ACTA Acta Sci. Pol., Hortorum Cultus 11(3) 2012, 101-116

THE FERTILIZER VALUE OF SUMMER CATCH CROPS PRECEEDING VEGETABLES AND ITS VARIATION IN THE CHANGING WEATHER CONDITIONS

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Abstract. With the uptake of organic farming the importance of green manures increases, and the cultivation of cover crops plays an ever important role both in agriculture and in horticulture. The fertilizer value of plants cultivated for green manures is largely dependent on the biomass produced, and also the nutrients that were accumulated within it. The aim of this work is to determine the influence of weather conditions in the second half of summer on the fertilizer value of catch crops intended for cultivation of vegetables. The research included: spring rye (*Secale cereale*), oats (*Avena sativa*), common vetch (*Vicia sativa*), white mustard (*Sinapis alba*), tancy phacelia (*Phacelia tanacetifolia*), buckwheat (*Fagopyrum esculentum*), fodder sunflower (*Helianthus annuus*). The catch crop plants, cultivated as a pre-crop for the cultivation of vegetables proved to be a rich source of organic matter and nutrients for the following crops. The course of weather had a major influence on the volume of biomass, and the chemical composition and fertilizer value of cover crops. Shortage of water and high temperatures after rainfalls, causing the formation of crust on the soil did mostly limit the growth of catch crops. The biggest biomass among the investigated catch crops was created by sunflowers, phacelia and rye, the lowest by common vetch. White mustard and sunflower provided the biggest amount of nitrogen in their role as catch crops. The sunflower proved to be a rich source of K, Ca and Mg. The most Ca was left in the field by tancy phacelia, which also proved to be a good source of K. The biomass of buckwheat provided large amounts of Mg, but it was poor in N, P and S. Rye and oats proved to be a rich sources of P, but they also contained small amount of Ca and Mg. The most sulphur was left over by the biomass of white mustard. The common vetch proved to be the most weather-sensitive of all plants. Its biomass left the least P, K, Mg and S in the field, the Ca content was also small, compared to other catch crops. Nitrogen content of dry matter of common vetch was high, but not the highest in the three year average.

Key words: precipitation, temperature, green manures

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INTRODUCTION

The need for environment protection makes the world horticulture turn to traditional forms of fertilization and sources of nutrients, in this case organic and natural fertilizers.

The widespread of organic farming causes the rise in importance of green manures, and the cultivation of cover crops plays an ever increasing role not just in agriculture but in horticulture as well [Jabłońska-Ceglarek and Franczuk 2002]. Cultivated as companion crop, stubble crop or winter catch crop introduce the biodiversity, limiting the occurrence of diseases and pests, and playing a weed-killing role [Wyland et al. 1996, Jodaugiene et al. 2006, Sawicka and Kotiuk 2007, Stokłosa et al. 2008, Błażewicz-Woźniak and Konopiński 2009, Lithourgidis et al. 2011]. Their biomass is being mixed with the soil or left on its surface, creating a living or frost-nipped protective layer. The covering of soil with plants during winter is one of the elements of conservation tillage [Dumanski et al. 2006]. The use of covering plants beneficially influences the structure of the soil, increases the water reserves stored in soil, improves a number of its physical and chemical properties. The cover crops do not only protect the soil from erosion and improve its nutrient balance, but also foster the biological activity of the soil, preventing the loss of mineral elements from the soil by their accumulation and passing-over to the after-plant crops [Richards et al. 1996, Kęsik et al. 2006, Gaskell and Smith 2007, Zhang et al. 2007, Błażewicz-Woźniak et al. 2008, Kęsik and Błażewicz-Woźniak 2010].

It seems to us, that the question of cultivation of after-crops is already well developed. We know both the terms and norms of sowing each of the recommended catch crops. But the horticultural practice is largely dependent on the course of weather. Especially in recent years the summer weather surprises us with frequent, previously unrecorded changes, which influences the growth of the plants, including the plants cultivated for green manures. The fertilizer value of the plants cultivated for green manures is determined by both the biomass created and the amount of the nutrients collected. Most of the studies of green manures or catch crops do only include averaged results for several years, forming the basis for estimation of the influence of cover crops on the yielding of main crops. There are no available studies that would show the different fertilizer value of those plants, depending on the course of weather, which largely influences the effects of their use in horticultural cultures.

This study, forming a proportion of wider research, aims at determining the influence of weather in the second half of summer on the fertilizer value of selected summer catch crops for vegetable cultures.

MATERIAL AND METHODS

The field experiment was conducted in the years 2009–2011 in Felin Experimental Station of the University of Life Sciences in Lublin (Poland, 51°23'N, 22°56'E), on a grey-brown podzolic soil derived from medium loam. These soils prove difficult in tillage, being prone to densification in rain, an later to formation of soil crust. Before the catch crops were sown the soil contained, on average, 1.06% to 1.15% of humus in the 0–20 cm layer and was mildly acidic (pH in 1 M KCl 5.76–5.90). The content of assimilable phosphorus, potassium and magnesium was: P – 146.8, K – 111.5, Mg – 102.9 mg kg^{-1} of soil. The sowing of the catch crops took place a year before the vegetables were cultivated, after the harvesting of pre-crop (winter wheat). The experiment was conducted according to the method of completely randomized blocks in 4 replications. The area of a single plot was 50 m^2. The area of the all experiment was 1600 m^2. The following cover crops were included in the experiment: spring rye (*Secale cereale*), oats (*Avena sativa*), common vetch (*Vicia sativa*), white mustard (*Sinapis alba*), tancy phacelia (*Phacelia tanacetifolia*), buckwheat (*Fagopyrum esculentum*), fodder sunflower (*Helianthus annuus*). The catch crops were sown on the same day each year, that is on August 1st, after the wheat was harvested. Directly after the harvest of pre-crop the soil was ploughed (15 cm deep) and harrowed. Taking the low crop yields of the catch crops from the previous years into account, we used higher than recommended sowing norms. The effect was that the norms for sowing of catch crops were as follows: rye – 300 kg, oats – 300 kg, vetch – 200 kg, mustard – 200 kg, phacelia – 50 kg, buckwheat – 200 kg, sunflower – 125 kg·ha^{-1}. In 2010 the plant emergence were so weak, that on August 18th additional 1.5 kg of phacelia seeds and 3.0 kg of vetch seeds were sown on 200 m^2 surface. The biomass of the catch crops, after its prior fragmentation (on October 5th, each year), was either mixed with the soil before winter or left on the surface of the soil in form of mulch. The weather conditions and soil moisture during the cultivation period of catch crops are shown in figure 1 and table 1.

