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The productivity of two yellow lupine (*Lupinus luteus* L.) cultivars as an effect of different farming systems

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ABSTRACT

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Between 2011 and 2015, a two-factor field experiment on yellow lupine was conducted in Gorzyń, Poland (52°34'07''N, 15°54'33''E). The first-order factor was the farming technology: low-input (LI; without fertilization and chemical protection); medium-input (MI; medium level of fertilization and chemical protection) and high-input (CONV; high level of fertilization and chemical protection). The second-order factor was the cultivar (indeterminate cv. Mister and determinate cv. Perkoz). The research assessed the productive and economic effects of two yellow lupine cultivars grown in different farming systems. The weather conditions significantly influenced the yield in consecutive years of the research. A change from the LI farming system to the MI and CONV systems increased the seed yield by 13.1% and 22.0%, respectively. The research also showed differences in the yield of the cultivars under study. The indeterminate cv. Mister yielded more seeds than the determinate cv. Perkoz (1.95 t/ha vs 1.81 t/ha). The research also showed that when the EU subsidies were added, the value of production increased along with the cultivation intensity. However, an increase in the outlay on industrial means of production in higher-intensity technologies caused a decrease in the gross agricultural income value.

Keywords: legumes; weed infestation; intensification of cultivation technologies; profitability

The interest in native species of the Fabaceae family has increased due to the growing demand for feed protein in Poland and in some EU and European countries it is still growing right now (Reckling et al. 2016). Although the cultivation of legumes is still undergoing recession (Czerwińska-Kayzer and Florek 2012), it is necessary to remember that these plants are a valuable source of cheap feed protein (Podleśna et al. 2014). Many authors think that lupines are the most suitable crops for cultivation not only in Poland, but also in other European countries (Voisin et al. 2014, Faligowska and Szukała 2015, Reckling et al. 2016) because they have low soil and climate requirements and they leave good sites for follow-up crops. Apart from that, improvement in lupine cultivation agrotechnology is one of the most important issues also, or first of all, for biological progress leading to high and stable yields and increasing the economic importance of the crop (Bieniaszewski et al. 2012). Previous studies have shown that low-intensity technologies are chiefly used for the production of legumes in Poland (Prusiński et al. 2008). However, it is necessary to remember that attempts to increase the yield of legumes and the use of new cultivars (Bieniaszewski et al. 2012) require more industrial means of production. Researchers thus started searching for new more effective and environment-friendly methods of cultivation (Pelzer

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et al. 2012, Jaśkiewicz 2017). The rising prices of production means, growing number of people who need to be nourished and the decreasing farmland area per capita encourage scientists to search for farming technologies which would guarantee satisfactory yield, high quality and positive influence on the natural environment (Bhardwaj et al. 2004). The aim of this study was to assess the productive and economic effects of two yellow lupine cultivars (indeterminate cultivar and determinate cultivar) grown in different farming systems (low-input, medium-input and high-input).

MATERIAL AND METHODS

Between 2011 and 2015, field experiments were conducted on yellow lupine at the Experimental and Educational Station in Gorzyń (Poland) (52°34'07''N, 15°54'33''E). There were four replicates of the two-factor experiments conducted in a split-plot design. The first-order factor was the farming technology: low-input (LI), medium-input (MI) and high-input (conventional, CONV). The second-order factor was the cultivar (indeterminate cv. Mister and determinate cv. Perkoz). Table 1 shows detailed characteristics of individual farming technologies. The trials were carried out on grey-brown podzolic soil under ordinary growing conditions. Every year the pre-crop for lupine cultivations was the winter wheat. The area of the experimental plots was 20 m^2. Each year before lupine was sown, the soil was ploughed and harrowed. The recommended sowing standards for seeds capable of germination were 100 pieces per 1 m^2 for the indeterminate cv. Mister and 115 pieces per 1 m^2 for the determinate cv. Perkoz. The seeds were sown at a depth of 4 cm in rows spaced at 18 cm.

