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THE INFLUENCE OF STRIP CROPPING AND ADJACENT PLANT SPECIES ON THE CONTENT AND UPTAKE OF N, P, K, Mg AND Ca BY MAIZE (*ZEA MAYS* L.)

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ABSTRACT

Strip cropping is a form of intercropping in which two or more crop species are grown in adjacent strips. Maize is often grown in strip cropping because it strongly reacts to the edge effect with increased yield. A field experiment was conducted in the years 2008-2010 at the Experimental Station in Zamość, University of Life Sciences in Lublin (50°42'N, 23°16'E). Two cropping methods, sole cropping and strip cropping (narrow-leafed lupin, dent maize and spring oats in adjacent strips), and two weed control methods, mechanical and chemical, were compared. The aim of the study was to assess the impact of the cropping systems and weed control methods on content and uptake of nitrogen, phosphorus, potassium, magnesium and calcium by maize. The impact of the position of the row in strip cropping and of the adjacent plant species on changes in nutrient content and uptake was also studied. Strip cropping significantly increased potassium and calcium content in the maize, but decreased the content of nitrogen, phosphorus and magnesium. In strip cropping, proximity to oats contributed to higher potassium content in the maize, while placement next to lupin led to greater accumulation of phosphorus and calcium. Uptake of nitrogen, phosphorus, magnesium and calcium by the maize was higher in the border rows next to lupin. The results indicate that selection of different species for strip cropping can affect the chemical composition of the plant. This can be a cost-effective way to mitigate mineral shortages in crops.

Key words: Strip cropping, interspecific facilitation, macronutrients, weed control.

INTRODUCTION

Strip cropping is a form of intercropping in which different crop species are grown in adjacent strips, allowing for independent, mechanical cultivation of each species. Temporal and spatial variation in plants in strip cropping minimizes the competition between them and increases yield, especially in the border rows of the strips (Ghaffarzadeh et al., 1994; Lesoing and Francis, 1999). Most studies on strip cropping focus on yield and aboveground plant biomass, but little attention has been paid to the influence of the edge effect on nutrient uptake by plants. Research confirmed the importance of interspecific interactions in the rhizosphere on nutrient availability and uptake in intercropping (Wasaki et al. 2003). Intercropping of legumes/cereals increases the availability and retrieval of nitrogen (Karpenstein-Machan and Stuelpnagel, 2000; Hauggaard-Nielsen et al., 2001). Li et al. (2003) reported that chickpea contributes to higher content of phosphorus in maize/wheat intercropping. This may result from the release or activation of enzymes and release by the roots of carboxylates, which improve the solubility of phosphorus in the rhizosphere and increase its acquisition. Intercropping may also increase the availability of calcium and magnesium to plants (Li et al., 2004). In strip cropping, placing the plants in separate strips can reduce the strength of the interaction between plants in the border rows of adjacent strips and its effect on nutrient uptake. However, few studies confirm the impact of strip cropping on the content and uptake of macronutrients in plants (Li et al. 2001a). Ghaffarzadeh et al. (1998) suggested that a significant increase in maize yield in the edge rows of the strip causes nitrogen uptake to increase, and that it is advisable to apply additional nitrogen fertilizer. Głowacka (2011) observed an increase in magnesium and calcium in maize strip-cropped with common beans and spring

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wheat in comparison to sole cropping. Content of elements in the maize in strip cropping was also affected by the adjacent plant species. Proximity to wheat led to higher calcium content, while placement next to beans increased phosphorus content in maize (Głowacka et al., 2011).

Research conducted in south-eastern Poland also confirmed that strip cropping reduces the density and biomass of weeds in beans, while only reducing the number of weeds in maize. In both beans and maize the effect of strip cropping was particularly pronounced in conditions of mechanical weed control (Głowacka, 2013a). This in turn can affect competition between weeds and maize in uptake of nutrients. Crops are an important source of food for people and animal feed, so their nutritional value and the composition and proportions of nutrients are very important to human and animal health (Graham et al., 2007). Thus, the aim of this study was to evaluate the impact of strip cropping of dent maize with narrow-leafed lupin and spring oats on the content and uptake of nitrogen, phosphorus, potassium, magnesium, and calcium by maize.

