Journal of Elementology ISSN 1644-2296

Wilczewski E., Szczepanek M. 2018.
Accumulation of bioelements in the biomass of plants grown as stubble catch crops depending on the sowing time.
J. Elem., 23(1): 261-272. DOI: 10.5601/jelem.2016.21.4.1330

ORIGINAL PAPER

ACCUMULATION OF BIOELEMENTS IN THE BIOMASS OF PLANTS GROWN AS STUBBLE CATCH CROPS DEPENDING ON THE SOWING TIME

Edward Wilczewski, Małgorzata Szczepanek

Department of Agrotechnology
UTP University of Science and Technology in Bydgoszcz, Poland

Abstract

Stubble catch crops are currently appreciated mainly because of their beneficial effect on the soil environment. It manifests itself through limiting the risks of eutrophication caused by the leaching of soil nutrients, especially nitrogen and potassium. Catch crops uptake assimilable forms of elements from the soil and store them in their biomass during autumn and winter. The mass of nutrients accumulated in stubble catch crop biomass depends on their content in the plant and yield of biomass. A field study aiming to evaluate the effect of the sowing time of stubble catch crops on the content and uptake of macroelements was carried out in Mochełek near Bydgoszcz, in 2013-2015. The experiment was set up on Luvisol soil and involved three cultivated crops (white mustard cv. Warta, common buckwheat cv. Panda and common vetch cv. Fama) sown at 2 dates (early – 08-12.08, and delayed – 10 days after the early time). The tested plants varied in the potential of taking up elements from soil, which was very high for potassium (from 28.27 kg ha^{-1} K in buckwheat to 65.24 kg ha^{-1} K in mustard) and nitrogen (from 17.61 kg ha^{-1} N in buckwheat to 64.94 kg ha^{-1} N in vetch). Phosphorus and magnesium were taken up by plants in small amounts, namely 5.413 kg ha^{-1} P and 3.257 kg ha^{-1} Mg. Vetch surpassed the other plants in terms of the content and uptake of N and P. Mustard took up most K, whereas buckwheat was inferior to the other species in the uptake of all the assessed elements in biomass as well as the content of N, P and K in both aerial parts and postharvest residue. A delay of catch crop sowing by 10 days resulted in a significant decrease in the N, P, K, Ca and Mg uptake by plants. Vetch showed the strongest response to this factor, and mustard – the weakest.

Keywords: white mustard, common buckwheat, common vetch, magnesium, stubble catch crop, uptake.

dr hab. inż. Edward Wilczewski, Department of Agrotechnology, UTP University of Science and Technology in Bydgoszcz, 85-225 Bydgoszcz, Poland, e-mail: edward.wilczewski@utp.edu.pl
This research was financed by the Ministry of Science and Higher Education of the Republic of Poland.

INTRODUCTION

Long-term intensive fertilization used in commodity crop cultivation on arable land results in an increased risk of groundwater contamination with nitrates and eutrophication of water bodies (Rask et al. 1999, Thorup--Kristensen et al. 2003, Nagare et al. 2012). Therefore, when applying fertilization, it is necessary to consider the demand of a cultivated plant for used fertilization components and the recovery of nutrients from soil elements left after crop harvesting. An effective way of limiting these unfavourable phenomena is to grow stubble catch crops, which both reduce the risk of eutrophication (Vos, van der Putten 1997, Eichler et al. 2004, Askegaard, Eriksen 2008, Kondo et al. 2013) and have a positive effect of the soil's biological properties (Piotrowska, Wilczewski 2012). According to Kondo et al. (2013), maize as a catch crop reduces mineral nitrogen leaching by about 90% in summer and autumn and by about 70% in winter. In the study by Askegaard, Eriksen (2008), an average annual reduction in $N\text{-}NO_3$ leaching by a stubble catch crop of perennial ryegrass and white clover was estimated at 40-80%. The mass of mineral elements accumulated by stubble catch crops depends on their content in the plant biomass and on the generated yield. Effective stubble catch crops may remove 40-180 kg ha^{-1} of nitrogen and 70-220 kg ha^{-1} of potassium from soil between August and October (Eichler et al. 2004, Wilczewski 2010). The most important agronomic factors affecting the yield of crops grown as a stubble catch crop include a proper selection of species (Skinder, Wilczewski 2004, Müller et al. 2006, Brant et al. 2011) and a sowing time, which determines the length of the growing period (Vos, van der Putten 1997, Kisielewska, Harasimowicz-Hermann 2008). Under the climatic conditions of Poland, white mustard is a plant well adapted to the currently preferred late sowing of stubble catch crops (Skinder, Wilczewski 2004, Kisielewska, Harasimowicz-Hermann 2008). This is a plant with highly stable yielding and the ability to absorb large amounts of nitrogen from soil (Wilczewski 2004, Kisielewska, Harasimowicz-Hermann 2008). Common vetch requires early sowing. It is no match for non-legume crops in terms of biomass yield. Its advantage is a high protein content in the biomass (Lithourgidis et al. 2006, Kokten et al. 2009).

