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Assessment of lupine seed fodder quality depending on the variety and tillage system used as factors for sustainable agriculture

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A b s t r a c t. Legumes are the primary source of plant protein in human food production, but also in pig and poultry feed. In this study, the fodder value of the seeds of three popular species of lupine was evaluated with reference to its variety and the tillage system used to produce it. The plant materials were subjected to chemical analyses to assess their macronutrient (nitrogen – N, phosphorous – P, potassium – K, calcium – Ca, magnesium – Mg and sodium – Na) contents and based on these results, the data ratios of the individual nutrients were calculated as mass ratios of N:P, K:Mg, K:Na, Ca:P, Ca:Mg, K:(Ca+Mg) and (K+Na):(Ca+Mg). Among the calculated nutrient ratios, the highest values were observed for narrow-leaved lupine and the lowest for yellow lupine. No-tillage was conducive to a greater amount of N and Ca being taken up by the narrow-leaved lupine seeds, while conventional cultivation promoted a higher uptake of N, P and Mg by yellow lupine. It was found that the variety grown and tillage system used had little effect on changes in the nutrient ratio values or in nutrient uptake with lupine seed yields. The lupine seeds took up the most nitrogen and the least sodium. The nutrient ratio values used for the fodder value assessment of lupine seeds should be perceived as a useful tool verifying their usefulness and at the same time indicating possible deficiencies and excesses in the amounts of nutrients taken up.

K e y w o r d s: nutrient ratio values, variety, tillage, lupine

INTRODUCTION

The growth in the world's population is associated with the need to increase food production. At the same time, the need to use sustainable agriculture methods is increasingly being emphasized at present. As reported by Tahat *et al.* (2020) two sustainable agricultural management strategies are aimed at increasing the volume of soil organic matter and reducing erosion through improvements in plant diversity and conservational tillage such as no-tillage, reduced and strip. In this respect, the authors emphasize the importance of legumes which can fix atmospheric N in the soil, reduce the risk of NO_3^- leaching and improve both physical and chemical soil properties. Moreover, legumes play an important role in global food security, as their seeds have valuable nutritional and nutraceutical properties (Jimenez-Lopez *et al.*, 2020; Panasiewicz, 2022) they are often used as seed-based foodstuffs, but also as silage and forage (Faligowska *et al.*, 2014; Lucas *et al.*, 2015). Due to their relatively high tolerance to various environmental stresses such as excess nitrates, a low root temperature, excess lime and salinity, lupines can be grown all over the world (Bartkiene *et al.*, 2016). In addition, pulses have the ability to improve soil quality by fixing nitrogen (Peoples *et al.*, 2009; Kumar and Yadav, 2018; Panasiewicz *et al.*, 2020). The quality of the plants cultivated for both cooking and fodder purposes is largely determined by their nutritional value. Obligatorily it is described by the macronutrient contents in the biomass of the plant and only occasionally it is expressed by the mutual quantitative ratios of the nutrients (Rady *et al.*, 2016; Jakubus and Bakinowska, 2020a; Jakubus and Graczyk, 2022). Although the relationships between the various macronutrients are often ignored, their importance is very significant because they determine the

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proper development of plants and ensure a high quality of biomass and grain yield. Additionally, it can be assumed in most cases that the plant nutrient ratios provide a better index of the deficiency of macronutrients than their concentration. Agrotechnical treatments have an impact on quantitative changes in macronutrients in plants and/or seeds, which are most often analysed in the context of fertilization (Rady *et al*., 2016; Manas *et al*., 2018; Jakubus and Bakinowska, 2020a; Jakubus and Graczyk, 2022). These treatments have been justified and proven through fertilization effects on the quantitative changes of nutrients in plant biomass, and therefore their mutual relationship has been proven. However, this only partially explains the impact of agricultural engineering on the above-mentioned parameters which are as yet only broadly understood, therefore we should also include tillage systems or plant variety. However, the use of the nutrient ratio value to assess the quality of seeds is not a popular approach, and thus it has not been comprehensively clarified to date. But it could be an interesting alternative method to those currently used, all the more so because it provides more information than just a one-sided statement of the amount of nutrients as a characteristic of the plants. According to the current state of knowledge, the effect of various tillage systems have not been analysed in this context.

The introduction of reduced tillage practices in soil cultivation primarily results from the need to reduce production costs, which in the case of legumes determines their profitability and cropped area (Panasiewicz *et al*., 2020). In addition, due to progressing climate change, the reduction of cultivation, including the elimination of ploughing, is considered to be particularly valuable for soil and environmental protection (Kordas, 2005; Morris *et al*., 2010). Significant changes in the cost of fuel and herbicides, especially in recent years, are contributing to the increasing popularity of zero-tillage, because it is becoming more commercially attractive. Furthermore, reduced tillage leads to lower CO_2 emissions due to fuel combustion during machinery usage (Morris *et al*., 2010; Powlson *et al.,* 2014). Yields obtained on sites with reduced soil management may be equal or lower than those after ploughing, but small decreases in yields may be considered acceptable if production costs are significantly lower than those incurred by ploughing (Holland, 2004). The studies conducted to date indicate that reduced tillage practices modify the seed yield (Soane *et al*., 2012; Panasiewicz *et al.,* 2020), the seed sowing value (Heenan *et al*., 2000; Panasiewicz 2020a; Panasiewicz 2020b) and also the chemical composition of lupine seeds (Panasiewicz, 2022). However, there is no reference to the differential response of lupine cultivars in the literature.