MATERIAL AND METHODS

A field experiment was conducted in the years 2008, 2009 and 2010 at the Experimental Station of the Faculty of Agricultural Sciences in Zamość, University of Life Sciences in Lublin (50°42'N, 23°16'E), on brown soil, slightly acidic (pH_{KCl} – 6.0), with average content of organic matter (18 g kg^{-1}), high content of available phosphorus and potassium (175 mg P kg^{-1} and 206 mg K kg^{-1}) and medium magnesium content (57 mg Mg kg^{-1}).

The experiment was carried out in a split-plot design with four replications. The following factors were investigated in the experiment: I. Cropping methods (CM): (1) – sole cropping (cultivation of a single species), with 10 rows of maize planted on each plot, spaced at 65 cm.; (2) – strip cropping, in which narrow-leafed lupin (*Lupinus angustifolius* L.), dent maize (*Zea mays* L.), and spring oat (*Avena sativa* L.) were grown in adjacent strips, each 3.3 m wide. Five rows of maize were planted in the strip, spaced at 65 cm. II. Weed control method (WC): (A) – Mechanical: maize – double interrow weeding (first at the 5-6 leaf stage BBCH 15/16, then at stage BBCH 16/17, about two weeks later); (B) - chemical – maize: herbicide: a.i. bromoxynil + terbuthylazine at 144 g ha^{-1} + 400 g ha^{-1} at the 4-6 leaf stage (BBCH 14/16).

The Celio (FAO 250) hybrid cultivar of maize was grown for silage, with spring oats as a forecrop. In the successive years of the study the maize was sown on 28th April and 2nd and 5th May, and harvested at the milky wax stage – BBCH 79/83. Narrow-leafed lupin was grown for dry seeds, with maize as a forecrop. The forecrop for spring oats was narrow-leafed lupin. In the successive years of the study lupin and oats were sown on 12th, 15th and 19th April. Lupin was harvested at stage BBCH 89 in the second or last third of August, and oats in the first or second third of August (BBCH 89). Mechanical and chemical weed control methods were also used in the lupin and oat crops. A detailed description of the conditions of the study and the agricultural techniques used for the maize and accompanying plants is presented in an earlier paper (Głowacka, 2013b).

Plant material was collected for analysis every year before the maize harvest. Three plants were collected from the inner rows of the sole cropping plots. From each strip cropping plot three plants were taken from the border rows adjacent to the lupin and oats and from the middle row. The plants were crushed, dried and ground, and content of the following macronutrients was determined: nitrogen by the Kjeldahl method, phosphorus by spectrophotometry, potassium and calcium by flame photometry, and magnesium by flame atomic absorption spectrometry (FAAS). The analyses were performed at the Regional Chemical and Agricultural Station in Lublin, in accordance with standard analytical procedures. The results were converted to dry weight and uptake of each element by the maize was calculated per hectare. The results were analysed statistically by ANOVA using STATISTICA PL. Differences between averages were determined using Tukey's test, at $P<0.05$. Pearson's correlation coefficients between yield and the content and uptake of the elements were also calculated. Since analysis of variance did not confirm a significant interaction of years × cropping methods or years × weed control methods, data for content and uptake of macronutrients are given as the mean for the 3 years of research.

RESULTS

Maize yield

Effect of strip cropping on the yield of maize, lupin and oats will be discussed in detail in other paper. In this work only yield of maize (average for experiment) is presented, because the uptake of nutrients is related to the yield. Maize yield was higher about 13% in the strip cropping, than in the sole cropping, but the difference was statistically insignificant.

The maize yield in the strip cropping changed depending on the row position in the strip. Significantly higher yields were recorded in the edge rows – by about 27-28.9% on average in the row adjacent to the lupin, and 16.3-18.8% in the row adjacent to the oats (Table 1).