The aim of this study was to assess the dependence of the uptake of mineral elements by a stubble catch crop on a cultivated crop species and a sowing date.

MATERIAL AND METHOD

A field study was carried out at the Research Station of the Faculty of Agriculture and Biotechnology in Mochełek near Bydgoszcz (53°13′ N; 17°51′ E).

The field experiments were carried out over 2013-2015, in soil classified as Luvisol (IUSS Working Group WRB 2007) of the very good rye complex, formed from heavy loamy sand. The soil was characterized by neutral reaction (pH in 1 M KCl was 7.1) and very high abundance of assimilable phosphorus (88.20 mg P kg^{-1}), potassium (208.6 mg K kg^{-1}) and magnesium (114.5 mg Mg kg^{-1}). A controlled, two-factorial field experiment was conducted in a randomized split plot design with four replications.

The experimental factors were:

– the sowing time of a stubble catch crop: early (08-12 August); delayed (10 days after the early time);
– the species of a plant grown as a stubble catch crop: white mustard cv. Warta, common buckwheat cv. Panda and common vetch cv. Fama.

The preceding crop for the stubble catch crops was spring barley. After harvesting the preceding crop, pre-sowing soil tillage consisting of ploughing made to a depth of 18 cm was performed using a skim plough. Prior to sowing the catch crops, the soil was cultivated using a cultivation unit consisting of a cultivator and a string roller. No fertilization was applied in the stubble catch crop cultivation.

Seeds of the tested crops were sown in a row spacing of 21 cm, in the amounts: white mustard – 15 kg ha^{-1}, common buckwheat and common vetch – 110 kg ha^{-1}. White mustard and common buckwheat were sown at a depth of 2-3 cm, whereas common vetch was seeded at a depth of 4-5 cm. The dates of sowing and harvesting stubble catch crops are presented in Table 1.

After cutting plants from each plot, samples of the aerial biomass and post-harvest residues of the catch crops were collected, and the content of the basic bioelements (N, P, K, Ca and Mg) was determined. The determination was performed with the following methods: total N – with the Kjeldahl method; P – with the vanadium-molybdenum method; K and Ca – with flame photometry; Mg – colorimetrically with titanium yellow. The uptake of bioelements from soil was calculated based on their content in green matter and

Table 1

Sowing and harvesting times of stubble catch crops

Sowing time	Year	Sowing time	Harvesting time	Number of the growth days
Early	2013	12.08.	08.10.*	57
			21.10.&	70
	2014	08.08.	16.10.	69
	2015	09.08.	17.10.	69
Delayed	2013	22.08.	08.10.*	47
			21.10.&	60
	2014	18.08.	16.10.	59
	2015	19.08.	17.10.	59

* common buckwheat; & other plants

post-harvest residues and the yield of green matter and postharvest residue, according to the formula:

Element uptake (kg ha^{-1}) = (A · B/1000) + (C · D/1000),

A – element content in green matter (g kg^{-1} d.m.),

B – green matter yield (kg ha^{-1} d.m.),

C – element content in post-harvest residues (g kg^{-1} d.m.),

D – postharvest residues yield (kg ha^{-1} d.m.).

The results were subjected to an analysis of variance for a randomized split plot design using computer software AWAR, developed by the IUNG in Puławy. The lowest significant differences (LSD) were calculated using the Tukey's test at a significance level $\alpha = 0.05$.