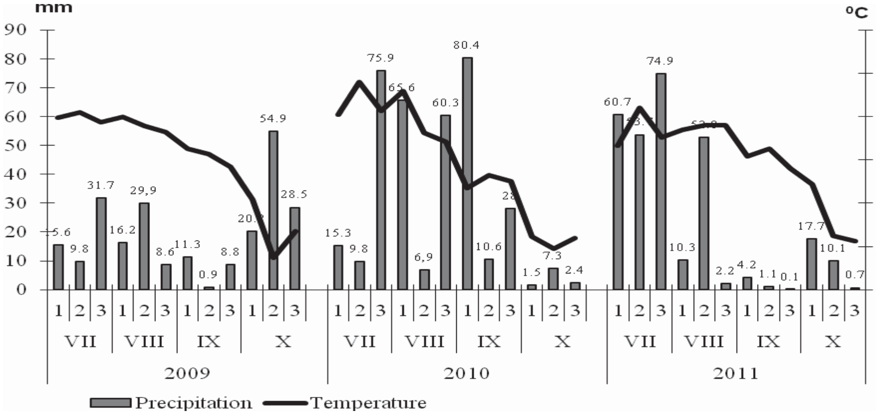

Fig. 1. Mean decade air temperatures and amount of precipitation in ES Felin in years 2009–2011
Rys. 1. Średnie dekadowe temperatury powietrza i sumy opadów w GD Felin w latach 2009–2011

Before the fragmentation of catch crops and pre-winter tillage were completed, the biomass of the catch crops from each plot (in 4 replications × 1 m^2) was calculated (on October 5th, each year), and then samples of plant material for chemical analysis were taken. The volume of the biomass and the content of N, P, K, Ca, Mg, S in the above-ground parts an roots of plants were taken. The total nitrogen content was set using the

Table 1. Soil moisture during vegetation period of catch crops in years 2009–2011
Tabela 1. Wilgotność gleby w okresie wegetacji międzyplonów w latach 2009–2011

Year Rok	Soil layer Warstwa (cm)	Soil moisture (%) – Wilgotność gleby		
		*July lipiec	August sierpień	September wrzesień
2009	0–20	15.9	12.5	12.3
	20–40	16.8	12.7	13.9
	0–40	16.4	12.6	12.6
2010	0–20	13.9	9.3	18.5
	20–40	14.7	9.4	18.3
	0–40	14.3	9.4	18.4
2011	0–20	16.3	11.2	9.4
	20–40	15.5	12.8	11.0
	0–40	15.9	12.0	10.2

*Soil samples were collected on the 15th day of each month – Próby gleby pobierano 15 dnia każdego miesiąca

Kjedahl method (Foss-Tecator 1002), and, after burning the mass dry: P-calorimetrically (Nicolette Evolution 300 spectrophotometer), K, Ca, Mg – AAS (Perkin--Elmer Analyst 300) [Ostrowska et al. 1991]. The results were subject to statistical analysis of variance. The significance of differences was tested with the use of the Tukey's test with p = 0.05.

RESULTS AND DISCUSSION

The cover crop plants used as pre-crop in 2009 for the cultivation of vegetables were a rich source of biomass (tab. 2). Regardless of species they provided, on average, 35.9 t·ha^{-1} of fresh organic matter, 34.5 t of that were aboveground parts of plant and 1.4 t in form of residual roots in soil. After the catch crops have dried prior to the winter, the surface of the field was covered with dry plant mass in average amount of 5.9 t ha^{-1}. In the years 2010 and 2011 the cover crop plants produced significantly lower amounts of biomass. During these years the plants developed larger root mass, compared to 2009 observations, but their aboveground parts were much less developed. Soil water deficit stimulate the growth of roots. Average biomass of catch crops, independent from their species, was between 12.5 and 14.8 t·ha^{-1}, and the dry mulch left over, covering the soil during winter averaged between 3.2 and 4.2 t·ha^{-1}. Irrespective of the factors of the experiment the average catch crop biomass for the period of 3 years was 22.5 t·ha^{-1} of fresh plant mass, averaging to 5.0 t·ha^{-1}of dry mass.

