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ORIGINAL PAPER

YIELD AND THE CONTENT OF MACROELEMENTS IN COMMON PEA/SPRING RYE MIXTURES CULTIVATED FOR GREEN MATTER*

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Abstract

Yields of mixtures are usually more reliable that those of pure stands of the species which the mixtures contain, which is due to better exploitation of habitat conditions, including macroelements and water stored in the soil. The quantity of macroelements which is supplied into a diet with the biomass of fabaceae/cereal mixtures may vary greatly and be dependent on a species composition, percentage share of the components in a mixture as well as a harvest time. This work presents results of research conducted from 2010 to 2012 in order to determine the effect of the share of components in a mixture and the harvest date on fresh matter yield and mineral composition in mixtures of common pea and spring rye. An experiment was conducted to study the following two factors: I − share of components in the mixture: 100% common pea cultivated in pure stand, 100% spring rye grown in pure stand, 75% common pea + 25% spring rye, 50% common pea + 50% spring rye, 25% common pea + 75% spring rye; II − harvest date: common pea flowering stage, common pea flat green pod stage. During harvest fresh matter yield of the mixtures was determined in each plot, and macroelement content was recorded in samples collected. The results demonstrated that the highest fresh matter yield was harvested for a mixture which contained 50% common pea and 50% spring rye. The mineral content in common pea/spring rye mixtures harvested at the stage of common pea flowering stage was significantly higher than in mixtures harvested at the stage of common pea flat green pod.

Keywords: legume, cereal, efficiency of forage, content of minerals, harvest date.

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INTRODUCTION

Yields of mixtures are usually more reliable that those of pure stands of the species which the mixtures contain, which is due to better exploitation of habitat conditions, including macroelements and water stored in the soil.

The roots of cereals are better at penetrating the surface soil layer whereas fabaceae plants reach the deeper soil layers (Buraczyńska, Ceglarek 2009, Staniak et al. 2012, Wojciechowski et al. 2013). Plant species are also characterised by different critical periods of demand for water and nutrients. If soil and weather conditions in a given year are less conducive to the development of one species (mixture component), they are usually better for the other species, which then plays the role of a yield stabiliser (by increasing plant mass). However, the situation may be reverse in the next year. The advantages of fabaceae/cereal mixtures include a low demand for outlays associated with agricultural chemicals, which makes them particularly suitable for use in sustainable and organic agriculture (Księżak, Staniak 2013, Huňady , Hochman 2014).

The mineral composition of fabaceae/cereal mixtures is affected by many factors, in particular the soil type, soil nutrient availability and pH, amount and kind of fertilisation, as well as the course of the weather during the growing season (Staniak et al. 2012, Płaza et al. 2017). As a result, amounts of individual nutrients supplied into a diet by the biomass may differ greatly and is dependent on a species composition, percentage share of components in the mixture and a harvest date. There is paucity of reports on the subject, hence the need to carry out this type of research. The purpose of the study reported here was to determine the effect of the share of components in a mixture and a harvest date on fresh matter yield and macroelement content in common pea/spring rye mixtures.

MATERIAL AND METHODS

Field research was conducted at the Zawady Experimental Farm (52°03′39″ N, 22°33′80″ E), which belongs to Siedlce University of Natural Sciences and Humanities. The experimental soil was Albic Luvisol (Arenic) characterised by neutral reaction, average content of available phosphorus, potassium and magnesium, and humus content of 1.39% (Table 1). The experiment was arranged in a split-block design with three replicates. Two factors were examined: I. – share of components in the mixture: 100% common pea cultivated in pure stand, 100% spring rye grown in pure stand, 75% common pea + 25% spring rye, 50% common pea + 50% spring rye, 25% common pea + 75% spring rye; II. – harvest date: common pea flowering stage (BBCH 65), common pea flat green pod stage (BBCH 79). A detailed

Table 1

Some of the physical and chemical properties of the soil layer before the experiment was established in 2010-2012

