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UTILIZATION OF NITROGEN AND OTHER MACROELEMENTS BY NON-PAPILIONACEOUS PLANTS CULTIVATED IN STUBBLE INTERCROP

ZAGOSPODAROWYWANIE AZOTU I INNYCH MAKROSKŁADNIKÓW PRZEZ ROŚLINY NIEMOTYLKOWATE UPRAWIANE W MIĘDZYPLONIE ŚCIERNISKOWYM

Abstract: Field experiments were carried out in 2002–2004 at the Research Station of the University of Technology and Life Sciences in Mochelek (17°51′E, 53°13′N), on soil of very good rye complex, in randomized split-plot design. The experimental factors were: 1) nitrogen dose: 0, 45 and 90 kg · ha^{-1}; 2) species of plant cultivated in intercrop: oilseed radish 'Adagio', common sunflower 'Wielkopolski', and tansy phacelia 'Stala'. The aim of the study was to estimate the ability to utilize nitrogen and other macroelements in the aboveground biomass and crop residue of plants cultivated in stubble intercrop. Tested non-papilionaceous plants cultivated in stubble intercrop utilized considerable amounts of nitrogen and potassium left after forecrop harvest. Radish had a significantly higher potential for accumulation of nitrogen, phosphorus, potassium and calcium than sunflower and phacelia. Tested plants accumulate nitrogen mostly in the aboveground biomass. Only 19.5 % (sunflower) to 31.7 % (radish) of this component have been accumulated in crop residue. An increase in nitrogen fertilization of oilseed radish, common sunflower, and tansy phacelia cultivated in stubble intercrop up to 90 kg · ha^{-1} significantly increased the accumulation of nitrogen and other macrocomponents in the aboveground biomass and crop residue of these plants.

Keywords: utilization of macroelements, stubble intercrop, nitrogen, oilseed radish, tansy phacelia, common sunflower

Consumption of mineral fertilizers in Poland is relatively low. In recent years, however, an upward tendency can be observed. In the economic year 2001–2002 mineral fertilizer use was only 93.2 kg · ha^{-1} NPK, and in 2005–2006 it rose to 123.3 kg · ha^{-1} NPK [1]. Statistical data indicate considerable differentiation in the amount of fertilizers applied in particular regions of our country. The least is used in Podkarpackie province (61.3 kg · ha^{-1} NPK), and the most in Kujawy-Pomerania, Opole and

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Wielkopolska provinces (182.3; 175.0 and 161.0 kg · ha^{-1} NPK, respectively). Thus, in conditions of low level of fertilizer component supply of plants, there are areas where high or very high rates of mineral fertilizers are applied. In these areas there is a risk of losses of mineral components, which are not utilized during plant growth and released into soil during mineralization of crop residue of these plants.

The mass of nitrogen leached out of soil in the autumn and winter periods depends on soil properties, the crop species, the amount of precipitation and air temperature [2, 3]. Under condition of low total rainfalls nitrogen leaching is small, whereas heavy rains in this period contribute to leaching of 50–90 kg · ha^{-1} N.

Apart from the loss of fertilizer components, which potentially could be utilized by a successive crop, certain negative environmental consequences appear [4–6]. The longer the period from harvesting of a given plant to sowing the successive plant, the higher these consequences are. The longest period when soil remains not covered with plants occurs when spring crops come in succession after the harvesting of rape or winter cereals. In these conditions, cultivation of intercrops, which take up fertilizer components from soil and accumulate them in their biomass, seems necessary.

The aim of this study was to estimate the ability to utilize nitrogen and other macroelements in the aboveground biomass and crop residue of oilseed radish, tansy phacelia and common sunflower cultivated in stubble intercrop.

Material and methods

Field experiments were carried out in 2002–2004 at the Research Station of the University of Technology and Life Sciences in Mochelek (17°51′E, 53°13′N), in Kujawy-Pomerania province, on lessive soil formed of heavy loamy sand of a very good rye complex. The soil is characterized by a very high content of available phosphorus (95.5 mg P in 1 kg) and potassium (330.0 mg K in 1 kg) and a moderate content of magnesium (59.8 mg Mg in 1 kg). The total content of nitrogen was 625 N in 1 kg of soil.

