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THE IMPACT OF THE SELECTION OF COMPONENTS AND DIFFERENT WAYS OF USING LEGUME-GRASS SWARD ON THE CHEMICAL COMPOSITION OF POST-HARVEST RESIDUES

Summary

The studies were performed on the organic plot of AES of IUNG in Grabów in 2012. Experimental factors were: 4 legume-grass mixtures (the first factor): 1 – Trifolium repens (25%) + Trifolium pratense (25%) + Lolium perenne (15%) + Dactylis glomerata (15%) + Festuca pratensis (10%) + Festuca rubra (10%); 2 – Trifolium pratense (50%) + Lolium perenne (20%) + Festuca pratensis (20%) + Phleum pratense (10%); 3 – Medicago x varia (50%) + Dactylis glomerata (20%) + Festuca pratensis (20%) + Phleum pratense (10%); 4 – Trifolium repens (25%)+ Medicago x varia (25%) + Lolium perenne (15%)+Dactylis glomerata (15%) + Festuca pratensis (10%) + Festuca rubra (10%) and 2 ways of using sward: hay/pasture and pasture (the second factor). The purpose of the research was to assess the effects of the species composition of several legume-grass mixtures utilized in a hay/pasture or pasture way (periodic cow grazing) on the weight and content of nutrients in the aerial and underground fraction of post-harvest residues. The conducted studies have shown that legume-grass mixtures left behind a large weight of post-harvest residues with a high percentage of grasses. The weight of nutrients brought into the soil varied depending on their percentage in the post-harvest residues. Most of the post-harvest residues were left by a mixture of alfalfa with grasses. More potassium was left by mixtures on pastures, while the weight of other nutrients was similar in the tested ways of sward use.
Key words*: organic farming, legume-grass mixture, hay/pasture, pasture, plant residues mass, concentration of micronutrients in the plant residues*

WPŁYW DOBORU KOMPONENTÓW I RÓŻNYCH SPOSOBÓW UŻYTKOWANIA RUNI BOBOWATO-TRAWIASTEJ NA MASĘ I SKŁAD CHEMICZNY RESZTEK POZBIOROWYCH

Streszczenie

Badania przeprowadzono na polu ekologicznym w RZD IUNG Grabów w 2012 roku. Czynnikami badawczymi w doświadczeniu były: 4 mieszanki bobowato-trawiaste (I czynnik): 1 – Trifolium repens (25%) + Trifolium pratense (25%) + Lolium perenne (15%) + Dactylis glomerata (15%) + Festuca pratensis (10%) + Festuca rubra (10%); 2 – Trifolium pratense (50%) + Lolium perenne (20%) + Festuca pratensis (20%) + Phleum pratense (10%); 3 – Medicago x varia (50%) + Dactylis glomerata (20%) + Festuca pratensis (20%) + Phleum pratense (10%); 4 – Trifolium repens (25%)+ Medicago x varia (25%) + Lolium perenne (15%)+Dactylis glomerata (15%) + Festuca pratensis (10%) + Festuca rubra (10%) i 2 sposoby użytkowania runi: kośno/pastwiskowy i pastwiskowy (czynnik II). Celem badań była ocena wpływu składu gatunkowego czterech mieszanek bobowato-trawiastych użytkowanych kośno/pastwiskowo i pastwiskowo (okresowy wypas krów) na masę oraz zawartość składników pokarmowych w nadziemnej i podziemnej frakcji resztek pozbiorowych. Przeprowadzone badania wykazały, że po mieszankach bobowato-trawiastych pozostała duża masa resztek pozbiorowych, szczególnie wysoki był w nich udział traw. Masa wnoszonych do gleby składników pokarmowych zależała od ich procentowej zawartości w resztkach pozbiorowych. Najwięcej resztek pozbiorowych pozostawiały mieszanki lucerny z trawami. Więcej potasu pozostało po mieszankach na pastwisku, masa pozostałych składników pokarmowych była podobna w porównywanych sposobach wykorzystaniu runi.
Słowa kluczowe*: warunki ekologiczne, mieszanki bobowato-trawiaste, użytkowanie kośno-pastwiskowe, użytkowanie pastwiskowe, masa resztek pozbiorowych, koncentracja makroskładników w resztkach pozbiorowych*

1. Introduction

An interest in the cultivation of small-seed legumes has recently increased mainly due to a positive impact of these plants on the environment [1, 2, 8, 9, 12]. In 2015, small-seed legumes took up an area of approximately 212 thous. ha in the arable land structure [7]. The reason of the increase in the cultivation acreage of small-seed legumes resulted from an increasing interest in the organic and integrated forms of cultivation, in which this group of plants together with coarse-grained should constitute approximately 30% of the sowing structure. In recent years, legumes have been introduced to cultivation in some farms not only due to their important function of fertilization and protection of land, but also for financial reasons (subsides). In 2010, a special area payment was introduced for growing legumes and legume-grass mixtures. In recent years, the requirements for obtaining direct payments for growing plants have increased. One of the requirements assume to grow plants in crop rotation. This issue concerns mainly farms with a high share of cereals in the sowing structure, another-crop diversification on large farms. In order to meet these requirements, farmers grow legumes which improve soil fertility, plant health in crop rotations, and yields. Another problem concerns non-livestock farms which are short of natural fertilizers. In this group of farms, the sowings of small-seed legumes and legume-grass mixtures are ploughed to rebuild organic matter and bring nutrients to the soil. As has been shown in the literature, the impact of "green fertilizers" on successive crops is higher or comparable to natural fertilizers [3]. According to Bawolski [4], one of the precursors of research on the impact of post-harvest residues, the weight of root residues, rich in microelements, is several-fold higher than of the residues remaining after legume-grass mixtures compared with the aerial weight.

