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Changes in the uptake of Cu, Zn, Fe and Mn by dent maize in blue lupin/spring oat strip cropping system

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Abstract

Strip cropping is a form of intercropping used in both tropical and temperate climate zones. Maize is a species often grown in strip cropping, because it responds to the edge effect with a substantial increase in yield. In the experiment, strip cropping of maize with blue lupin and oat was compared to sole cropping of maize in the conditions of mechanical and chemical weed control. A field experiment was conducted in 2008–2010 at the Experimental Station in Zamość, University of Life Sciences in Lublin (50°42′ N, 23°6′ E). The study examined the effects of the cropping method and weed control methods on the content of copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn) in maize biomass and their uptake by maize. The impact of the position of the row in the strip and of the adjacent plant species on the content and uptake of these micronutrients was analysed as well. Strip cropping significantly increased Zn and Fe content in maize biomass, reduced Mn content, and did not significantly affect the accumulation of Cu. In the strip cropping, interspecific facilitation between neighbouring plant species was also observed. Placement adjacent to the oat strip contributed to higher Cu content in the maize, while placement next to blue lupin increased the content of Fe and Zn. The highest Mn content was noted in maize grown in the centre row. The results indicate that appropriate selection of plant species for strip cropping can affect the chemical composition of the plants. This makes it possible to eliminate or mitigate mineral deficiencies in the plants.

Key words: cropping methods, interspecific facilitation, micronutrients, weed control.

Introduction

Intercropping, the cultivation of two or more plant species in the same field at the same time has been used for many years in numerous parts of the world (Borghi et al., 2012; Dordas et al., 2012). This system can bring many benefits. It reduces damage to plants due to pests and diseases and allows for more efficient use of resources (Zhuo, Zhang, 2009; Arlauskienė et al., 2011). Interaction between plants in the rhizosphere in the intercropping system can also increase the availability of nutrients for the plants (Gunes et al., 2007). Li et al. (2004) observed that intercropping of wheat and chickpea increased uptake of calcium and magnesium by crop plants. Zuo et al. (2000) stated that the rhizosphere interactions between peanut and maize in intercropping improved the Fe nutrition of peanut. Strip cropping is a form of intercropping. In this system, plants are placed in separate strips, thus minimizing competition between them and increasing yield, especially in the edge rows of the strip (Coll et al., 2012). The selection of species with different development cycles and morphology enables efficient use of nutrients, water and light, which can also affect the chemical composition of the plants (Kanwar et al., 2005). Few studies confirm the impact of strip cropping on the content of macroelements in plants (Li et al., 2001; Głowacka et al., 2011). Li et al. (2001) reported greater phosphorus and potassium uptake by plants in wheat/maize strip intercropping, but no effect of wheat/soybean strip intercropping on phosphorus and potassium accumulation. Research by Głowacka (2011) shows that neighbouring plants in strip cropping affect macronutrient contents in maize. Plants in rows adjacent to common beans contain more phosphorus and less potassium than those from the middle rows and from rows adjacent to wheat, whereas maize grown in a row adjacent to wheat contained more calcium than maize grown adjacent to beans (Głowacka et al., 2011). It has also been observed that the direction and degree of the changes depend on the methods of weed control. Very little information is available about the potential impact of the strip cropping system on the content of micronutrients such as Cu, Zn, Fe and Mn, which play a important role in plant and animal or human organisms (Salgueiro et al., 2000; White, Broadley, 2009). In plants, Cu is an activator of many enzymes involved in nitrogen metabolism and an essential constituent of plastocyanin, protein which is a component of the electron transport chain of photosystem (Losak et al., 2011). Mn in plants activates several enzymes involved in the metabolism of proteins, carbohydrates and lipids. Fe is a component of many redox enzymes. Especially important is the function of Fe as an activator in the synthesis of chlorophyll and some proteins. Zn is involved in the metabolism of carbohydrates, proteins, and phosphorus compounds and together with Cu and Mn, has a significant effect on carbohydrate metabolism (Kabata-Pendias, 2010). Intercropping may provide an ecological method to manage weeds with less use of herbicides (Hauggard-Nielsen et al., 2001). Maize cultivation with wide inter-row spacing is conducive to the use of mechanical methods of weed control. Therefore, the aim of this study was to evaluate the impact of strip cropping of blue lupin/dent maize/spring oat and various weed control methods on the content and uptake of Cu, Zn, Fe and Mn by maize.

