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Effect of rainfall amount and distribution on growth, development and yields of determinate and indeterminate cultivars of blue lupin

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Abstract. The experiment was run at the Agricultural Experiment Farm, Grabów, operated by the Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy in the years 2005–2007. The study comprised blue lupin varieties: cv. Graf, cv. Zeus (indeterminate type), cv. Sonet, cv. Boruta (determinate type). The experiment was arranged as a split-plot-split-block design with four replications and set up on a good wheat complex soil rated as crop production class IIIa. Amount and distribution of rainfall in each year had a large impact on morphological characters of blue lupin. Shortage of rain in the period of spring and summer negatively affected plant height and restricted leaf area. Yields were to the largest extent dependent on the amount of rainfall in June, i.e. in the blooming period of the plant. Decrease in yield observed in years in which the weather was unfavourable to the production of blue lupin was due to reduced values of yield components, including, first of all, number of pods per plant and number of seeds per plant since the 1000-seed weight was not altered significantly. The indeterminate cultivars, Graf and Zeus, turned out to be less sensitive to periodical shortages of water in soil in comparison to the determinate cultivars Sonet and Boruta.

key words: blue lupin, determinate cultivar, indeterminate cultivar, rainfall requirements, weather pattern, growth and development, yields

INTRODUCTION

Shortage of rainfall is one of the major factors that restrict the yields of legumes, especially in the so-called critical period i.e. at blooming and pod setting (Jasińska, Kotecki, 1993). If occurring in that period the drought causes substantial reduction of yield and yield components (Costa-Franca et al., 2000; Podleśny and Kocoń, 2006; Barrios et al., 2005; Baigorri et al., 1999; Xia, 1997). It is a common opinion that large year-to-year variation (COBORU 2008) is one of the reasons behind little interest that farmers show in the production of that crop. Given the situation, it seems to be advisable to look for genotypes that resist drought stress. The problem has been gaining in importance recently as climatic changes are bringing about more and more frequently long drought spells in the months of spring and summer (Łabędzki and Leśny, 2008). Owing to advances in crop improvement determinate cultivars of blue lupin with altered morphology and with growth and development pattern different from that in conventional varieties have been developed (Prusiński, 2007; Martyniak, 1997). Preliminary studies have shown that determinate varieties of some legumes are poorer yielders and are more sensitive to water deficit (Podleśny, 2001; Podleśny and Kocoń, 2006; Grzesiak et al., 1997; Podleśny, 2001; Podleśny and Podleśna, 2003) as well as to high temperatures at blooming (Jansen, 2008; Podleśny and Podleśna, 2010a) than indeterminate varieties. At the same time, they give a smaller biomass yield which may be linked to a lower requirement for water during growth (Podleśny and Podleśna, 2010b) related to lower transpiration.

The objective of this study was to determine the effect of shortage and uneven distribution of rainfall on yield and yield variability in different genotypes of blue lupin.

METHODS

The results for this study were derived from field experiments conducted in the years 2005–2007 at the Agricultural Experiment Farm, Grabów, operated by the Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy. Each year the experiment plots were seeded to the same blue lupin cultivars: Graf and Zeus (indeterminate type) and Sonet and Boruta (determinate type). Plot area at harvest was 32 m^2. Lupin seeds were dressed with Sarfun T 450 FS (carbendazim, thiuram) and drilled using the Amazone drill to a depth of 2–3 cm at a density of 100 plants/m^2. The experiment was arranged

