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# YIELD AND MINERAL COMPOSITION OF SEEDS OF LEGUMINOUS PLANTS AND GRAIN OF SPRING WHEAT AS WELL AS THEIR RESIDUAL EFFECT ON THE YIELD AND CHEMICAL COMPOSITION OF WINTER OILSEED RAPE SEEDS\*

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## Abstract

A controlled field experiment was carried out in 2011-2014 in order to determine yields and chemical composition of selected genotypes of leguminous plants and spring wheat, as well as their value as a preceding crop (crop volume, mineral composition of seeds) for winter oilseed rape grown in Northern Poland. Chemical analysis of the content of macronutrients and micronutrients in seeds and grain was conducted using standard methods after mineralisation in  $H_2SO_4$  with  $H_2O_2$  as an oxidant (macronutrients), or in a mixture of the acids  $HNO_3+HCl+HClO_4$  (micronutrients). It was proven that among the examined species and seasonal types of legumes, the highest total seed and protein yield volume was obtained from both field bean forms, traditional and determinate one. The lowest yield was achieved from blue lupine. The yield of winter wheat grain oscillated around  $5.6 t ha^{-1}$ . Blue lupine seeds were characterised by the highest total protein content. Seeds of both field bean forms were distinguished by the highest content of potassium, phosphorus, copper and zinc, while blue lupine seeds had the highest content of calcium, magnesium and manganese. The research showed a clear tendency towards a higher winter oilseed rape yield in a field after determinate field bean and seed pea. Spring wheat proved to be the worst previous crop for winter oilseed rape. The tendency for greater accumulation of nitrogen, phosphorus, calcium, copper, iron and zinc in winter oilseed rape seeds was observed in a field after determinate field bean. The lowest content of macronutrients and micronutrients was characteristic for seeds of winter oilseed rape grown after spring wheat. Winter oilseed rape seeds in a field after determinate field bean and blue lupine were rich in

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manganese. The research proved a positive relationship between the total nitrogen content in soil after harvest of pre-crop plants and winter oilseed rape seeds yield ( $r = 0.864$ ).

**Keywords:** yield macro- and microelements, blue lupine, indeterminate of field bean, determinate of field bean, pea.

## INTRODUCTION

After a dramatic decline in the production of legumes in Poland, their cultivation area has been slowly increasing in the recent years. The system of subsidies for the cultivation of legumes introduced in 2010 has generated a renewed interest among farmers in seeds of leguminous plants. According to many authors (MC EWEN et al. 1989, SIELING et al. 1997, VAN KESSEL, HARTLEY 2000, CHRISTEN 2001, KAUL 2004, VON RICHTHOFEN 2006*ab*, FLOREK et al. 2012, KOPINŃSKI, MATYKA 2012), this direction in plant production should be pursued owing to the positive effect of these plants on the soil environment and on successive plants, as well as a possible use of legumes as an indigenous source of protein in fodder production. Atmospheric nitrogen fixation is a remarkable distinguishing feature of these plants (JENSEN 1997, KUO, SAINJU 1998, VAN KESSEL, HARTLEY 2000, GHOSH et al. 2007). Numerous studies indicate that legumes contribute to soil between 32 (GHOSH et al. 2007) and 110 kg N ha<sup>-1</sup> (KAUL 2004). The inclusion of legumes in crop rotation makes it possible to reduce the application of mineral fertilisers by up to 20-25% (VON RICHTHOFEN 2006*b*, PRUSIŃSKI et al. 2008). Crop residue of leguminous plants in soil enriches it with humus, nitrogen, potassium and phosphorus (JASIŃSKA, KOTECKI 1997). Their deep and well-developed root system reduces soil degradation through its structure-forming and irrigating effect, which improves the physical properties of soil and enhances its microbiological activity (KAUL 2004, GHOSH et al. 2007). The available literature contains many reports on winter oilseed rape fertilisation both with NPK and S, and on the fertiliser value of crop residue left in soil (JANKOWSKI et al. 2014, SZCZEPANIAK 2014, JANKOWSKI et al. 2015), contrary to which there are relatively few studies on the residual effect of legumes on winter oilseed rape yielding and chemical composition, especially as regards nitrogen management. Whether or not legumes can serve as a preceding crop for winter oilseed rape depends primarily on their harvest date (JASIŃSKA et al. 1995). Thus, despite their beneficial features, not all legumes are a suitable preceding crop for early sown winter oilseed rape (KOTECKI 1995*a*). Owing to its short growth time, seed pea is considered to be one of the best preceding crops for winter oilseed rape (KAUL 2004). In some regions of Poland, field bean can also be seen as a proper preceding crop for this plant, especially its determinate forms, which have a shorter growth period (KOTECKI 1995*a*).

