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UTILIZATION OF NITROGEN FROM DIFFERENT SOURCES BY SPRING TRITICALE (*Triticosecale* Wittm. ex. A. Camus) GROWN IN THE STAND AFTER YELLOW LUPINE (*Lupinus luteus* L.)*

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Abstract. This study estimated the amount of nitrogen taken up by spring triticale from different sources depending on varied nitrogen fertilization and the development phase when the previous crop – yellow lupine was harvested. Lupine was cultivated in three fertilization variants: without nitrogen fertilization and after the application of rates 30 kg·ha^{-1} N and 150 kg·ha^{-1} N. Lupine harvest was performed in full flowering and full maturity phases. At the first harvest time, the whole biomass was introduced into soil. At the second time, seeds were collected and the other parts of lupine were introduced into soil. Spring triticale as a successive crop was cultivated without additional fertilization with nitrogen and harvested in the full maturity phase. Ammonium sulfite enriched in nitrogen ^{15}N isotope was used in the study as well as the method of isotopic dilution. The highest yield of grain and the whole biomass as well as the total amount of nitrogen taken up by triticale were obtained after the application under lupine of 150 kg·ha^{-1} N. Yields and nitrogen uptake by triticale were higher when the previous crop was harvested in flowering than in full maturity. Nitrogen content in triticale grain and biomass was not dependent on the harvest phase and nitrogen fertilization of the previous crop. Proportion of nitrogen taken up by triticale from soil resources, from parts of lupine introduced into soil and from mineral fertilizer applied under lupine amounted to 71,0; 17,2 i 11,8%, respectively, of the total amount of this macroelement accumulated in the biomass. Triticale took up on average 20.9% of biologically reduced nitrogen introduced into soil with the lupine biomass.

Key words: biologically reduced N_2, isotope ^{15}N, nitrogen, spring triticale, utilization of nitrogen, yellow lupine

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INTRODUCTION

In recent years in Poland a slow increase in legume cultivation area has been recorded. At present their cultivation for seeds, green forage and in mixtures with cereals accounts for 1.8% in the structure of cropland in our country [GUS 2011]. Bearing in mind the need for promoting the production of food products and animal feeds of high quality, natural, and genetically unmodified, as well as decreasing dependence of national animal production on imported feed components with high protein content, further increase in the acreage occupied by legumes should be of great importance [Prusiński and Kotecki 2006, Buraczewska *et al*. 2010, Jerzak *et al*. 2012]. Also non-production qualities of this group of plants should be appreciated, which manifest themselves, among other things, in increasing soil abundance in nutrients – mostly in nitrogen [Latif *et al*. 1992, Haynes *et al*. 1993, Buraczyńska and Ceglarek 2011a]. Increasing the amount of this element in soil occurs as a result of the process of biological reduction of atmospheric N_2 by microorganisms living in symbiosis with legumes. Besides the estimation of the amount of nitrogen fixed in the process of biological reduction, a vital issue is to estimate the availability of nitrogen from this source for successive crops cultivated in the stand left by legumes.

The research hypothesis assumed that the main source of nitrogen for spring triticale will be the nitrogen introduced into soil with the biomass of yellow lupine, including N_2 fixed in the process of biological reduction. Moreover it was assumed that the time of harvest and fertilization of yellow lupine with nitrogen will have an effect on the amount of this macroelement taken up by the successive crop from different sources.

The aim of this study was to estimate the utilization of nitrogen (including biologically reduced N_2) by spring triticale (*Triticosecale* Wittm. ex. A. Camus) grown in the stand after yellow lupine (*Lupinus luteus* L.).

MATERIAL AND METHODS

The experiment was established in the land of the University of Natural Sciences and Humanities in Siedlce (52°10' N; 22°17' E). Spring triticale ('Milewo') was cultivated as a successive crop in the following year in the stand after yellow lupine ('Parys') that was grown in 2009. The previous crop was cultivated in 3 fertilization combinations (according to the presented scheme – Table 1):

A) without nitrogen fertilization,
B) nitrogen at a rate of 30 $kg \cdot ha^{-1}$ N (i.e. 3 $g \cdot m^{-2}$ N),
C) nitrogen at a rate of 150 $kg \cdot ha^{-1}$ N (i.e. 15 $g \cdot m^{-2}$ N).

The second experimental factor was the development phase when the harvest of yellow lupine was performed:

a) full flowering, more than 50% of flowering plants (65 BBCH),
b) full maturity, more than 80% of mature pods (90 BBCH).