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as a split-plot-split-block design with four replications and set up on a good wheat complex soil rated as crop production class IIIa. After seeding the plots were harrowed to cover the seeds and to level the surface of the field. The weeds were controlled by applying Afalon Dyspersyjny 450 SC (linuron) to the soil at a rate of 1.5 kg·ha^{-1}. In the period of blooming and pod setting the crop was protected against fungal diseases, mainly anthracnose, by spraying twice with Rovral Flo 255 SC (iprodione) at a rate of 1.5 l·ha^{-1}. Pre-plant fertilizers were applied at following rates: P – 30 and K – 50. During growth detailed observations were made of plant growth and development, plants were scored for incidence and severity of pests and diseases, and records were taken of the dates of major phenological stages: emergence, 2–3-leaf stage, 5–6-leaf stage, blooming, seed setting, seed filling, ripeness. Plant losses during growth were assessed by counting the number of plants after emergence and at harvest on an area of 1 m^2. In addition, on 10 plants picked at random measurements were made of stalk length, leaf area and dry weight of the aerial parts. Prior to harvest plant height was measured and after harvest the crop was analysed for yields and yield components: number of pods and number of seeds per plant, weight of seeds per plant and moisture content of seeds. Lupine seeds were harvested with plot combine "Seedmaster". In order to assess the effect of weather conditions on seed yield Selianinov's index, also called the water supply coefficient or the arbitrary moisture balance, was used (Radomski, 1977). The index is defined as the ratio of the total precipitation to the sum of daily air temperatures in a given period $K=10P/\Sigma t$, where P is total precipitation and Σt is a sum of mean daily air temperatures. The hydrothermal Selianinov's index is used to asses the duration and intensity of drought in its agro-climatic sense. Dry period is defined as a period in which K is lower than 1.0 and extreme dry period (drought) in which K is lower than 0.5.

The results were analyzed by ANOVA and Tukey's confidence half-interval was used to separate the means. If there were no significant differences for the analysed trait among the varieties of a given type, means for a given group of varieties were compared.

RESULTS AND DISCUSSION

The pattern of weather conditions in the study years modified the emergence, growth and development as well as the yields of blue lupin. From literature data it follows that the factor that influences crop yields is more water-related than thermal (Bombik et al., 1997; Michalska, 1998). Therefore, considerations on how weather conditions influenced those characteristics were based primarily on the analysis of the amount and distribution of precipitation over decades and on the value of Selianinov's hydrothermal index (Radomski, 1977). In the years 2005 and 2007 there was little rainfall in March and April which made it possible to start working the soil early and to sow the seeds at the beginning of April. Contrastingly, in the analogous period of 2006 rainfall was abundant and sowing was possible only in the second half of April. Seeds sown in 2006 germinated quickly since a large amount of rainfall was recorded in April (Table 1) resulting in even emergence that occurred as early as 8–10 days after sowing. In the years 2005 and 2007, though, the precipitation in April was almost three times lower than in 2006 and, consequently, emergence came about 16 days after sowing. Abundant rainfall in the sowing-emergence period of 2006 as contrasted with substantial shortages in 2005 and 2007 is also reflected by Selianinov's index values: 0.40 and 0.53, respectively (Table 2).

In each study year, plant density obtained was similar to that projected. Population density before harvest was much lower than that found after emergence as the stand progressively thinned due to competition for water, light and nutrients. Plant losses varied considerably from year to year.

The years 2005 and 2006 were characterized by substantial rainfall shortages, especially in the periods from emergence to the 2-leaf stage and from full blooming to onset of ripening, with Selianinov's index below 0.5. Under those conditions plant losses in the stands of indeterminate lupin varieties were larger by 7.5 and 10.5 percentage points and those of determinate varieties by 7.0 and 4.4 percentage points than those recorded in 2007, respectively. Due to

Table 1. Decade sums of rainfalls through the growth period of blue lupin (mm).

Month	Years												Rainfall demands[#]
	2005				2006				2007				
	decades of month												
	I	II	III	Σ	I	II	III	Σ	I	II	III	Σ	
April	3.2	0.1	6.9	10.2	19.7	7.8	2.6	30.1	8.9	2.0	2.4	13.3	32.6
May	56.5	27.2	0.3	84.0	10.3	27.9	15.2	53.4	20.9	28.9	24.8	74.6	62.9
June	16.4	10.6	1.3	28.3	22.2	0.1	15.9	38.2	76.6	11.7	11.6	99.9	80.6
July	42.0	29.5	61.3	132.8	0.0	7.6	2.4	10.0	45.8	25.7	4.0	75.5	46.9
Total				273.3				131.7				263.3	223.0

[#] according to Dzieżyc (1989)

Table 2. Value of Sielianinov's hydrothermal index at different periods of growth and development of lupin.