The differences of catch crop biomass were a direct result of the very variable weather conditions during the years of the experiment (fig. 1). In analyzing the growth of the plants we must conclude, that the most favourable conditions for the growth of catch crops occurred in 2009. The plants were sprouting steadily, they grew and devel-

Table 2. The biomass of catch crops left in the field in years 2009–2011
Tabela 2. Masa roślin międzyplonowych pozostawiona na polu w latach 2009–2011

	Catch crop Międzyplon	Biomass – Masa (t ha^{-1})							
		fresh – świeża				dry – sucha			
		2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$
Aboveground parts of plants Części nadziemne	*Secale*	22.6	16.8	16.6	18.7	4.7	3.9	5.5	4.7
	Avena	19.7	17.3	12.2	16.4	4.7	4.4	4.0	4.4
	Vicia	18.8	3.7	8.2	10.3	3.8	1.2	1.7	2.2
	Sinapis	24.8	18.8	15.2	19.6	5.7	5.9	5.2	5.6
	Phacelia	60.0	7.0	22.3	29.7	7.1	1.3	4.6	4.3
	Fagopyrum	26.2	6.6	4.9	12.6	6.2	3.1	2.1	3.8
	Helianthus	69.6	17.5	23.9	37.0	8.8	2.8	6.7	6.1
	$\bar{x}$	34.5	12.5	14.8	20.6	5.9	3.2	4.3	4.5
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon A	33.5	13.0	16.3	10.8	n.s.	3.7	5.0	2.4
	years – lata B				5.5				1.2
	A × B				23.1				5.1
Roots Korzenie	*Secale*	2.0	4.9	5.7	4.2	0.7	1.1	1.8	1.2
	Avena	1.5	5.4	4.2	3.7	0.7	1.5	1.0	1.1
	Vicia	0.1	0.1	0.9	0.4	0.1	0.0	0.2	0.1
	Sinapis	0.8	1.4	1.1	1.1	0.5	0.6	0.4	0.5
	Phacelia	1.5	0.3	1.6	1.1	0.3	0.1	0.4	0.3
	Fagopyrum	0.8	0.4	0.5	0.6	0.3	0.2	0.2	0.2
	Helianthus	3.1	2.1	2.4	2.5	0.5	0.3	0.5	0.5
	$\bar{x}$	1.4	2.1	2.4	1.9	0.4	0.6	0.7	0.6
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon A	2.3	2.0	1.3	0.9	0.3	0.4	0.5	0.2
	years – lata B				0.5				0.1
	A × B				1.9				0.4
Total biomass Cała biomasa	*Secale*	24.6	21.8	22.3	22.9	5.4	5.0	7.3	5.9
	Avena	21.2	22.7	16.4	20.1	5.4	5.9	5.1	5.5
	Vicia	18.9	3.8	9.1	10.6	3.9	1.2	1.9	2.3
	Sinapis	25.5	20.1	16.3	20.7	6.3	6.5	5.7	6.1
	Phacelia	61.5	7.2	23.9	30.9	7.4	1.4	5.0	4.6
	Fagopyrum	27.0	7.0	5.4	13.1	6.5	3.4	2.2	4.0
	Helianthus	72.7	19.6	26.3	39.5	9.3	3.2	7.3	6.6
	$\bar{x}$	35.9	14.6	17.1	22.5	6.3	3.8	4.9	5.0
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon A	34.8	14.7	17.3	11.4	n.s.	3.9	5.5	2.4
	years – lata B				5.8				1.3
	A × B				24.4				5.4

*n.s. – no significant differences – różnice nieistotne statystycznie

oped correctly. During that year both August and September were warm and the cooler weather only set in the middle of October, that is after the fragmentation of the catch crops. The precipitations were sparse, but evenly spaced apart. Such weather fostered the stable hydration of the soil (tab. 1) and the growth of plants. When they were fragmented (October 5th) the sunflower, buckwheat, phacelia and vetch were during phase of flowering, rye and oats were heading and the mustard has already blossomed and was developing pods. The years 2010 and 2011, in spite of differences in the distribution of precipitations, did negatively influence the vegetation of catch crops, delaying their growth. The year 2010, although the general water supply was good, in the first decade of August, just after sowing of catch crops, was an intensive period of rain, followed by drought, that caused the soil to crust and prevented the plant emergence. It was also accompanied by very high air temperatures. The additional sowing of vetch and phacelia thus proved necessary, and the growth of all species was largely delayed, especially taking into account, that a very humid September was followed by a dry and cold October. The summer of 2011 was characterized by violent weather phenomena. Rainstorms and thunderstorms lasted till the middle of August. In the third decade of August a period of draught set on, lasting on to November. The effect was, that although the well emergence, the catch crops did not grow, and when they were fragmented before the winter, their biomass was significantly lower than in 2009 (tab. 2).

The selected species of catch crops have reacted differently to this changing weather conditions. In 2009 the largest aboveground biomass was produced by sunflower (69.6 $t \cdot ha^{-1}$) and phacelia (60.0 $t \cdot ha^{-1}$), in 2010 by mustard, sunflower and oats, and in 2011 by sunflower and phacelia again. As we see, the sunflower created the biggest biomass during all of the years of the experiments, which is a direct result of the biological characteristics of this species, but in 2009 its mass was almost 4 times as big as in 2010 and 3 times as big as in 2011. Also in the research of Agele [2003] in the late cropping season, declining status of stored soil water and increasing intensities of water deficits had profound effect on sunflower biomass. Phacelia produced a record biomass in 2009, a large biomass in 2011 (still, 2.69 times smaller), but a very small in 2010 (with just 7.3 $t \cdot ha^{-1}$). Spring rye produced in 2011 a proportionally large mass of both the aboveground parts and roots. All years of the experiment have shown, that the smallest biomass was produced, both in aboveground parts and in roots, by common vetch (10.6 $t \cdot ha^{-1}$) and buckwheat (13.1 $t \cdot ha^{-1}$). In the experiments of Jabłońska-Ceglarek and Rosa [2002] the fresh mass of common vetch, sown as a pre-crop in spring, averaged, for a 3 year period, 11.54 $t \cdot ha^{-1}$. Majority of investigated species produced the largest aboveground mass in 2009 and the smallest in 2011. The exceptions were the sunflower, phacelia and vetch, which in 2011 formed a larger mass than in 2010. It can be connected with the xerophytic properties of both the sunflower and phacelia, which allowed them a better growth in conditions of draught. Smaller crops of phacelia and vetch in 2010 was also a result of weak emergence of these species. The largest average mass, for the period of 3 years, was produced by sunflower, phacelia and spring rye, the lowest by common vetch. In the research of Zaniewicz-Bajkowska et al. [2010] the volume of ploughed organic mass and macroelements with sunflower catch crop decreased with the later period of sowing and shortening of the vegetative period from 92 to 64 days. During the present experiment, the sunflower, although having the same vegetation period of 65 days every year, was in full flowering in 2009, when it was fragmented, and in the stage of creating inflorescences in the later years. Drought during plant growing season of sunflower, reduces the main stem height, stem diameter, number of nodes or leaves and leaf area [Agele 2003, Rauf 2008].