In Poland, yellow lupine, pea and field bean are the major leguminous crops in the national economy (FAOSTAT, FLOREK et al. 2012). Domestic le-

gumes are characterised by high yield variation, resulting from agrotechnical and environmental (especially weather-related) factors. They show high sensitivity to rainfall shortage during stages critical for these plants, i.e. while blooming and during pod setting. Water shortage may lead to the shedding of generative primordia, and consequently the yield is reduced (GRABOWSKA, BANASZKIEWICZ 2009).

The purpose of this research was to determine yield and chemical composition of the selected species and seasonal forms of legumes as well as spring wheat, and their preceding crop value on the yield volume and mineral composition of subsequent winter oilseed rape grown in Northern Poland.

## MATERIAL AND METHODS

The research results originate from a controlled field experiment conducted at the Production and Experimental Station in Balcyny. Two series of trials were designed in order to test the following:

- I. The yield and mineral composition of seeds (grain) from some legumes and spring wheat species grown in Northern Poland. This experiment was carried in 2011-2013 and included 4 replications. The following plants were tested: spring wheat cv. Trappe, and legumes such as narrow-leaf seed pea cv. Tarchalska, blue lupine traditional cv. Zeus, field bean traditional cv. Olga, field bean determinate cv. Granit.
- II. The residual effect of some legumes and spring wheat species on the yield and mineral composition of winter oilseed rape seeds. A one-way experiment with 4 replications was conducted in 2012-2014.

The experiment was established on Haplic Luvisol developed from boulder clay (JUSS Working Group WRB, 2006). The trials were carried out on slightly acidic soil (pH in 1M of KCl from 5.7 to 5.8), in which the content of phytoavailable forms of P, K, and Mg varied depending on the year of the experiment. Overall, the phosphorus content in soil ranged from high to very high (72.5-108.7 mg P kg<sup>-1</sup> of soil); the potassium content was moderate (117-153 mg K kg<sup>-1</sup> of soil), whereas the soil magnesium content was high (74-80 mg Mg kg<sup>-1</sup> of soil).

Spring wheat was used as the preceding crop of legumes and spring wheat. The total area covered by the experiment reached 2,500 m<sup>2</sup> (125 m<sup>2</sup> x 5 species x 4 replications). Nitrogen fertilisation was carried out using ammonium nitrate (34% N); 30 kg N ha<sup>-1</sup> was applied before sowing the legumes. Nitrogen fertilisation for spring wheat consisted of 30 kg N ha<sup>-1</sup> applied before sowing and 60 kg N ha<sup>-1</sup> added at the stage of stem extension. Phosphate and potassium fertilisers were applied before sowing. Superphosphate (17.4% P) was supplied in the following doses: 26.16 kg P ha<sup>-1</sup> under

