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THE YIELD OF INDETERMINATE AND DETERMINATE CULTIVARS OF WHITE LUPIN (*Lupinus albus* L.) DEPENDING ON PLANT DENSITY

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ABSTRACT

Background. Intensification of breeding and agronomic techniques in white lupine have given new types of cultivars differing in their reaction to plant density and some morphological traits of plants that are dependent on the technology of cultivation. The aim of the study was to determine the number of plants per unit of area of morphologically diversified cultivars of white lupine that would provide the maximum seed yield with the minimum usage of expensive sowing material.
Material and methods. The 2-way field experiment was conducted in a randomized split-plot design at the Experimental Station in Mochełek (Poland). The experimental factors included two cultivars of white lupine: indeterminate cv. Butan and the determinate cv. Boros, as well as four plant densities: 40, 60, 80 and 100 plants per m^2.
Results. The average lupine seed yield was 3.49 Mg·ha^{-1} and was differentiated over four years by weather conditions, especially by the sum and distribution of rainfall. Indeterminate cv. Butan had a 22% higher yield than the determinate cv. Boros. The highest seed yields from cv. Butan (4.05 Mg·ha^{-1}) were obtained with a plant density before harvest of 77 per m^2, and from cv. Boros (3.83 Mg·ha^{-1}) with 96 plants per m^2. Significantly more pods containing more seeds were developed by plants of the indeterminate cv. Butan. Plant density affected significantly only the number of pods in plants of both cultivars; more pods were obtained from plants growing at the lowest density. The 1000-seed weight and seed number per pod mainly contributed to the yield increase in both cultivars as the density increased from 40 to 80 plants per m^2.
Conclusion. The factor most strongly determining seed yield, the number of pods, seeds per pod and weight of 1000 seeds was the course of weather in the years of the research. Increasing plant density resulted in an increase in the seed yield. A significantly higher yield was obtained from indeterminate cv. Butan at a density of 77 plants per m^2, while for determinate cv. Boros the highest yield was with 96 plants per m^2.

Key words: cultivar type, plant density, yield components, weather course, white lupin

INTRODUCTION

In Europe, an alternative for soybean may be native species of *Fabaceae*, among which lupines (*Lupinus* spp.) have an important position, as they are characterized by a high content of good quality protein in their seeds. In addition they have a beneficial effect on the environment and the yield of subsequently grown crops, their lower requirement for N and P a rich increasing biodiversity (Nemecek *et al.*, 2008). In recent years a growing interest in lupine cultivation in Europe has brought about an increase in the area of its cultivation as well as an intensification of breeding and agronomic techniques (Lucas *et a*l., 2015; Pospišil and Pospišil, 2015). White lupine has the highest yield-producing potential among lupines and its yield

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is dependent on the cultivar and local environmental conditions. An appropriate division of the produced biomass into vegetative and generative organs that contribute to obtaining higher and more stable seed yields of lupines is provided by a proper canopy architecture. One of the important components is plant density as this determines light access, and supply of water and nutrients to each plant and consequently influences the seed yield (Huyghe, 1998). Increasing plant density increases competition between plants, as well as the seed yield and harvest index, and most of the structural components of the yield are negatively correlated with plant density (Clapham and Elbert-May, 1989; Ayaz *et al*., 2001).

Determinate cultivars of white lupine, if compared with indeterminate ones, are characterized by a lack or reduction of lateral branches, lower growth, earlier maturation, lower leaf area ratio and lower biomass yield. Additionally, the better access of light to plants with a determinate growth habit may affect a change in the photosynthetic activity of particular plant organs (Huyghe, 1998), however, the seed yield from such cultivars comes almost entirely from the main stem (Julier *et al*., 1995), while in indeterminate cultivars the contribution of the main stem to the seed yield varies from 46 to 66%, depending on plant density (Herbert, 1977).

Our studies aimed at determining the number of plants per unit of area of morphologically diversified cultivars of white lupine that provided the maximum seed yield with the minimum usage of expensive sowing material.