The fertilizer value of after-crops is determined by their dry matter left in the soil and their chemical composition. The largest mass of dry plant parts was left on the field by sunflower, white mustard and spring rye, the smallest by common vetch (tab. 2). In 2009 the sunflower and phacelia dominated this aspect, in 2010 – it was white mustard and in 2011 – spring rye and sunflower. Similarly to the fresh biomass volumes, the smallest amount of dry plant remains, during all of the years of the experiment, was left in the field by the common vetch (2.33 $t \cdot ha^{-1}$ on average).

The chemical composition of both the aboveground parts and roots of the cover crops is shown in table 3. The common vetch has shown the largest general content of nitrogen, both in aboveground parts and in roots, averaged for the 3 years of experiments. Buckwheat gathered the least amount of this element. The catch crops did not differ very much in their content of phosphorus in aboveground parts of the plant, the largest amount of this element in roots was collected by grains (rye and oats) and phacelia. The aboveground parts and roots of phacelia and sunflower proved to be the richest source of potassium. The smallest amount of this element in aboveground organs was found in buckwheat and in roots of oats and rye. Csavajda [2003] has confirmed, that phacelia was found to be a good accumulator of K (2.47–3.09 – 2.07%), and also Mg (0.35–0.26 – 0.49%), Zn (32.99–20.16 – 19.80 ppm) and Cu (8.50–6.41 – 3.84 ppm). Also the experience of Płaza et al. [2009] has shown, that among the non-leguminous plants phacelia proved to have the highest content of macro-elements. High content of potassium and calcium in green parts of phacelia and sunflower was also observed by Wilczewski et al. [2008]. Our own experiments have also shown, that the largest concentration of calcium in aboveground parts and roots was accumulated by phacelia, while the lowest in aboveground parts – by rye and oats and by sunflower and rye – in roots. The largest amount of magnesium in biomass was accumulated by buckwheat, sunflower and phacelia. It also confirms the results obtained by Wilczewski et al. [2008]. The grains and white mustard accumulated the smallest amounts of magnesium. The white mustard dominated, when it came to the content of sulphur in its aboveground parts, which is understandable as sulphur forms an important component when forming glucosinolates, characteristic for plants of the *Brassicaceae* family. The least amount of sulphur was found in buckwheat, and when it comes to roots – also in oats and sunflower.

Although the catch crops were sown on the same day each year, their growth differed and when their biomass was mixed with the soil, they were at different stages of development. It is widely known, that leaves are the richest source of ash components. During fruiting P and K are transferred towards the generative organs, and during the process of plant ageing its content of N, P and K declines, while content of Ca rises [Starck, 2002]. According to the results of study of Hirpa et al. [2009], nutrient (particularly N and K) concentrations of shoot tissue showed a declining trend with increasing plant age. This explains the differences in content of selected nutrient elements in biomass of the same species. Also, during the 3 years of the experiment, not only the pre-

Table 3. Content of nutrients in catch crops in the years 2009–2011

Tabela 3. Zawartość składników pokarmowych w roślinach międzyplonowych w latach 2009–2011