field bean, seed pea and spring wheat; 34.88 kg of P ha<sup>-1</sup> under blue lupine. Potassium fertilisers (in the form of potassium salt 49.8% K) were applied in the following quantities: 83 kg K ha<sup>-1</sup> under field bean, seed pea and spring wheat; 116.2 kg K ha<sup>-1</sup> under blue lupine. In the second experiment, the plot size was 30 m<sup>2</sup>. Fertilisation with phosphorus and potassium was the same as in experiment I, i.e. 34.88 kg P ha<sup>-1</sup> and 99.6 kg K ha<sup>-1</sup>. There was no nitrogen fertilisation. Seeds of winter oilseed rape cv. Californium were sown in the last ten days of August. All cultivation and plant protection procedures were carried out in line with conventional tillage recommendations. The research results demonstrated seed (grain) yields, protein content and yield of legumes and spring wheat. The protein content in seeds (grain) was calculated with the coefficient 6.25 (ISO 5983-1:2005). Moreover, the total nitrogen content in soil was determined after the harvest of preceding crops, and the content of macronutrients and micronutrients in seeds (grain) was assessed. The phosphorus content was determined by the vanadium-molybdenum method, calcium and potassium - by atomic emission spectrometry (AES), magnesium – by atomic absorption spectrometry (AAS), total nitrogen – by the hypochlorite method. The content of micronutrients was examined according to test procedure PB07 ed. 3 of December 3, 2012. This method involves material mineralisation in a mixture of nitric and perchloric acids, with subsequent determinations using flame atomic absorption spectrometry. Certified reference material OBTL 5 was used to complete the analyses.

The results of chemical analyses were verified statistically. The least significant difference was assumed at  $p = 0.05$ . All calculations were accomplished with STATISTICA v. 10, while the classification and principal component analyses were performed with MVPS v.3.1 software.

The thermal and humidity conditions during the growing season of legumes and spring wheat were favourable for their growth and yielding (Table 1).

Table 1

Weather conditions in 2011-2014 (data from the Meteorological Station in Balcyny)

Month	Mean monthly temperature (°C)					Precipitation total (mm)				
	2011	2012	2013	2014	mean from 1961-2000	2011	2012	2013	2014	mean from 1961-2000
January	-	-2.0	-4.5	-3.3	-3.1	-	87.7	34.6	44.0	29.0
February	-	-7.5	-0.8	2.0	-2.2	-	24.9	21.3	11.4	22.3
March	2.0	3.4	-4.0	5.4	1.4	8.6	21.3	14.0	55.7	28.5
April	9.7	8.4	6.3	9.5	7.0	33.7	44.7	22.2	26.1	35.4
May	13.4	13.8	15.0	13.1	12.5	41.5	42.5	46.2	34.9	57.6
June	17.5	15.2	17.4	14.8	15.8	56.2	107.2	45.4	72.2	69.5
July	18.0	19.0	17.9	21.0	17.2	171.9	112.2	163.8	20.4	81.6
August	18.0	17.9	18.1		16.8	83.6	25.7	25.3		75.2
September	14.6	14.0	11.5		12.6	38.9	41.0	69.3		59.0
October	8.7	7.9	9.3		7.9	29.9	57.6	15.4		55.3
November	3.1	4.9	5.0		2.8	9.6	48.5	23.2		19.8
December	2.4	-3.3	2.3		-1.2	46.0	15.1	34.1		41.4

The temperature values were higher than the long-term mean. On the other hand, the total precipitation was close to the long-term values except in June 2012 and in July in all the analysed years. In some years (2011 and 2013), rainfall was more than double the multiannual mean. The weather conditions during winter oilseed rape growing season were also favourable for the growth, wintering and yielding of this species. Low temperatures in winter and in early spring did not cause any significant losses during the wintering of winter oilseed rape because high snowfall effectively protected the plants against freezing out. The thermal and humidity conditions in spring usually fostered winter oilseed rape growth and yielding. Heavy rainfalls, exceeding the multiannual mean, occurred in July of 2012 and 2013, especially in the second decades of these months. However, high temperatures and moderate precipitation at the end of July and beginning of August fostered plant ripening and attaining high winter oilseed rape yields. The year 2014 was characterised by beneficial temperatures and moisture for winter oilseed rape growth and development.

