY). Different letters indicate significant differences between factors (Tukey's multiple range test).

Figure 5. Plant density before harvest in 2011 (C × SDY). Different letters indicate significant differences between factors (Tukey's multiple range test).

Figure 6. Plant height in 2011 (SDH × SDY). Different letters indicate significant differences between factors (Tukey's multiple range test).

Bobas indeterminate cultivar were characterized by higher plants using all sowing rates. The highest plants were observed in Bobas using 45 seeds per m², while the lowest were seen in Granit cultivar using the same number of seeds per m² (Figure 7).

Figure 7. Plant height in 2011 (C × SDY). Different letters indicate significant differences between factors (Tukey's multiple range test).

In the years 2011–2013, independently sowing depth in indeterminate morphotypes of faba bean yielded higher compared to determinate type of growth. Decrease of sowing depth in Bobas, contradictory to Granit, resulted in increased seed yield in 2011. In 2013, a sowing depth of 8 cm enhanced Granit productivity (Figure 8).

Figure 8. Seed yield in 2011 and 2013 (SDH × C). Different letters indicate significant differences between factors (Tukey's multiple range test).

Deeper sowing using 45 seeds per m² enhanced led to an increase of seed yield. Change the sowing rate from 45 to 60 pcs per m² caused also higher faba bean productivity (Figure 9).

Bobas cultivar had the greater than Granit seed yield using all sowing rates in 2011 and 2013. Determinate cultivar increase yield when changing the sowing rate from 45 to 60 pcs m² in these years. The most beneficial sowing rate in Bobas cultivation for seeds in 2013 was 75 pcs m². However, in 2011 seed yield obtained from indeterminate morphotype did not vary significantly between tested sowing densities. (Figure 10).

Figure 9. Seed yield in 2011 (SDH $\times$ SDY). Different letters indicate significant differences between factors (Tukey's multiple range test).

Figure 10. Seed yield in 2011 and 2013 (C $\times$ SDH). Different letters indicate significant differences between factors (Tukey's multiple range test).

The greatest straw yield was stated in Bobas cultivar in all range of sowing rate, compared to Granit (Figure 11). The least straw yield was found in determinate morphotype using 45 seeds per m^2 (Figure 11).

Figure 11. Straw yield in 2011 (C $\times$ SDY). Different letters indicate significant differences between factors (Tukey's multiple range test).

Tested cultivars did not differently affect straw yield. This trait in both cultivars was significantly higher on deeper sowing (Figure 12).

Figure 12. Straw yield in 2013 (SDH × C). Different letters indicate significant differences between factors (Tukey's multiple range test).

Straw yield increased with deeper placement of seeds (8 cm) in all range of seeding rate. The highest straw yield was gained while using the most dense seeds at 1 m² sown 8 cm deep (Figure 13).

Figure 13. Straw yield in 2013 (SDH × SDY). Different letters indicate significant differences between factors (Tukey's multiple range test).

4. Discussion

4.1. The Effect of Weather Conditions on the Plant Development of Faba Bean

Direct adverse effects of weather conditions (such as drought or high temperatures) can lead to abiotic stress in plants, which may contribute to the low yield stability of legumes [24]. Weather conditions affect the features determining plant density and yield components. Water requirements for faba beans during the growing season are estimated to be between 300–500 mm [24]. In our experiment, the annual precipitation ranged from 332.7 to 408.1 mm, and therefore was favourable for faba bean production (Table 4, Figures 1–3).

Taking into account thermal requirements, it can be defined as moderate. Generally, the germination and first stage growth of this plant is mainly related to temperature, especially daytime temperature when water is not a limiting factor. Low temperatures during the first stages of faba bean development can contribute to better vernalization and positively affect the root system expansion [24]. In turn, high temperature during ripening time can lead unfavourable to shortening this stage, influencing on seed yield quantity and quality. According to Pszczółkowska et al. [25] favourable moisture conditions in the emergence stage (BBCH10) had no inhibitory effect on germination and seed yield. According to Barłóg et al. [26] the growing season determines green seed yield. In turn, Podleśny [27] analyzed the effect of weather conditions on faba bean yield and stated that the greatest effect on yield was observed after rainfall in June during the flowering stage. In turn, Podleśny [27] claimed that cultivars of faba beans are characterized by different sensitivity to weather conditions. In our research, the greatest vegetative period concerned the year 2011 with 46 days and the shortest 39 days in 2013 with the highest total sum of precipitation (116.4 mm) (Table 4). The longest generative period was related to the year 2012, with 96 days for Bobas cultivar with the lowest sum of precipitation in this period (202.6 mm), what could be connected with the highest seed and straw yield. In López-Bellido et al. [14] review, in the early phases of vegetative growth, there can be found a linear correlation between dry matter accumulation and the sowing density per square meter. The length of the growing season and weather conditions during vegetative growth are important to the compensatory capacity of faba beans because they affect the number of stems per plant.