MATERIAL AND METHODS

Study site and experimental design

The two-way field experiment was carried out in a randomized split-plot design in 4 replications in the years 2012–2015 at the Experimental Station in Mochełek (53°13’ N; 17°51’ E). Every year the experiment was set up on soil of a very good/good rye complex. The subject of research were Polish cultivars of white lupine: indeterminate cv. Butan and determinate (deprived of lateral branches) cv. Boros. 40, 60, 80 and 100 germinating seeds were sown on 1 m^2 with a row spacing of 20 cm and a sowing depth of 3–4 cm. The area of plots for harvest was 24 m^2.

Sampling and analysis

Before harvest, 20 plants were randomly sampled from each plot to evaluate structural components of the yield. The yield of seeds and their components are presented for a 15% water content.

Meteorological conditions

Conditions of white lupine growth and development in successive vegetation seasons were generally beneficial, except for in 2015. Favourable moisture conditions in the spring-summer of 2012 and 2013 satisfied the demand for water in plants during flowering and early pod setting. Although there was on average sufficient water in 2014 the poorer moisture conditions in June and July resulted in lower seed yields. An extremely dry vegetation season was observed in 2015, which resulted in the lowest seed yields of the test cycle.

Statistical analysis

Statistical calculations were made with the use of the program ANALWAR-5.3 FR. The obtained results were subjected to 2-way analysis of variance in a split-plot design. Significance of differences was verified with the use of Tukey test with p = 0.05. Regression curves have been calculated and presented graphically with the use of MS Excel. The evaluation of the effect of plant density on the seed yield and its structural components was conducted with the use of the relative growths of the studied traits and their contribution to increasing/decreasing the seed yield (Rudnicki, 2000).

RESULTS AND DISCUSSION

Climatic conditions, and especially the amount and distribution of rainfall in the period of plant growth, are included in important factors affecting plant height (Šariková *et al*., 2011) and the unsatisfactory yield stability in *Fabaceae* (Mey *at al*., 1989; Nemecek *et al*., 2008; Cernay *et al*., 2015). During the years of the research, different weather conditions were found to significantly shape the yield of white lupine. The significant influence of weather conditions on legume species (Nemecek *et al*. 2008, Cernay *et al*. 2015), including white lupine yield (Mey *et al*. 1989, Šariková *et al*. 2011), has already been noted in other research. The average air temperature in the years of our study did not differ significantly from the multi-annual average. Significant water shortages were experienced in the 2015 season (Table 1). There were favourable humidity conditions in 2012 and 2013 that met plant demands for water during flowering and early pod formation and this resulted in high seed yields (4.19 and 4.48 $Mg \cdot ha^{-1}$, respectively). In spite of sufficient water in the growing season of 2014, the seed yields obtained were lower (3.01 $Mg \cdot ha^{-1}$). This was mainly due to poorer humidity conditions in June and July during formation and filling of pods. The exceptionally dry vegetation season in 2015 resulted in a significant decrease in the yield of both varieties of lupine (2.27 $Mg \cdot ha^{-1}$).

In each research year the indeterminate cv. Butan had a significantly higher yield than the determinate cv. Boros, on average by 22% over the whole period (Table 2). A lower yield of determinate cultivars of white lupine was also found by Milford *et al*. (1993), Prusiński (2002), Podleśny (2007) and Gorynowicz *et al*. (2014). The effect of the lack of lateral branches in cultivars of this type is a lower biomass yield, and consequently, a lower seed yield (Julier *et al*. 1995), which follows from the lower leaf area index, LAI, and hence the lower photosynthetic potential of the plant (Dautokov *et al*., 2015). Cernay *et al*. (2015) found that significant variation in the yield of legumes may also be caused by factors such as the high sensitivity of the biological process of fixing nitrogen to biotic and abiotic stresses, the lack of cultivars well adapted to local agro-climatic conditions, a lack of effective plant protection or shortfalls in modern techniques of sowing and harvesting seeds.

In the research years, the actual average plant density before harvesting white lupine cv. Butan was 40, 56, 77 and 88, and for the determinate cv. Boros it was 40, 58, 76 and 96 plants per m^2 as compared to the planned density before sowing of 40, 60, 80 and 100 plants per m^2. During vegetation there occurred slight, a few percent, plant losses, that became higher with an increase in the planned density. Similarly to the study of Podleśny (2007), higher losses in the density before harvest compared with the planned density were found in cv. Butan (5.6%) than in the determinate cv. Boros (3.1%).