## RESULTS AND DISCUSSION

A very high yield of seeds (grains) was produced in all the years of the experiment (Table 2). The highest seed yields for pea and both field bean forms were obtained in 2012, and for blue lupine – in 2013. On the other hand, the third year of the research (2013) turned out to be the most advantageous for spring wheat. In the first year of the research (2011), the determinate cultivar of field bean gave the highest yield, whereas its traditional form and seed pea yielded slightly lower. In contrast, the lowest yield in all the years was obtained from blue lupine. The average spring wheat grain yield was *ca* 6.5 t per ha. In the second (2012) and third (2013) year of the research, pea and both field bean forms gave much more yield than blue lupine. In the third (2013) year of the research, seed pea yield was the highest among all the legumes. Both field bean forms and seed pea proved to be the species giving highest yields of all the tested legumes in Northern Po-

Table 2

Yield of legume plants and spring wheat

Plant species	Yield (t ha <sup>-1</sup> )			Previous crop LSD <sub>0.05</sub>
	2011	2012	2013	
Pea	4.60	6.44	5.40	1.276
Blue lupine	2.48	3.08	3.73	1.110
Interminatte cv. of field bean	5.15	6.13	4.92	0.910
Determinate cv. of field bean	5.46	6.27	5.20	n.s.
Spring wheat	5.63	6.50	7.25	1.310

land. This is also confirmed by the research results of FLOREK et al. (2012), who pointed out field bean and pea were the most productive in the Polish conditions, while the lowest yield was obtained from yellow lupine.

The average yield of winter oilseed rape seeds in the analysed years was much the same in each year, ranging from 4.77 t ha<sup>-1</sup> (2012) to 4.72 t ha<sup>-1</sup> (2013) – Figure 1. The research results showed a considerable effect of the

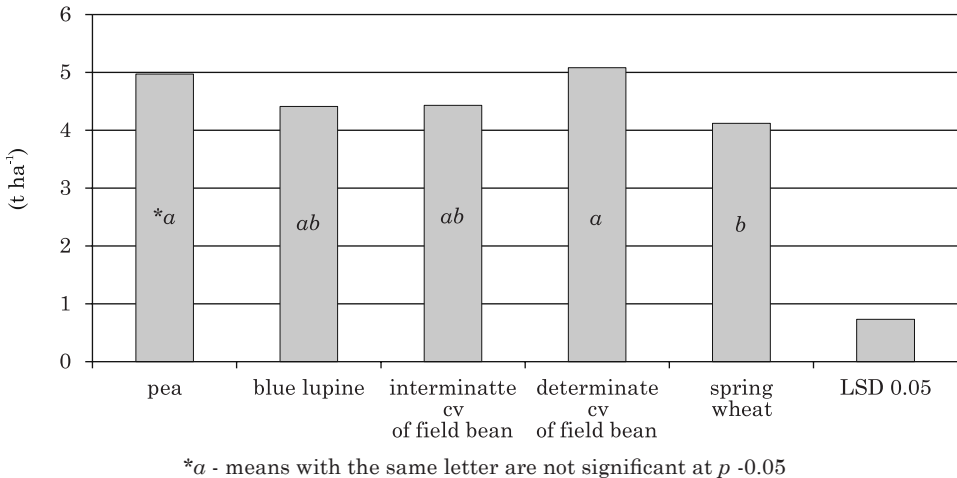


Fig. 1. Yield of winter oilseed rape seeds (t ha<sup>-1</sup>) after legume and spring wheat previous crops