Days that allow to enter to the flowering stage are one of the most essential elements that can give information about faba bean duration longevity of the reproductive period. In our research, the generative period lasted on average 82 for Granit cultivar and 86 days for Bobas cultivar, the longest in 2012—96 days for indeterminate cultivar, and the shortest in 2013—75 days for determinate cultivar (Table 4).

According to Pszczółkowska et al. (2020) [25] at the stage of developed 3 leaves, the precipitation exceeded considerably the perennial average monthly precipitation, which negatively affected the seed yield. At the 6–7 leaf developed stage (BBCH 16–17/36–37), temperature had no significant effect on faba bean yield. Faba bean yield tended to decrease slightly ($R = -0.42$). In our research the highest seed yield was obtained in the second year of experiment (2012), where the average temperature for the vegetative period amounted to 15.8 °C, while the highest temperature in this period was noted in 2013 (17.4 °C) with the lowest seed yield in 2013.

The time needed for plant seed germination depends on the sowing depth, size of seed, and the length of plumose and coleoptiles of individual plants [17,28]. Sowing too shallow may result in poor germination due to insufficient soil moisture in the upper layer of the soil, whereas deep sowing can lead to reduce plant emergence and yield [29]. Baye et al. [17] noticed that 7 days after sowing emergence was observed from seeds sown at depth 4 and 6 cm, while after 12.5 days at 12 cm depth. In turn, Singh et al. [28] stated that medium depth (8 cm) took a longer time (8.5 days) for germination compared to 12 cm (7.8 days). Increasing depth of seeding according to this author expanded the days to set the first flowering prolonged. Shallow depth of sowing (4 cm) took the minimum time (around 59.3 days) compared to 8 and 12 cm of sowing depth to set the first flowering, which was prolonged. In turn, negative effect of sowing depth was observed by Nabi et al. [30] who stated that seedling emergence was reduced with increasing sowing depth in cotton cultivation. The deeper the seeds were sown, the more power they needed to push the shoots above the soil surface. Siddique and Loss [18] claimed in turn, that sowing depth had no effect on crop phenology of faba bean as well as in our studies. According to Ali et al. [19] sowing depth had also no significant effect on germinated seeds. In our study, there was no effect of sowing depth on the length of the vegetative period. The length of vegetative period was the same for both cultivars.

4.2. Effect of Examined Factors on Plant Density, Height of Plants before Harvest and Seed and Straw Yield

Plant density is one of the primary factors controlling crop production. According to Jettner et al. [15] sowing seed rate can affect plant density, dry matter yield, plant height, seed yield, weed competition, the development of fungal and viral diseases, and radiation interception. In our research deeper sowing resulted in greater faba bean density in 2013 and lower number of plant per m² before harvest in 2011. Increase sowing rate affected on larger plant density.

In Baye et al. [17], there was a significance difference in plant height between sowing depths. On the base of their research, the highest plant height was recorded in case of seeds sown at 8 cm depth, whereas the lowest at 12 cm planting depth. Similar results were obtained, taking into account 4 and 12 cm of sowing depth in Singh et al. study (2013) [28]. In our research at 8 cm depth, the plants of faba bean were higher in the year with the lowest precipitation during vegetative period. Divergent results were found in the year with the highest rainfall. In Al-Suhaibani et al. [31] research, no significant variation between the two varieties (Giza 716 and Giza 843) with respect to plant height was found. In our study, indeterminate cultivar (Bobas) was higher than determinate (Granit). According to Al. Suhaibani et al. (2013) [31] sowing density had a significant impact on various vegetative growth parameters, including plant height at 70 and 100 days after sowing. The low sowing density resulted in a decrease in plant height at 70 and 100 days after sowing, comparing to the high plant density (12 plants dripper⁻¹), contradictory to our results.