Year	Percentage content of mechanical fractions with diameter in mm			The content of assimilable forms (mg kg^{-1} soil)			pH in KCl	Content of humus (g kg^{-1})
	sand 1-0.1	particu-lates 0.1-0.2	floatable particles <0.02	P	K	Mg		
2010	53	29	18	5.34	12.23	5.67	6.7	14.0
2011	53	27	20	5.24	11.35	5.56	6.4	14.7
2012	51	26	21	5.15	11.20	5.49	6.5	14.2
Mean	52	27	20	5.24	11.59	5.57	6.5	14.3

description of the mixtures and their sowing quantities are as follows: common pea 170 kg ha^{-1}, spring rye 200 kg ha^{-1}, common pea 128 kg ha^{-1} + spring rye 50 kg ha^{-1}, common pea 85 kg ha^{-1} + spring rye 100 kg ha^{-1}, common pea 43 kg ha^{-1} + spring rye 150 kg ha^{-1}.

In all the study years, mixtures were preceded by winter triticale. Phosphorus (triple granulated superphosphate) and potassium (potassium salt) fertilisers were applied in autumn at doses (pure element) adjusted to the soil chemical composition, that is 35.2 kg P ha^{-1} and 99.6 kg K ha^{-1}. Nitrogen fertilisers (ammonium sulphate) were applied in spring prior to seed sowing at a dose of 30 kg N ha^{-1} (ammonium sulphate) in all the plots, excluding common pea grown in pure stand. At the stage of stem elongation, an additional amount of 50 kg N ha^{-1} (ammonium sulphate) was supplied to spring rye, and 30 kg N ha^{-1} (ammonium sulphate) was delivered to common pea/ spring rye mixtures. Common pea (cv. Roch - Poznań Plant Breeding) seeds and spring rye (cv. Bojko - Smolice Plant Breeding) were seeded in early April. Harvest was performed in late June (stage of common pea flowering-BBCH 65) and in early July (stage of common pea flat green pod-BBCH 79). During harvest, fresh matter yield was determined in each plot and fresh matter samples were taken to conduct chemical analyses.

Analytical methods

The chemical analyses were performed in the Departmental Laboratory of Structural Research and Environmental Analysis of UPH in Siedlce. The content of total nitrogen was determined in the collected plant material using the Kjeldahl method in a 2300 Kjeltec Analyzer Unit, Foss Tecotor apparatus, Denmark. The content of phosphorus, potassium, calcium and magnesium was determined after mineralisation by emission spectrometry with excitation in inductively coupled plasma, including an optical detector (ICP-OES) and using an emission spectrometer Perkin Elmer Optima 8300, United States. The dried material was ground in a planetary-ball mill Retch PM 100, Germany, resulting in the final fineness of 1 mm.

Statistical analyses

Each of the characteristics studied was analysed by means of ANOVA for a split-block arrangement. Comparison of means for significant sources of variation was achieved by means of the Tukey's test at the significance level of $P \leq 0.05$. All the calculations were performed in Statistica®, version 12.0 and MS Excel.

Weather conditions

The years of the study were characterised by significantly changeable weather conditions (Table 2). In 2010, mean air temperatures during

Table 2

Pluvio-thermal conditions in the growing season of pea and oat mixtures in 2010-2012 according to the Meteorological Station in RSD Zawady

Year	Month				Mean
	April	May	June	July	
Temperature (°C)					
2010	8.9	14.0	17.4	21.6	15.5
2011	10.1	13.4	18.1	18.3	15.0
2012	8.9	14.6	16.3	20.7	15.1
Long-term mean 1990-2005	8.2	14.2	17.6	19.7	14.9
Precipition (mm)					
2010	10.7	93.2	62.6	77.0	243.5
2011	31.0	36.1	39.1	120.2	226.4
2012	29.9	53.4	76.2	43.0	202.5
Long-term mean 1990-2005	37.4	47.1	48.1	65.5	198.1

the growing period fluctuated around the mean long-term temperatures. The precipitation totals, except for April, were higher than the mean long-term total precipitation. This year should be regarded as favourable for the cultivation of mixtures of field peas with oat. In 2011, the mean monthly air temperatures slightly differed from the mean long-term temperatures. However, the rainfall totals were lower than the mean long-term totals, except for July, where the recorded precipitation was 120.2 mm. In 2012, the average air temperature and total precipitation fluctuated around the long-term average. It was a good year for the cultivation of pea and spring rye mixtures because the sums of rainfall in May and June were higher than the average sum from many years.