The weather conditions are shown by calculating, the hydrothermal coefficient of water supply for individual years according to the Sielianinov's index (K). The following formula was applied:

$$K = \frac{M_o \times 10}{D_t \times dni}$$

Where: K – hydrothermal coefficient for individual months; M_o – total monthly precipitation; D_t – mean daily temperatures in a particular month.

During the experiments, in each growing season with the sampling areas of 1 m^2, two weeks before the seeds were harvested, the weed infestation was assessed on each plot. Next, the weeds collected from the site were dried in a laboratory drier at 80°C for 48 h. Weed infestation was expressed as the number and dry mass of weeds per unit area (m^2). The following traits of yellow lupine were assessed: the actual plant density per 1 m^2 before harvest, the biometric traits of 10 randomly selected plants before harvest (the number of pods per plant, the number of seeds per plant and the number of seeds per pod) and the 1000-seed weight. Each year in August, lupine was harvested at one stage with a 1.5-m wide Wintersteiger plot combine. The seed yield per 1 ha was calculated, allowing for a moisture of 15%.

The economic analysis of individual farming technologies was based on the calculation of the value of production, total costs per ha and gross agricultural income. Calculations were performed separately for each year and the profitability presented as a mean of five years of study in the results and discussion chapter (Table 2). The value

Table 1. The characteristics of farming systems

Agronomic treatment	Low-input	Medium-input	High-input
Seed conditioning	*Bradyrhizobium lupini*	carboxin, thiram, *Bradyrhizobium lupini*	carboxin, thiram, *Bradyrhizobium lupini*
Weed control	mechanical	mechanical, linuron (direct after sowing)	linuron + clomazone (direct after sowing), metamitron (after emergence)
Soil fertilization (kg/ha)	N – 0; P – 0; K – 0	N – 15; P – 21.8; K – 58.1	N – 30; P – 30.5; K – 83
Foliar application of fertilizers	without extra feeding	without extra feeding	multiple micro- and macroelements
Disease control	without protection	chlorothalonil (tetrachloroizoftalonitryl)	chlorothalonil (tetrachloroizoftalonitryl)
Insects control	without protection	without protection	alfa-cypermethrin (after emergence)
Desiccation before harvest	without desiccation	without desiccation	diqwat (dibromide formula)

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Table 2. Economic analysis of profitability of yellow lupine cultivation under different farming systems in years 2011–2015 (EUR)

Parameter	Cv. Mister			Cv. Perkoz		
	low-input	medium-input	high-input	LI	MI	CONV
Production value* per ha	786.32	866.05	921.16	761.90	825.46	848.57
Total cost per ha	353.87	546.40	886.16	387.98	580.50	920.28
Gross agricultural income per ha	432.45	319.65	35.00	373.92	244.96	–71.71
Cost of 1 t seed production**	328.97	397.70	624.40	288.66	419.40	571.66

*yield per ha × price of 1 t seeds + subsidies of EU; **total cost/yield per ha

of production was calculated by averaging the seed yield separately in each year of the research. The amount of outlay on the cultivation of yellow lupine in individual farming technologies was calculated separately for each year and included the following elements: the costs of purchasing seeds, fertilizers, crop protection products and the costs of agrotechnical treatments, labour, services, taxes and insurance. The calculations were based on the prices of means of production and the average seed purchase price in each year of the research (https://www.cenyrolnicze.pl/). The calculations included EU subsidies for legumes in each year of the research (http://www.arr.gov.pl/). The subsidies included: single area payment, additional payment to the surface of legumes and direct payments to seeds. The EU subsidies in each year of the research were: 2011 – 292.33 EUR; 2012 – 386.24 EUR; 2013 – 402.41 EUR; 2014 – 350.58 EUR and 2015 – 318.56 EUR. The gross agricultural income was calculated as the difference between the value of production and total costs per ha. All prices and costs were calculated according to the average annual Euro exchange rate in each year, as quoted by the National Bank of Poland (http://www.nbp.pl/homen.aspx?f=/kursy/kursyen.htm).