In recent years, breeding work has resulted in the introduction of traditional (indeterminate) and self-terminating (determinate) varieties within the lupine species. Self-finishing varieties are characterized by a different type of plant growth, a shorter growing season, earlier and more uniform maturation, and different dynamics of assimilate accumulation in biological and agricultural yields than traditional varieties. In addition, these varieties are characterized by the absence of or a substantial reduction in the growth of lateral shoots, which is associated with better light conditions in the canopy due to mutual shading between plants (Woźniak and Rachoń, 2022). According to Abraham *et al.* (2019), in the future breeding work should focus on generating suitable biological material (genotypes/cultivars) and maximizing its yield and productivity, this in turn would lead to an increase in the economic value of lupine cultivation and raw material processing. As yet, there is no evidence either confirming or denying the influence of the tillage system on nutrient uptake from seed yield or nutrient ratios. Moreover, there is limited information concerning nutrient ratios in seeds of various lupine varieties. In practice, three species of lupines are used: narrow-leaved lupine (NL), yellow lupine (YL) and white lupine (WL), which are characterized by different habitat preferences and nutritional requirements. According to the current trends in sustainable agricultural engineering, three different tillage systems were taken under account: conventional (CT), reduced (RT) and no-tillage (NT). In summary, the research focused on the potential impact of the lupine variety and the tillage system on: 1) variability in macronutrient intake with regard to the yield of the plant seeds, and 2) changes in the values of the nutrient ratios which were researched together with the verification of their optimal ranges as a criterion of their nutritional quality.

MATERIALS AND METHODS

The seeds of three lupine species, *i.e.* yellow lupine (YL), narrow-leaved lupine (NL), and white lupine (WL) were obtained from field experiments carried out in the Przebędowo Research Station in the Wielkopolska region, Poland (52°35′ 14” N, 17°01′ 11”E) in the years 2014 – 2015. Yellow lupine (*Lupinus luteus* L.) is a plant with erect, straight stems, it is usually 25-60 cm high, and it has yellow flowers. Narrow-leaved lupine (*Lupinus angustifolius* L.) is a plant with an average height of about 50-60 cm and flowers with a blue to purple colour. White lupine (*Lupinus albus* L.) is a plant with an average height of 30 to 120 cm, it has white flowers, among the three described species, it is characterized by more demanding soil requirements and a longer vegetation period. The research factors included: A – variety (indeterminate: NL – 'Dalbor', YL – Lord, WL – 'Butan'; determinate: NL – 'Regent', YL – 'Perkoz', WL – 'Boros'); B – tillage system (conventional – CT, reduced tillage – RT, no-tillage – NT). The field experiments were carried out on soils where reduced tillage practices have been applied since 2011. The conventional tillage system (CT) included the full range of cultivation operations after preharvesting, discing, prewinter ploughing and presowing.

The reduced tillage system (RT) was simplified by replacing ploughing with disc harrow tillage. In the no tillage system (NT) all soil tillage was abandoned, it was limited to one application in autumn, a herbicide sold under the brand name of Roundup 360 SL (glyphosate) was applied at a dose of 2.0 l ha^{-1}. The field experiments were established on soils classified as Haplic Luvisols according to FAO-WRB (2014) which had a light loamy sandy texture. The basic soil properties are given in Table 1. Due to the fact that the effect of the tillage system on given soil properties was insignificant during the analysed period of time, Table 1 presents a ranges of values. Soil properties were determined using methods commonly used in chemical and agricultural analysis, and therefore soil pH was determined potentiometrically in 1 M KCl, organic matter (OM) through the loss of ignition method, total nitrogen (N_{tot}) through the Kjeldahl method, available amounts of P and K through the Egner-Riehm method, available Mg through the Schachtschabel method, and the amounts of Ca and Na were determined through the Pallmann method. A detailed description of the methods used is provided by Jakubus (2021). For each species, the experiments were assumed to be two-factorial in a system of random complete blocks in four repetitions. In our research in 2014, during the lupine vegetation period for all months except August, the average air temperature was higher than in 2015. On the other hand, June turned out to be an unfavourable month due to the lack of rainfall. In turn, in 2015 for the most part April and May were unfavorable in terms of low precipitation, which was also confirmed by the calculated values of the Selyaninow index (Table 2). All of the other details of the experiments are included relevant study (Panasiewicz, 2022).

Table 1. Basis soil properties

Soil property	Unit	Range of values independent of the tillage system
pH	–	5.1-5.3
OM	(g kg^{-1})	13.0-13.9
N_{tot}		0.527-0.532
P	(mg kg^{-1})	13.9-14.7
K		10.9-12.0
Mg		9.3-11.0
Ca		115.2-118.4
Na		2.6-3.1

Table 2. Weather conditions in the vegetation periods of lupine for the years 2014-2015

Year	Months					
	March	April	May	June	July	August
Temperature (°C)						
2014	7.2	10.4	14.8	17.6	23.8	20.8
2015	5.7	8.7	13.2	15.9	19.6	22.4
Precipitations (mm)						
2014	70.9	59.1	75.6	39.9	71.7	120.6
2015	48.4	25.2	43.1	97.0	94.4	14.3
Selyaninov hydrothermal index (K)						
2014	3.28	1.89	1.70	0.76	1.00	1.93
2015	2.83	0.96	1.09	2.03	1.60	0.21

A random sample of seeds for chemical analysis was taken from each plot after harvesting. The samples thus prepared were stored in sealed containers at a temperature of 4°C. The samples were ground sufficiently to pass through a 0.5 mm sieve. The plant material was ashed in a furnace at 450°C for 6 h. The ash was dissolved in 5 mL of 6 mol dm^3 HCl (Ostrowska *et al*., 1991) and diluted to a constant volume with distilled water. The obtained extracts were subjected to an assessment of the K, Ca, Mg and Na contents using atomic absorption spectrophotometry (AAS) in a Varian Spectra AA 220 FS apparatus. The total phosphorus (P) content was measured colorimetrically using the vanadium-molybdenum method. All of the assays identifying the amounts of nutrients in the tested samples were performed in three replications. On the basis of the recorded amounts, the following quantitative nutrient ratios: N:P, K:Mg, K:Na, Ca:P, Ca:Mg, K:(Ca+Mg) and (K+Na):(Ca+Mg) were calculated. The selection of the listed nutrient ratios was purposeful and based on literature reports (Jakubus and Graczyk, 2022; Jakubus and Bakinowska, 2020a; Grzegorczyk *et al*., 2017; Ostrowska and Porębska, 2017; Maćkowiak *et al*., 2011), because certain ratios are considered to be useful parameters in the assessment of plant quality and some of them are used obligatorily in routine chemical tests for agricultural purposes. In addition, the study presents the uptake of macronutrients using the yield of lupine seeds. These values are expressed in g per hectare because the yield was determined in accordance with accepted standards in field experiments in terms of per unit area, in this case per hectare.