The experiment was conducted in three replications in the soil with the granulometric composition of heavy loamy sand, classified as the very good rye complex of agricultural suitability, of soil quality class IVa, with a slightly acid reaction. The total content of carbon and nitrogen determined on the CHN autoanalyser by Perkin-Elmer in a soil sample collected before the establishment of the experiment from the layer 0-30 cm amounted to 23.2 and 1.78 $g \cdot kg^{-1}$, respectively.

Table 1. Scheme of experiment
Tabela 1. Schemat doświadczenia

1st year, 2009 – I rok, 2009			2nd year, 2010 – II rok, 2010	
cultivated plant uprawiana roślina	fertilization nawożenie	harvest phase faza zbioru	cultivated plant uprawiana roślina	fertilization nawożenie
Yellow lupine Łubin żółty	0 kg·ha^{-1} N 100 kg·ha^{-1} K	full flowering pełnia kwitnienia	in autumn 2009 year: winter rye, in spring 2010: liquidation this plantation and sowing spring triticale jesienią 2009 r.: żyto ozime, wiosną 2010 r.: likwidacja plantacji i wysiew pszenżyta jarego	100 kg·ha^{-1} K
		full maturity pełna dojrzałość		
	30 kg·ha^{-1} N 100 kg·ha^{-1} K	full flowering pełnia kwitnienia		
		full maturity pełna dojrzałość		
	150 kg·ha^{-1} N 100 kg·ha^{-1} K	full flowering pełnia kwitnienia		
		full maturity pełna dojrzałość		

Plots with an area of 1 m^2 were randomly marked out in the stand of cultivated plants. Nitrogen in mineral compounds was introduced into the soil before sowing yellow lupine in the form of ammonium sulfite with 10% enrichment in ^{15}N isotope. Phosphorus and potassium rates were determined based on determination of the amounts of available forms of these elements with the Egner-Riehm method in a soil sample collected before the establishment of the experiment (as above). Potassium was applied presowing at a rate corresponding to introducing into soil 100 kg·ha^{-1} K (i.e. 10 g·m^{-2} K) in the form of potash salt. Due to a very high phosphorus content in assimilable forms for plants, fertilization with this nutrient was not used. Harvest of whole plants of yellow lupine (together with roots from the layer 0-30 cm) was performed in the flowering phase and in the full maturity phase. After weighing and collecting representative samples, the whole biomass of lupine harvested at flowering and the roots, straw and stripped pods collected in the full maturity phase were introduced into soil where this crop was cultivated, and the soil was dug over using a spade. In the period from 11th to 20th September, soil samples were collected from the layer 0-30cm in which the total nitrogen content was determined on the CHN autoanalyzer by Perkin-Elmer. Then potassium fertilization was applied in the amount corresponding to 100 kg·ha^{-1} K and winter rye was sown in an amount of 170 kg·ha^{-1}. Due to unfavorable weather conditions in the winter period, only few live plants were left on the plantation in the spring. The rye plantation was liquidated and in this place spring triticale was sown in an amount of 220 kg·ha^{-1} (plant density was 500 plants per 1 m^2). At the beginning of tillering of this plant Chwastox Turbo 340 SL was applied once in a dose of 2 dm^3·ha^{-1}.

Spring triticale (whole plants) was harvested after reaching full maturity – from 1st to 10th August. Roots were dug out to a depth of 25 cm from the whole plot and then separated from the soil residues with a stream of water. Biomass obtained separately from each plot was divided into roots, straw, chaff and grain. In each obtained sample there were determined as follows:

- dry matter content – with drying weighing method,
- total nitrogen content with the modified Kjeldahl method [Kalembasa *et al*. 1989],
- enrichment in ^{15}N isotope on the emission spectrometer NOI-6e.

Moreover, from each plot soil samples were collected from the layer 0-30 cm in which the total nitrogen content was determined using the CHN autoanalyser by Perkin--Elmer.