Developmental stage of lupin	Years		
	2005	2006	2007
Sowing (BBCH-00) – emergence (BBCH-10)	0.40	0.89	0.53
Emergence (BBCH-10) – 2 leaves unfolded (BBCH-12)	0.32	0.10	1.08
2 leaves unfolded (BBCH-12) – 5 leaves unfolded (BBCH-15)	1.34	0.37	0.68
5 leaves unfolded (BBCH-15) – Flower buds present, still enclosed by leaves (BBCH-50)	0.71	1.60	1.41
Flower buds present, still enclosed by leaves (BBCH-50) – Full flowering (BBCH-65)	0.65	0.60	2.34
Full flowering (BBCH-65) – Beginning of ripening (BBCH-80)	0.20	0.14	1.14
Beginning of ripening (BBCH-80) – Fully ripe (BBCH-89)	1.61	0.53	0.39

a stouter morphology resulting in more mutual shading by plants, indeterminate cultivars Graf i Zeus showed more plant losses than their determinate counterparts Sonet and Boruta (Table 3).

When compared with the data on the demand for water by lupin obtained by Dzieżyc (1989) results from this study indicate that in none of the months of 2006 was there enough rainfall to obtain an optimum yield of seeds. By contrast, in 2007 the amount of rainfall was sufficient to meet the requirement of lupin for rainfall water almost throughout the growing season. It is only in April that a substantial shortage was recorded. Along with the amount, also the even distribution of rainfall is essential for plant growth. The year 2005 stood out in this respect as long-lasting periods of soil water deficit alternated with two periods of very abundant rainfall.

The pattern of weather conditions also affected the development of the morphological features of lupin plants. To name a few, clear differences were found for plant height and for leaf area (Table 4). In 2005 and 2006, due to rainfall shortage in June the plants of indeterminate varieties were shorter at blooming by 27.9 and 31.2%, respectively, than in 2007, the latter year being characterized by fairly abundant rainfall in that period; for the determinate varieties the respective values were 38.0 and 32.0%. In all study years the plants of indeterminate lupin varieties, Zeus and

Table 3. Plant density and plant losses during growth.

Years	Varieties					
	indeterminate			determinate		
	number of plants per 1 m^2		losses [%]	number of plants per 1 m^2		losses [%]
	after emergence	before harvest		after emergence	before harvest	
2005	78.6 a[#]	58.4 a	25.7 b	94.2 b	79.1 b	16.0 c
2006	84.3 b	60.1 b	28.7 b	88.1 a	76.3 a	13.4 b
2007	88.4 b	72.3 b	18.2 a	86.7 a	78.9 b	9.0 a
Mean	83.8	63.6	24.2	89.7	78.1	12.8

[#] Values marked with the same letters do not differ significantly.

Table 4. Values of some morphological features of blue lupin in flowering period.

Years	Varieties					
	indeterminate			determinate		
	height of plants [m]		leaf area in flowering period $[(m^2 plant^{-1})\cdot10^{-2}]$	height of plants [m]		leaf area in flowering period $[(m^2 plant^{-1})\cdot10^{-2}]$
	flowering	before harvest		flowering	before harvest	
2005	0.44 a[#]	0.49 a	0.36 a	0.31 a	0.35 a	0.25 a
2006	0.42 a	0.47 a	0.35 a	0.34 a	0.34 a	0.27 a
2007	0.61 b	0.67 b	0.50 b	0.50 b	0.54 b	0.46 b
Mean	0.49	0.54	0.40	0.38	0.41	0.33

[#] Values marked with the same letters do not differ significantly.

