ACTA *Acta Sci. Pol., Agricultura 12(1) 2013, 65-79*

CATCH CROPS FOR GREEN MANURE: BIOMASS YIELD AND MACROELEMENT CONTENT DEPENDING ON THE SOWING DATE

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Abstract. Catch crop cultivation with the aim of incorporation should be a constant element of improving soil fertility. The most frequently recommended type of green manures for vegetables is stubble catch crops. It is not always possible to sow plants at the optimum date, that is in the second half of July. The aim of the study was to determine the yield of fresh and dry matter of stubble catch crops and macroelement accumulation in them depending on the sowing date. The experiment was carried out in central-east Poland. In years 2004-2006, the yield of fresh and dry matter and macroelement contents were estimated in the following catch crops: phacelia (*Phacelia tanacetifolia* Benth.), amaranth (*Amaranthus cruentus* L.), sunflower (*Helianthus* L.), seradella (*Ornithopus sativus*), and faba bean (*Vicia faba* L. ssp. *minor*). The seeds were sown on three dates: July 21st, August 4th, and August 18th. In the third decade of October, plant samples were collected in order to estimate the yield of fresh and dry matter, as well as macroelements in the catch crops. The amount of biomass and macroelement content depended on the length of catch crop growth season. The highest organic matter yield and macroelement contents were characteristic for the catch crops sown on July 21st, and the lowest ones for the catch crops sown on August 18th. Due to high fresh and dry matter yields, sunflower was the best species to be sown on July 21st, sunflower and phacelia on August 4th, and phacelia on August 18th. Faba bean accumulated the highest amounts of nitrogen and phosphorus in the dry matter. Sunflower accumulated the highest total mass of macroelements (N + P + K + Ca + Mg) in the dry matter yield. The smallest percentage decrease in dry the matter yield and amount of macroelements as a result of delaying the catch crop planting date was found for seradella.

Key words: amaranth, faba bean, macroelement contents, phacelia, seradella, sunflower

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INTRODUCTION

Green manures should become a permanent element of improving soil fertility in the integrated and organic farming systems. It is a factor that alleviates the negative effect of farming intensification, excessive soil compaction, and one-sided mineral fertilization [Grassbaugh *et al*. 2004, Kristensen and Thorup-Kristensen 2004, Rogers *et al*. 2004]. Additionally, it allows farmers to apply lower amounts of herbicides and pesticides [Abdul-Baki *et al*. 1996, 1997].

Increasing numbers of farms where no livestock is raised have led to a significant deficit of farmyard manure [Małecka *et al*. 2004]. Due to the fact that animal manure supply is decreasing in Poland, cultivation of catch crops is gaining more and more importance, the crops being either incorporated into the soil as green manures or retained on the soil surface as mulch [Songin 1998, Mazur *et al*. 2003]. Catch crops have a wide range of positive effects on the cropping systems, in conventional as well as organic farming [Kolbe *et al*. 2004]. They are introduced into the rotation to supply biomass. Moreover, catch crops have important ecological functions, since they reduce soil erosion by covering the soil, improve soil fertility through an input of organic matter, and increase water-holding capacity of the soil [Joyce *et al*. 2002]. They prevent leaching of plant-available nutrients, in particular nitrogen, to the subsoil and groundwater [Clark *et al*. 2007, Collins *et al*. 2007]. Numerous studies have shown that cultivation of catch crops reduces nitrates leached into groundwater by 40%-60% [Martinez and Guiraud 1990, Jensen 1991, Hansen and Djurhuus 1997], which is of great importance as far as the protection of the agricultural environment is concerned. It also makes it possible to apply lower amounts of mineral fertilizers [Anderson *et al*. 1990]. Many species cultivated as catch crops play a phytosanitary role in reducing disease occurrence in subsequent crops [Davis *et al*. 1996]. Effectiveness of green manures depends to a large extent on incorporated plant matter, mineralization rate, and weather conditions [Brzeski *et al*. 1993].

The possibility of using green manures as a source of organic matter in vegetable cultivation has been reported by many authors [Sharma *et al*. 1988, Creamer 1996, Mwaja *et al*. 1996, Jabłońska-Ceglarek *et al*. 2004, Kołota and Adamczewska-Sowińska 2004]. In Poland, stubble catch crops are the most commonly applied types of green manures in vegetable production. Stubble catch crops are sown from late July to mid-August and are incorporated in late October. They precede vegetables planted in the early spring of the following year. In the autumn, whole plants of catch crops are usually ploughed down. In the case of species that produce a lot of green mass, the above-ground parts of plants are cut or crushed by rolling in order to make incorporation easier. A special role in increasing soil fertility is attributed to legumes. High-yielding legume catch crops may increase subsequent yields as much as farmyard manure incorporated at the rate of 25 $t \cdot ha^{-1}$ or even 60 $t \cdot ha^{-1}$ [Songin 1998, Franczuk and Jabłońska-Ceglarek 2002]. Catch crop plants can represent other botanical families, too. The most frequently grown species include: phacelia *(Phacelia tanacetifolia* Benth.*)*, oat (*Avena sativa* L.), rye (*Secale cereale* L.), rapeseed (*Brassica napus* L. var. *oleifera*), and white mustard (*Sinapis alba* L.). Catch crops sown in late July produce the highest yields due to the most favourable growth conditions. It is not always possible to sow plants at the optimal date, that is between the 20th and 25th of July. What is more, it is often necessary to slightly delay the sowing time due to vegetables being harvested later in the growth season.