preceding crop on winter oilseed rape seed yield volume. The highest yield was reached in the field after determinate field bean (5.38 t ha<sup>-1</sup>) and pea (5.06 t ha<sup>-1</sup>). A slightly lower yield was observed for winter oilseed rape grown after blue lupine (4.75 t ha<sup>-1</sup>) and the traditional form of field bean (4.59 t ha<sup>-1</sup>), although yield values for oilseed rape grown after the above crops did not differ significantly. The lowest winter oilseed rape yield was harvested from a field after spring wheat, although a statistically significant difference occurred only for seed yield obtained after determinate field bean and pea. The research proved a positive relationship between the total nitrogen content in soil after the harvest of preceding plants and the yield of winter oilseed rape seeds ( $r = 0.864$ ) – Figure 2. The statistical analysis revealed that seed yield increased with the increasing total nitrogen content in soil. Also, KOTECKI and BRODA (1995a) showed a high winter oilseed rape yield after both traditional field bean (cv. Nadwiślański), and determinate forms. The positive effect of two pea cultivars (Opal and Fidelia) sown as a previous crop at different sowing densities was also proven in another experiment by KOTECKI and BRODA (1995b). According to JASIŃSKA et al. (1995), cereals are regarded as poorer crops preceding winter oilseed rape than legumes because they cause a significant drop in seed yield. A positive effect of pea as a previous plant on winter oilseed rape was also shown by KAUL (2004). Oilseed rape cultivated after pea gave a yield reaching 5.36 t ha<sup>-1</sup>, after field bean – 4.81 t ha<sup>-1</sup>, after flax 2.27 t ha<sup>-1</sup>, and after white lupine –

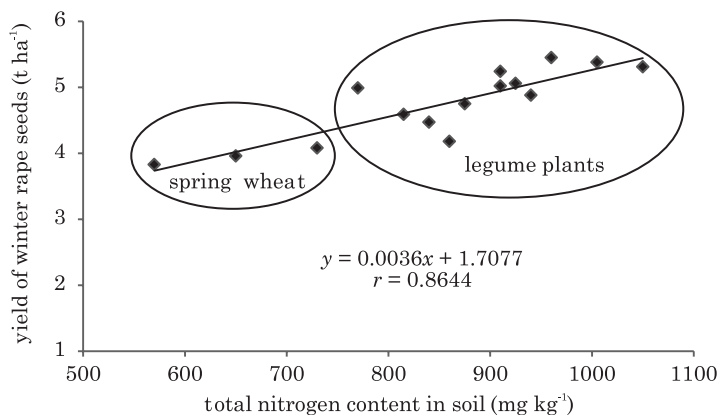


Fig. 2. Linear regression between yield of winter oilseed rape seeds ( $\text{t ha}^{-1}$ ) and total nitrogen content in soil depending on legume plants and spring wheat as previous crops

just  $1.33 \text{ t ha}^{-1}$ . A higher yield of oilseed rape seeds grown after pea compared to wheat as a preceding crop was also confirmed by CHRISTEN and SIELING (2001).

The lowest total protein content was found in spring wheat grain (Table 3). Blue lupine proved to have the highest protein content ( $321 \text{ g kg}^{-1} \text{ d.m.}$ ) of all legumes. A slightly lower protein concentration was determined in seeds of both field bean forms (ranging from  $286$  to  $295 \text{ g kg}^{-1} \text{ d.m.}$ ). The total protein content in seed pea seeds was  $207 \text{ g kg}^{-1} \text{ d.m.}$  Much the same values of total protein in seeds of legumes were obtained in long-term research carried out by the COBOR – The Research Centre for Cultivar Testing (*Descriptive List ...* 2010). The stability of the total protein concentration in pea seeds irrespective of a cultivation system was also shown by WOŹNIAK et al. (2014). Significantly the highest three-year average total protein yield was obtained from both field bean forms (from  $1642$  to  $1652 \text{ kg ha}^{-1}$ ) – Table 3, and the

Table 3

Content of total protein and protein yield in legumes and spring wheat seeds after previous crops

Plant species	Content of total protein ( $\text{g kg}^{-1} \text{ d.m.}$ )	Protein yield ( $\text{kg ha}^{-1}$ )
	legumes and spring wheat	legumes and spring wheat
Spring wheat	111.1	731.7
Pea	207.0	1127.7
Blue lupine	321.0	1006.8
Interminate cv of field bean	295.0	1641.6
Determinate cv of field bean	286.0	1651.7
LSD <sub>0.05</sub>	24.6	51.22

protein yield achieved from pea seeds was considerably lower (by 32%). The lowest total protein yield of 732 kg ha<sup>-1</sup> was determined in spring wheat grain.