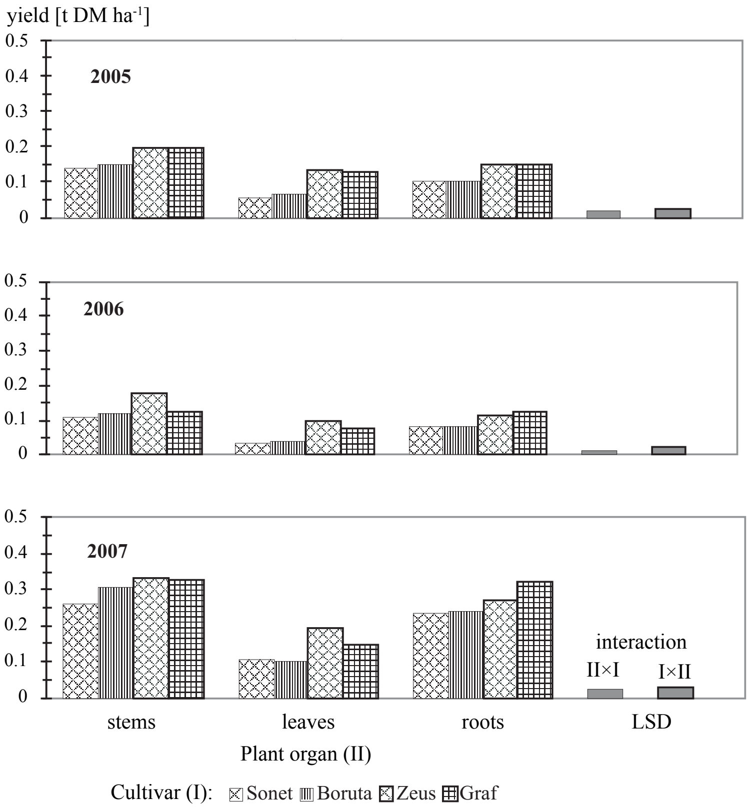

Fig. 1. Yield of dry matter of vegetative organs of lupin in flowering period.

Graf, were decisively taller than those of the determinate Sonet and Boruta. The height of the determinate varieties was more severely depressed by rainfall shortage than was that of indeterminate varieties. Likewise, weather conditions modified leaf area in lupin plants. In the year 2007, advantageous for the production of that crop, the leaf area of the indeterminate lupin varieties was larger than it was in 2005 and 2006 by 38.9 and 42.9, respectively. For the determinate varieties the respective values were 84.0 and 70.4%. Throughout the study, the indeterminate lupin varieties developed a larger leaf area than did the determinate varieties. In the ripening period, leaf area diminished due to withering and shedding of leaves, the process proceeding most rapidly in 2006. In that year a substantial shortage of rain occurred in July coinciding with plant ripening. According to Herz et al. (1992) shortage of water in the soil causes a decline in the leaf area of horse bean through restriction of the leaf number and size and through accelerated leaf ageing. Decrease in leaf area caused by deficit of water in the soil was also found by Barrios et al. (2005) for another legume – bean. In addition, those authors demonstrated that soil water deficit while bringing down the area of leaves on the lateral shoots by 60.1% reduces the leaf area of the main stalk by only 10.4%.