The objective of the work was to evaluate the yield of fresh and dry matter and the accumulation of macroelements in catch crops, in particular in the species that are not currently used as green manures in Poland in vegetable cultivation, that is sunflower and amaranth. Different sowing dates were chosen to determine the effect of delayed sowing of catch crops on their growth.

MATERIAL AND METHODS

Study site and treatments

Field experiment was conducted in years 2004-2006 at the Experimental Farm in Zawady, located in central-east Poland (52º03’ N; 22º33’ E), 115 km east of Warsaw.

In all the study years, temperatures were higher by 0.4-0.7°C than the many-years’ average (1951-1990). In the years 2004 and 2005, precipitation during the growth season of catch crops planted at all the three dates was lower than the many-years’ average. In 2006, precipitation was lower only in the growth season of catch crops sown on the third date (Table 1). Growth of catch crops in the years 2004 and 2005 was hampered because of the shortage of precipitation.

Table 1. Weather conditions during the period of study

Year	Mean air temperature, °C				Precipitation, mm			
	yearly	in the growth period of catch crop sowing			yearly	in the growth period of catch crop sowing		
		July 21st	August 4th	August 18th		July 21st	August 4th	August 18th
2004	7.9	15.0	13.8	13.1	430.5	129.5	109.7	65.8
2005	8.0	15.3	13.7	13.9	353.6	139.0	61.2	16.1
2006	8.2	16.6	14.4	13.7	428.4	272.9	270.5	83.0
Mean 1951-1990	7.5	13.8	12.5	11.0	514.9	174.0	140.0	100.2

The soil in the experiment was luvisol. Soil organic matter (SOM) content averaged 1.5% and its humus horizon reached the depth of 0.3-0.4 cm. The value of pH determined in H_2O was 5.8. The total phosphorus content was 71, potassium 92, calcium 379, magnesium 42, $N\text{-}NO_3$ 11, and $N\text{-}NH_4$ 7 $mg \cdot kg^{-1}$ a.d.m. (aerial dry matter).

The experiment was set up as a split-block design in four replications. The following plants were grown for green manures (with seeding rates in brackets): phacelia (17 $kg \cdot ha^{-1}$), amaranth (3 $kg \cdot ha^{-1}$), sunflower (30 $kg \cdot ha^{-1}$), seradella (60 $kg \cdot ha^{-1}$), and faba bean (250 $kg \cdot ha^{-1}$). Phacelia, faba bean, and seradella are common green manures in Poland. However, there is a lack of research regarding the fertilizing values of amaranth and sunflower. These species are of interest because of high green mass production over a short period of time. Selection of new species cultivated for green manure allows farmers to vary rotation, improve the growth conditions and health of plants, and, as a result, increase yields of the crops that follow them. The seeds of catch crops were sown at three dates at two-week intervals, namely: date I – July 21st, date II – August 4th, and date III – August 18th. Growth season for the studied catch crops lasted for 92, 78, and 64 days for sowing dates I, II, and III, respectively. Preplant nitrogen fertilizer applications were made at the rate of 80 kg $N \cdot ha^{-1}$ for phacelia, amaranth, and sunflower, and 20 kg $N \cdot ha^{-1}$ for legumes - seradella - and faba bean. Phosphorus and potassium fertilization for all the catch crops amounted to 26 kg $P \cdot ha^{-1}$ and 66 kg $K \cdot ha^{-1}$. The applied mineral fertilizers included ammonium nitrate, triple superphosphate, and 60% potassium chloride. The mineral fertilizers were applied in each sub-block five days before seed sowing. Amounts of mineral fertilizers were formulated following the recommendations for the particular species of crops cultivated for green manure. Catch crops were part of the agricultural-vegetable rotation. The forecrop was winter barley. Mineral fertilizers supplied nutrients for catch crops cultivated for green manure preceding early vegetables cultivated in the following year.

The whole experimental area was 5200 m^2 and one plot for harvest had 56 m^2. The whole experimental area included spaces between the plots.