A multivariate analysis of variance MANOVA was carried out in order to determine whether the nutrient ratios as well as the nutrient uptake, taken together, vary between the lupine varieties (factor A) and also whether they are influenced by different tillage systems (factor B). The calculated F statistic for the analysed parameters amounted to: $F_A = 4.75$ and $F_B = 3.89$. The null hypothesis tested whether the average values of the examined parameter are equal for each of the tillage systems as well as the varieties against the alternative hypothesis which states that not all averages are equal. As a result of the rejection of the null hypothesis the least significant differences were calculated using the Tukey method at the significance level $\alpha = 0.05$. Tukey's analysis was performed in order to distinguish homogeneous groups among the analysed parameters (a mean comparison in which a p value < 0.05 is considered different and these differences were characterized using Tukey's honest significant difference test – HSD). Homogeneous groups are indicated by the use of the same letters. The data were analysed using the STATOBL software working in the Windows 10 environment. Additionally, Box-Whiskers plots were constructed to represent macronutrient uptake with lupine seed yields as well as the values of the nutrient ratios in lupine seeds. In the boxplot figures the distribution of data is given by the minimum value, maximum value, and the median and also the first and third quartiles are shown for each parameter.

RESULTS

The data shown in Fig. 1 is a visual representation of the differences between the lupine species in the uptake of macronutrients, and therefore the highest uptake of macronutrients was found for WL and the lowest for YL. The amounts of nutrients taken up by the plants decreased in the following series: N > K > P > Ca > Mg > Na. Nitrogen was not only taken up in the largest amounts by the plants,

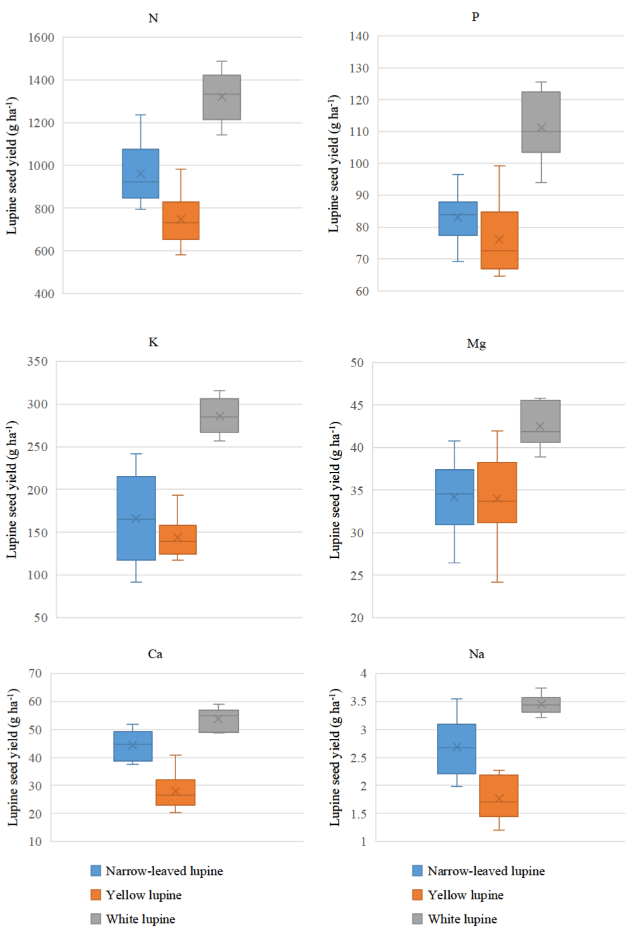

Fig. 1. Macronutrient uptake with lupine seed yield (g ha^{-1}) regardless of experimental factors.

but also this uptake was strongly influenced by experimental factors, which was confirmed statistically (Table 3). In general terms, the experimental factors showed a weak influence on the uptake of other macronutrients with regard to the seed yield. As may be observed in Table 3, the differences in sodium uptake were not significant for any species of lupine. The uptake of all nutrients with the yield of WL seeds was not determined to any significant extent by experimental factors, except for nitrogen, the amounts being taken up differed, therefore 'Butan' took up more of this nutrient as compared to 'Boros'. Significant differences in K amounts taken up were found for NL and YL. The 'Regent' – NL and 'Perkoz' – YL varieties showed a higher K uptake. Additionally, 'Perkoz' also had a higher Ca uptake in relation to the data calculated for Lord. In the case of Ca and N uptake for the NL seed yield, the tillage system was of importance. No-tillage cultivation was found to be conducive to a greater amount of nitrogen and calcium being taken up by the NL seeds. On the other hand, YL responded better to conventional cultivation, because under those conditions a higher uptake of N, P and Mg was determined. Conventional tillage also had a significant effect on K accumulation in the seeds of YL (Table 3).