The influence of the intensity of the cultivation system of two different yellow lupine cultivars on the traits assessed was subjected to a two-way analysis of variance (ANOVA) conducted with the SAS program (SAS Institute, 1999). The least significant difference was verified with the Tukey's test at the significance levels of $P < 0.05$ and $P < 0.01$.

RESULTS AND DISCUSSION

There were considerable differences in the conditions of yellow lupine growth and development in individual years of the research (Table 3). On average, during the whole growing period of yellow lupine years 2011 and 2015 were the least favourable due to low hydrothermal coefficients referring to soil humidity. However, it is noteworthy that in all the years of the research, during the plants' highest demand for water, i.e. during the florescence and emergence of pods (June/July) the value of Sielianinov's coefficient amounted to at least 1.0. Thus, it can be stated that at the most critical period of yellow lupine development the plants had relatively good supply of water. According to the reference publications (Podleśna et al. 2014, Faligowska et al. 2017), the total amount and distribution of rainfall during the entire plants' growing period are some of the most important determinants of the volume and quality of the yield of legumes. According to Atkins and Smith (2004), a rainfall deficit combined with high temperature of the air is particularly unfavourable during the florescence and emergence of pods because plants shed their flowers and pods and in consequence, the seed yield is reduced. This observation was confirmed in our study, because the weather conditions in individual years of the research significantly modified the yield of the yellow lupine seeds (Table 4). The lowest yield was noted in 2011 – 0.60 t/ha, on average. The yield of seeds was so low because of drought and semi-drought conditions (K coefficient lower

Table 3. Sielianinov's index in the vegetation periods for years 2011–2015 (recorded at the Agrometeorological Observatory in Gorzyń, Poland)

Year	April	May	June	July	August
2011	0.25	0.58	0.89	3.18	0.48
2012	0.80	0.84	2.26	2.27	1.90
2013	0.53	1.63	2.10	0.87	0.49
2014	1.99	2.50	0.97	1.18	1.74
2015	1.30	0.43	1.02	1.22	0.17

Sielianinov's index: < 0.5 – drought; 0.5–1.0 – semi-drought; 1.0–1.5 – border of optimal moisture; > 1.5 – excessive moisture

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Table 4. Yellow lupine seed yields (t/ha) in the research years (Y)

	2011	2012	2013	2014	2015	Average
Farming systems (FS)						
Low-input	0.55	1.78	2.46	2.46	1.14	1.68
Medium-input	0.57	1.88	2.60	2.63	1.82	1.90
Conventional	0.68	1.99	2.76	2.79	2.03	2.05
$LSD_{0.05}$	FS = 0.061**; FS × Y = 0.237**					
Cultivars (C)						
Mister	0.50	1.96	2.64	2.90	1.73	1.95
Perkoz	0.70	1.81	2.57	2.35	1.60	1.81
Average for years	0.60	1.88	2.61	2.63	1.66	
$LSD_{0.05}$	C = 0.054**; C × Y = 0.335**					

**$P < 0.01$

than 1.0) during the plants' growth. Only in July 2011 there was high rainfall (K = 3.18), but it was too late for yellow lupine to give an adequately high yield of seeds. In 2015, the weather conditions were not favourable to the yield of yellow lupine, either. The average yield of seeds in that year amounted to 1.66 t/ha. On the other hand, the best weather conditions, which favoured the high yield of seeds, were noted in 2013 (2.61 t/ha) and 2014 (2.63 t/ha). Individual yellow lupine cultivation systems significantly modified the yield of seeds. The increase in intensity from the LI system to the MI and CONV systems caused the seed yield to rise by 13.1% and 22.0%, respectively. Borowska et al. (2015) observed similar dependences in their research on three lupine cultivars. According to the authors, higher yields of lupine seeds in higher-intensity farming technologies may have resulted from the dressing of seeds to improve their health status, lesser competition of weeds, plants' positive reaction to seed dressing before sowing, better supply of nutrients, favouring symbiosis with rhizobia and improving photosynthesis efficiency. The authors observed the highest yield of yellow lupine in MI and CONV systems. The study conducted by Faligowska et al. (2017) on white lupine also showed that the seed yield increased by 20.3% when the intensity of the farming system increased. Our study showed significant differences in the yield of the cultivars under analysis. On average, in all the years of the research the indeterminate cv. Mister gave the highest significant yield of seeds (1.95 t/ha), which was 7.2% greater than the yield of the determinate cv. Perkoz. Only in the first year of the research, i.e. 2011 when the weather was dry, the determinate cv. Perkoz gave a significantly higher yield than the indeterminate cultivar. Borowska et al. (2015) also indicated that the yield of yellow lupine seeds from the indeterminate cultivar could be higher than from the determinate cultivar. The authors observed a difference of 11.6% but it was not confirmed statistically.