Taking into account previous studies on the activity of "green fertilizers" and post-harvest residues, it was decided to use a field experiment with yields and feed quality of legume-grass mixtures, cultivated in a hay/pasture and pasture ways to obtain additional information on soil enrichment with nutrients from post-the ploughed harvest residues , after the use of these mixtures for animal feed.

The aim of the study was to evaluate the effect of species composition of several legume-grass mixtures, treated in a mown-grazed way (successively) or in a grazed way (periodical grazing of cows) on the weight and content of nutrients in the aerial and underground fraction of post-harvest residues.

2. Material and methods

In the organic field at the Agricultural Experimental Station IUNG-PIB in Grabów (Mazowieckie voivodeship), a two-factor experiment was set up in a split-block system. Four mixtures, similarly to grasses, were studied with a 50% share of legumes in pure sowings. The study included also mixtures of the following species composition (the first factor): 1 – *Trifolium repens* (25%) + *Trifolium pratense* (25%) + *Lolium perenne* (15%) + *Dactylis glomerata* (15%) + *Festuca pratensis* (10%) + *Festuca rubra* (10%); 2 – *Trifolium pratense* (50%) + *Lolium perenne* (20%) + *Festuca pratensis* (20%) + *Phleum pratense* (10%); 3 – *Medicago x varia* (50%) + *Dactylis glomerata* (20%) + *Festuca pratensis* (20%) + *Phleum pratense* (10%); 4 – *Trifolium repens* (25%)+ *Medicago x varia* (25%) + *Lolium perenne* (15%)+*Dactylis glomerata* (15%) + *Festuca pratensis* (10%) + *Festuca rubra* (10%). The second research factor involved two ways of using legume-grass sward: H/P – hay/pasture (understood as a combination of these two in the same growing, the so called periodical grazing) and P - pasture use.

The studies related with the assessment of yields of four legume-grass mixtures cultivated in a hay/pasture and pasture ways, as well as with the concentration of nutrients in the obtained feed were carried out in the years 2009-2012. The methodology of agronomic research was described in the study of Gaweł [5], while the concentration of macronutrients in the evaluated sward was provided in another research covering this issue [6]. After the harvest of the third regrowth of the sward, which was the last in that growing period due to drought growing season in the third year of full use of the sward (2012), it was decided to collect the samples of post-harvest residues from each plot from the area of 1 m^2. After being rinsed and weighed, the post-harvest residues were separated into an aerial fraction comprising plant fragments from above collar-roots at legumes, and fragments from above tillering node up to the old stubble height (about 5 cm above the ground) at grasses and a underground root fraction produced by plants down to the depth of about 15 cm. The dry weight of post-harvest residues was determined taking into account the aerial fraction and roots of legumes, grasses, and weeds. The dry matter of the prepared plant material was determined for: the content of dry matter by gravimetric method (PN-R-04013: 1988), total nitrogen - by flow analysis (CFA) PB 33. 1-ed. II-05. 03. 2014, phosphorus – by flow analysis (CFA) PB 33. 1-ed. II-05. 03. 2014, potassium – by atomic emission spectrometry PB 32. 1- ed. II- 08. 03. 2014, calcium – by flame atomic absorption spectrometry (FAAS) PB 32 1-ed. II-08. 03. 2014, and magnesium – flame atomic absorption spectrometry (FAAS) PB 32 1-ed. II-08. 03. 2014.

A statistical analysis of the weight of post-harvest residues and their chemical composition (ANOVA)was performed in a two-factor, non-replicate experiment, where the first factor was constituted by four legume-grass mixtures, and the second factor included the way of using the sward: H/P and P. The obtained average concentration of each macronutrient was compared by Tukey's test at the significance level of $\alpha = 0.05$.

3. Results and discussion

Literature shows the dependence of the weight of post-harvest residues on agronomic factors, crop species, weather, soil conditions, and methods of cultivation [4, 11]. Bawolski [4] obtained from 8.6 to 10.3 $t \cdot ha^{-1}$ of post-harvest residues after cultivation of perennial legumes in pure stands and in mixtures with grasses. In the studies of this author, mixtures of alfalfa with grasses left more residues than red clover with grasses and other legume plants. The data presented in Table 1 confirmed the significant impact of the species composition of mixtures on the weight of post-harvest residues, known from studies of Bawolski [4], Baluch and Benedycki [1], Baluch et al. [2] Orzech et al. [11], and Zając i Antonkiewicz [15]. In our study, mixtures of alfalfa with grasses and of white clover and alfalfa with grasses (mixtures: 3 and 4) left more post-harvest residues than mixtures of white clover with red clover and of red clover with grasses (mixtures: 1 and 2). This statement applies to post-harvest residues remaining after legumes, roots fractions, or total weed weight, as well as to and total weight of post-harvest residues left by all groups of plants in the mixtures-legumes, grasses, and weeds (Table. 1). These studies confirm the results obtained by Bawolski [4] and Szczepaniak et al. [13] on the higher weight of post-harvest residue remaining after alfalfa-grass mixtures.