The data presented in Fig. 2 allows for their easier interpretation, this is because the ranges of the nutrient ratios calculated for the seeds of individual lupine species are presented and may be compared to the values that are optimal and appropriate (the red line shows this). In general terms, the highest values of the calculated nutrient ratios were characteristic of NL while the lowest ones were characteristic of YL. It should be noted that the seeds of the studied lupine species very occasionally showed optimal values of nutrient ratios (Fig. 2), this was noted for the most part in YL in relation to the following ratios: K:Mg, K:(Ca+Mg), (K+Na):(Ca +Mg). In general, the values of K:Mg, K:Na, K:(Ca+Mg), K:Ca, (K+Na):(Ca+Mg) that were calculated for lupines were significantly higher than the recommended values. This may indicate an excessively high uptake and the accumulation of K in plant seeds in relation to Ca, Mg and Na. In turn, the excessively low amount of Ca taken up with seed yield was expressed by the significantly lower values of Ca:Mg or Ca:P in relation to those that should be optimal. In addition, the above-mentioned Ca:P and N:P values theoretically underline the excessive amounts of P in the lupine seeds. It may be observed from the data contained in Tables 4-6, that the experimental factors did not generally have a significant effect on the values of the calculated nutrient ratios, this was noted in particular for Ca:P, K:Ca, Ca:Mg, K:(Ca+Mg), (K +Na):(Ca+Mg). 'Dalbor' was characterized by higher values of K:Mg, K:Na, K:Ca, Ca:Mg, K:(Ca+Mg) and (K+Na):(Ca+Mg), but this was only confirmed statistically for the first two nutrient ratios. Conventional tillage favoured higher nutrient ratios, however, this was not confirmed statistically. For 'Regent' the nutrient ratio values were frequently found to be close to

Table 3. Macronutrient uptake with lupine seed yields (g ha^{-1}) depending on experimental factors

Variety	Tillage system			Mean
	Conventional	Reduced	No-tillage	
		N		
Dalbor	927.44	793.25	1024.60	915.1
Regent	916.85	867.60	1237.74	1007.39
		LSD for AxB = n.s.*		LSD for A factor = n.s.
Mean	922.14ab	830.43b	1131.17a	
Lord	679.29b	778.94ab	739.81b	732.68
Perkoz	982.31a	724.21b	581.45b	762.66
Mean	830.80a	751.58ab	660.64b	LSD for A factor = n.s.
Butan	1488.45	1397	1373.59	1419.83a
Boros	1295.85	1141.89	1237.54	1225.1b
		LSD for AxB = n.s.		
Mean	1392.15	1269.67	1305.57	LSD for B factor = n.s.
		P		
Dalbor	84.48	69.19	83.44	79.04
Regent	80.07	85.06	96.51	87.21
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	82.27	77.12	89.97	LSD for B factor = n.s.
Lord	67.66b	79.99b	72.29b	73.31
Perkoz	99.26a	72.60b	64.64b	78.83
Mean	83.46a	76.29ab	68.46b	LSD for A factor = n.s.
Butan	121.35	125.61	110.79	119.25
Boros	94.08	109.26	106.54	103.29
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	107.72	117.43	108.66	LSD for B factor = n.s.
		K		
Dalbor	125.52	91.71	126.29	114.51b
Regent	206.17	204.17	241.7	217.35a
		LSD for AxB = n.s.		
Mean	165.84	147.94	183.99	LSD for B factor = n.s.
Lord	127.33b	141.03b	137.20b	135.19b
Perkoz	193.56a	145.81b	117.04b	152.14a
Mean	160.45a	143.42ab	127.12b	
Butan	315.22	302.86	298.70	305.65
Boros	272.07	256.68	270.73	266.49
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	293.65	279.77	284.71	LSD for B factor = n.s.

*n.s. – not significant. The same letters indicate homogeneous groups.

Table 3. Continuation

Variety	Tillage system			Mean
	Conventional	Reduced	No-tillage	
		Mg		
Dalbor	32.38	26.43	35.95	31.59
Regent	36.28	33.09	40.75	36.71
		LSD for A x B = n.s.		LSD for A factor = n.s.
Mean	34.33	29.76	38.35	LSD for B factor = n.s.
Lord	33.90ab	37.06a	33.53ab	34.83
Perkoz	41.99a	33.55ab	24.18b	33.24
Mean	37.94a	35.30ab	28.85b	LSD for A factor = n.s.
Butan	45.81	45.56	41.88	44.41
Boros	38.92	41.18	41.95	40.68
		LSD for A x B = n.s.		LSD for A factor = n.s.
Mean	42.37	43.36	41.91	LSD for B factor = n.s.
		Ca		
Dalbor	46.93	39.07	51.86	45.95
Regent	42.37	37.56	48.47	42.80
		LSD for A x B= n.s		LSD for A factor = n.s
Mean	44.65ab	38.31b	50.16a	
Lord	20.20b	28.03ab	25.20b	24.48b
Perkoz	40.85a	29.19ab	23.88b	31.30a
Mean	3.52	28.61	24.54	LSD for B factor = n.s.
Butan	59.13	55.33	54.75	56.4
Boros	49.11	48.84	56.10	51.54
		LSD for A x B = n.s.		LSD for A factor = n.s.
Mean	54.12	52.08	55.43	LSD for B factor = n.s.
		Na		
Dalbor	2.94	1.98	2.85	2.59
Regent	2.28	2.50	3.55	2.78
		LSD for A x B = n.s.		LSD for A factor = n.s.
Mean	2.61	2.44	3.20	LSD for A factor = n.s.
Lord	1.63	2.27	1.78	1.89
Perkoz	2.16	1.51	1.20	1.63
		LSD for A x B = n.s.		LSD for A factor = n.s.
Mean	1.89	1.89	1.49	LSD for B factor = n.s.
Butan	3.74	3.21	3.51	3.49
Boros	3.37	3.34	3.51	3.41
		LSD for A x B = n.s.		LSD for A factor = n.s.
Mean	3.56	3.28	3.51	LSD for B factor = n.s.

*n.s. – not significant. The same letters indicate homogeneous groups.