RESULTS AND DISCUSSION

The fresh matter yield of common pea/spring mixtures was significantly affected by the experimental factors and their interaction (Figure 1).

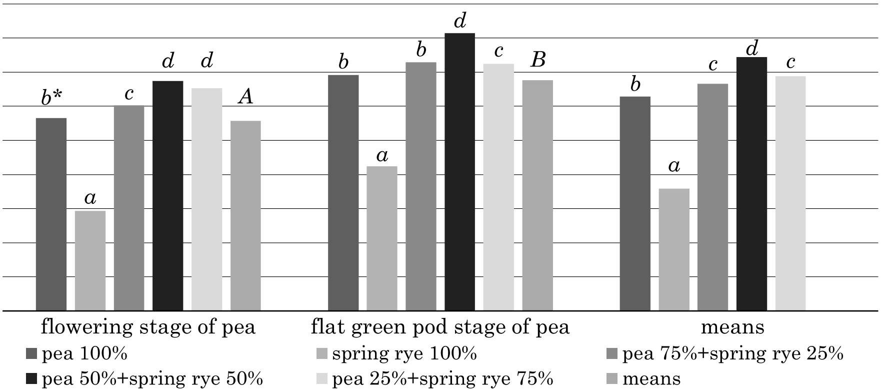

Fig. 1. Fresh matter yield of common pea/spring rye mixtures, means across 2010-2012 (t ha^{-1}).
* Values in columns followed by the same small letter and values in rows followed by the same capital letter do not differ significantly at $P < 0.05$

The highest fresh matter yield was harvested for the mixture consisting of 50% common pea and 50% spring rye. According to Idziak and Michalski (2003), Bedoussac and Justes (2009), Buraczyńska and Ceglarek (2009), Eskandari et al. (2009), Wojciechowski at al. (2013), Księżak and Staniak (2013) and Bojarczuk et al. (2014), crops grown in mixtures produce higher yields than pure stands because they make better use of changeable habitat conditions. In the study reported here, fresh matter yield of the remaining mixtures was significantly lower but still higher than the yield of common pea cultivated in pure stand, and of spring rye (whose yield was significantly the lowest) in particular. The harvest date had a significant effect on the yield of common pea/spring rye mixture fresh matter. Higher yields were obtained when common pea/spring rye mixtures were harvested at the stage of common pea flat green pod. Also, Faligowska and Szukała (2009), Staniak et al. (2012), Wojciechowski et al. (2013) and Bojarczuk et al. (2014) reported that fabaceae and cereal crops grown in mixtures harvested at a later development stage produced more biomass. In the experiment reported here, an interaction between the studied factors was observed. The highest fresh matter yield was produced by the common pea/spring rye mixture whose component composition was 50 + 50% and which was harvested at the stage of common pea flat green pod, the yield being the lowest for spring rye harvested at the stage of common pea flowering.

Statistical analysis revealed a significant effect of the experimental factors and their interaction on the nitrogen content in common pea/spring rye mixtures (Table 3). The highest concentration of nitrogen was determined

Table 3

Nitrogen (N) and phosphorus (P) content in common pea/spring rye mixtures, means across 2010-2012 (g kg^{-1} DM)

Composition of mixture	Harvest date		Means
	flowering stage of pea	flat green pod stage of pea	
Nitrogen (N)			
Pea 100%	22.88 *b**	22.08 *b*	22.48 *C*
Spring rye 100%	19.20 *a*	17.76 *a*	18.48 *A*
Pea 75% + spring rye 25%	21.76 *b*	20.64 *b*	21.20 *B*
Pea 50% + spring rye 50%	20.64 *a*	19.36 *a*	20.00 *B*
Pea 25% + spring rye 75%	19.20 *a*	17.92 *a*	18.56 *A*
Means	20.74 *B*	19.55 *A*	-
Phosphorus (P)			
Pea 100%	5.271 *c*	4.490 *c*	4.881 *C*
Spring rye 100%	2.874 *a*	2.162 *a*	2.518 *A*
Pea 75% + spring rye 25%	4.880 *b*	4.084 *b*	4.482 *C*
Pea 50% + spring rye 50%	4.293 *b*	3.493 *b*	3.893 *B*
Pea 25% + spring rye 75%	3.692 *a*	2.891 *a*	3.292 *B*
Means	4.202 *B*	3.424 *A*	-