Based on the obtained results, nitrogen content in spring triticale derived from different sources and the utilization of biologically reduced nitrogen from yellow lupine by this crop were calculated according to equations given by Kalembasa [1995]:

1) the percentage of nitrogen in triticale derived from lupine:

$$PNDF = a/b \cdot 100$$

PNDF – percentage of nitrogen in triticale derived from lupine,
a – at% ^{15}N in triticale,
b – at% ^{15}N in lupine;

2) nitrogen recovered by triticale from lupine:

$$RF = (PNDF \cdot TN)/AN$$

RF – percentage of nitrogen recovered by triticale from lupine,
PNDF – percentage of nitrogen derived from lupine in triticale,
TN – total amount of nitrogen taken up by triticale,
AN – amount of nitrogen introduced into soil with lupine;

3) the amount of nitrogen derived from lupine in triticale:

$$ANF = RF \cdot TN$$

ANF – total amount of nitrogen derived from lupine,
RF – percentage of nitrogen recovery by triticale from lupine,
TN – total amount of nitrogen taken up by triticale;

4) the proportion of nitrogen taken up by triticale from the fertilizer:

$$FN = (b - a)/(b - c)$$

FN – fraction of nitrogen derived from fertilizers,
a – at% ^{15}N in triticale cultivated after lupine,
b – at% ^{15}N in lupine,
c – at% ^{15}N contained in applied fertilizer;

5) the amount of nitrogen taken up by triticale from fertilizers:

$$NF = FN \cdot NT$$

NF – total amount of nitrogen taken up by triticale from fertilizers,
FN – fraction of nitrogen taken up from fertilizers,
NT – total amount of nitrogen uptake;

6) the amount of nitrogen taken up by triticale into soil:

$$NS = TN - NF - AFN$$

NS – total amount of nitrogen taken up by triticale from soil,
TN – total nitrogen uptake by triticale,
NF – total amount of nitrogen taken up by triticale from fertilizers,
ANF – total amount of nitrogen derived from lupine;

7) the amount of nitrogen derived from biological reduction in triticale:

$$BNF = \%Ndfa_R \cdot ANF$$

BNF – amount of nitrogen derived from biological reduction,
$\%Ndfa_R$ – percentage of nitrogen derived from air present in lupine [Kalembasa *et al*. 2014],
ANF – total amount of nitrogen derived from lupine.

The results of the analyses were analyzed statistically using the analysis of variance. The significance of effect of the studied factors on values of individual traits were assessed based on the Fisher-Snedecor F test, and $LSD_{0.05}$ values for detailed comparison of the means were calculated using Tukey`s test. Statistical calculations were made using Statistica 10 PL package (StatSoft, Tulsa, USA).

Total precipitation amounts in particular months and mean monthly air temperatures during the cultivation of winter rye and spring triticale were presented in Table 2. It shows that precipitation was improperly distributed during the triticale growth period in relation to the needs of cereals [Dzieżyc *et al*. 1987]. In April, June and July the amount of precipitation was lower and in May it considerably exceeded the rainfall needs of cereals.

Table 2. Rainfall and air temperatures during the test crop (data from Hydro-Meteorological Station in Siedlce, given by IMiGW PIB in Warsaw)
Tabela 2. Opady i temperatura powietrza podczas uprawy roślin (dane ze Stacji Hydrologiczno-Meteorologicznej w Siedlcach, podane przez IMiGW PIB w Warszawie)

Month – Miesiąc	Monthly rainfall, mm Opady miesięczne, mm		Averages monthly temperatures, °C Średnia miesięczna temperatura, ºC	
	study period badany okres	multiyears (1981-2008/2009) średnia z wielolecia	study period badany okres	multiyears (1981-2008/2009) średnia z wielolecia
		2009		
September – wrzesień	13.4	52.7	14.2	12.9
October – październik	97.4	29.3	6.3	8.2
November – listopad	44.0	34.3	4.9	2.5
December – grudzień	46.7	32.8	-1.9	-1.1
		2010		
January – styczeń	37.3	26.6	-9.3	-2.3
February – luty	32.7	22.3	-2.8	-1.7
March – marzec	17.8	30.4	3.2	2.0
April – kwiecień	24.3	32.3	8.9	8.0
May – maj	111.3	55.1	13.7	13.6
June – czerwiec	49.2	71.6	17.3	16.2
July – lipiec	48.3	66.1	21.1	18.3
August – sierpień	161.7	63.8	19.5	17.7

RESULTS AND DISCUSSION

The yields of individual parts and the whole biomass of spring triticale were higher when it was grown after yellow lupine harvested in the flowering phase than in the

phase of full maturity (Table 3). The total biomass of triticale cultivated after lupine harvested in the first time was by 14.4% higher than in the second time. The grain yield of triticale cultivated after lupine harvested in the flowering phase was by 10.3% higher when lupine was harvested in the full maturity. The biomass of individual parts and the total yield of spring triticale were the highest when nitrogen was applied in lupine cultivation at a rate of 150 kg·ha^{-1}. The total amount of biomass and grain yield in this treatment were by 15.8 and 12.4% higher, respectively, than in the control treatment. The total biomass of triticale cultivated after lupine fertilized with 150 kg·ha^{-1} N was by 10.8% higher than after the application of 30 kg·ha^{-1} N, whereas the grain yield was similar after the application of 30 and 150 kg·ha^{-1} N. Yields of individual parts and the whole biomass of triticale were similar in the control treatment and after the application under lupine of 30 kg·ha^{-1} N.