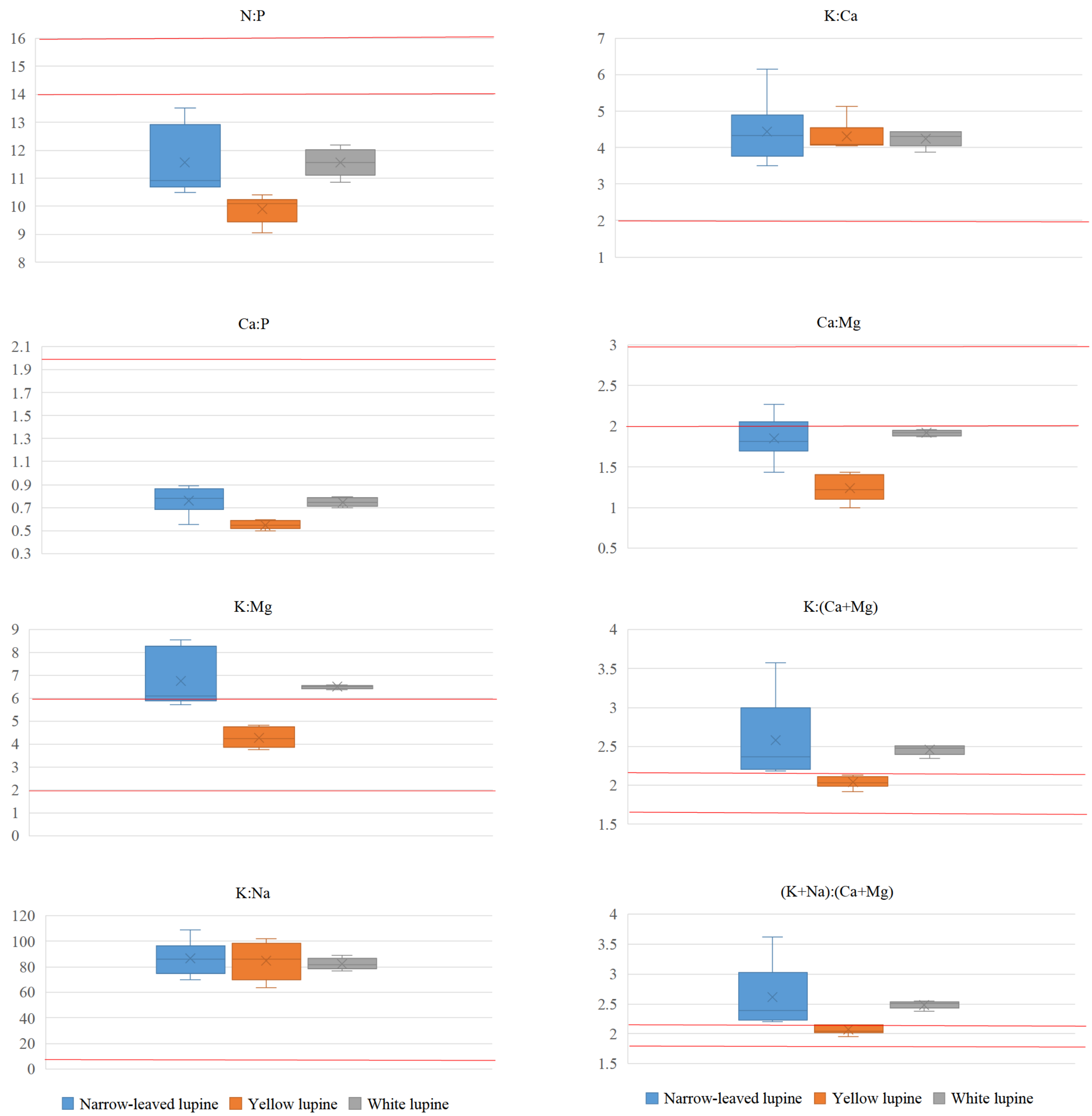

Fig. 2. Nutrient ratios in lupine seeds. Red lines show the optimal range of values for individual nutrient ratios.

optimal, this finding was especially marked for N:P (11.6), K:Mg (5.9), K:(Ca+Mg) (2.3) and (K+Na):(Ca+Mg) (2.3). By taking into consideration the tillage system only in the case of no-tillage, the NL seeds most often showed values of nutrient ratios comparable to their optimal ranges, although only for N:P was this confirmed statistically (Table 4). According to the data presented in Table 5, regardless of the variety or tillage system yellow lupine seeds represented the optimal values of K:Mg, K:(Ca+Mg) and (K+Na):(Ca+Mg). Generally the values of the nutrient ratios calculated for ‘Perkoz’ were closer to the optimal ranges than in the case of Lord. This was especially evident for Ca:P, K:Ca and Ca:Mg. However, the value of N:P was found to be more favourable for Lord than for Perkoz, this was confirmed statistically. Regardless of the YL variety used, the plants cultivated using the reduced tillage system showed values of nutrient ratios in their plant seeds that were close to the optimal ones (Table 5). The influence of the tillage system on potential changes in the values of the nutrient ratios was non-significant with the exception of K:Na. The data in Table 6 shows that the seeds of both white lupine varieties were not characterized by optimal

Table 4. Nutrient ratios in narrow-leaved lupine depending on experimental factors