Grasses, especially their root fraction, were the main source of post-harvest residues in own studies, carried out in adverse climatic conditions characterized by periodic droughts, violent rainfall storms, and snowless winter which froze almost all the plants of white clover and meadow [5, 6]. In the total weight of post-harvest residues, grass roots constituted about 72% of Mixture 1, 61% - of Mixture 2, 42% - of Mixture 3, and about 60% - of Mixture 4 (Table. 1). Szczepaniak et al [13] also found a high, amounting to an average 8 t·ha^{-1}, yield of crop root residues left by temporary grasslands. The aerial weight of post-harvest grass residues did not differ in terms of the species composition of mixtures. It was similar to the root fraction, and the total aerial and root weight left by grasses. Earlier studies on yields and feed quality of these mixtures revealed the fastest and highest weed infestation in the meadow clover-grass mixtures (Mixture 2) [5, 6]. This mixture also had the largest weight of weed roots and the total weight of weeds (aerial and underground, Tab. 1), whereas the smallest weight of weed post-harvest residues was recorded for the mixtures of white clover and red clover with grasses (Mixture 1, Tab. 1).

Three years of growing legume-grass mixtures left a total of 5.09 to 7.99 t·ha^{-1} of post-harvest residues (aerial fraction+ roots of legumes, grasses, and weeds), in which the roots constituted from 79.8% for the mixture of red clover with grasses (Mixture 2) to 81.2% - for the mixture of white clover and alfalfa with grasses (Mixture 4) (Table. 1). A significantly higher root weight as well as aerial and root fraction were left by the mixtures of alfalfa with grasses and of white clover and alfalfa with grasses (Mixtures 3 and 4). The results are consistent with the previous studies of Bawolski [4].

In the case of the aerial fraction of legumes and total weight of post-harvest residues under pasture use, the weight of post-harvest residues was higher than under hay/pasture use. These results also proved a better stability and development of legumes under using sward for grazing compared to hay/pasture use, where legumes are subjected to two types of stress connected with cutting the sward and grazing animals. Other results were obtained in the case of grasses, which left a significantly higher weight of aerial post-harvest residues under the hay/pasture use (Table. 1).

The highest percentage share of nitrogen in the post-harvest residues of legumes, in particular in their aerial fraction (from 2.34-2.47% N) was noted (Table 2). In general, aerial residues of legumes, grasses and weeds had higher nitrogen concentrations of nitrogen than the residues of roots (Table 2). The experimental factors had no significant effect on the nitrogen concentration in the post-harvest residues of individual mixture components.

The rate of mineralization depends on the average percentage of nitrogen in the residues introduced into the soil. According to Lewis [10], process of retreating of this component occurs when the average concentration of nitrogen introduced into the soil in the post-harvest residues was higher than 1.2%. Under the average nitrogen concentration in the post-harvest residues exceeding 1.8%, mineralization process starts in the soil. In the residues of the compared mixtures, the average percentage concentration of nitrogen took on intermediary values between the limit values (Table 2), which suggests the occurrence of two processes - retreating and mineralization, with the predominance of the latter process. Szczepaniak et al. [13] believe that a separate evaluation of the percentage share of nitrogen in the aerial part and underground parts of post-harvest residues is helpful in the evaluation of the processes occurring in the soil. By following these recommendations, the average nitrogen concentration in the aerial parts of the sward (legumes, grasses, weeds) calculated in our studies indicates the occurrence of the process of mineralization (concentration >1.8% N). The average nitrogen concentration calculated for the root parts of post-harvest residues ranged between 1.2-1.8% N. This result can be interpreted as a balancing of immobilization and mineralization of nitrogen (Table 2).

Grasses, which dominated in the total mass of post-harvest residues, were the species which determined the amount of nitrogen in these residues in four legume-grass mixtures. Legumes accumulated more nitrogen than weeds (Table 2). As is commonly known, the mass of the accumulated nitrogen is the product of weight of post-harvest residues multiplied by the percentage of this component in the dry matter. Earlier studies show that legumes have a much higher percentage at the final stage of mixture use than weeds [6], which explains the higher accumulation of nitrogen by this group of plants. In the aerial fraction of legumes, the mixture of alfalfa with grasses (Mixture 3) collected significantly more nitrogen in relation to red clover-grass mixture (Mixture 2). A high accumulation of nitrogen in this case was also ensured by a high yield of post-harvest residues (Tab. 1 and 2). Among the post-harvest residues of the compared mixtures, the most nitrogen was accumulated by grasses (from about 35 to 61,5 kg N·ha^{-1}), especially grass root fraction (from about 27,5 to 45,9 kg N·ha^{-1}) (Tab. 2).