	Species Gatunek	Nutrient (% d.m.) – Składnik pokarmowy (% s.m.)																							
		N-total – N-ogółem				P				K				Ca				Mg				S-SO$_4$			
		2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$
Aboveground parts of plants Części nadziemne	*Secale*	2.22	2.02	1.27	1.83	0.42	0.41	0.20	0.34	2.79	2.29	1.80	2.29	0.48	0.50	0.29	0.42	0.13	0.10	0.07	0.10	0.16	0.13	0.09	0.12
	Avena	1.95	1.56	1.57	1.69	0.41	0.38	0.25	0.34	3.88	2.29	2.63	2.93	0.48	0.41	0.43	0.44	0.14	0.11	0.10	0.12	0.18	0.15	0.10	0.14
	Vicia	3.85	4.04	4.24	4.04	0.32	0.37	0.27	0.32	3.06	2.44	2.66	2.72	1.29	1.17	1.07	1.18	0.25	0.14	0.22	0.20	0.14	0.14	0.10	0.13
	Sinapis	2.20	2.34	1.65	2.06	0.30	0.22	0.20	0.24	2.29	1.93	2.22	2.15	1.99	1.79	1.17	1.65	0.13	0.10	0.13	0.12	0.34	0.36	0.21	0.30
	Phacelia	1.95	2.38	1.75	2.03	0.31	0.37	0.23	0.30	4.56	3.37	2.35	3.42	2.29	2.63	2.98	2.63	0.18	0.24	0.25	0.22	0.16	0.14	0.12	0.14
	Fagopyrum	1.74	1.66	1.22	1.54	0.30	0.34	0.24	0.29	2.29	1.90	1.46	1.88	1.16	0.99	1.04	1.06	0.29	0.20	0.26	0.25	0.07	0.09	0.09	0.08
	Helianthus	1.93	2.02	1.22	1.72	0.25	0.34	0.11	0.23	4.42	3.48	1.40	3.10	1.70	1.72	1.03	1.48	0.23	0.23	0.21	0.22	0.14	0.14	0.09	0.12
	$\bar{x}$	2.26	2.29	1.85	2.13	0.33	0.35	0.21	0.29	3.33	2.53	2.07	2.64	1.34	1.32	1.14	1.27	0.19	0.16	0.18	0.18	0.17	0.16	0.11	0.15
	NIR$_{0.05:}$																								
	species	0.11	0.05	0.06	0.04	0.02	0.02	0.02	0.01	0.14	0.15	0.12	0.06	0.10	0.19	0.11	0.07	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01
	years				0.02				0.01				0.03				0.03				0.01				0.01
Roots Korzenie	*Secale*	1.24	1.04	0.59	0.95	0.37	0.25	0.18	0.27	1.38	1.25	0.71	1.11	0.73	0.42	0.31	0.49	0.12	0.10	0.08	0.10	0.14	0.08	0.08	0.10
	Avena	1.31	1.13	0.68	1.04	0.33	0.23	0.16	0.24	1.33	1.14	0.83	1.10	0.87	0.42	0.38	0.55	0.13	0.10	0.10	0.11	0.08	0.05	0.05	0.06
	Vicia	3.34	3.73	3.19	3.42	0.23	0.26	0.21	0.23	1.87	2.36	2.04	2.09	1.00	0.80	0.66	0.82	0.15	0.17	0.18	0.16	0.16	0.18	0.12	0.15
	Sinapis	0.86	0.87	0.87	0.86	0.22	0.22	0.19	0.21	1.50	1.73	1.10	1.44	0.53	0.45	0.52	0.50	0.06	0.07	0.07	0.07	0.10	0.10	0.09	0.09
	Phacelia	1.10	1.37	0.83	1.10	0.28	0.28	0.19	0.25	3.48	3.43	1.85	2.92	1.09	0.94	1.26	1.09	0.12	0.17	0.12	0.13	0.11	0.10	0.08	0.10
	Fagopyrum	0.92	0.87	0.60	0.80	0.21	0.19	0.17	0.19	1.66	1.06	1.14	1.29	0.99	0.67	0.77	0.81	0.24	0.19	0.21	0.21	0.08	0.07	0.06	0.07
	Helianthus	0.87	1.00	0.60	0.82	0.23	0.26	0.09	0.19	3.55	3.10	1.51	2.72	0.44	0.48	0.41	0.44	0.13	0.12	0.17	0.14	0.07	0.07	0.06	0.06
	$\bar{x}$	1.38	1.43	1.05	1.28	0.27	0.24	0.17	0.23	2.11	2.01	1.31	1.81	0.81	0.60	0.62	0.67	0.14	0.13	0.13	0.13	0.11	0.09	0.08	0.09
	NIR$_{0.05:}$																								
	species	0.11	0.11	0.05	0.04	0.03	0.03	0.02	0.01	0.08	0.41	0.12	0.12	0.08	0.11	0.07	0.04	0.02	0.03	0.03	0.01	0.02	0.03	0.02	0.01
	years				0.02				0.01				0.06				0.02				n.s.				0.01

*n.s. – no significant differences – różnice nieistotne statystycznie

cipitation levels differed, but also the temperatures, which largely influences the accumulation and distribution of nutrients in plant [Perby and Jensen 1986]. Generally speaking the largest amount of nutrients was accumulated by the plants in the year 2009, which beneficially influenced the growth of catch crops. In this year their organs (leaves and stems) were best developed. The least amount of nutrients was found in the 2011 biomass. The draught of that year inhibited the growth of the plants. The exception was phacelia, which in 2011 accumulated the largest concentration of calcium, compared to previous years (2.98% of Ca in dry mass). The element, which accumulation showed the smallest dependence on weather and growth pace of catch crops, was magnesium. Its content did not differ much throughout the years of the experiment.

Based on the performed chemical analyses of the plant material and the biomass created by the plants, the fertilizing value of catch crops was assessed. The amount of nutrients left in the field, with the biomass of the selected catch crops are shown in tables 4, 5 and 6.

The best sources of nitrogen, among the compared species of cover crops, in the period of 3 years proved to be white mustard and sunflower, which left over in their biomass respectively 113.3 and 98.8 kg N-total·ha^{-1} (tab. 4) in the field. The least nitrogen was contained in the biomass of buckwheat (59.5 kg N-total·ha^{-1}). Due to the differences in growth of the plants and accumulation of nutrients (as described above) in different years of the experiments, large variations occurred in this aspect. In 2009 sunflower and common vetch proved to be the richest source of nitrogen for after-crops. White mustard only dominated in this aspect in the following years (2010 and 2011). The least amount of nitrogen was left in the field, in 2009 by oats, in 2010 by phacelia, and in 2011 by buckwheat. In the study of Wyland et al. [1996] phacelia and rye produced over 4 t·ha^{-1} of dry matter and accumulated over 100 kg N·ha^{-1} in it. The largest amount of phosphorus was left over, in 2009, with the biomass of sunflower, phacelia and rye (tab. 4). The content of P in the biomass of these species exceeded 20 kg·ha^{-1}. Rye proved to be the richest source of phosphorus also in the following years. Vetch proved to be the poorest source of phosphorus throughout all of the years of the experiment. But the study of Franchini et al. [2004] proved, that *Vicia sativa* was the most efficient cover crop species as P carrier into the roots from superficial layer to lower layers. The biomass of common vetch also provided the least amount of potassium during the 3 years of the experiment (tab. 5), although in 2011 the least amount of this element was left over in the field with the biomass of buckwheat (30.5 kg K·ha^{-1}). The largest amount of potassium was left over in the field with the biomass of sunflower (191.2 kg·ha^{-1} on average) and phacelia (153.9 kg·ha^{-1} on average). This interdependence was particularly visible in 2009, when those catch crops have left in the field 377.7 and 306.8 kg K·ha^{-1} (respectively). White mustard and oats also proved to be rich sources of potassium in the following years. Phacelia and sunflower were also the richest sources of calcium (tab. 5). Phacelia, which biomass provided 107.0 kg Ca·ha^{-1} on average and 152.6 kg Ca·ha^{-1} in 2009, dominated this aspect. In 2010 the largest amount of calcium was left in the field with the biomass of white mustard (101.6 kg Ca·ha^{-1}). The smallest amounts of calcium were provided by rye and oats, which plant residues only introduced from 23.2 to 23.3 kg Ca·ha^{-1} to the soil. The high fertilizer value of phacelia was confirmed by Jabłońska-Ceglarek and Franczuk [2002], who demonstrated