Variety	Tillage system			Mean
	Conventional	Reduced	No-tillage	
		N:P		
Dalbor	10.76	11.04	12.72	11.51
Regent	10.82	10.51	13.53	11.62
		LSD for AxB factor = n.s*		LSD for A factor = n.s.
Mean	10.79b	10.77b	13.12a	
		Ca:P		
Dalbor	0.55	0.88	0.85	0.76
Regent	0.80	0.73	0.76	0.76
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	0.67	0.81	0.81	LSD for B factor = n.s.
		K:Mg		
Dalbor	8.56	8.20	6.14	7.63a
Regent	5.73	6.08	5.93	5.91b
		LSD for AxB = n.s.		
Mean	7.15	7.14	6.04	LSD for B factor = n.s.
		K:Na		
Dalbor	92.67b	108.70a	76.59cd	92.65a
Regent	88.88bc	82.53bcd	70.12d	80.51b
Mean	90.77a	95.61a	73.36b	
		K:Ca		
Dalbor	6.16	4.49	3.50	4.72
Regent	3.85	4.47	4.19	4.17
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	5.0	4.48	3.85	LSD for B factor = n.s.
		Ca:Mg		
Dalbor	1.44	2.27	1.98	1.90
Regent	1.78	1.82	1.82	1.81
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	1.61	2.04	1.90	LSD for B factor = n.s.
		K:(Ca+Mg)		
Dalbor	3.57	2.80	2.18	2.85
Regent	2.21	2.41	2.31	2.31
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	2.89	2.61	2.24	LSD for B factor = n.s.
		(K+Na):(Ca+Mg)		
Dalbor	3.61	2.83	2.21	2.88
Regent	2.24	2.44	2.34	2.34
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	2.92	2.63	2.28	LSD for B factor = n.s.

*Explanations as in Table 3.

Table 5. Nutrient ratios in yellow lupine depending on experimental factors

Variety	Tillage system			Mean
	Conventional	Reduced	No-tillage	
		N:P		
Lord	10.13a	10.06a	10.41a	10.20a
Perkoz	9.60ab	10.19a	9.04b	9.61b
Mean	9.86	10.13	9.72	LSD for A factor = n.s.*
		Ca:P		
Lord	0.50	0.52	0.54	0.52
Perkoz	0.58	0.59	0.55	0.58
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	0.54	0.56	0.56	LSD for B factor = n.s.
		K:Mg		
Lord	3.76	3.88	4.1	3.91b
Perkoz	4.74	4.35	4.83	4.64a
		LSD for AxB = n.s.		
Mean	4.24	4.11	4.46	LSD for B factor = n.s.
		K:Na		
Lord	86.82abc	63.57c	102.09a	84.16
Perkoz	72.09bc	85.14abc	97.5ab	84.91
Mean	79.45b	74.35b	99.79a	LSD for A factor = n.s
		K:Ca		
Lord	5.13	4.1	4.35	4.53
Perkoz	4.08	4.05	4.09	4.08
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	4.61	4.07	4.22	LSD for B factor = n.s.
		Ca:Mg		
Lord	0.99	1.13	1.16	1.09
Perkoz	1.41	1.29	1.43	1.37
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	1.20	1.21	1.30	LSD for B factor = n.s.
		K:(Ca+Mg)		
Lord	2.04	1.92	2.02	1.99
Perkoz	2.11	2.02	2.13	2.09
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	2.07	1.96	2.07	LSD for B factor = n.s.
		(K+Na):(Ca+Mg)		
Lord	2.06	1.96	2.04	2.01
Perkoz	2.14	2.05	2.15	2.11
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	2.10	2.0	2.09	LSD for B factor = n.s.

*Explanations as in Table 3.

Table 6. Nutrient ratios in white lupine depending on experimental factors

Variety	Tillage system			Mean
	Conventional	Reduced	No-tillage	
		N:P		
Butan	11.96	10.86	11.79	11.53
Boros	12.19	11.21	11.34	11.58
		LSD for AxB factor = n.s.*		LSD for A factor = n.s.
Mean	12.07a	11.03b	11.56b	
		Ca:P		
Butan	0.74	0.70	0.75	0.73
Boros	0.80	0.71	0.79	0.77
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	0.77	0.71	0.77	LSD for B factor = n.s.
		K:Mg		
Butan	6.59	6.51	6.53	6.54
Boros	6.56	6.43	6.38	6.45
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	6.57	6.47	6.46	LSD for B factor = n.s.
		K:Na		
Butan	83.63	89.15	85.7	86.16a
Boros	79.26	76.86	79.01	78.38b
		LSD for AxB = n.s.		
Mean	81.44	83.0	82.36	LSD for B factor = n.s.
		K:Ca		
Butan	4.18	4.44	4.11	4.24
Boros	4.42	4.45	3.89	4.25
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	4.30	4.45	4.0	LSD for B factor = n.s.
		Ca:Mg		
Butan	1.94	1.88	1.96	1.93
Boros	1.91	1.87	1.94	1.91
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	1.92	1.88	1.95	LSD for B factor = n.s.
		K:(Ca+Mg)		
Butan	2.46	2.51	2.42	2.46
Boros	2.51	2.49	2.34	2.45
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	2.48	2.5	2.38	LSD for B factor = n.s.
		(K+Na):(Ca+Mg)		
Butan	2.49	2.54	2.44	2.49
Boros	2.54	2.52	2.37	2.48
		LSD for AxB = n.s.		LSD for A factor = n.s.
Mean	2.52	2.53	2.41	LSD for B factor = n.s.

*Explanations as in Table 3.

nutrient ratios. The closest values to the optimal ones were found for the following ratios: K:Mg (from 6.38 to 6.59); Ca:Mg (from 1.87 to 1.96); K:(Ca+Mg) (from 2.34 to 2.51) and (K+Na):(Ca+Mg) (from 2.37 to 2.54). Regardless of the experimental factors, the recorded nutrient ratio values were found to be comparable and the differences were not significant. An exception to this tendency was found for the N:P values produced under conventional tillage, with seeds of WL showing significantly higher values relative to the other tillage systems. Also, the calculated K:Na ratio differed significantly between varieties, with 'Butan' showing higher values in comparison with 'Boros'. Taking into account the correct criteria of the calculated nutrient ratios, it most often concerned the seeds of the 'Boros', while the no-tillage system more often favoured the determination of the close-to-optimal nutrient ratios.