Response measurements

In late October, plant material samples (whole plants with roots) were collected from 1 m^2 in two randomly selected places in each sub-plot by means of the frame method in order to determine:

– yield of fresh matter (FM) and dry matter (DM) of the catch crops,

– macroelement contents in the catch crops (plants with roots).

Dry matter content (DM) in the catch crops was determined with the use of oven-drying gravimetric method according to the norm PN-88/R-04013. Total Kjeldahl N of all plants was determined by Tecator Kjeltec System 1026 analyzer. Phosphorus content was measured by colorimetry with SPEKOL 221 spectrophotometer. Potassium and calcium were determined with FLAPHO 41 flame photometer. Magnesium was determined with SOLAR 929 ATI UNICAM atomic absorption spectrophotometer.

Statistical analysis

The results of the experiment were statistically analysed by means of the analysis of variance, following the mathematical model for the split-block design. Significance of differences was determined by the Tukey's test at the significance level of $P = 0.05$. Calculations were performed using the author's program base.

RESULTS

Yields of fresh and dry matter of catch crops

Fresh and dry matter yields of catch crops depended on the interaction between the planting dates and catch crop species (Figs 1 and 2).

Sunflower, which produced 40.4 $t \cdot ha^{-1}$ fresh matter and 7.4 $t \cdot ha^{-1}$ dry matter, was the best crop to plant on June 21st. Of the legumes sown in July, faba bean was definitely better (32.5 $t \cdot ha^{-1}$ FM and 5.4 $t \cdot ha^{-1}$ DM) than seradella (16.7 $t \cdot ha^{-1}$ FM and 2.9 $t \cdot ha^{-1}$ DM). When the planting date was delayed by 2 weeks (August 4th), similar fresh and dry matter yields of sunflower (33.7 $t \cdot ha^{-1}$ and 5.9 $t \cdot ha^{-1}$, respectively) and phacelia (33.7 $t \cdot ha^{-1}$ and 5.5 $t \cdot ha^{-1}$, respectively) were recorded, the decrease in phacelia yield being lower than in sunflower. Of the legumes, yields of faba bean were higher (25.2 $t \cdot ha^{-1}$ FM and 4.1 $t \cdot ha^{-1}$ DM) than seradella (15.8 $t \cdot ha^{-1}$ FM and 2.7 $t \cdot ha^{-1}$ DM). When the planting date was delayed by 4 weeks (August 18th), fresh and dry matter yields of phacelia were higher by 3.7 and 0.4 $t \cdot ha^{-1}$, respectively, than sunflower yields. However, the yields of fresh and dry matter of seradella did not differ significantly from the yields of faba bean.

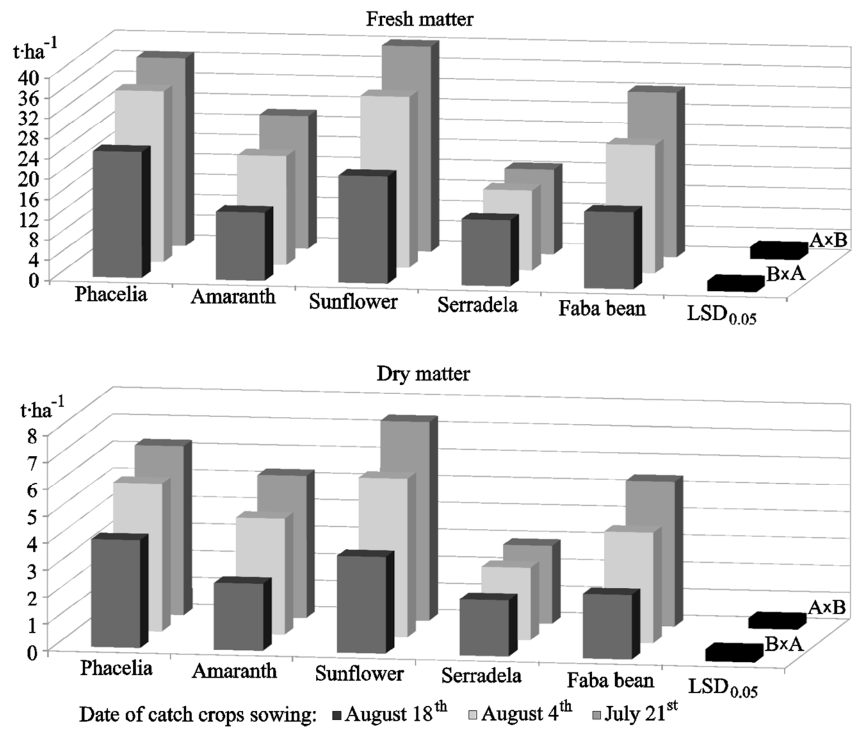

Fig. 1. Quantity of fresh and dry matter incorporated with catch crops depending on the sowing date: mean values for 2004-2006