Table 3. The biomass yield of spring triticale, D.M. g·m^{-2}
Tabela 3. Plon biomasy pszenżyta jarego, g·m^{-2} s.m.

Harvest phase of yellow lupine Faza zbioru łubinu żółtego	Nitrogen rate in lupine cultivation Dawka azotu w uprawie łubinu kg·ha^{-1}	Part of spring triticale – Część pszenżyta jarego				Total biomass Biomasa ogółem
		roots korzenie	straw słoma	chaff plewy	grain ziarno	
Full flowering Pełnia kwitnienia	0	24.2	342.3	92.7	305.3	764.5
	30	22.3	318.4	91.4	305.7	737.8
	150	28.5	401.1	101.1	352.9	883.6
	mean – średnia	25.0	353.9	95.1	321.3	795.3
Full maturity Pełna dojrzałość	0	18.1	262.5	78.3	272.3	631.2
	30	19.6	303.2	93.3	305.0	721.1
	150	19.2	324.4	92.9	296.4	732.9
	mean – średnia	19.0	296.7	88.2	291.2	695.1
Mean for N doses Średnia dla dawek N	0	21.2	302.4	85.5	288.8	697.9
	30	21.0	310.8	92.4	305.3	729.5
	150	23.9	362.7	97.0	324.7	808.3
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:	lupine harvest phase fazy zbioru łubinu	1.7	19.8	5.4	22.2	45.6
	nitrogen rate dawki azotu	2.5	29.8	8.1	33.3	68.4

The mean nitrogen content in the whole biomass of spring triticale was not significantly dependent on the harvest phase and nitrogen fertilization of the previous crop – yellow lupine (Table 4). A higher content of nitrogen was observed in roots and straw of triticale cultivated after lupine harvested in the full maturity phase than when it was harvested in the flowering phase. Nitrogen content in grain and chaff of triticale was not significantly differentiated depending on the harvest phase of lupine. Nitrogen content in the chaff of triticale cultivated after lupine fertilized with 150 kg·ha^{-1} N was higher than when lupine was not fertilized with this element or at the applied rate of 30 kg·ha^{-1} N. In the other parts of triticale (roots, straw and grain) the content of nitrogen was not significantly dependent on the rate of this element applied under lupine.

Table 4. Nitrogen content in spring triticale biomass, g·kg^{-1} N
Tabela 4. Zawartość azotu w biomasie pszenżyta jarego, g·kg^{-1} N

Harvest phase of yellow lupine Faza zbioru łubinu żółtego	Nitrogen rate in lupine cultivation Dawka azotu w uprawie łubinu kg·ha^{-1}	Part of spring triticale – Część pszenżyta jarego				Mean Średnia
		roots korzenie	straw słoma	chaff plewy	grain ziarno	
Full flowering Pełnia kwitnienia	0	7.58	5.57	9.15	21.45	12.41
	30	7.27	5.62	9.00	19.16	11.70
	150	6.96	5.57	9.07	20.03	11.79
	mean – średnia	7.27	5.59	9.07	20.21	11.96
Full maturity Pełna dojrzałość	0	7.75	6.47	8.60	20.62	12.87
	30	8.04	6.94	8.65	20.57	12.96
	150	7.77	6.23	10.90	20.44	12.61
	mean – średnia	7.85	6.55	9.38	20.54	12.81
Mean for N rates Średnia dla dawek N	0	7.67	6.02	8.88	21.04	12.64
	30	7.66	6.28	8.83	19.87	12.33
	150	7.37	5.90	9.99	20.24	12.20
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:	lupine harvest phase fazy zbioru łubinu	0.47	0.38	ns – ni	ns – ni	ns – ni
	nitrogen rate dawki azotu	ns – ni	ns – ni	0.84	ns – ni	ns – ni

ns – ni – non-significant differences – różnice nieistotne

Enrichment in ^{15}N isotope of all parts of spring triticale was higher when yellow lupine was harvested in the flowering phase than in the full maturity phase (Table 5). Enrichment in ^{15}N isotope of individual parts of triticale cultivated after lupine fertilized by 30 kg·ha^{-1} N was lower than after the application of 150 kg·ha^{-1} N.