Table 1. The weight of post–harvest residues in. t·ha^{-1} left by the legume-grass mixtures in the hay/pasture and pasture use
Tab. 1. Masa resztek pozbiorowych pozostawionych przez mieszanki bobowato-trawiaste w t·ha^{-1} w kośno-pastwiskowym i pastwiskowym użytkowaniu

Specification	Legumes			Grasses			Weeds			Total		
	S*	R**	Σ	S	R	Σ	S	R	Σ	S	R	Σ
Mixtures												
1***	0,22	0,39	0,67	0,89	4,41	5,31	0,10	0,14	0,24	1,21	4,94	6,16
2	0,11	0,22	0,33	0,55	3,10	3,65	0,37	0,74	1,11	1,03	4,06	5,09
3	0,50	2,48	2,99	0,88	3,30	4,19	0,16	0,50	0,66	1,55	6,29	7,84
4	0,40	1,50	1,90	0,98	4,77	5,75	0,12	0,21	0,34	1,50	6,49	7,99
NIR	0,23	1,56	1,76	r.n.	r.n.	r.n.	r.n.	0,59	0,78	r.n.	1,97	2,15
Utilization												
H/P	0,19	0,77	0,99	1,00	4,28	5,29	0,18	0,27	0,46	1,37	5,33	6,71
P	0,43	1,52	1,95	0,651	3,51	4,16	0,19	0,33	0,72	1,28	5,56	6,83
NIR	0,12	r.n.	0,93	0,343	r.n.	r.n.	r.n.	r.n.	r.n.	r.n.	r.n.	r.n.

S* - Stubble , R** - Roots, H/P – Hay/Pasture, P – Pasture,
1*** - *Trifolium repens* (25%)+*Trifolium pratense* (25%)+*Lolium perenne* (15%)+*Dactylis glomerata* (15%)+*Festuca pratensis* (10%)+*Festuca rubra* (10%); 2 – *Trifolium pratense* (50%)+ *Lolium perenne* (20%)+*Festuca pratensis* (20%)+ *Phleum pratense* (10%); 3 – *Medicago x varia* (50%)+ *Dactylis glomerata* (20%)+*Festuca pratensis* (20%)+ *Phleum pratense* (10%); 4 – *Trifolium repens* (25%)+ *Medicago x varia* (25%) + *Lolium perenne* (15%) + *Dactylis glomerata* (15%)+*Festuca pratensis* (10%) + *Festuca rubra* (10%)

Source: own work / Źródło: opracowanie własne

Table 2. Accumulation of nitrogen in the biomass of post –harvest residues
Tab. 2. Akumulacja azotu w suchej masie resztek pozbiorowych w kg·ha^{-1}

Specification	N (zawartość % N) (concentration % N)											
	Legume			Trawy/ Grass			Chwasty/ Weeds			Total (L + G + W)		
	S	R	Σ	S	R	Σ	S	R	Σ	S	R	Σ
Mixtures												
1	5,12 (2,36)	7,66 (1,96)	12,78	15,62 (1,79)	45,86 (1,03)	61,48	1,37 (1,58)	2,04 (1,38)	3,42	22,12	55,56	77,68
2	2,85 (2,35)	4,38 (1,93)	7,23	7,42 (1,35)	27,47 (0,88)	34,89	5,30 (1,45)	10,28 (1,42)	15,59	15,57	42,13	57,69
3	11,93 (2,39)	47,32 (1,91)	59,26	13,05 (1,49)	37,83 (1,22)	50,88	3,88 (2,38)	8,29 (1,64)	12,17	28,86	93,44	122,30
4	9,95 (2,47)	24,75 (1,43)	34,69	15,22 (1,54)	42,96 (0,92)	58,19	2,39 (1,98)	12,31 (1,78)	14,70	27,56	80,02	107,59
NIR	9,33 (r.n.)	r.n. (r.n.)	r.n.	r.n. (r.n.)	r.n. (r.n.)	r.n.	3,43 (r.n.)	r.n. (r.n.)	r.n.	r.n.	48,80	55,06
Utilization												
H/P	4,64 (2,38)	13,55 (1,69)	18,19	14,95 (1,47)	34,02 (0,79)	48,97	2,86 (1,65)	8,35 (1,49)	11,21	22,45	55,92	78,37
P	10,28 (2,41)	28,51 (1,92)	38,79	10,71 (1,61)	43,04 (1,24)	53,75	3,62 (2,04)	8,11 (1,62)	11,73	24,61	79,66	104,26
NIR	4,35 (r.n.)	r.n. (r.n.)	r.n.	r.n. (r.n.)	r.n. (r.n.)	r.n.	r.n. (r.n.)	r.n. (r.n.)	r.n.	r.n.	22,76	25,68

S* - Stubble , R** - Roots, H/P – Hay/Pasture, P – Pasture, 1*** - see tab. 1 *Source: own work / Źródło: opracowanie własne*

Literature describes legumes as plants determining the weight of nitrogen accumulated by the mixtures (distinguished by their high nitrogen concentration in the dry matter), and their fertilizer value and nitrogen accumulation by the mixtures depended on the legume species [15]. Table 2 shows a similar nitrogen accumulation among the tested mixtures. The weight of post-harvest residues that they left had the biggest influence on its accumulation in grasses (Table 1 and 2). However, the impact of the species composition of mixtures on nitrogen accumulation was not recorded for this species.