Weather conditions had a substantial impact on the rate at which yield was produced by individual organs of blue lupin (Fig. 1). In the initial period of growth and development no clear difference was found among the studied varieties for dry matter yield. Throughout the study, in the period from blooming to full ripeness the indeterminate varieties of blue lupin gave higher dry matter yield than did the varieties of determinate growth type. It was due to differences in plant morphology. Likewise, the effect of weather conditions on matter accumulation became manifest only in the later stages of plant development as the plants reached a fairly large size and started to compete mainly for water, light and nutrients. The plants of all lupin varieties produced the highest mass of vegetative organs in 2007, the year in which weather conditions favoured the crop, the lowest mass was produced in 2006 when water was in short supply throughout the growing season. It is noteworthy that the highest yield of vegetative organs was obtained in the years in which the yield of generative organs was also the highest (Table 5). This fails to confirm the generally known notion that excessively abundant growth of the vegetative mass restricts the yield of seeds (Jasińska and Kotecki, 1993). In all probability, such a relationship is valid for old-line lupin varieties which used to develop a much greater vegetative mass than do new cultivars. In all study years, in the blooming period the indeterminate varieties were found to have a greater weight of stalks, leaves and roots than the determinate varieties.

Over the study period, weather conditions affected substantially the length of the growth period in lupin. From among the three years, the longest growth period, 127 days, was recorded in 2007, the year in which rainfall was more abundant and, first of all, more evenly distributed than in the remaining two years. In the years 2005 and 2006 the growth period for lupin was 116 and 94 days, respectively. In 2005, the considerable rainfall shortage in the months of spring and summer notwithstanding, there were abundant rains in the first decade of July which lengthened the growth period of lupin markedly, the respective figures for cvs. Sonet, Boruta, Zeus and Graf being 110, 115, 117 and 118 days. For comparison, in 2006 the duration of growth for those varieties was 88, 90, 97 and 93 days, respectively. Rainfall shortages occurring in 2005 and 2006 caused the differences between the indeterminate vs. determinate varieties to diminish. In 2007 the difference was 12 days whereas in 2005 and 2006 they were 5 and 6 days, respectively.

Amount and distribution of rainfall produced a large impact on the seed yield of lupin (Table 5). The highest seed yields were obtained in 2007 in which the value of Selianinov's index at the most important growth and development stages was above 1 and the amount and distribution of rainfall approximated the values considered by Dzieżyc (1989) as optimal for that species. Even distribution of rainfall as essential for lupin seed yields is testified by the comparison of yields in 2005 against those in 2007. The total rainfall in lupin's growth period was similar for both years and was much in excess of the requirements for that species. This notwithstanding, the seed yields in 2005 were nearly 25% of those in 2007.

Table 5. Seed yield of blue lupin (t ha^{-1}).

Years	Varieties			
	indeterminate		determinate	
	Zeus	Graf	Sonet	Boruta
2005	2.86 a	2.83 a	2.12 a	2.28 a
2006	2.77 a	2.75 a	2.00 a	2.24 a
2007	3.45 b	3.58 b	3.17 b	3.24 b
Mean	3.03	3.05	2.43	2.59

Values marked with the same letters do not differ significantly.

On the other hand, weather conditions in the years 2005–2006 did not favour the production of that crop as there was a shortage of rainfall in April and June as well as in July of 2006 which negatively affected growth, development and yields of lupin. By having analyzed the effect of weather conditions on seed yields of lupin it can be stated that they were to the largest extent dependent on the amount of rainfall in June and July or in the period of blooming and pod setting. In spite of a substantial rainfall shortage in June of 2005, abundant rains occurred in July which allowed the seed yields to be higher than those in 2006 which was characterized by rainfall shortage throughout the growth season of lupin. Those findings are borne out by the study of Podleśny and Kocoń (2006) in which was shown that faba bean has a very high sensitivity to insufficient water in the period of blooming and pod setting. An earlier study by Demidowicz (1990) shows that faba bean has the greatest requirement for water also in June that is when the plants are in bloom and when they set pods. Critical periods of availability of water for lupin and faba bean are similar to those for other crops. It follows from the studies of Radzka et al. (2008) and Siuta (1999) that the amounts of rainfall in May and June are also essential for the yield of cereal crops.