According to Singh et al. [28], sowing depth has a significant impact on seed yield of faba bean. With the increase of depth in Singh et al. study [28], the yield of faba bean decreased. The greatest seed yield was obtained at a shallow depth of sowing (4 cm) gaining 3536.6 kg ha⁻¹ while the lowest (3420.3 kg ha⁻¹) with 12 cm of sowing depth. The study stood in agreement with our study where seed yield also decreased with increased sowing depth in 2011 and 2012. In turn, in the last year of experiment the results were opposite, greater yield was obtained at deeper sowing depth. According to Siddique and Loss [18] deep sowing did not reduce seed yield, and in some cases seed yield was higher with deeper sowing of chickpea and faba bean. The optimum sowing depth for field beans, according to these authors, is 5–8 cm. Deep sowing can also contribute to improve crop establishment while moisture from summer and autumn precipitation is stored in the subsoil below 5 cm, allowing for reduced damage from herbicides that are used immediately before or after sowing, and by improving the survival rate of Rhizobium inoculated on seeds due to more favourable soil conditions at depth.

According to Gasim et al. [32] the values of yield and yield components in faba bean inbred lines are different. These differences could be caused by genetic or genetic and environmental factors [32]. In Al-Suhaibani et al. [31] a significant difference between the two varieties in yield has been observed. Similar results were found in our research, where Bobas characterized by higher seed yield compared to Granit in all years of experiment.

Optimal sowing density contributes to increased yield and a reduction in the competition between plants for inputs. According to Aquilera-Diaz and Recalde-Manrique [33], increased plant density from 10 to 16 plants per m² contributed to the seed yield increase, however, further increase to 21 plants per m² did not cause significantly the increased of yield.

According to Dahmardeh et al. [34], increasing plants density from 12.5 to 20 plant per m² contributed significantly to the biological yield increase. In our experiment, seed yield was significantly dependent on plant density only in 2013. Increasing the sowing rate from 45 to 60 seeds on m² let to enhanced seed yield.

In Neugschwandtner et al. [8], straw yield may depend on the cultivar, which was confirmed by our study, where the indeterminate cultivar yielded higher in two years of the study. El-Sadek and Salem [35] found that higher seeding rates lead to higher straw yields, as also confirmed by our 2011 and 2013 field studies.

Optimum sowing density depends on cultivars, species, number of branches, or time of sowing. According to Al-Suhaibani et al. [31], increasing sowing density contributed to a decrease in all yield components of individual plants of faba bean, but the yield had increased. In our research, the seed and straw yield have increased with increased sowing density. According to Mellendorf [36] the correlation between sowing density and yield can be described by two concepts. Maximum yield can be achieved if the plants are able to produce sufficient leaf area to ensure maximum light interception during reproductive growth. Secondly, the distance between plants maximises yield because it minimises plant–plant competition. Our results cannot be inscribed in this concept. Plant density is lower or higher compared to optimal results in lower yield, what cannot be proved by own research where a decrease of the yield has not been found. A reduction in yield caused by the high sowing density can be explained by competition between plants. The effect of sowing density on the growth and yield of faba beans may be characterized by differences in genotypes of faba bean.

According to Bond et al. [37], the recommended densities that are usually used range from 15 to 60 plants per m², taking into account the cultivar and region, whereas in our study this was 60 and 75 seeds per m².

5. Conclusions

Faba bean (*V. faba* L. var. *minor*), next to peas and lupins, is a traditional *Fabaceae* crop grown in Poland and its productivity in such weather conditions can be promising. From the results of this study, Bobas (indeterminate cultivar) compared to Granit (determinate cultivar) had a longer growing season (2–5 days), higher plants height, and seed yield. Therefore, it can be recommended to cultivate in conditions of south-west Poland.

It can be concluded that sowing depth had varying effect on faba bean yield. Earlier sown faba bean in lower temperatures during the vegetative period had a higher yield at shallow sowing depths. In turn, deeper seeding resulted in higher yield in case of delayed sowing. A slight tendency of higher seed yield under increased sowing was found. However, changing the number of seeds sown from 45 to 60 per m² resulted in higher yields in the last year of the trial.

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