The experimental factors were as follows:

1) nitrogen fertilization rate: 0, 45 and 90 kg · ha^{-1};

2) species of the plant cultivated in stubble intercrop: oilseed radish 'Adagio', common sunflower 'Wielkopolski', and tansy phacelia 'Stala'.

Field experiments were conducted in randomized split-plot design in four replications. Seeds were sown after the harvest of spring barley within the period of 5–9 August. Plants were harvested after 71–77 days from sowing, from plots with an area of 27 m^2.

After the harvest of forecrop (spring barley), phosphorus (26 kg · ha^{-1} P) and potassium (66 kg · ha^{-1} K) fertilizers were applied. After that, the soil was disked, and next ploughed at a depth of about 12 cm. Nitrogen fertilization was applied in the form of ammonium nitrate, before seedbed preparing by means of a cultivation unit.

Seeds of plants cultivated in stubble intercrop were sown after the seedbed preparation by means of a plot drill, with a row spacing of 12.5 cm and a depth of

2–3 cm. The sowing rate was respectively: radish – 12, sunflower – 30, phacelia – 10 $kg \cdot ha^{-1}$.

Plant harvest was conducted at the beginning of flowering stage of radish and phacelia and at budding stage of sunflower. After plant cutting, 1 kg of the aboveground biomass of intercrops was taken from each plot in order to estimate the content of macroelements. Crop residue was collected from soil monoliths 25 × 25 × 25 cm, which were screened and rinsed with water.

Chemical analyses of the aboveground biomass and crop residue of intercrops were performed after the mineralization of shredded plant material (wet combustion with perhydrol and sulphuric acid) applying the following methods: total N – the Kjeldahl method [7] , P – the vanadium-molybdenum method [8], K the flame photometry method [9], Ca – the flame photometry method [10], Mg – colorimetry with titan yellow [7].

Results concerning yielding, the content and accumulation of total nitrogen were presented in the study by Wilczewski et al [11].

The significance of differences was determined with Tukey's confidence half--intervals at the significance level $\alpha = 0.05$.

Results

Very favorable weather conditions during the study period were observed (Table 1). High total rainfall in whole intercrops growing period in 2002 and 2004 effected in high biomass yield [11]. In 2003 definitely low rainfall occured over that period. Neverthe-less the growth and development of the crops was correct and high yields were obtained. This resulted from a high amount of rainfall in July. Moreover in the year 2003 very favorable temperature conditions occured in September and a very intensive plants growth and development was observed in that month.

Table 1

Weather conditions at the research site

Months	Years			Average for 1949–2005
	2002	2003	2004	
Total monthly rainfall [mm]				
July	77.9	106.2	53.5	71.3
August	58.0	17.7	138.7	49.3
September	70.5	16.7	40.0	41.4
October	111.8	34.0	63.8	32.5
Total VII–X	318.2	174.4	296	194.5
Average air temperature [^{o}C]				
July	18.9	19.2	16.4	17.8
August	19.9	18.4	17.9	17.4
September	12.9	13.6	12.7	13.2
October	6.2	4.7	8.8	8.3
Average VII–X	14.5	14.0	14.0	14.2

The tested plants were characterized by varied potential for element accumulation in the biomass. The most nitrogen in aboveground parts and crop residue was accumulated by radish, while significantly less by sunflower and phacelia (Table 2).

Table 2

Nitrogen accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	50.8	59.0	59.2	56.4
45	67.7	79.5	82.2	76.5
90	86.5	98.2	118.1	100.9
Average	68.3	78.9	86.5	77.9
LSD for: I –13.03; II – 4.41; II × I –7.64; I × II – 13.31				
Crop residue				
0	14.2	14.0	31.5	19.9
45	16.9	19.4	41.9	26.1
90	26.7	23.9	47.0	32.5
Average	19.3	19.1	40.1	26.2
LSD* for: I – 4.98; II – 4.55; II × I – ns; I × II – ns				

* – LSD – lowest significant difference; ns – non-significant.