RESULTS

The sowing time had a significant effect on total nitrogen content in the green matter of crops grown as a stubble catch crop (Table 2). After the delayed sowing, it was higher than after the earlier sowing time in all the studied crops. The effect of the sowing time on the nitrogen content in green matter was the highest in white mustard and common buckwheat (26 and 28%, respectively), and the lowest in common vetch (8%). Particular crops contained different amounts of total nitrogen. It was the highest in common vetch, significantly lower in the green matter of white mustard and the lowest in common buckwheat. Variations in the nitrogen content in the post-harvest residues of crops grown as stubble catch crops were also significant but lower than in the aerial biomass. Irrespective of the sowing time, the post-harvest residues of common vetch were more abundant in nitrogen

Table 2

Content of nitrogen (g kg^{-1} d.m.) – average values from 2013-2015

Parts of plants	Sowing time (I)	Species of plant (II)			
		white mustard	common buckwheat	common vetch	mean
Green matter	early	23.89	18.78	41.85	28.17
	delayed	30.18	24.09	45.27	33.18
	mean	27.03	21.43	43.56	30.68
	LSD (Tukey's test): I - 2.41; II - 1.46; II w I -2.07; I w II - 2.48				
Post-harvest residues	early	9.33	6.57	24.89	13.60
	delayed	9.91	8.24	27.22	15.12
	mean	9.62	7.40	26.06	14.36
	LSD (Tukey's test): I -3.02; II - 2.78; II w I - 3.94; I w II - 3.81				

than the post-harvest residues of the other two crops, which did not differ significantly in this respect. No effect of the sowing time on the nitrogen content in the post-harvest residues of the studied crops was found.

The content of phosphorus (P) in the dry matter biomass of catch crops was in the range from 3.349 to 3.961 g kg^{-1} in green matter and from 2.150 to 3.469 g kg^{-1} in post-harvest residues (Table 3). The effect of the sowing time

Table 3

Content of phosphorus (g kg^{-1} d.m.) – average values from 2013-2015

Parts of plants	Sowing time (I)	Species of plant (II)			
		white mustard	common buckwheat	common vetch	mean
Green matter	early	3.556	3.349	3.762	3.556
	delayed	3.879	3.479	3.961	3.773
	mean	3.717	3.414	3.861	3.664
	LSD (Tukey's test): I - 0.260; II - 0.022; II w I - 0.024; I w II - 0.222				
Post-harvest residues	early	2.771	2.150	3.150	2.690
	delayed	3.469	2.191	3.119	2.926
	mean	3.120	2.171	3.134	2.808
	LSD (Tukey's test): I - 0.532; II - 0.169; II w I - 0.240; I w II - 0.461				

on this character was different in particular crops. It was significant only in white mustard, in which a delay in sowing resulted in an increase in the phosphorus content ,both in green matter and in post-harvest residues. Of the studied crops, common vetch contained most phosphorus in the green matter, and common buckwheat contained the least of this element both in the green matter and in post-harvest residues. Concentrations of phosphorus in the post-harvest residues of white mustard and common vetch were similar, although in the case of mustard a delay in sowing resulted in a significant increase and in vetch the sowing time had no effect on this character.

The content of potassium (K) in the biomass of crops grown as a stubble catch crop (Table 4) was about 9-fold higher than the content of phosphorus. The delay in sowing did not have an effect on the average content of potassium in the aerial biomass and post-harvest residues of common buckwheat and common vetch. Nevertheless, a significant increase in the potassium concentration in the aerial biomass of white mustard was observed as a result of the delayed sowing. This plant accumulated significantly higher amounts of potassium in the biomass than common buckwheat and common vetch. An interaction between the sowing time and the species of a crop grown as a stubble catch crop was found in respect of this character. In white mustard, the delay in a sowing time resulted in an increase in the content of potassium in the green matter. In the other crops, no significant effect of the sowing time on this character was observed.