According to our own studies, blue lupine seeds were characterised by significantly the highest magnesium and calcium content of all the analysed species (Table 4). On the other hand, seeds of both field bean forms contained most potassium and phosphorus. The content of the analysed macronutrients in spring wheat grain was the lowest. Significantly more copper and zinc accumulated in seeds of both field bean forms (Table 5). In contrast, the seeds of pea, blue lupine and traditional field bean form were characterised by the highest iron concentration, while blue lupine seeds were the richest in manganese.

Table 4

Macronutrient content in legume crops and spring wheat seeds (g kg<sup>-1</sup> d.m.)

Plant species	P	K	Mg	Ca	Na
Pea	4.47	9.73	1.17	1.33	0.02
Blue lupine	4.80	10.39	1.66	3.62	0.03
Interminatte cv of field bean	5.10	12.34	1.32	1.99	0.06
Determinate cv of field bean	5.14	11.39	1.05	1.28	0.02
Spring wheat	3.45	4.74	1.18	0.54	0.01
LSD <sub>0.01</sub>	0.423	0.485	0.286	0.168	0.003

Table 5

Micronutrient content in legume crops and spring wheat seeds (mg kg<sup>-1</sup> d.m.)

Plant species	Cu	Fe	Zn	Mn
Pea	5.06	49.51	32.67	9.35
Blue lupine	4.42	48.23	28.68	32.60
Interminatte cv of field bean	7.46	49.29	43.69	14.04
Determinate cv of field bean	7.10	35.30	47.57	14.52
Spring wheat	3.20	38.38	24.21	15.23
LSD <sub>0.01</sub>	0.239	1.797	1.535	0.803

The analysis of the concentrations of elements (N, P, K, Ca, Mg, Na, Cu, Fe, Zn, Mn) based on the chemical composition of legume seeds demonstrated considerable differences (Figure 3). The two field bean forms, traditional and determinate one, composed the first group with the highest probability (91.8%) in terms of the closest similarity of the chemical constitution of seeds. Pea seeds were the nearest to that group (86.6%). The content of macronutrients and micronutrients in blue lupine seeds and spring wheat grain diverged considerably from the degree of similarity in the chemical constitution of seeds of the former plants: 82.3% and 82.1%, respectively.



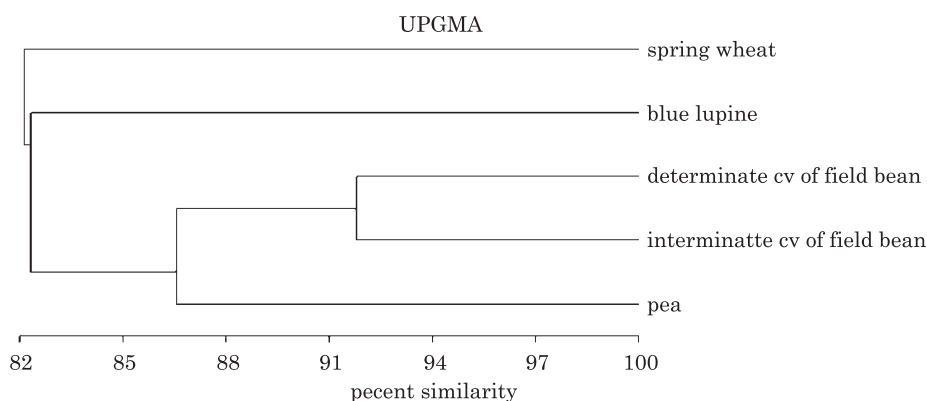


Fig. 3. Dendrogram similarity of the chemical composition of macro- and microelements in seed and grain of the crops used in the experiment

According to SANDBERG (2002), the content of mineral elements, especially iron, zinc and magnesium, in seeds of legumes is high. WOŹNIAK and MAKARSKI (2013) showed that spring wheat grain harvested from a crop rotation with legumes contained more phosphorus, calcium, iron and zinc than grain from a monoculture.