Table 5. ^{15}N isotope enrichment in spring triticale biomass, % ^{15}N
Tabela 5. Wzbogacenie biomasy pszenżyta jarego w izotop ^{15}N, % ^{15}N

Harvest phase of yellow lupine Faza zbioru łubinu żółtego	Nitrogen rate in lupine cultivation Dawka azotu w uprawie łubinu kg·ha^{-1}	Part of spring triticale – Część pszenżyta jarego			
		roots korzenie	straw słoma	chaff plewy	grain ziarno
Full flowering Pełnia kwitnienia	30	0.128	0.091	0.052	0.087
	150	0.414	0.349	0.325	0.409
	mean – średnia	0.271	0.220	0.189	0.248
Full maturity Pełna dojrzałość	30	0.053	0.059	0.046	0.095
	150	0.300	0.287	0.243	0.305
	mean – średnia	0.177	0.173	0.144	0.200
Mean – Średnia		0.224	0.196	0.167	0.224

The total amount of nitrogen taken up by spring triticale was higher when yellow lupine was harvested in the flowering phase than in the full maturity phase (Table 6). The biomass of nitrogen accumulated in roots and grain of triticale cultivated after lupine harvested in the first time was higher when lupine was harvested in the second

time. The amount of nitrogen accumulated in straw and chaff of triticale was not significantly dependent on the harvest time of the previous crop. The highest amount of nitrogen taken up by the aboveground parts of triticale and by the whole plant was obtained after the application under lupine of 150 kg·ha^{-1} N. The amount of nitrogen accumulated in triticale roots was not significantly dependent on the rate of this element. The total amount of nitrogen taken up by triticale cultivated after lupine not fertilized with nitrogen and fertilized with a rate of 30 kg·ha^{-1} did not differ statistically.

Table 6. The uptake of nitrogen by spring triticale from different sources, g·m^{-2} N
Tabela 6. Ilość azotu pobranego przez pszenżyto jare z różnych źródeł, g·m^{-2} N

Harvest phase of yellow lupine Faza zbioru łubinu żółtego	N rate in lupine cultivation Dawka N w uprawie łubinu kg·ha^{-1}	Nitrogen source Źródło azotu	Part of spring triticale Część pszenżyta jarego				Total Ogółem
			roots korzenie	straw słoma	chaff plewy	grain ziarno	
Full flowering Pełnia kwitnienia	0	–	0.183	1.907	0.848	6.549	9.487
	30	lupine – łubin	0.035	0.276	0.073	0.864	1.248
		fertilizer – nawóz	0.007	0.115	0.057	0.355	0.534
		soil – gleba	0.120	1.398	0.693	4.638	6.849
		total – suma	0.162	1.789	0.823	5.857	8.631
	150	lupine – łubin	0.044	0.419	0.160	1.554	2.177
		fertilizer – nawóz	0.034	0.549	0.217	1.602	2.402
		soil – gleba	0.120	1.266	0.540	3.913	5.839
		total – suma	0.198	2.234	0.917	7.069	10.418
Full maturity Pełna dojrzałość	0	–	0.140	1.698	0.673	5.615	8.126
	30	lupine – łubin	0.015	0.229	0.068	1.098	1.410
		fertilizer – nawóz	0.009	0.131	0.054	0.210	0.404
		soil – gleba	0.134	1.744	0.685	4.966	7.529
		total – suma	0.158	2.104	0.807	6.274	9.343
	150	lupine – łubin	0.027	0.347	0.147	1.106	1.627
		fertilizer – nawóz	0.024	0.361	0.176	0.551	1.112
		soil – gleba	0.098	1.313	0.690	4.401	6.502
		total – suma	0.149	2.021	1.013	6.058	9.241
Mean for sources of N Średnia dla źródeł N		lupine – łubin	0.030	0.318	0.112	1.156	1.616
		fertilizer – nawóz	0.019	0.289	0.126	0.680	1.114
		soil – gleba	0.118	1.430	0.652	4.480	6.680
		$LSD_{0.05}$ – $NIR_{0,05}$	0.025	0.328	0.130	0.868	1.290
Mean of total N uptake Średnia ilość pobranego N	for lupine harvest phase – dla fazy zbioru łubinu	full flowering pełnia kwitnienia	0.181	1.977	0.862	6.492	9.512
		full maturity pełna dojrzałość	0.149	1.941	0.831	5.982	8.903
		$LSD_{0.05}$ – $NIR_{0,05}$	0.011	ns – ni	ns – ni	0.318	0.508
	for N rate dla dawki N	0	0.162	1.803	0.760	6.082	8.807
		30	0.160	1.947	0.815	6.065	8.987
		150	0.174	2.127	0.965	6.564	9.830
		$LSD_{0.05}$ – $NIR_{0,.05}$	ns – ni	0.164	0.088	0.476	0.761