Table 4

Content of potassium (g kg^{-1} d.m.) – average values from 2013-2015

Parts of plants	Sowing time (I)	Species of plant (II)			
		white mustard	common buckwheat	common vetch	mean
Green matter	early	37.12	26.07	36.12	33.10
	delayed	44.55	24.90	38.95	36.14
	mean	40.84	25.48	37.54	34.62
	LSD (Tukey's test): I - 7.34; II - 1.39; II w I - 1.97; I w II - 6.15				
Post-harvest residues	early	25.82	18.10	24.79	22.90
	delayed	26.62	20.51	22.62	23.25
	mean	26.22	19.30	23.71	23.08
	LSD (Tukey's test): I - 6.42; II - 2.31; II w I - 3.26; I w II - 5.76				

The delay in sowing resulted in an increase in the calcium content in the green matter of white mustard and common buckwheat, whereas it did not have a significant effect on the content of this element in the green matter of common vetch and post-harvest residues of all the studied crops (Table 5). White mustard contained more calcium in the green matter than the other crops. The post-harvest residues of common buckwheat were more abundant in calcium than those of white mustard and common vetch.

Magnesium was the element that was accumulated by plants in smallest amounts, ranging from 2.274 to 2.874 g kg^{-1} in green matter and from 1.272 to 1.784 g kg^{-1} in post-harvest residues (Table 6). The sowing time usually did not affect this character. It was only in the green matter of white mustard that an increase in the concentration of this bioelement was observed as a result of the delay in sowing. Common buckwheat contained

Table 5

Content of calcium (g kg^{-1} d.m.) – average values from 2013-2015

Parts of plants	Sowing time (I)	Species of plant (II)			
		white mustard	common buckwheat	common vetch	mean
Green matter	early	17.21	13.43	15.85	15.50
	delayed	20.24	20.00	16.11	18.78
	mean	18.73	16.71	15.98	17.14
	LSD (Tukey's test): I -2.47; II - 1.81; II w I - 2.56; I w II - 2.76				
Post-harvest residues	early	8.95	18.11	10.81	12.62
	delayed	9.17	19.61	11.08	13.28
	mean	9.06	18.86	10.94	12.95
	LSD (Tukey's test): I - 1.95; II - 1.62; II w I - 2.29; I w II - 2.32				

Table 6

Content of magnesium (g kg^{-1} d.m.) – average values from 2013-2015

Parts of plants	Sowing time (I)	Species of plant (II)			
		white mustard	common buckwheat	common vetch	mean
Green matter	early	2.274	2.754	2.389	2.472
	delayed	2.456	2.874	2.291	2.540
	mean	2.365	2.814	2.340	2.506
	LSD (Tukey's test): I - 0.152; II - 0.020; II w I - 0.022; I w II - 0.134				
Post-harvest residues	early	1.308	1.272	1.784	1.455
	delayed	1.291	1.383	1.590	1.421
	mean	1.299	1.327	1.687	1.438
	LSD (Tukey's test): I - 0.150; II - 0.144; II w I - 0.238; I w II - 0.212				

the most of magnesium in the green matter of the studied crops. The post--harvest residues of common vetch were significantly more abundant in magnesium than those of the other crops.

The equivalent ratio of potassium to the sum of calcium and magnesium (K: (Ca+Mg) in the dry aerial matter ranged from 0.51-0.80: 1 for common buckwheat to 0.99-1.06: 1 for common vetch (Figure 1). The sowing time did not affect the value of this index in white mustard and common vetch. A decrease in this index was found in the aerial dry matter of common buckwheat as a result of the delayed sowing.

The uptake of macroelements by crops grown as a stubble catch crop ranged on average from 3.257 kg ha^{-1} for Mg to 49.97 kg ha^{-1} for K (Table 7). The accumulation of bioelements in the biomass of crops grown as a stubble catch crop was dependent on both a plant species and a sowing time. Com-

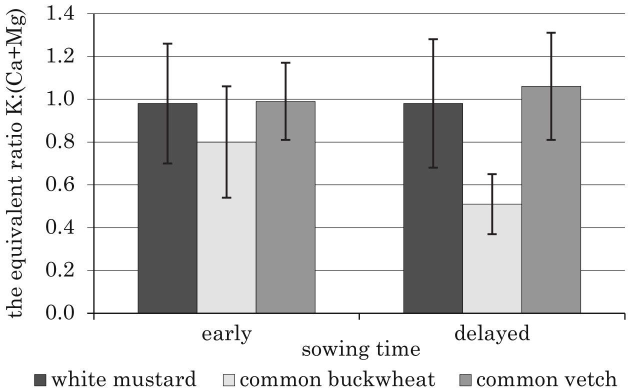

Fig. 1. The equivalent K:(Ca+Mg) ratio in the aerial dry matter of catch crops – average values from 2013-2015 (bars show standard errors)