DISCUSSION

At present, plant production is being carried out for many different reasons, including the production of food and fodder, as well as the production of biomass for energy. A particular challenge is the sustainable production of food of animal origin while meeting the challenge of providing enough protein (Chatellier, 2021; Henchion *et al*., 2021). After cereals, legume seeds are the most important global plant protein source (Smýkal *et al*., 2014). This family of plants may be divided into edible legumes intended for human consumption and fodder legumes intended to feed animals (Kapusta, 2012). Currently, in modern agriculture the role of legumes is being emphasized. This is due to the number of functions they have, which include, apart from their significant nutritional value, their role in increasing soil fertility due to nitrogen fixation and also being a very good precursor plant for other crops or their use as cover plants for mitigating erosion processes (Lucas *et al*., 2015; Preissel *et al*., 2015; Kumar and Yadav, 2018). In numerous studies (Diaz *et al*., 2006; Grela *et al*., 2017; Margier *et al*., 2018; Sterna *et al*., 2020; Struti *et al*., 2020) devoted to legumes, the nutritional value for humans and animals is emphasized due to the fact that plants from this family are a rich source of proteins, starch, B-complexes, vitamins and other vital health protective compounds. An overview of the literature data (Margier *et al*., 2018; Sterna *et al*., 2020; Struti *et al*., 2020; Panasiewicz, 2022) indicates that individual chemical constituents are present in a relatively wide range depending on the species. Panasiewicz (2022) found that the highest protein content was observed in yellow lupine seeds, and the lowest in narrow-leaved lupin. Similar results were obtained by Porres *et al.* (2007) and Bartkiene *et al*. (2016). According to Erberdobler *et al.* (2017) legume seeds are also rich in minerals such as K, P, Ca, Mg, Mo, Mn, Fe, Cu and Zn. It has been well established that macronutrients are necessary for the proper development and functioning of animals, because they participate in most enzymatic processes, they form the structural compounds of organs and tissues, and they are co-responsible for the functioning of the endocrine system as well as many other vital functions. As a result, the nutritional properties of these plants are now gaining in importance with regard to animal feeding. Most often, in a qualitative assessment of plants intended for food or fodder, after the verification of organic nutritional compounds, the contents of macro- and micronutrients are analysed (Struti *et al*., 2020; Jarecki and Migut, 2022). Unfortunately, the mutual relationships of nutrients are often overlooked and this aspect, according to Kumar and Soni (2014), should also be taken into consideration, because it directly determines the usefulness of fodder plants, and thus their impact on animal health. This would seem to be very important in the case of legume seeds, because their chemical composition depends on many factors, including both weather conditions and agricultural practices (Popović *et al*., 2013). Usually the assessment of the effect of agricultural factors on the chemical compounds of plant biomass is conducted in one way throughout fertilization (Manas *et al*., 2018; Jakubus and Bakinowska, 2020b; Herencia *et al*., 2011). However, the reports may occasionally be found (Rady *et al*., 2016; Jakubus and Bakinowska, 2020a; Jakubus and Graczyk, 2022) related to the assessment of the effect of fertilization on the ratios between the nutrients. In cited studies it has been clarified and confirmed that fertilization influences the nutrient contents in plant biomass, as well as the relationship between them. However, this has not exhausted the issue of the impact of broadly understood agronomic operations on the above-mentioned parameters. At present, it is known that the varieties of the cultivated plant and the cultivation systems used should also be taken into account. With reference to lupines, three species of these plants are currently being cultivated: narrow-leaved, yellow and white, which are characterized by different nutritional needs and habitat requirements (Soane *et al*., 2012; Szymańska *et al*., 2017; Woźniak and Rachoń, 2022). As a result, differences in the chemical composition of the plant biomass and their seeds were observed (Struti *et al*., 2020; Jarecki and Migut, 2022). The cited authors studied three popular species of lupine (narrow-leaved, yellow and white) in terms of their chemical composition and found that the amounts of P, K, Mg and Ca in plant seeds were the lowest in white lupine and the highest in yellow lupine. This indicates a certain trend in the accumulation and thus the uptake of macronutrients by individual species of lupine, this finding was confirmed in our own research. The content of individual components is also determined by the variety planted. According to Porres *et al.* (2007), the amount of total and soluble protein nitrogen was not significantly affected by the different varieties within the same lupine species. Bartkiene *et al*. (2016) found that the concentrations of Mg and K in the seeds of YL 'Vilčiai' were greater than in the NL 'Vilniai'. Furthermore, higher contents of Ca and Na were detected in the seeds of hybrid lines in comparison with the YL 'Vilčiai' and the NL 'Vilniai'. Among the NL hybrid lines, the highest contents of Mg and K were determined in the seeds of line No. 1700. Previous studies by Panasiewicz (2022) also showed the significant effect of the tillage method on the chemical composition of lupine seeds. In cited studies the tillage system caused differences in the contents of potassium in the seeds of white lupin, for example, lower contents of this component were observed in the determinate variety 'Boros', which was cultivated using the conventional system. Woźniak and Rachoń (2022) observed that the content of potassium in yellow lupine seeds decreased in the no-tillage system as compared to the conventional and reduced systems. Regardless of the differences between species, nitrogen was collected from those particular seeds in the largest amounts, which may be attributed to the high specific root length promoting a high nutrient uptake (Wendling *et al*., 2016). When analysing the uptake of N, P, K, Ca and Mg by the root and shoot biomass of various cover crops of the legume family, the aforementioned authors found that the amounts of nutrients taken up decreased in the following series N> K > P > Ca > Mg, which confirms the results presented in this work. The research conducted showed a small influence of experimental factors on the uptake of nutrients. The varieties of lupines used were significant only for N (WL), K (NL and YL) and Ca (YL). Also, the tillage system with which the plants were cultivated had a weak effect on the uptake of nutrients with the yield of lupine seeds. It was statistically proven that significantly higher N, P, K and Mg uptake by the plants was found in the conventional tillage system and primarily this was shown for yellow lupine. The qualitative assessment of forage plants should not only focus on macronutrient intake, but it should also be associated with their mutual relationship, which is especially important for mineral balance. The observed mineral imbalance has a negative impact on forage quality, because it may cause an antagonistic effect on other elements. According to Kumar and Soni (2014), an imbalance of Ca, P, Mg and Na may cause rickets, lameness, milk fever, tetany or reduced appetites. In this context the cited authors focused on the ratios N:P, Ca:P and K:(Ca+Mg), because of the functions that the individual nutrients perform. Nitrogen and phosphorus are major constituents of amino acids and nucleic acids. Calcium is closely associated with P metabolism in bone formation. Moreover, rickets in animals occurs due to Ca and P deficiency. Additionally, Ca is involved in blood clotting and enzyme activation. Magnesium is closely related to calcium and is essential in energy metabolism, together with Ca it is responsible for the transmission of nerve impulses. Potassium is the major cation responsible for the normal functioning of the heart muscle and is also involved in several enzymatic reactions. In conjunction with other ions sodium maintains cell permeability in the active transport of nutrients across membranes. This element is also required for muscle contraction and nerve impulse transmission (Cherian, 2019). Despite the considerable importance of nutrient ratios and the appropriate balance of nutrients in fodder plants referenced in the literature, as yet there is only fragmentary information concerning the assessment of the quality of various crops (vegetables, grassland, crops, herbaceous or leguminous plants) using the ratios of their nutrients (Jakubus and Bakinowska, 2020a; Jakubus and Graczyk, 2022). Moreover, in the literature there are very different and broad ranges of nutrient contents given as optimal and critical levels for crops (Mahler, 2004; Prasad, 2017). A different situation may be noted in relation to nutrient ratios, where the relevant values are clearly defined, irrespective of the plant species cultivated or the agricultural management. This is particularly the case when assessing the nutritive value criteria of fodder, the correct ratios should be taken into account and the recommended optimal ratios should be as follows: N:P = 2:1; K:Mg = 2-6:1; K:Na = 5:1; Ca:P = 2:1; Ca:Mg = 2-3:1; K:(Ca+Mg) = 1.62-2.2:1; (K+Na):(Ca+Mg) = 1.9-2.1:1 (Jakubus and Bakinowska, 2020a; Maćkowiak *et al*., 2011). Kumar and Soni (2014) stated that a Ca:P higher than 2.0 can cause milk fever and K:(Ca+Mg) over 2.20 may cause grass tetany. The conducted experiment showed that the seeds of the three lupine species were generally not characterized by optimal values of the calculated nutrient ratios. The obtained values were either too high, as was the case for K:Mg, K:Na, K:(Ca+Mg), K:Ca, (K+Na):(Ca+Mg), or too low, as for N:P and Ca:P. This indicates an imbalance of nutrient amounts expressed in the form of an excess intake of P and K with a simultaneous insufficient intake of Ca, Mg and Na. The highest values of the nutrient ratios listed above may be explained by the phenomenon of the "luxury consumption" of potassium, where K is absorbed by plants in amounts greater than that required for the optimum yield (Herencia *et al*., 2011). Also, the antagonistic effect of K^+ to Ca^{2+}, Mg^{2+} and Na^+ ions should be considered in this interpretation. The weak and incidental influence of experimental factors on the possible differences in nutrient ratios should be emphasized for lupine varieties and it was expressed by significant differences between the values of K:Na (for NL and WL), K:Mg (for NL and YL) and N:P (for YL). Although this has not yet been confirmed statistically, nutrient ratios close to the optimal level were most often determined for narrow-leaved and yellow lupine. The NL and YL seeds were characterized by K:Na and N:P values closest to the optimal ones under conventional and reduced tillage conditions. At the same time, the lupine seeds cultivated under the NT system were characterized by nutrient ratio values that deviated the most from the advisable ones. Also, the tillage system applied had a weak influence on the nutrient ratios, because differences in the nutrition ratio values were only significant for N:P (for NL and WL) and K:Na (for NL and YL). The tillage systems used had little or no significant effect (CT, RT, NT) on the protein content