The amount of nitrogen taken up by individual parts of spring triticale can be arranged according to decreasing values in the following order: grain > straw > chaff > roots.

The main source of nitrogen for spring triticale grown after yellow lupine was soil (Table 6). Nitrogen derived from soil accounted on average for 71.0% of the total amount of this macroelement accumulated in the triticale biomass. The amount of nitrogen taken up by triticale from parts of lupine introduced into soil and from the mineral fertilizer applied under lupine did not differ significantly. Their percentage in the total uptake amounted to 17.2% and 11.8%, respectively.

The percentage of nitrogen derived from the process of biological reduction in the biomass of triticale grown after lupine harvested in the flowering an full maturity phases and fertilized with rates 30 and 150 kg·ha^{-1} N was similar and ranged from 7.5% to 10,7% (Table 7). Nitrogen derived from the process of biological reduction made about a half (on average 52.5%) of the amount of nitrogen taken up by triticale from yellow lupine. The proportion of nitrogen derived from biological reduction in the total amount of this element accumulated in the roots, straw, chaff and grain of triticale amounted to: 9.6; 8.1; 6.5 and 9.4%, respectively.

Table 7. The amount of nitrogen taken up by spring triticale from lupine, which was accumulated in biological reduction process (from atmosphere), g·m^{-2} N

Tabela 7. Ilość azotu pochodzącego z biologicznej redukcji i pobranego przez pszenżyto jare z łubinu, g·m^{-2} N

Harvest phase of yellow lupine Faza zbioru łubinu żółtego	Nitrogen rate in lupine cultivation Dawka azotu w uprawie łubinu kg·ha^{-1}	Amount of N taken up by lupine from air and applied into soil Ilość N pochodzącego z powietrza i wprowadzonego do gleby z łubinem g·m^{-2}	Units Jednostki	Part of spring triticale Część pszenżyta jarego				In whole plants Ogółem w roślinie
				roots korzenie	straw słoma	chaff plewy	grain ziarno	
Full flowering Pełnia kwitnienia	30	4.447	g·m^{-2}	0.021	0.169	0.044	0.528	0.762
			%*	60.0	61.2	60.3	61.1	61.1
	150	3.528	g·m^{-2}	0.020	0.193	0.074	0.716	1.003
			%*	45.5	46.1	46.3	46.1	46.1
Full maturity Pełna dojrzałość	30	3.979	g·m^{-2}	0.008	0.114	0.034	0.547	0.703
			%*	53.3	49.8	50.0	49.8	49.9
	150	4.231	g·m^{-2}	0.014	0.184	0.078	0.587	0.863
			%*	51.9	53.0	53.1	53.1	53.0

* in whole [%] of lupine like source – ogółem ilość [%] pochodząca z łubinu

The amount of nitrogen taken up by spring triticale and derived from the process of biological reduction was small in comparison with the total amount of nitrogen biologically reduced introduced into soil with yellow lupine (Table 7). The total value of the utilization coefficient of nitrogen derived from the process of biological reduction by the successive crop – spring triticale reached a maximal value of 28.4% (Table 8). After the application of the rate 150 kg·ha^{-1} N a higher value of this coefficient was obtained when triticale was cultivated after lupine harvested in full flowering than in the

full maturity phase. After the use of 30 kg·ha^{-1} N, a similar utilization of biologically reduced nitrogen by triticale was observed, irrespective of the developmental phase when lupine was harvested. The utilization of nitrogen derived from biological reduction by triticale was higher after the application of 150 kg·ha^{-1} N in lupine cultivation, as compared with 30 kg·ha^{-1} N.