Table 7

Uptake of macroelements in the biomass of catch crops (kg ha^{-1}) – average values from 2013-2015

Macroelement	Sowing time (I)	Species of plant (II)			
		white mustard	common buckwheat	common vetch	mean
N	early	35.29	20.44	73.37	43.03 a
	delayed	32.62	14.78	56.51	34.64 b
	mean	33.96	17.61	64.94	38.84
	LSD (Tukey's test): I - 4.250; II - 1.750; II w I -2.475; I w II - 3.911				
P	early	6.545	4.378	7.556	6.159
	delayed	5.733	2.544	5.722	4.667
	mean	6.139	3.461	6.639	5.413
	LSD (Tukey's test): I - 0.513; II - 0.295; II w I - 0.418; I w II - 0.519				
K	early	70.30	37.42	64.86	57.53
	delayed	60.19	19.11	47.92	42.41
	mean	65.24	28.27	56.39	49.97
	LSD (Tukey's test): I - 12.64; II - 2.845; II w I - 4.024; I w II - 10.70				
Ca	early	26.89	19.54	28.68	25.04
	delayed	22.74	17.13	22.69	20.86
	mean	24.82	18.34	25.68	22.95
	LSD (Tukey's test): I - 2.874; II - 1.486; II w I - 2.101; I w II - 2.807				
Mg	Early	3.867	3.222	4.511	3.867
	Delayed	2.978	1.898	3.078	2.648
	Mean	3.422	2.556	3.795	3.257
	LSD (Tukey's test): I - 0.425; II - 0.173; II w I - 0.244; I w II - 0.390				

mon vetch took up significantly more N, P and Mg than the other crops. White mustard accumulated significantly the most of potassium. Common buckwheat took up significantly less N, P, K, Ca and Mg than the other crops. The delay in sowing by 10 days contributed to a significant decrease in the mass of elements taken up by the plants. An interaction was found between the experimental factors in respect of the mass of absorbed bioelements. The later sowing of common vetch contributed to a decrease in the uptake of all the elements studied. In common buckwheat, a significant decrease in the uptake of N, P, K and Mg was found, whereas in white mustard such a consequence was observed only for P, Ca and Mg.

DISCUSSION

According to Thorup-Kristensen, Rasmusen (2015), legumes have a significantly higher ability to accumulate nitrogen than plants from other botanical taxa. In the present study, nitrogen accumulation in the biomass of common vetch was almost twice as high as in white mustard and more than three-fold higher than in the biomass of common buckwheat. The uptake of nitrogen by white mustard and common buckwheat was very low. Accumulation of nitrogen in the biomass of catch crops grown without fertilization usually ranges from 50 to 110 kg ha^{-1} (Wilczewski et al. 2006, Rinnofner et al. 2008, Balkcom et al. 2011).

The increase in the content of N and Ca resulting from delayed sowing obtained in the present study is in line with the authors' expectations and results from the negative effect of this factor on the biomass yield (data not shown). In the case of P, K and Mg, a negative effect of early sowing on their content in the green matter was observed only in white mustard. The response of common buckwheat and common vetch to this factor was insignificant. The weaker response of buckwheat and vetch to the sowing time was connected with a smaller effect of this factor on the plant growth and development of these crops prior to harvest. White mustard sown at the early time reached the stage of full flowering or silique formation prior to harvest, and that sown at the delayed time reached the stage of budding or the beginning of flowering prior to harvest. This decrease in plant development progress created favourable conditions for a more significant increase in the element content in the biomass as a result of sowing delay than in the other crops. Common vetch, irrespective of a sowing date, reached the budding stage prior to harvest, and common buckwheat reached the flowering stage before it was harvested. In these crops, the content of P, K and Mg in the green mass was not dependent on a sowing time. The response of white mustard to a delayed sowing date is unusual. In the study by Zaniewicz-Bajkowska et al. (2013), including such plants as phacelia (*Phacelia tanacetifolia* Benth.), amaranth (*Amaranthus cruentus* L.), sunflower (*Helianthus* L.), seradella (*Ornithopus sativus*), and faba bean (*Vicia faba* L. ssp. *minor*), no effect of sowing dates on the element content was stated.