Throughout the study years, in terms of yields, the indeterminate cultivars Graf and Zeus outperformed the determinate cultivars Sonet and Boruta by 33.3% (Table 5). In the year 2007 recognized as beneficial for lupin, the seed yield of the indeterminate varieties was higher by 25.4% and that of determinate varieties by 48.2% than the respective yields in 2005–2006, when the conditions were not propitious for lupin. It may testify to a lower sensitivity to drought shown by indeterminate varieties compared to those with determinate growth type. Similar observations were made in earlier studies with white lupin (Podleśny and Podleśna, 2003) and with faba bean (Podleśny, 2001; Podleśny and Kocoń, 2006) performed in a wire-net protected plant growth facility. However, that finding does not apply to all lupin species as it appears from the study of Pszczółkowska (2003) in which different yellow lupin varieties responded with a similar yield decrease to water shortages in the soil. By contrast, Bieniaszewski et al. (2003) demonstrated that some determinate varieties of yellow lupin are more drought-resistant than indeterminate varieties.

Yield reduction observed in the years in which weather conditions were not propitious for lupin was caused by reduced values of yield components, primarily of number of pods per plant and number of seeds per plant since 1000-seed weight was not altered significantly (Table 6). It is corroborated by the study of Pszczółkowska et al. (2003) concerned with the response of yellow lupin to drought in which was shown that water deficit in soil significantly restricts number of seeds per plant but does not change weight of 1000 seeds.

Table 6. Values of some features of lupin yield structure.

Years	Variety					
	indeterminate			determinate		
	number of pods per plant	number of seeds per plant	weight of 1000 seeds (g)	number of pods per plant	number of seeds per plant	weight of 1000 seeds (g)
2005	10.0 a	38.9 a	150 b	7.7 b	30.2 a	150 a
2006	8.0 b	30.0 b	146 a	6.6 a	27.6 b	156 a
2007	15.1 c	58.1 c	146 a	13.5 c	52.8 c	158 a
Mean	11.03	42.3	147.3	9.27	36.9	154.7

Values marked with the same letters do not differ significantly.

Indeterminate lupin varieties, regardless of whether they grew in favourable or non-favourable conditions in terms of rainfall amount, set more pods and yielded more seeds from a plant than did determinate varieties. The reduction in the number of seeds per plant brought about by unfavourable weather conditions in 2006 as opposed to those in 2007 in which the highest seed yields were obtained, was 33.0 and 42.9% for indeterminate and determinate varieties, respectively. The number of pods produced by a single plant of an indeterminate variety in 2007 was higher by 51.0% than that in 2005 and higher by 88.7% than that in 2006. For the determinate varieties, the respective figures were 75.3 i 104.5%.

The studies of Sammler et al. (1982) and of Grzesiak et al. (1989) give evidence that in the periods of drought the legumes may shed flowers or even pods the effect of which is a reduced seed yield. From other studies, it appears that drought occurring during the growth of legumes may result in a reduction of the number of pods per plant by 65% (Mwanamwenge et al., 1999) an in a decrease of seed yield of as much as 70% (Lopez et al., 1996).

CONCLUSIONS

1. Amount and distribution of rainfall have a strong impact on the development of morphological characteristics in lupin. Shortage or uneven distribution of rainfall events in the period of spring and summer depress plant height and decrease leaf area.
2. Both lupin genotypes develop the greatest mass of vegetative organs under weather conditions which favour the production of lupin; the smallest mass is produced in years characterized by rainfall shortage throughout the growing season.
3. Seed yields of lupin were dependent to the largest extent on the amount of rainfall in June and July i.e. in the periods of blooming and pod setting
4. Reduction of seed yield in the years with weather conditions that did not promote lupin production was caused by the reduction in the values of yield components, primarily of the number of pods per plant and the number of seeds per plant as the weight of 1000 seeds was not altered significantly.
5. The lupin varieties in the study varied for their sensitivity, in terms of seed yield, to the pattern of weather conditions. The indeterminate lupin varieties Graf and Zeus responded with a smaller yield decrease to periodical soil water deficits than did the determinate varieties Sonet and Boruta

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