* Values in columns followed by the same small letter and values in rows followed by the same capital letter do not differ significantly at $P<0.05$.

in common pea, and the lowest in spring rye grown alone. According to Carr et al. (2004), Hoffman et al. (2008), Księżak and Staniak (2009), Szpunar--Krok et al. (2009*a*) as well as Wanic and Michalska (2009), fabaceae crops had a higher total protein content, including nitrogen, than cereals. In the present study, inclusion of common pea in mixtures with spring rye significantly increased the nitrogen content. The concentration of nitrogen in mixtures containing 75% common pea and 25% spring rye as well as 50% common pea and 50% spring rye differed insignificantly and was the lowest of all the mixtures. It was significantly lower only in the 25 + 75% mixture, which agrees with the findings of Płaza et al. (2017). By contrast, Huggaard-Nielsen (2001), Księżak and Staniak (2009) as well as Staniak et al. (2012) reported the highest total protein content, including nitrogen, in mixtures which contained 75% fabaceae plant. Eskandari et al. (2009), Redaelli et al. (2009) and Szpunar-Krok et al. (2009*a*) found that the total protein content in fabaceae/cereal mixtures containing 50 + 50% components was significantly higher compared with the cereal grown in pure stand. In the study reported here, the harvest date had a significant influence on nitrogen content in mixtures. Similarly to results achieved by Wanic and Michalska (2009), Bedoussac and Justes (2010) as well as Płaza et al. (2017), the nitrogen concentration was higher in fabaceae/cereal mixtures harvested at earlier development stages.

In the present work, common pea/spring rye mixtures harvested at the stage of common pea flowering had a higher nitrogen content than mixtures harvested at the stage of common pea flat green pod. An interaction was detected, which indicates that common pea harvested at the flowering stage had the highest nitrogen content, which in turn was the lowest in spring rye harvested at the stage of common pea flat green pod. Of the mixtures tested, common pea/spring rye mixtures containing 75 + 25% and 50 + 50% components harvested at the stage of common pea flowering, and the mixture consisting of 75% common pea and 25% spring rye harvested at the stage of common pea flat green pod had the highest nitrogen content.

Phosphorus content in common pea/spring rye mixtures was significantly affected by the experimental factors and their interaction (Table 3). The highest phosphorus content was recorded in pure-stand common pea and in the mixture containing 75% common pea and 25% spring rye, it being the lowest in spring rye cultivated in pure stand. Księżak and Staniak (2009), Szpunar-Krok et al. (2009*a*), Wanic and Michalska (2009), Staniak et al. (2012) as well as Płaza et al. (2017) reported that fabaceae plants had a higher phosphorus content than cereals. In the experiment reported here, the higher the share of common pea in a mixture, the higher the phosphorus content. Of the mixtures tested, the highest phosphorus content was determined in the mixture containing 75% common pea and 25% spring rye. The content was significantly lower in mixtures which contained 50% common pea and 50% spring rye as well as 25% common pea and 75% spring rye. A similar relationship was reported by Księżak and Staniak (2009) as well as Staniak et al. (2012). Also Szpunar-Krok et al. (2009*b*) and Płaza et al. (2017) found that fabaceae/cereal mixtures whose component shares were 50 + 50% had a higher concentration of phosphorus compared with cereals cultivated in pure stand. The present study demonstrated that harvest date had a significant effect on phosphorus content in mixtures. Similarly to findings by Wanic and Michalska (2009), Staniak et al. (2012) and Płaza et al. (2017), in the experiment reported here a higher phosphorus content was determined in fabaceae/cereal mixtures harvested at earlier development stages. The concentration of phosphorus was significantly higher in common pea/spring rye mixtures harvested at the stage of common pea flowering. An interaction was confirmed, which indicates that the highest phosphorus content was recorded in common pea cultivated in pure stand and the mixture which contained 75% common pea and 25% spring rye and was harvested at the stage of common pea flowering, it being the lowest in spring rye harvested at the stage of common pea flowering and of flat green pod.