Table 8. The values of utilization coefficient of nitrogen from biological reduction process by spring triticale, %

Tabela 8. Wartości współczynnika wykorzystania azotu pochodzącego z biologicznej redukcji przez pszenżyto jare, %

Harvest phase of yellow lupine Faza zbioru łubinu żółtego	N rate in lupine cultivation – Dawka N w uprawie łubinu kg·ha^{-1}	Part of spring triticale Część pszenżyta jarego				Total Ogółem
		roots korzenie	straw słoma	chaff plewy	grain ziarno	
Full flowering Pełnia kwitnienia	30	0.48	3.79	1.00	11.87	17.14
	150	0.58	5.47	2.09	20.29	28.43
	mean – średnia	0.53	4.63	1.55	16.08	22.79
Full maturity Pełna dojrzałość	30	0.19	2.86	0.86	13.74	17.65
	150	0.34	4.35	1.85	13.87	20.41
	mean – średnia	0.27	3.60	1.35	13.81	19.03
Mean for N rates Średnia dla dawek N	30	0.34	3.33	0.93	12.81	17.40
	150	0.46	4.91	1.97	17.08	24.42
$LSD_{0.05}$ – $NIR_{0.05}$ N rate and harvest phase of lupine – dawka N i faza zbioru łubinu		0.04	0.44	0.17	1.32	1.58
interaction – interakcja: harvest phase/N rate – faza zbioru/dawka N		ns – ni	ns – ni	ns – ni	1.87	2.24

Molecular nitrogen contained in the air in the process of biological reduction is introduced into soil in the form of organic compounds contained in residues or the whole biomass of plants. Transition of those unavailable forms of nitrogen into the forms taken up by plants occurs with the use of microorganisms in the process of mineralization, where the product is NH4+ [Porporato *et al*. 2003, Robertson and Groffman 2007]. Except for Wysokiński [2013], no data has been given in the available literature concerning the utilization of biologically reduced nitrogen by plants grown after yellow lupine. In contrast, stands left by legumes for cereals are frequently evaluated [Rutkowski and Fordoński 1994, Jasińska *et al*. 1997, Dubis and Budzyński 1998, Fowler *et al*. 2004]. The stands left by legumes for successive crops are assessed higher than the stands after cereals [Harasimowicz-Hermann 1997, Dubis and Budzyński 1998, Buraczyńska and Ceglarek 2011b]. Dubis and Budzyński [1998] while roughly estimating the previous crop value of yellow lupine for rye and winter triticale found that it was higher than that of oats by the quantity equal to the application of about 60 kg·ha^{-1} N.

Nitrogen assimilability from the plant biomass introduced into soil is to considerable extent dependent on the weather conditions in the autumn and spring period, which among other things determine the activity of soil microorganisms and the mineralization rate of organic compounds from post-harvest residues [Robertson and Groffman 2007]. Better utilization of nitrogen left by legumes is obtained by cultivation of winter crops than spring ones [Skrodzki and Brzozowski 1987], therefore in the present study the

successive crop was winter rye. Due to the poor overwintering, it was replaced by spring triticale. Obtained values of utilization coefficients of nitrogen derived from biological reduction by spring triticale grown after lupine, ranging from 17.1 to 28.4%, should be regarded as small. From a numerical point of view and calculating the nitrogen taken up by triticale per the area of 1 hectare, on average 16 kg N taken up from yellow lupine was obtained, of which 8 kg was nitrogen fixed in the process of biological reduction. Wysokiński [2013] growing winter rye in a field left by yellow lupine obtained the utilization of nitrogen from the process of biological reduction on average at the level of 75%.

After cultivation of yellow lupine harvested in the full flowering and full maturity phases the content of nitrogen in soil increased by 0.15 and 0.07 $g \cdot kg^{-1}$, respectively (on average for treatments fertilized and without fertilization with nitrogen, Table 9). Amounts of nitrogen determined in soil after the harvest of lupine in the flowering phase increased slightly along with increasing the amount of this component introduced into soil in the form of mineral fertilizer. The amount of nitrogen in soil after the harvest of lupine in full maturity was very similar, irrespective of the applied nitrogen fertilization. Nitrogen content in soil after the harvest of the successive crop (spring triticale) was most frequently lower than after the previous crop cultivation, but it still remained at a higher level than before the establishment of the experiment. Low values of utilization coefficients of nitrogen derived from biological reduction by spring triticale and a higher content of this element in soil after growing triticale than before the establishment of this experiment show that a part of nitrogen introduced into soil with the biomass of yellow lupine can be available for a plant cultivated in the following year.