Weeds occurring in the sward accumulated from 3.4 to 15.6 kg N·ha^{-1}. The significantly highest amount of this nutrient in post-harvest residues of the aerial were collected by the weeds in the most weed-infested mixture of red clover with grasses (Mixture 2) [6], while the lowest – by the weeds in a mixture of white clover and red clover with grasses.

The post-harvest residues of mixtures (legumes+ grasses+ weeds) may bring into the soil from 58 kg of N with a mixture of red clover with grasses (Mixture 2) up to about 122 kg of N - together with the ploughed weight of post-harvest residues of the mixture of alfalfa with grasses (Mixture 3) (Table 2). The difference in the weight of nitrogen accumulated in post-harvest residues in the above-mentioned mixtures was statistically proven. Nitrogen was introduced into the soil mainly by root weight. Indeed, the most of this component was found in the root fraction of alfalfa-grass mixture (Mixture 3), while the least – in the roots blend of red clover-grass mixture (Mixture 2). Symbiotic nitrogen may constitute a substantial portion of nitrogen in this pool. According to Prusiński and Kotecki [12], 1 tonne of post-legume leaves several dozens kilograms of symbiotic nitrogen (up to 100 kg) used wholly by the successive crops. In conventional farms, it generates large savings in terms of the costs of purchasing nitrate fertilizers which are used by plants only in 50%. Under ecological cultivation, nitrogen bound biologically limits the need for using natural fertilizers. The results concerning the accumulation of higher amounts of nitrogen by mixtures with alfalfa and the impact of the weight of post-harvest residues on collecting nitrogen correspond with the results described by Bawolski [4].

The aerial fraction of the post-harvest residues was characterized by a slightly larger percentage share of potassium than root fraction (Table 3). The weeds turned out to be more abundant in this macrocomponent compared to legumes and grasses. The species composition of mixtures and the way of using sward did not have a significant effect on the percentage share of potassium in the aerial fraction and in the roots and aerial parts of legumes, grasses, and weeds (Table 3).

Significantly highest amounts of potassium in the aerial parts and roots, and in the total post-harvest residues were collected by Lucerne from Mixture 3, while the least - red clover grown in Mixture 2 (Table 3). As previously described in the methodology of this research, in the last wintering after a period of frost (-7°C) lasting a whole month without snow cover on the plants, most of white clovers and red clovers fell out from the sward of the mixtures. The cause of this phenomenon could lie in a low concentration of potassium which is responsible for the frost-resistance of plants. In own studies, a higher mass of potassium after legumes was recorded in the root residues (Table 3). Contrasting results concerning the accumulation of potassium were obtained by Wilczewski [14], who found that more potassium was gathered in the aerial biomass of the tested legumes.

In general, legumes accumulated significantly more potassium in their post-harvest residues (aerial and below-ground parts) under pasture use than under hay/pasture use (Table 3). The percentage share of potassium in the post-harvest residues of grasses was higher than in legumes. The weight of grasses was also high, with the dominance of root residues, which probably contributed to the accumulation of a considerable mass of potassium (from 15,79 to 28,09 kg K ha^{-1}) (Table 3). Numerous authors report of the ability non-legume plants to collect larger amounts of potassium in comparison with legumes, these differences being attributed to higher-yields of the non-legumes [15]. Our research has confirmed this thesis.

Table 3. Accumulation of potassium in the biomass of post–harvest residues
Tab. 3. Akumulacja potasu w suchej masie resztek pozbiorowych w kg·ha^{-1}

Specification	K (concentration % K)											
	Legume			Grass			Weeds			Total (L +Gt + W)		
	S	R	Σ	S	R	Σ	S	R	Σ	S	R	Σ
Mieszanki/ Mixtures												
1	1,36 (0,56)	1,66 (0,48)	3,01	5,69 (0,62)	22,40 (0,50)	28,09	0,77 (0,86)	0,76 (0,51)	1,51	7,81	24,79	32,60
2	0,79 (0,68)	1,02 (0,55)	1,82	4,36 (0,75)	11,43 (0,36)	15,79	3,93 (1,07)	5,57 (0,80)	9,50	9,09	18,02	27,10
3	3,64 (0,71)	11,78 (0,46)	15,42	7,91 (0,91)	15,09 (0,48)	23,00	2,51 (1,54)	2,99 (0,57)	5,50	14,06	29,86	43,93
4	2,72 (0,65)	5,77 (0,35)	8,48	7,51 (0,76)	10,17 (0,23)	17,68	1,05 (0,90)	4,62 (0,61)	5,67	11,28	20,55	31,83
NIR	2,36 (r.n.)	10,47 (r.n.)	12,52	r.n. (r.n.)	r.n. (r.n.)	r.n.	1,91 (r.n.)	r.n. (r.n.)	r.n.	3,94	r.n.	r.n.
Utilization												
H/P	1,11 (0,59)	2,58 (0,45)	3,69	8,07 (0,79)	11,82 (0,29)	19,89	2,03 (1,04)	3,77 (0,66)	5,79	11,21	18,16	29,37
P	3,15 (0,71)	7,52 (0,47)	10,67	4,67 (0,75)	17,73 (0,49)	22,39	2,10 (1,15)	3,19 (0,59)	5,29	9,91	28,45	38,36
NIR	1,01 (r.n.)	4,88 (r.n.)	5,84	3,18 (r.n.)	r.n. (r.n.)	r.n.	r.n. (r.n.)	r.n. (r.n.)	r.n.	r.n.	r.n.	r.n.