(Sterna *et al*., 2020) and the macronutrient contents (Woźniak and Rachoń, 2022) in the lupine seeds are also shown. The lack of any significant differences in the calculated nutrient ratios between the varieties of the analysed lupine species and tillage systems indicate that these agrotechnical factors play a less significant function in determining the nutritional quality of the seeds. In view of the presented results, the fodder quality of the lupine seeds should be assessed negatively. Despite well-balanced fertilizer doses, the nutrients were probably not effectively taken up and used by the plants. Of course, this statement is a form of speculation, because the mobilization and availability of macronutrients in the soil was not the subject of this study. Nevertheless, such a thesis indicates the need for a comprehensive approach to the issue of plant quality assessment. The valorization of lupine seeds proposed in this paper with the use of nutrient ratios turns out to be a helpful tool that provides enhanced knowledge concerning deficiencies and excess amounts of nutrients.

CONCLUSIONS

1. The proposed innovative approach to the qualitative assessment of lupine seeds as fodder plants based on a nutrient ratio analysis should be positively perceived as a promising tool. Due to the valorization of seeds in this way, one can obtain enhanced knowledge not only concerning their potential usefulness as fodder, but also about possible deficiencies or excessive nutrient amounts resulting from the incorrect application of agricultural technology in terms of nutrient availability.

2. Based on the commonly used optimal ratios of macronutrients, the lupine seeds assessed in this study generally did not meet these criteria, being fodders of low mineral value.

3. The research conducted proved that the changes in nutrient ratios, as well as the uptake of nutrients with the yield of seeds, were determined to a limited extent by the species cultivated and also their varieties or tillage systems.

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