Table 4. The amount of nitrogen and phosphorus brought to the soil with catch crops in years 2009–2011

Tabela 4. Ilość azotu i fosforu wniesionych do gleby z międzyplonami w latach 2009–2011

	Catch crop Międzyplon	Nutrient – Składnik pokarmowy (kg ha^{-1})							
		N-total – N-ogółem				P			
		2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$
Aboveground parts of plants Części nadziemne	*Secale*	96.6	76.3	66.6	79.8	18.3	15.3	10.5	14.7
	Avena	85.1	65.7	60.5	70.4	17.7	15.8	9.7	14.4
	Vicia	135.9	46.7	68.7	83.8	11.3	4.2	4.3	6.6
	Sinapis	117.2	129.9	80.8	109.3	15.7	12.2	9.8	12.6
	Phacelia	127.5	29.0	76.7	77.7	19.9	4.5	9.9	11.4
	Fagopyrum	100.1	49.2	23.8	57.7	17.0	10.0	4.6	10.5
	Helianthus	157.0	53.2	76.2	95.5	20.0	9.0	6.9	11.9
	$\bar{x}$	117.1	64.3	64.7	82.0	17.1	10.1	7.9	11.7
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	51.6	n.s.	n.s.	n.s.	n.s.
	years – lata				25.3				4.0
Roots Korzenie	*Secale*	8.3	10.8	10.2	9.8	2.5	2.6	3.1	2.7
	Avena	8.4	16.3	6.7	10.5	2.1	3.3	1.6	2.3
	Vicia	2.4	0.9	5.0	2.8	0.2	0.1	0.3	0.2
	Sinapis	4.2	4.5	3.4	4.0	1.0	1.1	0.7	1.0
	Phacelia	2.8	1.4	3.2	2.5	0.7	0.3	0.7	0.6
	Fagopyrum	2.5	2.0	1.0	1.8	0.6	0.4	0.3	0.4
	Helianthus	4.2	3.0	2.9	3.4	1.1	0.8	0.4	0.8
	$\bar{x}$	4.7	5.6	4.6	5.0	1.2	1.2	1.0	1.1
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	6.7	n.s.	n.s.	n.s.	1.2
	years – lata				n.s.				n.s.
Total biomass Cała biomasa	*Secale*	104.9	87.1	76.8	89.6	20.8	17.9	13.6	17.4
	Avena	93.5	82.0	67.2	80.9	19.8	19.1	11.2	16.7
	Vicia	138.4	47.6	73.6	86.5	11.5	4.3	4.6	6.8
	Sinapis	121.4	134.3	84.3	113.3	16.8	13.3	10.5	13.5
	Phacelia	130.3	30.5	79.8	80.2	20.7	4.8	10.6	12.0
	Fagopyrum	102.6	51.2	24.9	59.5	17.6	10.4	4.9	11.0
	Helianthus	161.2	56.2	79.1	98.8	21.1	9.7	7.3	12.7
	$\bar{x}$	121.8	69.8	69.4	87.0	18.3	11.4	9.0	12.9
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	53.8	n.s.	n.s.	n.s.	8.7
	years – lata				26.8				4.4

*n.s. – no significant differences – różnice nieistotne statystycznie

Table 5. The amount of potassium and calcium brought to the soil with catch crops in years 2009–2011

Tabela 5. Ilość potasu i wapnia wniesionych do gleby z międzyplonami w latach 2009–2011