Table 1. Effect of row position in the strip on maize yield (mean for 2008-2010; t ha^{-1} d.w.)

Weed control (WC)	Strip cropping				Sole cropping
	Row in the strip			Mean for strip	
	Next to oat	Inner	Next to lupin		
A*	16.6	14.6	18.4	16.5	14.3
B	20.4	17.2	21.8	19.8	17.3
Mean	18.5	15.9	20.1	18.2	15.8

* Weed control: A - mechanical, B – chemical.

Content of macroelements

Year of research, cropping system, and weed control method significantly affected the content of the elements (Table 2). The highest nitrogen and potassium content and the lowest phosphorus, magnesium and calcium were noted in 2009, when maize yield was lowest. Taking into account the content of macronutrients on average for strip, it can be concluded that strip cropping significantly reduced content of nitrogen (-11%), phosphorus (-14%) and magnesium (about 5%) in the maize, and increased content of potassium (10.6%) and calcium (17.9%) compared to sole cropping. Chemical weed control led to higher content of all the macronutrients in the maize than mechanical weed control.

Table 2. Content of macroelements in maize (g kg^{-1} d.w.) (mean for 2008-2010)

I. Cropping method (CM)	II. Weed control (WC)	Element				
		N	P	K	Mg	Ca
Sole cropping	A*	13.30	2.10	8.44a	0.82a	1.53a
	B	14.39	2.42	9.27b	1.02c	2.62c
Strip cropping (mean for strip)	A	11.47	1.77	9.22b	0.81a	2.95d
	B	13.24	2.11	9.18b	0.94b	2.29b
$LSD_{(0.05)}$ for CM × WC		n.s.	n.s.	0.2	0.03	0.05
Average for factors						
CM	Sole cropping	13.88b	2.26b	8.85a	0.92b	2.08a
	Strip cropping - mean for strip	12.36a	1.94a	9.21b	0.87a	2.62b
$LSD_{(0.05)}$ for CM		0.2	0.02	0.2	0.03	0.05
WC	A	12.42a	1.93a	8.83a	0.82a	2.24a
	B	13.84b	2.27b	9.22b	0.98b	2.45b
$LSD_{(0.05)}$ for WC		0.6	0.02	0.1	0.02	0.04
Years	2008	12.03a	2.09b	8.61a	0.89ab	2.33ab
	2009	13.29c	2.00a	9.50c	0.86a	2.24a
	2010	12.54b	2.21c	8.97b	0.94b	2.47b
$LSD_{(0.05)}$		0.7	0.04	0.3	0.05	0.06

*Weed control: A - mechanical, B – chemical.
Means followed by the same letter are not significantly different at the P=0.05 level.

A significant interaction between cropping systems and weed control methods was noted with regard to K, Mg and Ca content in the maize. Phosphorus and magnesium content was significantly positively correlated with maize yield (Table 3).

Table 3. Correlation coefficient between yield and content and uptake of elements

Elements		Yield	Content				
			N	P	K	Mg	Ca
Content	N	0.252	-	-	-	-	-
	P	0.396*	0.934***	-	-	-	-
	K	0.304	-0.396**	-0.162	-	-	-
	Mg	0.547**	0.656***	0.851***	0.280	-	-
	Ca	0.292	-0.356**	-0.143	0.958***	0.256	-
Uptake	N	0.620***	0.809***	0.894***	-0.039	0.856***	-0.029
	P	0.656***	0.727***	0.875***	0.077	0.903***	0.074
	K	0.714***	0.097***	0.353**	0.705***	0.709***	0.657***
	Mg	0.699***	0.560***	0.758***	0.268	0.925***	0.241
	Ca	0.623***	-0.012	0.238	0.831***	0.611***	0.852***

*P< 0.05; **P< 0.01; ***P< 0.001.