Table 1. Weather conditions over vegetation period of white lupine

Year	Month				
	April	May	June	July	August
Air temperature, °C					
2012	8.4	14.5	15.2	18.8	17.6
2013	7.0	14.2	17.4	18.9	18.1
2014	9.9	13.3	16.0	21.5	17.2
2015	7.5	12.4	15.7	18.5	20.9
Mean air temperature 1949–2014	7.5	12.8	16.3	18.1	17.5
Total rainfall, mm					
2012	26.5	25.4	133.8	115.6	51.8
2013	13.6	91.7	49.3	79.0	56.6
2014	40.7	65.7	44.9	55.4	57.3
2015	15.6	21.6	33.0	50.4	20.3
Mean total rainfall 1949–2014	27.4	44.0	54.7	73.6	53.3

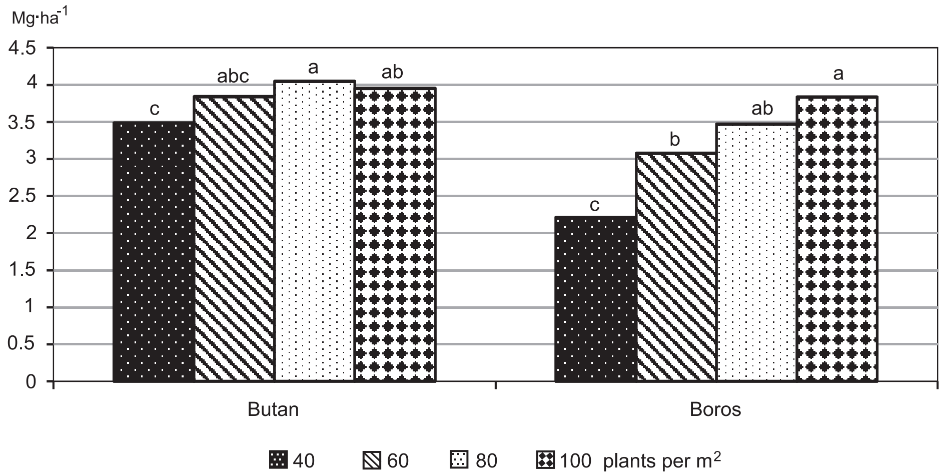
Table 2. Seed yield of white lupine in each year of the research and over the whole period, $Mg \cdot ha^{-1}$

Cultivar	Year				
	2012	2013	2014	2015	2012–2015
Butan	4.92 A	4.78 A	3.10 A	2.52 A	3.83 A
Boros	3.46 B	4.17 B	2.93 B	2.02 B	3.14 B
Mean	4.19	4.48	3.01	2.27	3.49

Mean values followed by the same capital letters in columns did not differ significantly

The seed yield of white lupine is to a large degree a function of plant density and its components (Mey *et al*., 1989). No significant differences were observed in the yield of cv. Butan with plant density from 60––100 plants per m^2, and in the determinate cv. Boros with 80–100 plants per m^2 (Fig. 1).

Nevertheless, the maximum seed yield (4.12 $Mg \cdot ha^{-1}$) of cv. Butan was obtained with 79 plants per m^2 before harvest (Fig. 2), which is in line with the research of Prusiński (2002) and Šariková *et al*. (2011). On the other hand, Podleśny (2007) and Babutiu and David (2010) obtained a maximum seed yield from indeterminate cultivars of white lupine with a plant density of 50–60 plants per m^2. In the USA it was found that the seed yield of the indeterminate cultivar of white lupine did not undergo a significant increase with a density higher than 44 plants per m^2 (Clapham and Elbert-May, 1989). On the other hand, the determinate cv. Boros had the highest yield (3.84 $Mg \cdot ha^{-1}$) with a density of 96 plants per m^2 before harvest. A higher yield from determinate cultivars growing at a density of 100–120 plants per m^2 has also been observed by Prusiński (2002), Podleśny (2007) and Dautokov *et al*. (2015). Pospišil and Pospišil (2015), however did not indicate any significant differences in the seed yield of this type of cultivar when plant density was increased from 60 to 90 plants per m^2, but they did note that an increased density above 60 plants per m^2 was accompanied by a decrease in the number of pods, seeds per pod, and seed weight per plant.