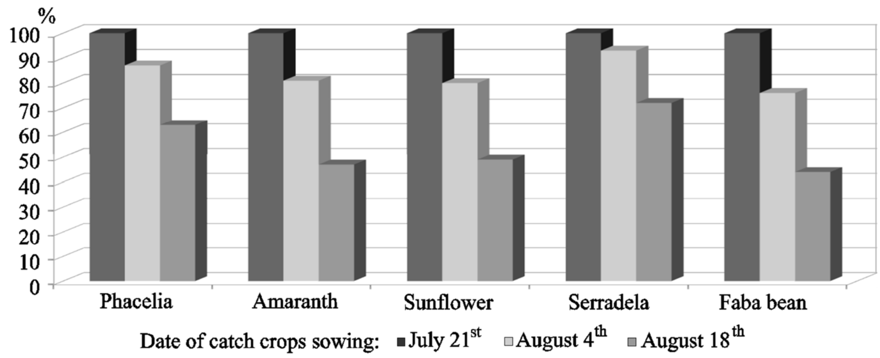

Fig. 2. Percentage decrease in the dry matter yield of catch crops while delaying their sowing date (yield of DM from the 1st sowing date = 100%), %

Mean dry matter amount incorporated with sunflower corresponded to the quantity introduced into the soil with 21.7 $t \cdot ha^{-1}$ farmyard manure. Ploughing down of phacelia supplied the soil with the same amount of dry matter as farmyard manure at the rate of 20.3 $t \cdot ha^{-1}$, the respective values for amaranth, faba bean, and seradella being 15.5, 15.3, and 9.9 $t \cdot ha^{-1}$, respectively.

Detailed data regarding individual planting dates are demonstrated in Table 2.

Table 2. Dry matter incorporated with catch crops counted as the suitable dose of farmyard manure: mean values for 2004-2006, t

Catch crop type	Catch crop sowing date			Mean
	July 21st	August 4th	August 18th	
Phacelia	24.2	21.2	15.4	20.3
Amaranth	20.4	16.6	9.6	15.5
Sunflower	28.5	22.7	13.9	21.7
Seradella	11.2	10.4	8.1	9.9
Faba bean	20.8	15.8	9.2	15.3

The lowest percentage decrease in dry matter yield following the delayed sowing of catch crops was associated with seradella (Fig. 2). Dry matter yield of seradella sown on August 4th and 18th was lower by 6.9% and 27.6%, respectively, compared with the dry matter yield of seradella sown on July 21st. Relatively small decrease (12.7%) in dry matter yield between planting date II and I was recorded for phacelia. Higher decrease in dry matter yield was found in faba bean, amaranth, and sunflower. When they were planted on August 4th and 18th, faba bean plants produced lower yield by, respectively, 24.1% and 55.6%, amaranth by 18.9% and 52.8%, and sunflower by 20.3% and 51.4% compared with the plants sown on July 21st.

Concentration of macroelements in the catch crops

The differences in the contents of macroelements in the catch crops sown on successive dates were small but statistically confirmed for nitrogen, phosphorus, and potassium. A two-week delay in catch crop sowing (August 4th) decreased nitrogen and potassium concentration. When planting was delayed by additional 2 weeks (August 18th), continued decrease in the concentration of nitrogen and phosphorus in the plants was recorded (Tables 3 and 4).

Of the plants sown on all the three dates, the highest nitrogen concentration was associated with the legumes, in particular with seradella, whereas the lowest with sunflower and phacelia.

Table 3. Nitrogen and phosphorus contents in the catch crops depending on the sowing date: mean values for 2004-2006, % DM

Catch crop type	Nitrogen				Phosphorus			
	catch crop sowing date			mean for catch crops	catch crop sowing date			mean for catch crops
	July 21st	August 4th	August 18th		July 21st	August 4th	August 18th	
Phacelia	1.66	1.63	1.57	1.62	0.40	0.38	0.37	0.38
Amaranth	2.15	2.07	2.00	2.07	0.51	0.51	0.49	0.50
Sunflower	1.59	1.56	1.53	1.56	0.26	0.27	0.26	0.26
Seradella	2.68	2.72	2.65	2.69	0.42	0.44	0.41	0.42
Faba bean	2.52	2.49	2.38	2.46	0.61	0.60	0.57	0.59
Mean for sowing date	2.12	2.09	2.03	2.08	0.44	0.44	0.42	0.43
$LSD_{0.05}$ for:								
catch crop sowing date			0.03				0.02	
catch crop type			0.09				0.03	
sowing date × catch crop type			0.06				0.02	
catch crop type × sowing date			0.05				0.02	