	Catch crop Międzyplon	Nutrient – Składnik pokarmowy (kg ha^{-1})							
		K				Ca			
		2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$
Aboveground parts of plants Części nadziemne	*Secale*	121.5	86.3	94.7	100.8	20.9	18.9	15.3	18.4
	Avena	169.4	96.5	101.6	122.5	21.0	17.3	16.4	18.2
	Vicia	108.0	28.1	43.0	59.7	45.6	13.5	17.3	25.5
	Sinapis	122.0	107.1	108.7	112.6	105.8	99.3	57.3	87.5
	Phacelia	297.9	41.2	103.0	147.3	149.7	32.2	130.3	104.1
	Fagopyrum	131.9	56.3	28.5	72.2	66.9	29.3	20.3	38.8
	Helianthus	360.6	91.7	87.5	179.9	138.3	45.2	64.0	82.5
	$\bar{x}$	187.3	72.4	81.0	113.6	78.3	36.5	45.9	53.6
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	79.6
	years – lata				83.2				39.7
Roots Korzenie	*Secale*	9.2	13.0	12.3	11.5	4.9	4.4	5.4	4.9
	Avena	8.5	16.4	8.1	11.0	5.6	6.0	3.7	5.1
	Vicia	1.4	0.6	3.2	1.7	0.7	0.2	1.0	0.6
	Sinapis	7.3	8.9	4.4	6.8	2.6	2.3	2.1	2.3
	Phacelia	8.9	3.6	7.1	6.5	2.8	1.0	4.8	2.9
	Fagopyrum	4.5	2.4	2.0	3.0	2.7	1.5	1.3	1.8
	Helianthus	17.1	9.2	7.4	11.3	2.1	1.4	2.0	1.8
	$\bar{x}$	8.1	7.7	6.4	7.4	3.0	2.4	2.9	2.8
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	9.2	n.s.	n.s.	n.s.	2.8
	years – lata				n.s.				n.s.
Total biomass Cała biomasa	*Secale*	130.7	99.3	107.0	112.3	25.8	23.3	20.6	23.2
	Avena	177.8	112.9	109.7	133.5	26.5	23.3	20.1	23.3
	Vicia	109.4	28.7	46.2	61.4	46.3	13.7	18.4	26.1
	Sinapis	129.3	116.0	113.1	119.5	108.4	101.6	59.4	89.8
	Phacelia	306.8	44.7	110.1	153.9	152.6	33.1	135.2	107.0
	Fagopyrum	136.3	58.7	30.5	75.2	69.6	30.8	21.6	40.7
	Helianthus	377.7	100.9	94.9	191.2	140.4	46.6	66.0	84.3
	$\bar{x}$	195.4	80.2	87.4	121.0	81.4	38.9	48.8	56.3
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	81.1
	years – lata				86.6				40.5

*n.s. – no significant differences – różnice nieistotne statystycznie

Table 6. The amount of magnesium and sulfur brought to the soil with catch crops in years 2009–2011

Tabela 6. Ilość magnezu i siarki wniesionych do gleby z międzyplonami w latach 2009–2011

	Catch crop Międzyplon	Nutrient – Składnik pokarmowy (kg ha^{-1})							
		Mg				S-SO$_4$			
		2009	2010	2011	$\bar{x}$	2009	2010	2011	$\bar{x}$
Aboveground parts of plants Części nadziemne	*Secale*	5.7	3.6	3.7	4.3	6.8	4.7	4.7	5.4
	Avena	6.1	4.4	3.9	4.8	7.9	6.1	3.9	5.9
	Vicia	8.7	1.6	3.6	4.6	4.9	1.6	1.5	2.7
	Sinapis	6.9	5.3	6.4	6.2	17.9	20.0	10.0	16.0
	Phacelia	11.4	2.9	11.0	8.4	10.5	1.7	5.0	5.7
	Fagopyrum	16.7	5.8	5.1	9.2	3.8	2.5	1.7	2.6
	Helianthus	18.8	5.9	12.8	12.5	11.0	3.7	5.6	6.8
	$\bar{x}$	10.6	4.2	6.6	7.1	8.9	5.8	4.6	6.4
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	8.3	n.s.	n.s.	n.s.	7.1
	years – lata				4.1				3.5
Roots Korzenie	*Secale*	0.8	1.0	1.3	1.0	0.9	0.8	1.3	1.0
	Avena	0.8	1.4	0.9	1.1	0.5	0.6	0.4	0.5
	Vicia	0.1	0.0	0.3	0.1	0.1	0.0	0.2	0.1
	Sinapis	0.3	0.4	0.3	0.3	0.5	0.5	0.4	0.4
	Phacelia	0.3	0.2	0.4	0.3	0.3	0.1	0.3	0.2
	Fagopyrum	0.6	0.4	0.4	0.5	0.2	0.2	0.1	0.2
	Helianthus	0.6	0.4	0.8	0.6	0.3	0.2	0.3	0.3
	$\bar{x}$	0.5	0.5	0.6	0.6	0.4	0.4	0.4	0.4
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	0.6	n.s.	n.s.	n.s.	0.4
	years – lata				n.s.				n.s.
Total biomass Cała biomasa	*Secale*	6.4	4.6	5.0	5.3	7.7	5.6	6.0	6.4
	Avena	6.9	5.9	4.8	5.9	8.3	6.8	4.3	6.5
	Vicia	8.8	1.7	3.8	4.8	5.1	1.7	1.7	2.8
	Sinapis	7.2	5.6	6.6	6.5	18.3	20.5	10.4	16.4
	Phacelia	11.8	3.0	11.4	8.7	10.7	1.8	5.3	5.9
	Fagopyrum	17.4	6.2	5.4	9.7	4.0	2.7	1.8	2.8
	Helianthus	19.4	6.3	13.6	13.1	11.4	3.9	5.9	7.0
	$\bar{x}$	11.1	4.8	7.2	7.7	9.3	6.1	5.1	6.8
	LSD – NIR$_{0.05}$:								
	catch crop – międzyplon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	7.3
	years – lata				4.3				3.6

*n.s. – no significant differences – różnice nieistotne statystycznie

that the biomass of this plant introduced significantly larger amounts of N, P, K, Ca and Mg to the soil, than the biomasses of rye, faba bean or winter vetch. According to Płaza et al. [2009] the biomass of phacelia introduced, on average, 112.3 kg of N, 37.2 kg of P, 92.8 kg of K, 43.4 kg of Ca and 21.0 kg of Mg into the soil, while the white mustard provided (accordingly) 114.8 of N; 26.4 of P; 120.6 of K; 47.3 of Ca and 16,5 kg Mg ha^{-1}. These values differ from those obtained in our experiments, which confirms, that the fertilizer value is largely subject to weather conditions. During the 3 years of the study the best sources of magnesium proved to be the sunflower and buckwheat, which left 13.1 and 9.7 kg Mg·ha^{-1} in the field, on average (tab. 6). A large amount of magnesium (11.4 kg Mg·ha^{-1}) was left in the field, in 2011, by phacelia. The biomass of vetch, rye and oats left the smallest amounts of this element. The biomass of white mustard proved to be the most abundant source of sulphur during all of the years of the experiment, leaving over from 10.4 to 20.5 kg SO_4·ha^{-1}, depending on the year of the experiment. Almost six times lower amounts of this element were left over in the field by the biomass of buckwheat (2.8 kg S-SO_4·ha^{-1}) and common vetch (2.8 kg·ha^{-1}).