With the increase in nitrogen fertilization, also the accumulation of this element in plants rose significantly, particularly in their aboveground biomass, where both introducing a rate of 45 kg · ha^{-1} N and increasing fertilization to 90 kg · ha^{-1} resulted in a significant rise in accumulation in all the tested plants. Accumulation of nitrogen in crop residue was to a lesser degree dependent on the nitrogen rate. Significant increase in the weight of nitrogen accumulated in crop residue of phacelia and sunflower was obtained only after introducing a rate of 90 kg · ha^{-1}. Accumulation of nitrogen in crop residue of radish increased significantly after introducing a nitrogen fertilization rate of 45 kg · ha^{-1}, while the increase to 90 kg · ha^{-1} did not exert a significant effect on accumulation of this element.

Oilseed radish accumulated significantly more phosphorus in the aboveground biomass and crop residue than the other plants (Table 3). Particularly big differences between the species were found in the amount of phosphorus accumulated in crop residue, in treatments fertilized with the highest nitrogen rate, in which radish accumulated 2–3 times more of this component than the other plants.

A rate of nitrogen applied before the sowing of intercrops influenced significantly the amount of phosphorus accumulated in their biomass. The extent of this effect was higher in relation to the aboveground parts, in which every increase in nitrogen rate caused a significant increase in phosphorus accumulation. In the biomass of crop residue, only in plants fertilized with a rate of 90 kg · ha^{-1} significantly higher accumulation of this element was found than in plants not fertilized with nitrogen.

Table 3

Phosphorus accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	11.0	12.3	10.7	11.3
45	15.4	15.9	16.3	15.9
90	17.0	16.8	22.0	18.6
Average	14.5	15.0	16.3	15.3
LSD for: I – 2.48; II – 1.14; II × I – 1.97; I × II – 2.76				
Crop residue				
0	4.8	3.8	11.3	6.6
45	6.0	5.4	13.3	8.2
90	7.8	5.5	14.5	9.3
Average	6.2	4.9	13.0	8.0
LSD for: I – 1.75; II – 1.62; II × I – ns; I × II – ns				

Potassium, like nitrogen and phosphorus, was accumulated mostly in the aboveground parts, where from 63.3 % (radish) to 77.3 % (sunflower) of the total weight of this component was located (Table 4).

Table 4

Potassium accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	99.8	128.3	116.2	114.8
45	141.5	154.8	126.5	140.9
90	139.8	171.5	168.7	160.0
Average	127.0	151.5	137.1	138.6
LSD for: I – 35.98; II – 11.21; II × I – 19.42; I × II – 36.13				
Crop residue				
0	30.0	31.9	67.7	43.2
45	38.3	49.4	86.0	57.9
90	52.1	51.7	85.0	63.0
Average	40.1	44.4	79.6	54.7
LSD for: I –11.10; II – 9.12; II × I – ns; I × II – ns				

Sunflower accumulated significantly more potassium than the other plants in the aboveground biomass. Oilseed radish accumulated significantly more this element in crop residue than phacelia and sunflower. Potassium accumulation in the aboveground biomass of intercrops increased with nitrogen fertilization intensification. Statistical confirmation of this increase was obtained for phacelia and sunflower only after increasing a nitrogen rate from 0 to 45 kg · ha^{-1}, and for radish, only after replacing a dose of 45 with a rate of 90 kg · ha^{-1} N.

Oilseed radish accumulated significantly more Ca than phacelia in crop residue (Table 5). Sunflower accumulated significantly less this component than phacelia. An increase in calcium accumulation in the aboveground biomass of intercrops was recorded with an increase of N rate. Statistically proved differentiation of this character values was found only after increasing a nitrogen rate from 0 to 90 kg · ha^{-1} N in the biomass of phacelia and sunflower. Radish did not respond to this factor significantly.

Table 5

Calcium accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	34.7	37.4	35.9	36.0
45	37.6	39.8	36.7	38.0
90	45.0	47.9	43.4	45.4
Average	39.1	41.7	38.7	39.8
LSD for: I – 9.44; II – 2.36; II × I – ns; I × II – 9.14				
Crop residue				
0	12.5	7.6	17.1	12.4
45	14.6	11.1	19.3	15.0
90	19.8	10.3	20.9	17.0
Average	15.6	9.7	19.1	14.8
LSD for: I – ns; II – 2.25; II × I – ns; I × II – ns				

Tested plants cultivated in stubble intercrop accumulated slight amounts of magnesium in their biomass (Table 6). Radish accumulated the most of this element in crop residue, while sunflower, in the aboveground parts. Phacelia accumulated significantly less magnesium than sunflower and radish, both in the aboveground biomass and in crop residue. The rate of nitrogen had a significant effect on Mg accumulated in the biomass of intercrops. Particularly strong influence was found in the aboveground biomass of intercrops, where both introducing a rate of 45 kg · ha^{-1} N and its increasing to 90 kg · ha^{-1} resulted in a statistically proved increase in the accumulation of this element. For the crop residue, a significantly higher accumulation of Mg occurred in treatments fertilized with nitrogen than in unfertilized intercrops. However, there were no differences between plants fertilized with 45 kg · ha^{-1} N and 90 kg · ha^{-1} N.