Table 4. Potassium, calcium, and magnesium contents in the catch crops depending on the sowing date: mean values for 2004-2006, % DM

Catch crop type	Potassium				Calcium				Magnesium			
	catch crop sowing date			mean for catch crops	catch crop sowing date			mean for catch crops	catch crop sowing date			mean for catch crops
	July 21st	August 4th	August 18th		July 21st	August 4th	August 18th		July 21st	August 4th	August 18th	
Phacelia	2.44	2.33	2.35	2.37	1.15	1.15	1.16	1.15	0.44	0.44	0.42	0.43
Amaranth	3.57	3.48	3.46	3.50	1.39	1.41	1.40	1.40	0.60	0.56	0.58	0.58
Sunflower	3.24	3.27	3.20	3.24	1.31	1.31	1.32	1.31	0.56	0.55	0.55	0.55
Seradella	1.79	1.67	1.79	1.75	0.46	0.47	0.45	0.46	0.29	0.30	0.30	0.30
Faba bean	2.05	2.00	2.00	2.02	0.56	0.50	0.55	0.54	0.35	0.36	0.35	0.36
Mean for sowing date	2.62	2.55	2.56	2.58	0.97	0.97	0.97	0.97	0.45	0.44	0.44	0.44
$LSD_{0.05}$ for:												
catch crop sowing date			0.05				ns				ns	
catch crop type			0.08				0.05				0.02	
sowing date × catch crop type			ns				ns				ns	
catch crop type × sowing date			ns				ns				ns	

ns – non-significant differences

The highest phosphorus content (0.59% d.m.) was found in faba bean and the lowest (0.26% d.m.) in sunflower. The remaining catch crops contained from 0.38% to 0.50% d.m. The differences between the species were significant (Table 3).

The examined plant species differed significantly in terms of potassium, calcium, and magnesium contents. Content analysis made it possible to establish the following order (most to least K, Ca, and Mg): amaranth, sunflower, phacelia, faba bean, and seradella. Non-legume plants contained significantly more potassium, calcium, and magnesium than legumes (Table 4).

The quantity of macroelements incorporated with catch crops

The quantity of minerals accumulated in catch crops is the outcome of their matter and percentage content of a given mineral. Due to biological N fixation, the legumes, seradella, and faba bean were a net source of nitrogen. In the present experiment, the planting date, catch crop species, and interaction between these factors had a significant effect on the quantity of macroelements incorporated with catch crops (Tables 5 and 6).

Of the catch crops sown on July 21st and August 4th, the highest amounts of nitrogen and phosphorus were accumulated in the tissues of faba bean, whereas of the crops sown on August 18th the highest amount of nitrogen was accumulated by phacelia, and phosphorus by phacelia, amaranth, and faba bean. Seradella accumulated significantly less nitrogen and phosphorus when planted on the first and second date. The quantity of nitrogen in the dry matter of seradella planted on the third date did not differ significantly from the remaining crops. In turn, the amount of phosphorus was significantly lower than the amounts found in faba bean, amaranth, and phacelia (Table 5).

Table 5. Quantity of nitrogen and phosphorus incorporated with catch crops depending on the sowing date: mean values for 2004-2006, kg·ha^{-1}

Catch crop type	Nitrogen				Phosphorus			
	catch crop sowing date			mean for catch crops	catch crop sowing date			mean for catch crops
	July 21st	August 4th	August 18th		July 21st	August 4th	August 18th	
Phacelia	105.4	90.9	64.3	86.9	25.1	21.2	14.7	20.3
Amaranth	113.9	88.2	50.4	84.1	26.9	21.5	12.3	20.3
Sunflower	117.5	91.9	56.0	88.5	19.5	15.9	9.4	14.9
Seradella	78.9	73.0	57.1	69.6	12.5	11.8	8.8	11.0
Faba bean	135.3	101.8	57.6	98.2	32.6	24.6	13.9	23.7
Mean for sowing date	110.2	89.2	57.1	85.5	23.3	19.0	11.8	18.1
$LSD_{0.05}$ for:								
catch crop sowing date			7.4				1.9	
catch crop type			9.9				2.6	
sowing date × catch crop type			10.5				2.4	
catch crop type × sowing date			9.0				2.0	

Potassium, calcium, and magnesium uptake by sunflower sown at all the dates was significantly higher compared with the remaining catch crops. This resulted from high dry matter yield of sunflower. Of the plants sown on July 21st and August 4th, the lowest amounts of potassium, calcium, and magnesium were accumulated by seradella, as well as by seradella and faba bean when sown on August 18th (Table 6).