Table 9. Nitrogen content in soil, $g \cdot kg^{-1}$ N
Tabela 9. Zawartość azotu w glebie, $g \cdot kg^{-1}$ N

Harvest phase of yellow lupine Faza zbioru łubinu żółtego	N rate in lupine cultivation – Dawka N w uprawie łubinu $kg \cdot ha^{-1}$	N content – Zawartość N		
		before establishment of experiment – przed założeniem doświadczenia	after 1st year po I roku	after 2nd year po II roku
Full flowering Pełnia kwitnienia	0	1.78	1.89	1.91
	30		1.92	1.86
	150		1.98	1.94
	mean – średnia		1.93	1.90
Full maturity Pełna dojrzałość	0		1.84	1.82
	30		1.86	1.87
	150		1.86	1.82
	mean – średnia		1.85	1.84

CONCLUSIONS

1. Higher biomass yield of spring triticale was obtained when it was grown after yellow lupine harvested in the phase of flowering than in the full maturity phase. Triticale biomass was larger when 150 $kg \cdot ha^{-1}$ N was applied in lupine cultivation as compared with 30 $kg \cdot ha^{-1}$ N.

2. Nitrogen content in the biomass of spring triticale did not depend on the developmental phase and nitrogen fertilization of yellow lupine as a previous crop.

3. The total amount of nitrogen taken up by spring triticale cultivated after yellow lupine harvested in the flowering phase was higher than in the full maturity phase. More nitrogen was taken up by triticale cultivated after lupine fertilized with 150 kg·ha^{-1} N than 30 kg·ha^{-1} N.

4. Spring triticale taken up more nitrogen from soil, less from the biomass of yellow lupine and from the mineral fertilizer applied under the previous crop, and the least of biologically reduced N_2.

5. The value of biologically reduced nitrogen utilization coefficient was higher from yellow lupine harvested in the flowering phase than in the full maturity and it was higher when 150 kg·ha^{-1} N was applied in lupine cultivation than 30 kg·ha^{-1} N.

6. Nitrogen content in soil after harvesting spring triticale was higher than before establishment of the experiment, which indicates enrichment of the soil in this nutrient for plants by yellow lupine.

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WYKORZYSTANIE AZOTU Z RÓŻNYCH ŹRÓDEŁ PRZEZ PSZENŻYTO JARE (*Triticosecale* WITTM. ex. A. CAMUS) UPRAWIANE W STANOWISKU PO ŁUBINIE ŻÓŁTYM (*Lupinus luteus* L.)

Streszczenie. W badaniach określono ilość azotu pobranego przez pszenżyto jare z różnych źródeł w zależności od zróżnicowanego nawożenia azotem i fazy rozwojowej, w której zebrano przedplon – łubin żółty. Łubin uprawiano w trzech wariantach nawozowych: bez nawożenia azotem oraz po zastosowaniu dawki 30 i 150 kg·ha^{-1} N. Zbiór łubinu przeprowadzono w fazie kwitnienia i pełnej dojrzałości. W pierwszym terminie zbioru do gleby wprowadzono całą biomasę. W drugim terminie zebrano nasiona, a pozostałe części łubinu wprowadzono do gleby. Pszenżyto jare jako roślinę następczą uprawiano bez dodatkowego nawożenia azotem i zbierano w fazie pełnej dojrzałości. W badaniach wykorzystano siarczan amonu wzbogacony w izotop azotu ^{15}N i zastosowano metodę izotopowego rozcieńczenia. Największy plon ziarna i całej biomasy oraz sumaryczną ilość pobranego azotu przez pszenżyto uzyskano po

zastosowaniu pod łubin 150 kg·ha^{-1} N. Plony i pobranie azotu przez pszenżyto były większe, gdy przedplon zbierano w fazie kwitnienia niż w fazie pełnej dojrzałości. Zawartość azotu w ziarnie oraz w biomasie pszenżyta nie była uzależniona od fazy zbioru oraz nawożenia azotem przedplonu. Udział azotu pobranego przez pszenżyto z zapasów glebowych, z części łubinu wprowadzonych do gleby oraz z nawozu mineralnego zastosowanego pod łubin wynosił odpowiednio 71,0; 17,2 i 11,8% całkowitej ilości tego makroelementu zgromadzonego w biomasie. Pszenżyto pobrało średnio 20,9% azotu biologicznie zredukowanego wprowadzonego do gleby z biomasą łubinu.

Słowa kluczowe: azot, izotop ^{15}N, łubin żółty, N_2 biologicznie zredukowany, pszenżyto jare, wykorzystanie azotu

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