The fertilizer value of the catch crops was the highest in 2009, when their biomass left the largest amount of the marked nutrients in the field. The following years have shown a smaller fertilizer value and the plant mulch left, on average 42.9% less nitrogen, 44.3% less phosphorus, 59.1% less potassium, 46.1% less calcium, 45.9% less magnesium and 39.8% less sulphur. Significant differences in the fertilizer values of 9 species of plants cultivated for green manure, depending on the course of weather were also found in the study of Miko et al. [2007]. The experiments subject to our analysis have shown, that due to differences in weather during the years of the experiments, the cover crop plants produced different volumes of aboveground biomass, thus their fertilizer value was different throughout the years of the studies, differing not just between the selected species, but also within the same catch crop. Large changes in weather in the following years of the experiment caused even the species known for their stability of chemical composition, to lower their fertilizer value as a result of their growth being limited by weather conditions.

CONCLUSIONS

1. Catch crops cultivated as pre-crops for the cultivation of vegetables were a rich source of both organic matter and nutrients for their after-crops.

2. The course of weather had a major influence on the volume of biomass, its chemical composition and, through that, on the fertilizer value of catch crops.

3. Shortage of water and high temperatures directly after precipitations, causing the soil to develop crust, were the most important factor in limiting the growth of catch crops.

4. Among the catch crop species subject to our experiment, the sunflower, phacelia and spring rye produced the largest volume of biomass, while the common vetch the smallest.

5. Common vetch proved to be the species mostly influenced by the changing weather. Its biomass left over the least amount of phosphorus, potassium, magnesium

and sulphur, and only small amounts of calcium, when compared to other cover crop plants. Although rich in nitrogen in its dry matter, it also proved not to be its the richest source throughout the three years of the experiment.

6. White mustard and sunflower provided the largest general content of nitrogen. Sunflower proved to be a rich source of potassium, calcium and magnesium. The biggest amount of calcium was left over in the field by phacelia, which also proved to be a good source of potassium. The biomass of buckwheat provided a large amount of magnesium, but it was poor in nitrogen, phosphorus and sulphur. Rye and oats proved to be a rich source of phosphorus, but they also proved to be poor in calcium and magnesium. The largest amount of sulphur was left over in the field by the biomass of white mustard.

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WARTOŚĆ NAWOZOWA MIĘDZYPLONÓW LETNICH POD WARZYWA I JEJ ZMIENNOŚĆ W ZALEŻNOŚCI OD PRZEBIEGU POGODY

Streszczenie. Wraz z upowszechnianiem się upraw ekologicznych wzrasta znaczenie nawozów zielonych, a uprawa roślin międzyplonowych odgrywa coraz większą rolę w praktyce nie tylko rolniczej, ale i ogrodniczej. O wartości nawozowej roślin uprawianych na zielony nawóz decyduje wielkość wytworzonej przez nie biomasy, jak też ilość zgromadzonych w niej składników pokarmowych. Celem opracowania było określenie wpływu przebiegu pogody w drugiej połowie lata na wartość nawozową wybranych międzyplonów ścierniskowych pod warzywa. W badaniach uwzględniono: żyto jare (*Secale cereale*), owies siewny (*Avena sativa*), wyka siewna (*Vicia sativa*), gorczyca biała (*Sinapis alba*), facelia błękitna (*Phacelia tanacetifolia*), gryka (*Fagopyrum esculentum*), słonecznik pastewny (*Helianthus annuus*). Rośliny międzyplonowe uprawiane jako przedplon pod uprawę warzyw były bogatym źródłem materii organicznej oraz składników pokarmowych dla roślin następczych. Przebieg pogody miał istotny wpływ na wielkość biomasy, skład chemiczny i wartość nawozową roślin międzyplonowych. Niedobór wody oraz wysokie temperatury po opadach powodujące zaskorupienie gleby w największym stopniu ograniczały wzrost roślin międzyplonowych. Spośród badanych roślin międzyplonowych największą biomasę wytworzyły słonecznik, facelia i żyto jare, a najmniejszą wyka siewna. Gorczyca biała i słonecznik, jako rośliny międzyplonowe dostarczyły najwięcej azotu ogółem. Słonecznik był bogatym źródłem K, Ca i Mg. Najwięcej Ca pozostawiła na polu facelia błękitna, która była też dobrym źródłem K. Biomasa gryki dostarczyła dużo Mg, ale była uboga w N, P i S. Bogatym źródłem P były żyto i owies, ale okazały się ubogie w Ca i Mg. Najwięcej siarki pozostawiła biomasa gorczycy białej. Wyka siewna najsilniej reagowała na zmienną pogodę. Z jej biomasą na polu pozostało najmniej P, K, Mg i S oraz mało Ca w porównaniu z pozostałymi międzyplonami. Pomimo wysokiej zawartości azotu w suchej masie w bilansie trzech lat wyka nie była najbogatszym źródłem tego składnika.

Słowa kluczowe: opady, temperatura, nawozy zielone

ACKNOWLEDGEMENTS

The research financed from the budget funds for science in 2010–2012 as research project N N310 210837

Accepted for print – Zaakceptowano do druku: 1.03.2012