Table 6. Quantity of potassium, calcium, and magnesium incorporated with catch crops depending on the sowing date: mean values for years 2004-2006, $kg \cdot ha^{-1}$

Catch crop type	Potassium				Calcium				Magnesium			
	catch crop sowing date			mean for catch crops	catch crop sowing date			mean for catch crops	catch crop sowing date			mean for catch crops
	July 21st	August 4th	August 18th		July 21st	August 4th	August 18th		July 21st	August 4th	August 18th	
Phacelia	153.8	128.5	94.7	125.7	73.0	64.0	46.8	61.3	27.7	24.3	17.1	23.0
Amaranth	188.3	147.5	86.8	140.9	73.3	59.9	35.0	56.1	31.6	23.9	14.5	23.3
Sunflower	239.4	192.8	117.1	183.1	96.1	77.4	47.1	73.5	41.0	32.6	19.8	31.1
Seradella	52.3	43.7	38.3	44.8	13.6	12.3	9.4	11.8	8.5	7.9	6.4	7.6
Faba bean	110.2	81.9	48.3	80.1	30.1	20.6	13.3	21.3	19.0	14.8	8.5	14.1
Mean for sowing date	148.8	118.9	77.0	114.9	57.2	46.8	30.4	44.8	25.6	20.7	13.3	19.8
$LSD_{0.05}$ for:												
catch crop sowing date			9.4				4.2				1.7	
catch crop type			9.9				4.7				1.9	
sowing date × catch crop type			14.0				6.3				2.5	
catch crop type × sowing date			12.0				5.3				2.2	

Estimates of dry matter yield of catch crops and macroelement contents were referred to the respective values for farmyard manure, which is the most commonly used type of manure in Poland. Dry matter and macroelement contents in farmyard manure are presented as average values in years 1980-2006. The quantities of dry matter and macroelements introduced into the soil with farmyard manure were converted to the farmyard manure (FYM) rate of 10 t·ha^{-1} (Table 7).

Table 7. Content and quantity of dry matter and macroelements introduced into the soil by farmyard manure at the rate of 10 t·ha^{-1}: mean values for 1980-2006

Dry matter	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Total macroelements
%	% DM					
25.7	1.39	0.66	1.98	0.85	0.51	–
t·ha^{-1}	kg·ha^{-1}					
2.6	35.7	16.9	50.8	21.7	13.0	138.10

Comparison of the plants sown on July 21st and August 4th showed that the quantity of nutrients per 1 ha in the dry matter of sunflower was the highest and corresponded to the quantity contained in 37.2 and 29.7 t farmyard manure, respectively (Table 8). Of the remaining plants, the highest rate of farmyard manure corresponded to the quantity of macroelements accumulated in the dry matter of amaranth and phacelia. In the case of plants sown on the third date, the highest quantity of farmyard manure (18.1 and 17.2 t) corresponded to the quantity of macroelements in the dry matter of sunflower and phacelia, respectively.

The quantity of macroelements in seradella on all the three dates corresponded to the lowest amount of farmyard manure.

Table 8. The quantity of total makroelements (N + P + K + Ca + Mg) incorporated with catch crops depending on sowing date: mean values for 2004-2006, kg·ha^{-1}

Catch crop type	N + P + K + Ca + Mg				Dose of farmyard manure contain the same quantity of macroelements, t			
	catch crop sowing date			mean for catch crops	catch crop sowing date			mean for catch crops
	July 21st	August 4th	August 18th		July 21st	August 4th	August 18th	
Phacelia	385.0	328.9	237.6	317.2	27.9	23.8	17.2	23.0
Amaranth	434.0	340.9	199.0	324.6	31.4	24.7	14.4	23.5
Sunflower	513.5	410.6	249.5	391.2	37.2	29.7	18.1	28.3
Seradella	165.8	148.7	120.0	144.8	12.0	10.8	8.7	10.5
Faba bean	327.2	243.7	141.6	237.5	23.7	17.6	10.3	17.2
Mean for sowing date	365.1	294.5	189.5	283.1	26.4	21.3	13.7	20.5
$LSD_{0.05}$ for:								
catch crop sowing date			23.5				1.7	
catch crop type			26.9				2.0	
sowing date × catch crop type			33.0				2.4	
catch crop type × sowing date			28.2				2.0	

DISCUSSION

One of the most important criteria in assessing and comparing the fertilizer value of catch crops is the quantity of dry matter they introduce into the soil when incorporated. Depending on the species and the stage of development, fresh and dry matter yields can be very different. Bochniarz [1998] reported that good stubble catch crops supply about 2-3 t of dry matter per ha. In the present studies, an average yield of sunflower dry matter amounted to 5.7 $t \cdot ha^{-1}$, phacelia 5.3 $t \cdot ha^{-1}$, amaranth and faba bean 4.0 $t \cdot ha^{-1}$, and seradella 2.6 $t \cdot ha^{-1}$. Similar yield of faba bean dry matter (4.3 $t \cdot ha^{-1}$) was reported by Zając and Antonkiewicz [2006] and of sunflower (5.5 $t \cdot ha^{-1}$) by González-Fernández [1980]. According to Rodríguez-Lizana *et al*. [2010], the dry matter yield of sunflower was lower and amounted to 2.5 $t \cdot ha^{-1}$. Wyland *et al*. [1996] showed that the dry matter yield of phacelia was lower than in the present studies and amounted to 3.64 $t \cdot ha^{-1}$. According to Gregorová *et al*. [2001], the dry matter yield of the above-ground parts of amaranth was 9.0 $t \cdot ha^{-1}$.