Another experiment carried out by WOŹNIAK et al. (2014) showed some variation in the mineral composition of pea seeds depending on a cultivation system. A higher phosphorus and potassium content was observed in seeds from the conventional and simplified cultivation systems compared to the one in which herbicides had been used, and seeds from simplified cultivation contained more calcium than those from the conventional system. The conventional cultivation of plants also increased the iron content, compared to the simplified and herbicide cultivation systems. On the other hand, the magnesium and zinc content was independent of an agricultural system and a research year, whereas the copper content was significantly higher in simplified cultivation than in the conventional and herbicide systems.

In our research, the content of macronutrients in winter oilseed rape seeds was varied and depended on the previous crop (Table 6). Distinct tendencies for accumulating a higher content of nitrogen, phosphorus and calcium in seeds were confirmed in the plots after determinate field bean. The differences in the magnesium content between individual treatments were not confirmed statistically. Seeds of oilseed rape grown after seed pea were characterised by a low phosphorus and calcium content. The content of the examined macronutrients after spring wheat was lower than in the remaining treatments; however, the differences were not significant statistically. Seeds of winter oilseed rape grown after determinate field bean were also distinguished by the highest content of copper, iron and zinc (Table 7). Seeds of winter oilseed rape after determinate field bean and blue lupine were rich in manganese. The distinctly lowest content of the analysed micronutrients

Table 6

Macronutrient content in winter oilseed rape seeds (g kg<sup>-1</sup> d.m.)

Plant species	N	P	K	Mg	Ca	Na
Pea	27.50	5.20	6.40	3.35	2.30	0.04
Blue lupine	27.60	5.80	6.95	3.15	3.30	0.01
Interminatte cv of field bean	27.50	5.75	6.90	3.05	3.30	0.03
Determinate cv of field bean	29.60	6.30	7.60	3.15	3.60	0.01
Spring wheat	26.30	6.00	6.45	3.05	3.50	0.01
LSD <sub>0.01</sub>	2.332	0.903	0.783	n.s.	0.409	0.0075

Table 7

Micronutrient content in winter oilseed rape seeds (mg kg<sup>-1</sup> d.m.)

Plant species	Cu	Fe	Zn	Mn
Pea	3.55	81.70	32.50	29.30
Blue lupine	3.70	75.40	32.35	38.55
Interminatte cv of field bean	3.50	61.35	27.68	34.45
Determinate cv of field bean	4.20	88.50	30.85	38.71
Spring wheat	2.80	60.30	26.90	25.95
LSD <sub>0.01</sub>	0.159	1.131	0.713	0.657

was characteristic for seeds of oilseed rape grown after spring wheat (statistically proven). The positive effect of pea and soybean as preceding crops on the content of some macro- and micronutrients in spring wheat grain was verified by WOŹNIAK and MAKARSKI (2012). STANISŁAWSKA-GLUBIAK and KORZENIOWSKA (2009) observed a higher calcium, iron and zinc content in the case of pea, while spring wheat grown after soybean contained more ash, potassium and magnesium.

## CONCLUSIONS

1. Out of the examined species and types of legumes grown in Northern Poland, the highest yield of seeds and total protein was obtained from both field bean forms. Blue lupine proved to produce the lowest yield.

2. Blue lupine seeds had the highest total protein content. A slightly lower concentration of protein was observed in seeds of both field bean forms.

3. Seeds of the examined field bean forms were characterised by the highest content of potassium, phosphorus, copper and zinc. Blue lupine seeds were the richest in calcium, magnesium and manganese.

4. The research showed a clear tendency towards higher yields produced by winter oilseed rape after determinate field bean and pea. Spring wheat proved to be the worst preceding crop for winter oilseed rape.

5. The research results revealed a tendency towards an increased accumulation of nitrogen, phosphorus, calcium, copper, iron and zinc in winter oilseed rape seeds grown after after determinate field bean, as compared to the other treatments.

6. Seeds of winter oilseed rape grown after spring wheat were characterised by the lowest content of macronutrients and micronutrients.

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