Table 6

Magnesium accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	7.0	8.7	6.4	7.4
45	8.1	10.7	8.5	9.1
90	8.7	12.5	11.0	10.7
Average	7.9	10.6	8.6	9.1
LSD for: I –1.56; II – 0.52; II × I – 0.90; I × II – 1.59				
Crop residue				
0	2.1	2.2	5.2	3.2
45	2.2	3.3	6.4	4.0
90	3.0	3.9	5.8	4.2
Average	2.4	3.1	5.8	3.8
LSD for: I – 0.73; II – 0.47; II × I – 0.81; I × II – 0.93				

A positive correlation between the nitrogen rate applied before sowing intercrops and the accumulation of macroelements in their biomass was observed in the study (Table 7). Nitrogen accumulation in the biomass increased to the largest extent. Correlation coefficients concerning nitrogen accumulation both in crop residue and in the aboveground biomass were significant for all the tested plants. A positive correlation between the nitrogen rate and phosphorus accumulation in the aboveground parts and all the biomass of intercrops, particularly in phacelia and radish, was also significant. Calcium was the element whose accumulation in the biomass of intercrops was least dependent on the nitrogen dose.

Table 7

Correlation coefficients between nitrogen rate and macroelement weight accumulated in intercrop biomass

Intercrop	N	P	K	Ca	Mg
	Aboveground biomass				
Tansy phacelia	0.64*	0.57*	0.26	0.31	0.27
Common sunflower	0.70*	0.41*	0.23	0.22	0.47*
Oilseed radish	0.66*	0.66*	0.49*	0.25	0.57*
Crop residue					
Tansy phacelia	0.50*	0.42*	055*	0.39*	0.43*
Common sunflower	0.43*	0.35	0.46*	0.25	0.53*
Oilseed radish	0.58*	0.38	0.32	0.20	0.15
Total accumulation					
Tansy phacelia	0.71*	0.63*	0.41*	0.41*	0.37
Common sunflower	0.70*	0.43*	0.33	0.24	0.55*
Oilseed radish	0.73*	0.75*	0.51*	0.31	0.51*

* Significant coefficient for $p < 0.05$; number of observations $n = 27$.

Discussion

Tansy phacelia, common sunflower and oilseed radish cultivated in stubble intercrop accumulated in the biomass considerable amounts of nitrogen and potassium, moderate amounts of calcium and small amounts of phosphorus and magnesium. The ability of plants cultivated in stubble intercrop to take up nitrogen left in soil after the harvest of forecrop plants is of great value. In the present study, this ability was shown in treatments without nitrogen fertilization, where the tested plants showed a remarkable potential. Oilseed radish, which as a plant of a high nitrogen content in the biomass [12, 13] is characterized by a high nitrogen requirement, proved to be of particular value. This plant also utilized nitrogen applied with fertilizers before sowing the intercrops to a remarkably higher degree. The total weight of nitrogen accumulated in the biomass of radish fertilized with a rate of 90 kg $\cdot$ ha^{-1} N was by 74.4 kg higher than that of unfertilized radish.

The investigations carried out have confirmed the large ability of macroelement utilization by non-papilionaceous plants cultivated in stubble intercrops that are already known from the literature [13–15]. A higher macroelement accumulation in the biomass of oilseed radish than in common sunflower and tansy phacelia, mostly resulted from a higher mass of macroelements accumulated in crop residue, indicates the usefulness of this plant for utilization of fertilizer components which were not used by the forecrop. It also confirms a high forecrop value of radish for cereals, which as successive crops can produce a higher yield than after other non-papilionaceous plants cultivated in stubble intercrop [5] or the yield with a higher total protein content [16].