The more delayed the sowing date and the shorter the period of plant growth, the smaller the dry matter yield. This is why the species selected for cultivation as catch crops are characterized by rapid growth rate and short growth season.

In the present study, delaying the sowing date by two and four weeks decreased the yields of fresh and dry matter of catch crops by the average of 16.6% and 44.8%, respectively. Similar relations were reported for eastern Canada by Abdin *et al*. [1997], who compared 12 catch crops and, when delaying planting by 10 days, obtained biomass yield which was lower by 17.5%-32%. Also Richards *et al*. [1996] showed that, in the weather conditions of England, earlier sowing (late August) of phacelia, Italian ryegrass, mustard, forage rapeseed, and rye was more beneficial than delayed sowing. Campbell and Abott [1982] claim that fresh matter yield of amaranth depended on the planting date and ranged from 4.0 to 16.5 $t \cdot ha^{-1}$.

The chemical composition of plants, or, more precisely, the parameters that determine soil organic matter susceptibility to biodegradation, that is nitrogen content, C-to-N ratio, and lignin, are the next factor that determines their potential fertilizer value [Jawson and Elliot 1986]. If the carbon content in the plant is assumed to be at the relatively stable level of about 40%, nitrogen content is the most important factor that influences the rate of biomass mineralization [Mazur 1995]. According to Lewis [1986], when the nitrogen content in the biomass is lower than 1.2%, the predominating biological processes retard mineral nitrogen accumulation in the soil. In turn, values of above 1.8% are associated with direct N mineralization (release).

Nitrogen concentration in the crops examined in the experiment was over 1.2%, which, when related to the criterions presented by Lewis [1986], indicates that the application of catch crops as green manure did not cause biological nitrogen immobilization. Amaranth, faba bean, and seradella contained more than 1.8% nitrogen, part of which could be a source of this macroelement for the subsequent plants, and partly replace nitrogen mineral fertilization.

Also Novoselova and Frame [1992] underscored that biological nitrogen, being the product of symbiosis with root-nodule bacteria, could be an alternative to mineral fertilization. Jabłoński [1993] showed that green manures of catch crops, including legumes, incorporated into light soils could supply more nitrogen than inappropriately fermented farmyard manure.

According to Wilczek and Ćwintal [1991], mineral content in plants (apart from species diversity) is conditioned by planting date. Nowak [1990] reported that mineral content in plants depends on their age and is higher in young plants. As plants grow and age, their mineral concentration decreases but the accumulated amount of dry matter increases. As a result, the overall amount of minerals in older plants is higher compared with younger plants. In those studies, lower percentage of nitrogen, phosphorus, and potassium was determined in the dry matter of plants sown at a later date when they were younger. Simultaneously, plants sown earlier accumulated significantly more nutrients due to the higher organic mass and concentration of macroelements.

The experimental legumes introduced the nitrogen amounts of seradella 69.6 $kg \cdot ha^{-1}$ and faba bean 98.2 $kg \cdot ha^{-1}$. According to Wilczewski and Skinder [2005], seradella accumulates a similar nitrogen quantity (62.1 $kg \cdot ha^{-1}$). Many authors have reported that the quantity of nitrogen taken up by legumes ranges from 50 to 100 $kg \cdot ha^{-1}$ [Rosolem *et al*. 2002, Balkcom and Reeves 2005].

Kärner and Kärner [1996] showed that legumes cultivated on light and acid soils could fix between 100 and 172 kg of nitrogen per hectare per year.

In the present studies, phacelia, amaranth, and sunflower accumulated 86.9, 84.1 and 88.5 $kg \cdot ha^{-1}$ nitrogen, respectively. Other authors claim that phacelia accumulates more nitrogen; Wyland [1996] reported the level of 106 kg $N \cdot ha^{-1}$, Thorup-Kristensen [1994] 147 kg $N \cdot ha^{-1}$, Richards *et al*. [1996] 166 kg $N \cdot ha^{-1}$, Jackson *et al*. [1993] and Bugg's [1995] 182 kg $N \cdot ha^{-1}$. According to Wilczewski and Skinder [2005], nitrogen accumulation in sunflower amounted to 79 $kg \cdot ha^{-1}$.