Uptake of macroelements

Total uptake of all the macronutrients was lowest in the second year of the study (2009). The differences between the first and third year were not significant (Table 4). Maize grown in sole cropping took up significantly more nitrogen and phosphorus than in the strip cropping. Strip cropping was conducive to greater uptake of potassium and calcium by the maize, but did not significantly affect accumulation of magnesium. Uptake of macronutrients by the maize was significantly positively correlated with their content in the plant and with maize yield (Table 2). Weed control methods significantly affected uptake of nutrients. Greater uptake of N, P, K, Mg and Ca was noted in chemical weed control conditions. Interaction of cropping system × weed control method was significant only for uptake of potassium, magnesium and calcium.

Table 4. Uptake of macroelements by maize (kg ha^{-1})
(mean for 2008-2010)

Method of cultivation (CM)	Weed control (WC)	Element				
		N	P	K	Mg	Ca
Sole cropping	A*	200.3	31.5	111.3a	12.3a	23.0a
	B	261.6	44.0	168.4b	18.5c	47.6c
Strip cropping (mean for strip)	A	166.3	28.0	162.4b	12.8a	46.8c
	B	227.9	39.3	170.8b	17.5b	42.6b
$LSD_{(0.05)}$		n.s	n.s.	2.9	0.6	1.7
Average for factors						
CM	Sole cropping	230.9b	37.7b	139.8a	15.4a	34.9a
	Strip cropping (mean for strip)	197.1a	33.7a	166.6b	15.2a	45.1b
$LSD_{(0.05)}$		3.3	1.3	2.7	0.4	1.5
WC	A	183.3a	29.8a	136.8a	12.6a	34.9a
	B	244.7b	41.6b	169.6b	18.0b	45.1b
$LSD_{(0.05)}$		2.5	1.0	2.1	0.3	1.2
Years	2008	230.1b	38.4b	165.2b	16.5b	43.2b
	2009	185.9a	31.0a	133.4a	13.3a	34.8a
	2010	225.9b	37.7b	161.0b	16.1b	42.0b
$LSD_{(0.05)}$		4.7	1.8	5.9	0.6	1.9

*Weed control: A - mechanical, B – chemical.
Means followed by the same letter are not significantly different at the P=0.05 level.

Effect of row position in the strip and adjacent crop on the content and uptake of the macronutrients

In the strip cropping, content and uptake of macroelements by maize varied depending on the row position and neighbouring plant species (Tables 5 and 6).

Whether maize was weeded mechanically or chemically, reduced nitrogen content was noted in the row adjacent to spring oats. The differences between the inner row and the border row next to lupin were small.

On plots with mechanical weed control, the highest nitrogen uptake was noted in maize grown adjacent to lupin. In the case of chemical weed control, greater nitrogen uptake was observed in the edge rows, irrespective of the adjacent crop species. Phosphorus content in maize was markedly reduced by proximity to oats. The differences between the inner row and the border row next to lupin were minor. The most P was taken up by maize growing in the row adjacent to lupin.

Table 5. Effect of row position in the strip on the content of macroelements in maize (mean for 2008-2010; g kg^{-1} d.w.)

Weed control (WC)	Row position in the strip	Element				
		N	P	K	Mg	Ca
A*	Next to oat	10.6	1.60	9.60	0.81	2.46
	Inner	12.7	1.83	9.81	1.01	3.01
	Next to lupin	12.4	2.10	8.39	0.99	3.40
B	Next to oat	12.5	1.90	9.40	0.85	1.90
	Inner	13.5	2.17	9.09	1.00	2.31
	Next to lupin	13.7	2.62	8.61	1.02	2.72

* Weed control: A - mechanical, B – chemical.