Among the yellow lupine yield components, the diversification of the farming system intensity and the type of cultivar significantly modified the number of pods and seeds per plant (Table 5). However, these factors did not influence the number of seeds per pod or the 1000-seed weight. The farming technologies did not differ in the plant density per 1 m^2. In the CONV system the number of pods and the number of seeds per plant were significantly greater than in the LI and MI systems. When the farming intensity increased from LI to MI, it did not result in significant differences in the values of these traits. Faligowska et al. (2017) made different observations in their study on white lupine. The authors proved that more intense use of industrial means of production in the MI technology resulted significantly in the largest number of pods and seeds per plant. In consequence, it resulted in the highest yield of seeds in this technology. According to Borowska et al. (2015), when industrial means of production are engaged, the increase in the seed yield from indeterminate and determinate cultivars is determined by an increase in the number of pods per plant (by 89.8–100% in indeterminate cultivars and 100% in the determinate ones). The number of seeds per pod influenced 73.3% of the seed yield of narrow-leaved lupine and 44.2% of the yield of other cultivars. According to these authors, the 1000-seed weight did not have much influence on the seed yield, except the yield of indeterminate white lupine cultivars. Our study showed that the indeterminate cv. Mister developed significantly more pods and seeds per plant (by 16.2% and 19.5%, respectively). In consequence, these plants yielded more seeds.

The analysis of weed infestation in our study showed that diversified intensity of industrial means of production influenced the dry weight and number of weeds in individual farming technologies (Table 6). In comparison with the LI and MI farming systems, the CONV technology allowed to get the smallest significant number of weeds per 1 m^2 (44.0 pcs.) and the lowest significant dry weight (118.1 g). On average, the dry weight of weeds in the CONV technology was 16.4% lower

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Table 5. The effect of farming systems and different cultivars on yield components

Parameter	Farming system			$LSD_{0.05}$	Cultivar		$LSD_{0.05}$
	low-input	medium-input	high-input		Mister	Perkoz	
Plant density (no./m^2)	82.0	78.8	84.9	ns	73.9	89.9	4.47**
Number of pods per plant	8.1	8.1	9.6	0.73**	9.3	8.0	0.64**
Number of seeds per plant	27.1	27.0	32.2	3.34**	31.3	26.2	2.15**
Number of seeds per plant pod	3.4	3.2	3.2	ns	3.3	3.2	ns
Weight of 1000 seeds (g)	136.6	137.8	136.9	ns	136.4	137.8	ns

**$P < 0.01$; ns – non-significant

than in the MI technology and 42.7% lower than in the LI technology. There were similar dependences in the number of weeds – the differences between the technologies amounted to 36.2% and 55.1%, respectively. Such low weed infestation in the CONV technology had a positive influence on the yield of seeds. Borowska et al. (2015) analysed weed infestation in white, yellow and narrow-leaved lupine plantations and observed the highest infestation in the plots where weeds were controlled only mechanically (LI technology). The authors also observed that when clomazone was additionally applied after sowing and metamitron after the emergence of plants, the dry weight of weeds was not significantly reduced in the CONV technology. The results of our study were also confirmed by the study on white lupine conducted by Faligowska et al. (2017). The authors proved that the intensity of weed infestation in individual farming systems was significantly influenced not only by the type of treatment applied but also by the number of lupine plants per area unit. When there were more lupine plants per 1 m^2, they were more competitive to weeds. These observations were confirmed by the results of our study, where the highest density of plants per 1 m^2 was noted in the CONV technology (Table 5). Undoubtedly, it directly affected the intensity of weed infestation in this technology. The averaged results of the five years of our study showed that the determinate cv. Perkoz was significantly less infested by weeds than the indeterminate cv. Mister (Table 2). This dependence was observed both in the dry weight of weeds and the number of weeds per 1 m^2. The determinate cv. Perkoz was more competitive to weeds than the indeterminate cv. Mister because it was characterised by significantly higher density of plants per area unit (Table 5).