Large amounts of plant material incorporated into the soil imply field level nutrient balances with large P and K surpluses [Riley *et al*. 2003]. In the present studies, the highest amount of phosphorus was accumulated by faba bean, and potassium, calcium, and magnesium by sunflower. Wilczewski and Skinder [2005] found that significantly more phosphorus, potassium, and calcium was accumulated by phacelia, sunflower biomass being characterized by the highest magnesium content.

More potassium was determined in non-legume catch crops than in legumes. They also accumulated significantly more potassium compared with the N amount supplied into the soil by mineral fertilizers applied before seed planting (phacelia 189%, amaranth 211%, and sunflower 275% of the quantity supplied by mineral fertilization). Wilczewski and Skinder [2005] showed that potassium quantity in catch crops could be higher by 267%-428% than the amount applied in fertilizers. The authors stressed the possibility of using catch crops to protect the soil against the loss of nutrients which remain unused by the crops that precede catch crops. In the present studies, the quantity of nutrients (N, P, K, Ca, and Mg) in catch crops corresponded to their quantity supplied by farmyard manure at the rate of 10.5 t (seradella) to 28.3 t (sunflower).

CONCLUSIONS

The highest yields of fresh and dry matter were produced by sunflower and phacelia. Phacelia can be recommend for delayed sowing, since it produced high biomass yield even at the planting date delayed by four weeks. Sunflower, amaranth, and faba bean sown at that date produced lower biomass, the drop ranging between 47% and 55%. Seradella, which produced the lowest yield at all the planting dates, was the most stable in terms of yield when it was necessary to delay sowing. Faba bean green manure provided the soil not only with a large quantity of organic matter, but also replaced, to a great extent, mineral N fertilization. Altogether, sunflower accumulated the highest amounts of N, P, K, Ca, and Mg in dry matter. Catch crops fixed substantial amounts of nitrogen and other nutrients taken up from the soil, and in this way prevented them from leaching into the deeper layers of the soil profile. However, the process was less and less effective as planting was delayed because plant mass yield was much lower.

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ROŚLINY MIĘDZYPLONOWE NA ZIELONY NAWÓZ: PLON BIOMASY I ZAWARTOŚĆ MAKROSKŁADNIKÓW W ZALEŻNOŚCI OD TERMINU SIEWU

Streszczenie. Uprawa międzyplonów w celu ich przyorania powinna być stałym elementem podnoszenia żyzności i jakości gleby. Najczęściej polecanym rodzajem nawozów zielonych pod warzywa są międzyplony letnie (ścierniskowe). Nie zawsze istnieje jednak możliwość ich siewu w optymalnym terminie, tj. w drugiej połowie lipca. Celem badań było określenie plonu świeżej i suchej masy międzyplonów ścierniskowych oraz akumulacji w nich makroskładników w zależności od terminu siewu. Eksperyment przeprowadzono w środkowo-wschodniej Polsce. W latach 2004-2006 określono plon świeżej i suchej masy oraz zawartość makroelementów w roślinach międzyplonowych: facelii (*Phacelia tanacetifolia* Benth.), szarłatu (*Amaranthus cruentus* L.), słonecznika (*Helianthus* L.), seradeli (*Ornithopus sativus*) i bobiku (*Vicia faba* L. ssp. *minor*). Międzyplony wysiewano w trzech terminach: 21 lipca, 4 i 18 sierpnia. W trzeciej dekadzie października pobrano próby roślin w celu określenia plonu świeżej i suchej masy oraz składników mineralnych w międzyplonach. Ilość wytworzonej biomasy oraz zawartość makroelementów zależała od długości okresu wegetacji roślin międzyplonowych. Największym plonem masy organicznej i składników mineralnych charakteryzowały się międzyplony posiane 21 lipca, najmniejszym posiane 18 sierpnia. Ze względu na wysoki plon świeżej i suchej masy do wysiewu 21 lipca najbardziej godnym polecenia gatunkiem okazał się słonecznik, 4 sierpnia – słonecznik i facelia, a 18 sierpnia – facelia. Najwięcej azotu i fosforu zakumulował w suchej masie bobik. Łącznie największą masą makroskładników (N + P + K + Ca + Mg) w plonie suchej masy charakteryzował się słonecznik. Najmniejszą procentową obniżkę w plonie suchej masy i ilości składników mineralnych w wyniku opóźnienia terminu siewu roślin międzyplonowych stwierdzono u seradeli.

Słowa kluczowe: bobik, facelia, seradela, słonecznik, szarłat, zawartość makroelementów

Accepted for print – Zaakceptowano do druku: 18.03.2013