Table 6. Effect of row position in the strip on the uptake of macroelements by maize (kg ha^{-1}) (mean for 2008-2010)

Weed control (WC)	Row position in the strip	Element				
		N	P	K	Mg	Ca
A*	Next to oat	174.6	26.6	165.2	14.2	43.7
	Inner	179.8	27.0	154.9	11.2	41.9
	Next to lupin	214.3	36.8	156.2	13.3	57.4
B	Next to oat	245.0	38.5	195.6	17.6	38.5
	Inner	219.8	37.3	154.9	16.8	39.8
	Next to lupin	262.8	51.5	176.9	20.4	56.4

* Weed control: A - mechanical, B – chemical.

This was the result of differences in P content and in the maize yield. Proximity to lupin reduced potassium content in the maize. Placement next to spring oats was more conducive to higher K content, especially in maize weeded mechanically. In mechanically-weeded maize, the row position in the strip did not significantly affect total potassium uptake by the maize. Where herbicides were used, however, the most K was taken up in the row adjacent to oats. Magnesium content in maize weeded chemically was lowest in the edge row adjacent to the oats strip. In the case of mechanical weed control, the row position in the strip did not affect Mg content in the maize. Irrespective of the weed control methods, proximity to spring oat reduced calcium content in the maize. The most Ca was taken up by maize growing in the edge rows adjacent to lupin, irrespective of weed control methods. This was due to different Ca content and higher maize yield in the edge rows of the strip, especially the row adjacent to lupin.

DISCUSSION

Interspecific interaction in the rhizosphere can affect the availability of nutrients for plants in intercropping (Li et al., 2003). Numerous studies show that legumes/cereals intercropping can increase nitrogen accumulation by plants (Hauggaard-Nielsen, 2001; Sharma and Gupta, 2002; Stern, 1993). However, this is not always the case, since Inal et al. (2007) did not observe an increase in nitrogen content in legumes/non-legumes intercropping. The plants accompanying maize in strip cropping and the potential for greater yield in the edge rows can affect nitrogen accumulation by maize. Li et al. (2001b) observed less uptake of nitrogen by maize in wheat/maize strip intercropping compared to sole cropping, but only in the earlier stages of development. In the later stages, after wheat harvest, accumulation of nitrogen was faster, and as a result nitrogen content in the strip-cropped maize in the full maturity stage was higher or similar to that in sole cropping. In the present study narrow-leafed-lupin/dent-maize/oats strip cropping significantly reduced the content and uptake of nitrogen by maize. The lowest nitrogen content was found in the edge row of the maize strip adjacent to the oats. Oats, sown three weeks earlier, developed rapidly during spring and early summer and could compete with the maize for nitrogen. Nitrogen uptake was lowest in the inner row of the maize strip, especially in conditions of chemical weed control.

However, according to Ghaffarzadeh et al. (1998), increased total nitrogen uptake by maize in the border rows of the strip, both next to oat and soy, suggests that maize has an advantage in nitrogen uptake over the neighbouring plants. The highest nitrogen uptake was noted in the edge row next to lupin. This may result from transfer of nitrogen to the maize from the lupin, which has been observed in a number of cases of legumes/cereal mixed intercropping (Brophy et al. 1987; Temperton et al., 2007).

Li et al. (2001b) observed greater P uptake by plants in wheat/maize strip intercropping, but no effect of wheat/soybean strip intercropping on phosphorus accumulation. However, the ability of wheat to take up P was greater than that of maize. In the present study, strip cropping significantly reduced phosphorus content in maize in comparison with sole cropping. This was due to the lower phosphorus content in the edge rows of the maize strip adjacent to the oats. The highest phosphorus content and uptake by maize in strip cropping were observed in the border row of the strip adjacent to narrow-leafed lupin. Legumes have the ability to recover phosphorus from unavailable forms. One mechanism is the secretion of organic acids which reduce the pH of the rhizosphere and release phosphorus from unavailable compounds. Bean and soybean mainly secrete citrates (Shen et al., 2002; Nwoke et al., 2008), while lupins, field peas and faba beans mainly secrete malate (Nuruzzaman et al., 2005). Like other species, pulses can release phosphatase enzymes, which decompose phosphorus organic compounds, into the soil. Inal et al. (2007) also observed an increase in phosphorus uptake in peanut/maize intercropping in a greenhouse experiment. This may be due mainly to a decrease in rhizosphere pH, and, to a greater extent, to increased phosphatase activity in the soil and roots in intercropping, and thus increased phosphorus concentration in the rhizosphere. In our study, the changes observed in phosphorus content and uptake in different rows of the maize strip confirm that interspecific differences in competitive abilities play an important role in the accumulation of phosphorus by plants in intercropping. In other studies, decreased potassium uptake in sorghum/chickpeas or sorghum/cowpea intercropping has been observed in comparison to sole cropping.