Statistical analysis demonstrated a significant effect of the experimental factors and their interaction on the potassium content in common pea/spring rye mixtures (Table 3). The significantly highest concentration of potassium was found in common pea grown in pure stand, and the lowest - in spring rye. Also studies conducted by Szpunar-Krok et al. (2009*b*), Staniak et al. (2012) and Płaza et al. (2017) revealed that fabaceae plants are characterised by a significantly higher potassium content compared with cereals. In the present study, an increase in the share of common pea in the mixture contributed to a significant increase in the green matter content of potassium, which was the highest in the mixture which contained 75% common pea and 25% spring rye. A similar relationship was observed by Bojarczuk et al. (2014) and Płaza et al. (2017). In turn, Księżak and Staniak (2009) reported a higher potassium content in a mixture containing 50% fabaceae crop and 50% cereal compared with the 75 + 25% mixture. In the experiment reported here, the potassium content in the remaining mixtures was significantly lower, although still higher than in spring rye grown in pure stand. The harvest date had a significant effect on the concentration of potassium in common pea/spring rye mixtures, which corresponds with findings reported by Wanic and Michalska (2009), Staniak et al. (2012) and Płaza et al. (2017), who demonstrated that mixtures harvested at earlier development stages had a distinctly higher potassium content. In the present work, a significantly higher potassium content was determined in common pea/spring rye mixtures harvested at the stage of common pea flowering. An interaction was confirmed, which indicates that the highest potassium content was determined in pure-stand common pea and in the mixture containing 75% common pea and 25% spring rye harvested at the stage of common pea flowering, whereas the lowest potassium content was in spring rye harvested at the stage of common pea flat green pod.

The calcium content in common pea/spring rye mixtures was significantly influenced by the share of components in the mixture, harvest date and their interaction (Table 4). The highest calcium content was recorded in common pea grown in pure stand, but the lowest was in spring rye. Larralde and Martinez (1991) as well as Księżak and Staniak (2013) point to fabaceae plants as a significant calcium source. In the present study, the highest calcium content was noted in the mixture consisting of 75% common pea and 25% spring rye. In the remaining plots, the calcium content was significantly lower, although still higher than the value recorded in spring rye cultivated in pure stand. In the studies conducted by Księżak and Staniak (2009), Staniak et al. (2012) as well as Płaza et al. (2017), an increase in the share of fabaceae plant in a mixture from 50 to 75% contributed to an increase in the calcium content. The research done by Szpunar-Krok et al. (2009*b*) revealed an insignificantly higher calcium content in fabaceae/cereal mixtures whose component shares were 50 + 50%, compared with cereals grown in pure stand. In the study reported here, the calcium content was higher in mixtures than in spring rye grown in pure stand. The harvest date had a significant effect on the calcium content in common pea/spring rye mixtures. A significantly higher concentration of this mineral was recorded in common pea/spring rye mixtures harvested at the stage of common pea flowering, which corresponds with findings reported by Księżak and Staniak (2013) as well as Płaza et al. (2017). An interaction was confirmed, which indicates that the highest calcium content was noted in common pea grown

Table 4

Potassium (K), calcium (Ca) and magnesium (Mg) content in common pea/spring rye mixtures, means across 2010-2012 (g kg^{-1} DM)