Despite a higher content of elements in the biomass of white mustard from the later sowing, their uptake by the catch crops from the early sowing time was higher, just as in the other species, which indicates a higher role of the yield than that of the content of elements in their accumulation in the yield. This also confirms the significant role of a sowing time in forming the pro-environmental effect of stubble catch crops (Vos, van der Putten 1997).

According to the present study, the effect of a sowing time on the accumulation of elements in the biomass is not identical for particular crop species grown as stubble catch crops. It is very high for common buckwheat and common vetch (12.3-48.1% and 20.9-31.7%, respectively) and much lower for white mustard (on average 7.6-23%). The sowing time had a low effect on the element accumulation in white mustard biomass, because this factor had a negative effect on the green matter yield (data not shown) and, at the same time, it had a positive effect on the element content in the green matter of this crop. For buckwheat and vetch, the content of most elements in the biomass did not depend on a sowing time. Therefore, a delay in sowing, and a consequent decrease in yield, had a larger effect on the level of element accumulation in the biomass than changes in the content of elements.

Despite an increase in the potassium content in the biomass of white mustard as a result of delayed sowing, no negative effect of this factor was observed on the green matter quality measured with the equivalent K:(Ca+Mg) ratio. No excess over the acceptable value of this index, amounting to 2.2:1, was observed in any of the studied crops (Kumar, Soni 2014). In common buckwheat, there was even a decrease in this ratio observed in common buckwheat as a result of the delay in sowing.

CONCLUSIONS

1. The analysed crops had different potential of taking up elements from soil. It was very high in respect of potassium and nitrogen, whereas phosphorus and magnesium were taken up by the crops in small amounts.

2. Common vetch surpassed common buckwheat and white mustard in terms of the content and uptake of N and P, white mustard took up the most K, whereas buckwheat was no match for the other species in respect of the uptake of all assessed elements in biomass and in respect of N, P and K content both in the aerial parts and in post-harvest residues.

3. A delay of sowing by 10 days usually resulted in a significant decrease in the N, P, K, Ca and Mg uptake from soil by catch crops. However, the extent of this decrease in element accumulation was different in particular crops. It was very high for common vetch and common buckwheat and considerably lower, and with respect to N and K statistically insignificant, in white mustard.

REFERENCES

Askegaard M., Eriksen J. 2008. *Residual effect and leaching of N and K in cropping systems with clover and ryegrass catch crops on coarse sand*. Agric. Ecosyst. Environ., 123: 99-108. DOI: 10.1016/j.agee.2007.05.008

Balkcom K.S., Massey J.M., Mosjidis J.A., Price A.J., Enloe S.F. 2011. *Planting date and seeding rate effects on Sunn Hemp biomass and nitrogen production for a winter cover crop*. Int. J. Agron., 2011: Article ID 237510, 8 pages. DOI: 10.1155/2011/237510

Brant V., Pivec J., Fuksa P., Necka´r K., Kocourkova D., Venclova V. 2011. *Biomass and energy production of catch crops in areas with deficiency of precipitation during summer period in central Bohemia*. Biomass Bioenerg., 35: 1286-1294. DOI: 10.1016/j.biombioe.2010.12.034

EICHLER B., ZACHOW B., BARTSCH S., KÖPPEN D., SCHNUG E. 2004. *Influence of catch cropping on nitrate contents in soil and soil solution*. Landbauforsch. Völk., 54: 7-12.

IUSS Working Group WRB. 2007. *World Reference Base for Soil Resources 2006, first update 2007*. World Soil Resources Reports No. 103. FAO, Rome.

KISIELEWSKA W., HARASIMOWICZ-HERMANN G. 2008. *Impact of the sowing time on accumulation of mineral elements by white mustard cultivated as an intercrop*. Rośliny Oleiste – Oilseed Crops, 29: 209-216. (in Polish)

KOKTEN K., TOKLU F., ATIS I., HATIPOGLU R. 2009. *Effects of seeding rate on forage yield and quality of vetch (Vicia sativa* L.*) – triticale (Triticosecale* Wittm.*) mixtures under East Mediterranean rainfed conditions*. Afr. J. Biotechnol., 8: 5367-5372.