S* - Stubble , R** - Roots, H/P – Hay/ asture, P – Pasture, 1*** - see tab. 1

Source: own work / Źródło: opracowanie własne

Hay/pasture use of sward promoted a higher potassium accumulation in the aerial post-harvest residues (Table 3). The abundance of aerial post-harvest residues of weeds in potassium was higher than of root residues (Table 3). Weed infestation of the red clover mixture sward (Mixture 2) was high, so out of all the compared mixtures, the weeds of this particular mixture accumulated the most potassium in their aerial post-harvest residues (Table 3). The factors examined in the experiment (mixtures, sward use) did not affect the accumulation of potassium either in the roots or in the total aerial and root weight of weeds.

The tested mixtures accumulated from 27.1 to 43.93 kg K·ha^{-1}in the post-harvest residues, which was about a half of the accumulated potassium by similar mixtures in the studies described by Bawolski [4]. In the aerial and root parts, the most total potassium was accumulated by the mixture of alfalfa with grasses (Mixture 3), characterized by high feed yields [5] and a large mass of post-harvest residues (Table 3). The ability of the mixtures with alfalfa to accumulate larger amounts of potassium in comparison with other legume plants (common sainfoin and birdsfoot trefoil) was described by Bawolski as well [4].

The percentage share of phosphorus was higher in aerial parts than in the roots of mixture components, with the exception of weeds (Table 4). The experimental factors did not differentiate the percentage abundance of post-harvest residues in phosphorus.

The root residues of legumes, grasses and weeds accumulated more phosphorus in kg·ha^{-1} than the aerial fraction. Legumes uptook a similar amount of phosphorus, regardless of the species composition of mixtures or the method of their use. Most of this nutrient was accumulated by grasses in their root fraction - from 4.06 to 6,93 kg P·ha^{-1} (Table 4). It was shown a significantly higher mass of phosphorus in the aerial fraction of the sward under hay/pasture use compared to aerial fraction of pasture sward (Table 4). In the aerial parts of weeds, the most phosphorus was accumulated by a mixture of red clover with grasses (Mixture 2), while significantly the least – by the mixture of white clover and red clover with grasses. In general, weeds accumulated small amounts of phosphorus, from 0,64 kg·P ha^{-1} to 3,22 kg·P ha^{-1}.

Phosphorus was a component accumulated in the post-harvest residues of legume-grass mixtures in lower amounts than nitrogen or potassium (Table 4). The total mass of this nutrient which fertilizes the soil, brought totally by the mixtures in their aerial and root parts ranged from 9.39 to 18.58 kg·P ha^{-1}, while the species composition of mixtures and ways of sward use did not affect its size. Literature describes a several-fold higher fertilizer value of the mixture of alfalfa with grasses, from 40 to 60 kg·P ha^{-1} [4] (Table 4), as compared to the value obtained in own studies.

A higher percentage share of calcium was recorded in the aerial fractions of post-harvest residues of the components of mixture sward (of legumes, grasses, and weeds) (Table 5). The highest share was observed in the weeds, followed by legumes, as can also be learnt from the study of Bawolski [4].

Legumes mixed with grasses left from 2,01 to 17,32 kg Ca·ha^{-1} (Table 5). Significantly more calcium in the root fraction and in the total of aerial and root fractions was remained by alfalfa from Mixture 3, while significantly less red clover from Mixture 2. It was found that aerial parts of legume post-harvest residues left more calcium mass under pasture use in comparison with hay/pasture sward use.

Among the sward components (of legumes, grasses, weeds), a significantly larger mass of calcium in the post-harvest residues was left by grasses, while the smallest- by weeds (Table 5). In the case of aerial fraction of post-harvest residues of weeds, the largest accumulation of calcium was recorded for the most weed-infected mixture of red clover with grasses (Mixture 2, Table 5).