Mean seed yield values followed by the same letters did not differ significantly

Fig. 1. Lupine yield depending on the scheduled plant density

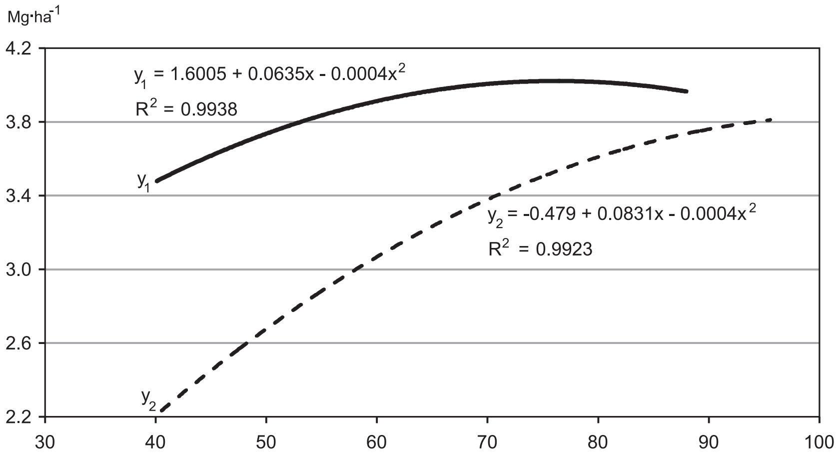


Fig. 2. The effect of plant density before harvest on the yield of indeterminate cv. Butan (y_1) and the determinate cv. Boros (y_2)

The effect of plant density on the seed yield and its structural components was calculated according to Rudnicki (2000). The increase in the seed yield from indeterminate cv. Butan after increasing plant density from 40 to 60 plants per m^2 resulted in 100% from an increase in 1000 seed weight (Table 3), and a further increase in the number of plants from 60 to 80 per m^2 caused an increase in the yield that was due in part to an increase in the number of seeds per pod (by 77%) and in part to the 1000 seed weight (by 23%).

An increase in plant density of the determinate cv. Boros from 40 to 60 per m^2 was accompanied by an increase in the seed yield (Table 4), which was to a 100% the result of an increase in the seed number per pod. The further increase in the seed yield in this cultivar with an increase in plant density to 80 and 100 plants per m^2 was 100% due to an increase in the 1000 seed weight.

Pod number per plant is the main component of the yield structure and determines it to a much higher degree than seed number per pod or 1000 seed weight (Herbert, 1977; Ayaz *et al*., 2001; Gonzalez-Andres *et al*., 2007). Significantly more pods with a higher number of seeds were developed by plants of the indeterminate cv. Butan than of the determinate cv. Boros (Table 5). However, a higher 1000 seed weight was characteristic of cv. Boros. An increasing plant density determined only the number of pods per plant for both cultivars; significantly more pods were developed by plants growing at the lowest plant density.

Linear correlation coefficient, which in our research was significant only for cv. Butan and was –0.55 (at $p < 0.05$), shows the negative correlation between the number of plants per unit of area and the number of pods per plant. Similar results were obtained by Herbert (1977), Mey *et al*. (1989) and Ayaz *et al*. (2001). According to Herbert (1977), a decrease in the number of pods per plant that accompanies an increase in plant density is the result of an increasing competition between plants for resources in the canopy at the stage of flowering, especially in cultivars of an indeterminate growth habit, and it occurs to a higher degree on lateral branches than on the main stem (Clapham and Elbert-May, 1989).