KONDO K., INOUE K., FUJIWARA T., YAMANE S., YASUTAKE D., MAEDA M., NAGARE H., AKAO S., OHTOSHI K. 2013. *Seasonal changes in the performance of a catch crop for mitigating diffuse agricultural pollution*. Water Sci. Technol., 68: 776-782. DOI: 10.2166/wst.2013.258

KUMAR K., SONI A. 2014. *Elemental ratio and their importance in feed and fodder*. Int. J. Pure App. Biosci., 2(3): 154-160.

LITHOURGIDIS A.S., VASILAKOGLOU I.B., DHIMA K.V., DORDAS C.A., YIAKOULAKI M.D. 2006. *Forage yield and quality of common vetch mixtures with oat and triticale in two seeding ratios*. Field Crop Res., 99: 106-113. DOI: 10.1016/j.fcr.2006.03.008

MÜLLER T., THORUP-KRISTENSEN K., MAGID J., JENSEN L.S., HANSEN S. 2006. *Catch crops affect nitrogen dynamics in organic farming systems without livestock husbandry - simulations with the DAISY model*. Ecol. Model., 191: 538-544. DOI: 10.1016/j.ecolmodel.2005.05.026

NAGARE H., FUJIWARA T., INOUE T., AKAO S., INOUE K., MAEDA M., YAMANE S., TAKAOKA M., OSHITA K., SUN X. 2012. *Nutrient recovery from biomass cultivated as catch crop for removing accumulated fertilizer in farm soil*. Water Sci. Technol., 66(5): 1110-1116. DOI: 10.2166/wst.2012.291

PIOTROWSKA A., WILCZEWSKI E. 2012. *Effects of catch crops cultivated for green manure and mineral nitrogen fertilization on soil enzyme activities and chemical properties*. Geoderma, 189-190: 72-80. DOI: 10.1016/j.geoderma.2012.04.018

RASK N., PEDERSEN S.E., JENSEN M.H. 1999. *Response to lowered nutrient discharges in the coastal waters around the island of Funen, Denmark*. Hydrobiologia, 393: 69-81.

RINNOFNER T., FRIEDEL J.K., DE KRUIJFF R., PIETSCH G., FREYER B. 2008. *Effect of catch crops on N dynamics and following crops in organic farming*. Agron. Sustain. Dev., 28: 551-558. DOI: 10.1051/agro:2008028

SKINDER Z., WILCZEWSKI E. 2004. *Forecrop value of non-papilionaceous plants cultivated in stubble intercrop for spring barley under various fertilization conditions*. EJPAU, Ser. Agron., 7(1): #03. http://www.ejpau.media.pl/volume7/issue1/agronomy/art-03.html

THORUP-KRISTENSEN K, MAGID J, JENSEN L.S. 2003. *Catch crops and green manures as biological tools in nitrogen management in temperate zones*. Adv. Agron., 79: 227-302. DOI: 10.1016/S0065-2113(02)79005-6

THORUP-KRISTENSEN K, RASMUSEN C.R. 2015. *Identifying new deep-rooted plant species suitable as undersown nitrogen catch crops*. J. Soil Water Conserv., 70(6): 399-409. DOI: 10.2489/jswc.70.6.399

WILCZEWSKI E. 2004. *Effect of fertilisation methods on the biomass productivity of non-papilionaceous plants grown as stubble intercrop*. Acta Sci. Pol., Agric., 3(1): 139-148. (in Polish)

WILCZEWSKI E. 2010. *Utilization of nitrogen and other macroelements by non-papilionaceous plants cultivated in stubble intercrop*. Ecol. Chem. Eng. A, 17(6): 689-698.

WILCZEWSKI E., LEMAŃCZYK G., SKINDER Z., SADOWSKI CZ. 2006. *Effect of nitrogen fertilization on the yielding and health status of selected non-papilionaceous plant species grown in stubble intercrop*. EJPAU, Ser. Agron., 9(2): #04. http://www.ejpau.media.pl/volume9/issue2/art-04.html

VOS J., VAN DER PUTTEN P.E.L. 1997. *Field observations on nitrogen catch crops. I. Potential and* *actual growth and nitrogen accumulation in relation to sowing date and crop species*. Plant Soil, 195: 299-309.

ZANIEWICZ-BAJKOWSKA, A., ROSA, R., KOSTERNA, E., FRANCZUK, J. 2013. *Catch crops for green manure: Biomass yield and macroelement content depending on the sowing date*. Acta Sci. Pol., Agric., 12(1): 65-79.