Increases in potassium accumulation have been found in corn/soybeans, corn/rice or sorghum/sunflower intercropping (Morris and Garrity, 1993).

In the present study, potassium content and uptake by maize in narrow-leafed lupin/maize/oats strip cropping was significantly higher, but only under conditions of mechanical weed control. This could be due to the effect of strip cropping, observed and discussed in another paper, to reduce the number and weight of weeds in maize weeded mechanically (Głowacka, 2103b). This in turn would reduce competition from weeds in potassium accumulation, particularly since the predominant weed species in maize, *Chenopodium album*, *Galinsoga parviflora* and *Echinochloa crus-galli*, are more competitive in potassium uptake and contain 5-6 times more K than maize. The highest potassium uptake in the strip cropping was observed in the row adjacent to oats, and the lowest in the row next to lupin. Similarly, Li et al. (2001a) observed an increase in K uptake in wheat/maize intercropping, but no effect of wheat/soybean intercropping on K accumulation.

Intercropping can also affect the availability in the rhizosphere of other minerals, such as calcium and magnesium. Li et al. (2004) showed that wheat/chickpeas intercropping did not affect calcium content in wheat, but increased Ca content in chickpeas and its uptake by both species. The interaction between wheat and chickpeas did not affect magnesium content in the plants, but increased Mg uptake by wheat and decreased uptake by chickpeas. The changes in accumulation of these nutrients depend on the sources of phosphorus used for mineral fertilization.The increased availability of nutrients for wheat and chickpea resulted from the reduced soil pH in the rhizosphere. Głowacka et al. (2011) also reported that strip cropping increased the content and uptake of magnesium and calcium by maize. The row position in the strip, adjacent crop species, and weed control methods affected calcium content in maize in strip cropping. In the present study, narrow-leafed-lupin/dent-maize/spring-oats strip cropping also significantly increased calcium content and uptake by maize. Proximity with lupin contributed to greater accumulation of calcium in the strip cropping.

Venkelaas et al. (2003) reported that legumes may release a large number of carboxylates through their roots, which may play a significant role in increasing the availability to the plants of Fe, Mn, Zn, and Ca from less soluble forms. In addition, legumes have a well-developed root system and may take up minerals such as P, K, Mg and Ca from deeper layers and move them into the soil profile, making them more available to other plants (Ae et al., 1990). The results show that interspecific competition and facilitation can co-exist in strip cropping. Below-ground competitiveness of the species is correlated with density, surface size, plasticity of root growth, and the properties of enzymes involved in the uptake of nutrients (Casper and Jackson, 1997). The competitive ability of plants may also depend on their initial size (Garry and Wilson, 1995).

CONCLUSIONS

The results of this study confirm the impact of strip cropping on the content of macronutrients in maize and their uptake. Strip cropping resulted in higher content of calcium and potassium, while reducing nitrogen, phosphorus and magnesium content. This was due to changes in the content of these elements in the maize depending on the position of the row in the strip and on the adjacent plant species.

In general, placement next to the narrow leafed-lupin strip resulted in higher content of phosphorus, calcium, and magnesium in the maize. Maize in the edge rows next to oats contained more potassium. Uptake of nitrogen, phosphorus, magnesium and calcium by the maize was higher in the border rows next to lupin. Appropriate selection of the crop species for strip cropping can be a cost-effective way to reduce shortages of some minerals in plants.

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