Table 4. Accumulation of phosphorus in the biomass of post–harvest residues

Tab. 4. Akumulacja fosforu w suchej masie resztek pozbiorowych w kg·ha^{-1}

Specification	P (concentration % P)											
	Legume			Grass			Weeds			Total (L + G + W)		
	S	R	Σ	S	R	Σ	S	R	Σ	S	R	Σ
Mixtures												
1	0,58 (0,27)	0,93 (0,22)	1,51	2,28 (0,25)	7,69 (0,17)	9,96	0,25 (0,27)	0,39 (0,25)	0,64	3,11	9,01	12,12
2	0,31 (0,29)	0,49 (0,24)	0,79	1,31 (0,23)	4,06 (0,13)	5,38	0,98 (0,27)	2,24 (0,31)	3,22	2,59	6,79	9,39
3	1,42 (0,28)	5,78 (0,23)	7,19	2,15 (0,24)	6,93 (0,22)	9,08	0,65 (0,40)	1,65 (0,32)	2,30	4,22	14,36	18,58
4	1,17 (0,27)	3,03 (0,18)	4,19	2,64 (0,26)	5,38 (0,11)	8,02	0,39 (0,33)	2,39 (0,35)	2,78	4,19	10,79	14,99
NIR	r.n. (r.n.)	r.n. (r.n.)	r.n.	r.n. (r.n.)	r.n. (r.n.)	r.n.	0,57 (r.n.)	r.n. (r.n.)	r.n.	r.n.	r.n.	r.n.
Utilization												
H/P	0,55 (0,29)	1,69 (0,21)	2,52	2,63 (0,26)	4,95 (0,12)	7,58	0,53 (0,29)	1,66 (0,29)	2,19	3,71	8,31	12,02
P	1,18 (0,27)	3,42 (0,22)	4,60	1,56 (0,24)	7,08 (0,21)	8,64	0,61 (0,34)	1,67 (0,33)	2,28	3,35	12,17	15,52
NIR	r.n. (r.n.)	r.n. (r.n.)	r.n.	0,99 (r.n.)	r.n. (r.n.)	r.n.	r.n. (r.n.)	r.n. (r.n.)	r.n.	r.n.	r.n.	r.n.

S* - Stubble , R** - Roots, H/P – Hay/Pasture, P – Pasture, 1*** - see tab. 1 *Source: own work / Źródło: opracowanie własne*

Table 5. Accumulation of calcium in the biomass of post–harvest residues

Tab. 5. Akumulacja wapnia w suchej masie resztek pozbiorowych w kg·ha^{-1}

	Ca (content % Ca)											
	Legume			Grass			Weeds			Total (L+ G+ W)		
	S	R	Σ	S	R	Σ	S	R	Σ	S	R	Σ
Mixtures												
1	1,73 (0,77)	1,86 (0,55)	3,59	5,16 (0,57)	23,05 (0,52)	28,20	0,69 (0,86)	0,64 (0,46)	1,34	7,58	25,55	33,13
2	0,93 (0,76)	1,08 (0,64)	2,01	3,89 (0,70)	15,29 (0,49)	19,16	3,81 (1,04)	3,51 (0,47)	7,32	8,61	19,88	28,49
3	4,63 (0,93)	12,69 (0,48)	17,32	6,21 (0,70)	14,73 (0,46)	20,94	2,11 (1,29)	2,87 (0,52)	4,98	12,95	30,29	43,24
4	3,62 (0,88)	7,93 (0,50)	11,55	6,66 (0,69)	22,93 (0,49)	29,59	1,51 (1,28)	3,84 (0,49)	5,35	11,78	34,69	46,48
NIR	r.n. (r.n.)	11,62 (r.n.)	15,05	r.n. (r.n.)	r.n. (r.n.)	r.n.	2,35 (r.n.)	r.n. (r.n.)	r.n.	r.n.	r.n.	r.n.
Utilization												
H/P	1,69 (0,81)	3,69 (0,55)	5,39	6,85 (0,69)	18,19 (0,43)	25,04	1,91 (1,03)	2,80 (0,49)	4,70	10,45	24,67	35,13
P	3,75 (0,86)	8,09 (0,54)	11,85	4,09 (0,64)	19,81 (0,55)	23,91	2,16 (1,02)	2,63 (0,49)	4,79	10,01	30,54	40,55
NIR	1,82 (r.n.)	r.n. (r.n.)	r.n.	2,43 (r.n.)	r.n. (r.n.)	r.n.	r.n. (r.n.)	r.n. (r.n.)	r.n.	r.n.	r.n.	r.n.

S* - Stubble , R** - Roots, H/P – Hay/Pasture, P – Pasture, 1*** - see tab. 1 *Source: own work / Źródło: opracowanie własne*

Legume-grass sward accumulated the total mass of calcium at the level of 28,49-46,48 kg Ca·ha^{-1}, which is less than the amount found by Bawolski [4] in his experiment conducted under conventional conditions with mineral fertilizers. Own research was carried out under organic system, characterized by a lower level of yielding, which determines the weight of the macronutrients remaining in the post-harvest residues after legume-grass mixtures. Species composition and the way of legume-grass sward use did not affect the total accumulation of calcium (Table 6).

The percentage share of magnesium in the aerial post-harvest residues of mixture components was greater than obtained for the roots (Table 6). There were no significant differences in the percentage of this component in legumes, grasses and weeds under the influence of the experimental factors.

The weight of magnesium left in the root residues of plants from the mixture swards exceeded the weight obtained for the aerial fraction. Significantly more magnesium was left by alfalfa roots and total –aerial and underground parts of this species in comparison with red clover from Mixture 2 (Table 6). Under pasture conditions, legumes left more magnesium in the aerial and root than under hay/pasture use.

The largest weight of magnesium remained after grasses in comparison with other components of the sward (Table 6), but there was no impact of the mixture species composition on the value of this parameter. Hay/pasture sward use promoted a larger accumulation of magnesium in the aerial post-harvest residues of grasses (Table 6).