Table 3. Share of structural yield components in determining the seed yield of cv. Butan

Yield components	Increasing plant density								
	from 40 to 60			from 60 to 80			from 80 to 100		
	input		share %	input		share %	input		share %
	$kg \cdot ha^{-1}$	%		$kg \cdot ha^{-1}$	%		$kg \cdot ha^{-1}$	%	
Number of pods per plant	-41.0	-11.8	–	-31.0	-8.5	–	0.00	0.0	–
Number of seeds per pod	-1.00	-0.2	–	9.00	2.4	77	-13.0	-3.1	-100
Weight of 1000 seeds, g	7.00	2.0	100	3.00	0.7	23	3.00	0.6	–

Table 4. Share of structural yield components in determining the seed yield of cv. Boros

Yield components	Increasing plant density								
	from 40 to 60			from 60 to 80			from 80 to 100		
	input		share %	input		share %	input		share %
	$kg \cdot ha^{-1}$	%		$kg \cdot ha^{-1}$	%		$kg \cdot ha^{-1}$	%	
Number of pods per plant	-110	-49.7	–	-7.00	-22.8	–	0.00	0.0	–
Number of seeds per pod	27.0	12.0	100	-1.00	-0.20	–	-71.0	-20.4	–
Weight of 1000 seeds, g	4.00	-1.60	–	32.0	10.5	100	34.0	9.8	100

Table 5. The effect of plant density on the structural components of the seed yield of white lupine

Cultivar	Plant density				Mean
	40	60	80	100	
Number of pods per plant					
Butan	13.8 a	10.6 b	8.6 c	8.0 c	10.3 A
Boros	8.3 a	7.2 ab	7.0 bc	5.9 c	7.1 B
Number of seeds per pod					
Butan	3.2 a	3.2 a	3.3 a	3.2 a	3.23 A
Boros	3.1 a	3.1 a	3.1 a	2.9 a	3.05 B
Weight of 1000 seeds, g					
Butan	288 a	296 a	300 a	302 a	297 B
Boros	313 a	312 a	316 a	327 a	317 A

Mean values followed by the same small letters in rows and capital in columns did not differ significantly

CONCLUSIONS

1. The weather during the experimental years strongly determined the seed yield and its components for both white lupine cultivars.
2. Mean seed yield of white lupine varied from 2.02 to 4.92 Mg·ha^{-1}. Indeterminate cv. Butan yielded significantly higher, on average by 22%, than the determinate cv. Boros.
3. An increasing plant density caused an increase in the seed yield. The indeterminate cv. Butan had the highest yield at a density of 77 plants per m^2, while for the determinate cv. Boros it was at 96 plants per m^2.
4. Among the yield components, only the number of pods per plant was determined by plant density; the greatest number of pods was harvested from plants growing at the lowest density, and this dependence concerned both cultivars.

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PLONOWANIE TRADYCYJNEJ I SAMOKOŃCZĄCEJ ODMIANY ŁUBINU BIAŁEGO (*Lupinus albus* L.) W ZALEŻNOŚCI OD OBSADY ROŚLIN

Streszczenie

Ścisłe 2-czynnikowe doświadczenie polowe w układzie losowanych podbloków wykonano w latach 2012––2015 w Stacji Badawczej Uniwersytetu Technologiczno-Przyrodniczego w Mochełku (53°13’ N; 17°51’ E). Czynnikami doświadczenia były zróżnicowane morfologicznie odmiany łubinu białego: tradycyjna (o niezdeterminowanym typie wzrostu) Butan i samokończąca (o zdeterminowanym wzroście) Boros oraz obsada roślin: 40, 60, 80 i 100 na 1 m^2. Średni plon nasion łubinu białego w wieloleciu wyniósł 3.49 $Mg \cdot ha^{-1}$. Odmiana tradycyjna Butan plonowała o 22% wyżej od samokończącej Boros. Najwyższe plony nasion odmiany Butan (4.05 $Mg \cdot ha^{-1}$) uzyskano przy obsadzie przed zbiorem 77, a odmiany Boros (3.83 $Mg \cdot ha^{-1}$) 96 roślin na 1 m^2. Istotnie więcej strąków zawierających więcej nasion wykształciły rośliny tradycyjnej odmiany Butan, natomiast wyższą masę 1000 nasion stwierdzono u odmiany Boros. Obsada roślin kształtowała istotnie jedynie liczbę strąków z rośliny obu odmian; więcej strąków zebrano z roślin rosnących w najmniejszym zagęszczeniu. Główny udział we wzroście plonowania obu odmian przy zwiększaniu obsady z 40 do 80 roślin na 1 m^2 miały masa 1000 nasion i liczba nasion w strąku.

Słowa kluczowe: gęstość siewu, łubin biały, plon nasion i jego składowe, przebieg pogody, typ odmiany