Composition of mixture	Harvest date		Means
	flowering stage of pea	flat green pod stage of pea	
Potassium (K)			
Pea 100%	40.82 *e**	32.02 *d*	36.42 *e*
Spring rye 100%	27.81 *a*	20.70 *a*	24.26 *a*
Pea 75% + spring rye 25%	38.04 *d*	30.62 *d*	34.33 *d*
Pea 50% + spring rye 50%	34.82 *c*	26.82 *c*	30.82 *c*
Pea 25% + spring rye 75%	31.14 *b*	24.22 *b*	27.68 *b*
Means	34.53 *B*	26.88 *A*	-
Calcium (Ca)			
Pea 100%	14.45 *d*	11.74 *d*	13.10 *E*
Spring rye 100%	7.660 *a*	5.870 *a*	6.770 *A*
Pea 75% + spring rye 25%	13.40 *d*	10.54 *d*	11.97 *D*
Pea 50% + spring rye 50%	11.33 *c*	9.030 *c*	10.18 *C*
Pea 25% + spring rye 75%	9.450 *b*	7.340 *b*	8.400 *B*
Means	11.26 *B*	8.904 *A*	-
Magnesium (Mg)			
Pea 100%	1.590 *b*	1.414 *C*	1.502 *B*
Spring rye 100%	1.262 *a*	0.971 *a*	1.117 *A*
Pea 75% + spring rye 25%	1.503 *b*	1.300 *b*	1.402 *B*
Pea 50% + spring rye 50%	1.350 *a*	1.163 *b*	1.257 *A*
Pea 25% + spring rye 75%	1.321 *a*	1.032 *a*	1.177 *A*
Means	1.405 *B*	1.176 *A*	-

* Values in columns followed by the same small letter and values in rows followed by the same capital letter do not differ significantly at $P<0.05$.

in pure stand, and in the common pea/spring rye mixture whose component share was 75 + 25% and which was harvested at the stage of common pea flowering, while being the lowest in spring rye harvested at the stage of common pea flat green pod.

The statistical analysis confirmed a significant effect of the experimental factors and their interaction on the magnesium content in common pea/spring rye mixtures (Table 4). The highest concentration of magnesium was determined in common pea grown in pure stand and in the mixture consisting of 75% common pea and 25% spring rye. In the remaining plots, the magnesium content in common pea/spring rye mixtures was significantly lower, being the lowest in spring rye cultivated in pure stand and in the common pea/spring rye mixture whose share of components was 25 + 75%. The same relationship was observed by Płaza et al. (2017). In contrast, Szpunar-Krok et al. (2009*b*) found no significant differences in the magnesium content between fabaceae crops grown in pure stand and their mixtures with different shares of both components. In the reports by Księżak and Staniak (2009) as well as Staniak et al. (2012), an increase in the share of fabaceae plant in the mixture was followed by insignificant changes in the magnesium content. However, according to Larralde and Martinez (1991) as well as Wanic and Michalska (2009), fabaceae plants contain more magnesium than cereals, which corresponds with results of the present work. In the experiment reported here, the harvest date significantly affected the magnesium content in common pea/spring rye mixtures. Mixtures harvested at the common pea flowering stage had a higher concentration of magnesium compared with mixtures harvested at the stage of common pea flat green pod. Also Wanic and Michalska (2009), Staniak et al. (2012) as well as Płaza et al. (2017) noted a higher magnesium content in mixtures harvested at earlier development stages. In the present study, an interaction was confirmed, which indicates that the highest magnesium content was characteristic of common pea cultivated in pure stand and in combination with spring rye, the respective components forming 75% and 25% of the mixture, both harvested at the stage of common pea flowering. The lowest concentration of magnesium was determined in spring rye grown in pure stand and in the mixture containing 25% common pea and 75% spring rye, both harvested at the stage of common pea flat green pod.

CONCLUSIONS

1. The highest fresh matter yield was harvested from the common pea/spring rye mixture where the share of components was 50 + 50%.

2. Common pea cultivated in pure stand and mixed with spring rye in the proportion 75 + 25% had the highest content of macroelements.

3. The mineral content of common pea/spring rye mixtures harvested at the stage of common pea flowering was significantly lower compared with mixtures harvested at the stage of common pea flat green pod, because in the later stages of development, the content of organic compounds increases and the content of mineral components in plants decreases.

4. For broad agricultural practice, it is recommended to cultivate a mixture of pea and spring rye with the share of 50 + 50% of components collected in the stage of common pea flat green pod.

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