The decision about production is affected by numerous factors. One of the most important factors is the profitability of production. According to Czerwińska-Kayzer and Florek (2012), gross agricultural income is a basic economic category indicating the profitability of agricultural production. Averaged in the years 2011–2015, our study showed that when the intensity of cultivation increased, so did the value of production of both cultivars when EU subsidies were added (Table 2). On the other hand, increased outlay in CONV technologies caused a decrease in the gross agricultural income value. The lowest value of 35.00 EUR per ha was noted for the indeterminate cv. Mister grown in the CONV technology, whereas the gross agricultural income value for the determinate cv. Perkoz was negative, i.e. –71.71 EUR per ha. The total costs per ha were the lowest in the LI technology for both cultivars, as they amounted to 353.87 EUR and 387.98 EUR, respectively. The cost of production of one tonne of seeds for on-farm feed production was the lowest in the LI technology. It amounted to 328.97 EUR for the indeterminate cv. Mister and 288.66 EUR for the determinate cv.

Table 6. Weed infestation per 1 m^2 depending on the intensity of farming systems and different cultivars

Parameter	Farming system (FS)			$LSD_{0.05}$	Cultivar		$LSD_{0.05}$
	low-input	medium-input	high-input		Mister	Perkoz	
Dry weight of weeds (g)	206.0	141.3	118.1	22.45**	180.5	129.8	18.13**
Number of weeds	98.0	69.0	44.0	17.34**	88.0	53.0	14.11**

**$P < 0.01$

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Perkoz. It was 47.3% and 49.5% lower than in the CONV technology, respectively. As this financial effect was noted in our study, higher intensity of yellow lupine cultivation does not seem to be economically justified. This thesis is confirmed by the study conducted by Czerwińska-Kayzer and Florek (2012). The authors analysed the costs of production of forage pea seeds, yellow lupine and narrow-leaved lupine and concluded that the cultivation of these crops was both agrotechnically and economically justified. The costs of agrotechnical treatments and subsidies are decisive factors influencing the profitability of production of legumes. The production of forage pea seeds proved to be the most cost-effective, whereas the production of yellow lupine was the least cost-effective. Its cost-effectiveness increased only when direct payments were added and when available nitrogen was entered into soil with follow-up crops. The authors also concluded that the unprofitability of yellow lupine cultivation was caused by a relatively low yield of seeds per area unit. Our studies have shown that yellow lupine cultivation is profitable if harvested seeds yield achieves above 2.5 t/ha. The research conducted by Faligowska et al. (2017) also showed that the production of white lupine in the LI farming system was the most profitable.

To sum up, an increase in the outlay on industrial means of production in the MI and CONV technologies caused a significant increase in the yield of seeds and reduced the intensity of weed infestation. However, it is noteworthy that the outlay on industrial means of production in these technologies, especially in the CONV system, was not compensated by good economic results. Without EU subsidies MI and CONV technologies would be unprofitable. The LI system resulted in the highest gross agricultural income and the lowest cost of production of one tonne of seeds of both yellow lupine cultivars. However, it is necessary to stress the fact that when this yellow lupine production technology was applied, the yield of seeds decreased and there was higher pressure of diseases, pests and weeds. Therefore, this farming system should be supplemented at least by chemical control of weeds by using herbicides. The main reason why indeterminate cv. Mister yielded more seeds than the self-completing cv. Perkoz was the fact that the cv. Mister plants developed more pods and seeds. On the other hand, the determinate cv. Perkoz was more competitive to weeds because there was higher density of these plants per area unit.

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