The basic weight of macrocomponents, accounting for from 65.7 % (phosphorus) to 74.8 % (nitrogen) of total accumulation, was located in the aboveground biomass of intercrops, and only from 25.2 to 34.3 % in crop residue. This resulted both from a higher yield of plant aboveground biomass than that of crop residue and from a higher concentration of the tested elements in the biomass, irrespective of the level of nitrogen fertilization [11, 17, 18]. The results confirm the conclusions of Batalin [19], who claimed that a sufficient water supply of plants favours the inflow of elements to aboveground parts and a decrease in crop residue proportion in yield, and consequently, results in a smaller accumulation of macroelements in crop residue.

Due to a significant increase in the biomass yield of plants cultivated in intercrops as a result of nitrogen fertilization [11], a positive effect of this factor on macroelement accumulation, expressed by positive correlation coefficients, is evident. However, it should be emphasized that the extent of this relation was different for particular elements and plant species cultivated in stubble intercrop. The accumulation of nitrogen, supplied in fertilizers, phosphorus and potassium, whose abundance in soil before establishing the experiment was very high, underwent the highest increase. Moreover, the weight of elements accumulated in the biomass of oilseed radish was more dependent on the nitrogen rate than those of the other plants. Sunflower and phacelia response to an increase in nitrogen rate was smaller, which resulted from a weaker effect of this factor on the dry matter yield of these plants [11].

Conclusions

1. Tested non-papilionaceous plants cultivated in stubble intercrop can utilize considerable amounts of nitrogen and potassium remaining after harvest of forecrop and applied preplant in the form of mineral fertilizers. Oilseed radish had a significantly higher potential of accumulating nitrogen, phosphorus, potassium and calcium than sunflower and phacelia.

2. Tested plants have accumulated nitrogen mainly in the aboveground biomass. Only 19.5 % (sunflower) to 31.7 % (radish) of this component have been accumulated in crop residue.

3. Higher rates of nitrogen fertilization in oilseed radish, common sunflower and tansy phacelia cultivated in stubble intercrop up to 90 kg · ha^{-1} have significantly increased the accumulation of nitrogen and other macroelements in the aboveground biomass and crop residue of these plants.

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ZAGOSPODAROWYWANIE AZOTU I INNYCH MAKROSKŁADNIKÓW PRZEZ ROŚLINY NIEMOTYLKOWATE UPRAWIANE W MIĘDZYPLONIE ŚCIERNISKOWYM

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Abstrakt: Badania polowe wykonano w latach 2002–2004 w Stacji Badawczej Uniwersytetu Technologiczno-Przyrodniczego w Mochełku (17°51′E, 53°13′N), na glebie kompleksu żytniego bardzo dobrego, w układzie losowanych podbloków. Czynnikami doświadczenia były: 1) dawka azotu: 0, 45 i 90 kg · ha^{-1};

2) gatunek rośliny uprawianej w międzyplonie: rzodkiew oleista 'Adagio', słonecznik zwyczajny 'Wielkopolski', facelia błękitna 'Stala'. Celem badań było określenie możliwości zagospodarowywania azotu i innych makroskładników w biomasie nadziemnej i resztkach pozbiorowych roślin uprawianych w międzyplonie ścierniskowym. Badane rośliny niemotylkowate, uprawiane w międzyplonie ścierniskowym zagospodarowywały znaczne ilości azotu i potasu pozostających po zbiorze przedplonu. Rzodkiew oleista ma istotnie wyższy potencjał akumulacji azotu, fosforu, potasu i wapnia niż słonecznik i facelia. Badane rośliny akumulowały azot głównie w biomasie nadziemnej. Jedynie 19,5 % (słonecznik) do 31,7 % (rzodkiew) tego składnika zostało zakumulowane w resztkach pozbiorowych. Zwiększanie nawożenia azotem rzodkwi oleistej, słonecznika zwyczajnego i facelii błękitnej, uprawianych w międzyplonie ścierniskowym, w zakresie do 90 kg · ha^{-1} znacznie zwiększało akumulację azotu i innych makroskładników w biomasie nadziemnej i resztkach pozbiorowych tych roślin.

Słowa kluczowe: zagospodarowywanie makroskładników, międzyplon ścierniskowy, azot, rzodkiew oleista, facelia błękitna, słonecznik zwyczajny