Table 6. Accumulation of magnesium in the biomass of post –harvest residues

Tab. 6. Akumulacja magnezu w suchej masie resztek pozbiorowych w kg·ha^{-1}

Specification	Mg (content % Mg)											
	Legume			Grass			Weeds			Total (L + G + W)		
	S	R	Σ	S	R	Σ	S	R	Σ	S	R	Σ
Mixtures												
1	0,56 (0,25)	0,58 (0,17)	1,14	1,55 (0,17)	6,38 (0,14)	7,94	0,25 (0,30)	O,31 (0,20)	0,56	2,95	8,62	11,57
2	0,28 (0,26)	0,33 (0,18)	0,62	0,96 (0,17)	3,25 (0,10)	4,21	1,04 (0,28)	1,594 (0,22)	2,63	4,97	13,77	18,74
3	1,11 (0,22)	3,05 (0,12)	4,16	1,62 (0,18)	5,43 (0,17)	7,05	0,67 (0,41)	1,19 (0,23)	1,86	4,21	11,07	15,28
4	1,09 (0,26)	1,86 (0,12)	2,95	1,95 (0,19)	4,62 (0,10)	6,57	0,44 (0,35)	1,80 (0,25)	2,25	4,11	10,01	14,11
NIR	r.n. (r.n.)	2,23 (r.n.)	3,26	r.n. (r.n.)	r.n. (r.n.)	r.n.	0,745 (r.n.)	r.n. (r.n.)	r.n.	r.n.	r.n.	r.n.
Utilization												
H/P	0,46 (0,26)	0,85 (0,16)	1,31	1,99 (0,19)	4,28 (0,10)	6,27	0,544 (0,29)	1,26 (0,22)	1,81	4,74	11,77	16,51
P	1,06 (0,24)	2,062(0,14)	3,12	1,05 (0,16)	5,56 (0,16)	6,61	0,65 (0,24)	1,19 (0,24)	1,84	3,38	9,96	13,34
NIR	0,58 (r.n.)	1,04 (r.n.)	1,52	0,84 (r.n.)	r.n. (r.n.)	r.n.	r.n. (r.n.)	r.n. (r.n.)	r.n.	r.n.	r.n.	r.n.

S* - Stubble , R** - Roots, H/P – Hay/Pasture, P – Pasture, 1^{***} - see tab. 1

Source: own work / Źródło: opracowanie własne

Significantly more magnesium was uptaken by the aerial fraction of the weeds from the mixture of red clover with grasses, while the smallest accumulation of this component was recorded for the mixture of white clover and red clover with grasses (Mixture 1).

The total mass of magnesium accumulated by legume-grass sward ranged from 11.57 to 18.74 kg Mg·ha^{-1} (Table 6). Legume-grass mixtures accumulated a similar amount of magnesium regardless of species composition and sward use.

4. Conclusions

1. After being used as fodder crops, small-seed legumes with grasses are a valuable source of macronutrients for the successive plants, as they leave from 5.09 to 7,99 t·ha^{-1} of post-harvest residues in which grasses constituted the main weight (from 3,65 to 5,75 t·ha^{-1}). Grasses constituted the component resistant to adverse weather conditions during the growing season and during wintering.
2. The most post-harvest residues were recorded in the root fractions, and their particularly high mass characterized alfalfa-grass mixtures: *Medicago x varia* (50%) + *Dactylis glomerata* (20%) + *Festuca pratensis* (20%) + *Phleum pratense* (10%) (Mixture 3) i *Trifolium repens* (25%)+ *Medicago x varia* (25%) + *Lolium perenne* (15%)+*Dactylis glomerata* (15%) + *Festuca pratensis* (10%) + *Festuca rubra* (10%) (Mixture 4).
3. Under hay/pasture and pasture sward use, the weight of post-harvest residues of the tested mixtures were similar. Only the aerial and underground weight of post-harvest residues were significantly higher on the pasture than under hay/pasture sward use. In contrast, grasses left more of these residues under hay/pasture use.
4. The percentage share of nitrogen, phosphorus, potassium, calcium and magnesium was higher in the aerial post-harvest residues of legumes compared to the roots.
5. The percentage share of macronutrients in the fractions of post-harvest residues was similar regardless of the species composition and the sward use in the tested legume-grass mixtures.
6. The weight of nutrient mixtures left by legume-grass mixtures for the successive plants depended on weight of post-harvest residues, while the percentage concentration of these components did not affect the weight of the accumulated macronutrients. The biggest weight of potassium and phosphorus were accumulated by the mixtures of *Medicago x varia* (50%) + *Dactylis glomerata* (20%) + *Festuca pratensis* (20%) + *Phleum pratense* (10%) – Mixture 3 and *Trifolium repens* (25%)+ *Medicago x varia* (25%) + *Lolium perenne* (15%)+*Dactylis glomerata* (15%) + *Festuca pratensis* (10%) + *Festuca rubra* (10%) – Mixture 4. In contrast, large amounts of nitrogen, calcium and magnesium were accumulated by the most weed-infected mixture: *Trifolium pratense* (50%) + *Lolium perenne* (20%) + *Festuca pratensis* (20%) + *Phleum pratense* (10%) (Mixture 2).
7. Post-harvest residues of legumes under pasture use were richer in potassium (additional enrichment of this component with animal waste) than under hay/pasture use. In the case of other nutrients, the use of sward did not affect their concentrations in the post-harvest residues left for the subsequent plants.

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