Materials and methods

The field experiment was carried out in 2008–2010 at the Experimental Station in Zamość, University of Life Sciences in Lublin (50°42′ N, 23°16′ E), on brown soil of the group *Brunic Cambisol* (*CMbr*), of texture of silt, which was slightly acidic (pH_{KCl} 6.0), with medium organic matter content (18 g kg^{-1}) and average abundance of available forms of copper (Cu) (3.9–6.2 mg kg^{-1}), zinc (Zn) (14.9–18.5 g kg^{-1}), manganese (Mn) (199–236 g kg^{-1}) and iron (Fe) (199–236 g kg^{-1}). The experiment was carried out in a split-plot design with four replications.

The following factors were analysed: I. Cropping method: 1) sole cropping (cultivation of a single species) with 10 rows of maize planted per plot and 65 cm spacing between rows; 2) strip cropping, in which three plant species: blue lupin (*Lupinus angustifolius* L.), dent maize (*Zea mays* L. convar. *dentiformis*) and spring oat (*Avena sativa* L.), were grown side-by-side in adjacent strips 3.3 m wide, with 5 rows of maize planted in each strip, spaced at 65 cm. II. Weed control: 1) mechanical – weeding of interrows twice: first at the 5–6 leaf stage (BBCH 15–16), and again two weeks later at six or seven leaf stage (BBCH 16–17); 2) chemical – herbicide: a.i. bromoxynil + terbuthylazine at 144 g ha^{-1} + 400 g ha^{-1} at the 4–6 leaf stage (BBCH 14–16). Maize hybrid cultivar 'Celio' (FAO 250) was grown for silage, on a site where the previous crop had been spring oat. 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). Mineral fertilization for maize was applied uniformly at rates of N 140, P 35, and K 100 kg ha^{-1}. Phosphorus and potassium fertilizers were applied once before pre-sowing treatments, and nitrogen was applied in split applications (half before sowing, and the remainder in the four or five leaf stage (BBCH 14–15). Blue lupin was grown for dry seeds on a site where the previous crop had been maize. Spring oat was grown on a site where the previous crop had been blue lupin. In the successive years of the study lupin and oat were sown on 12th, 15th and 19th April. Lupin was harvested at stage BBCH 89 in the second or third ten-day period of August and oat in the first or second ten-day period of August (BBCH 89). Mechanical and chemical weed control methods were also used in the lupin and oat crops. Weather conditions varied over the years of the study. Rainfall was lowest in 2009 and was lower than the long-term average. Moreover, rainfall was unevenly distributed over the year. A severe shortage occurred in April and July, while heavy precipitation was recorded in May and June. In the years 2008 and 2010, rainfall was much higher and exceeded the long-term average by 56.4–61.8 mm. Average monthly temperatures for each year were higher than the long-term average. A detailed description of the meteorological data are given in other paper (Głowacka, 2013 a).

After mechanical harvesting, dry matter yield of maize was determined for each plot in the sole cropping and the strip cropping. Each year prior to 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 oat and from the middle row. The plants were crushed, dried and ground, and content of Cu, Zn, Fe and Mn was determined (after wet mineralization in extra pure HNO_3) by atomic adsorption spectroscopy according to PN-EN ISO 6869:2002. The results were converted to dry weight and uptake of each element by the maize was calculated per hectare.

A two-way analysis of variance (*ANOVA*) was carried out to determine the effect of years, cropping method, weed control and cropping method × weed control interaction on the variability of maize yield and content and uptake of Cu, Zn, Fe and Mn. In addition, one-way analysis of variance (*ANOVA*) was performed to determine the effect of row position in the strip on the analysed traits. Differences between averages were determined using Tukey's test, at $P < 0.05$. Pearson's correlation coefficients were calculated to determine the relationship between the studied traits. Statistical computations were performed using *STATISTICA PL*.

Results

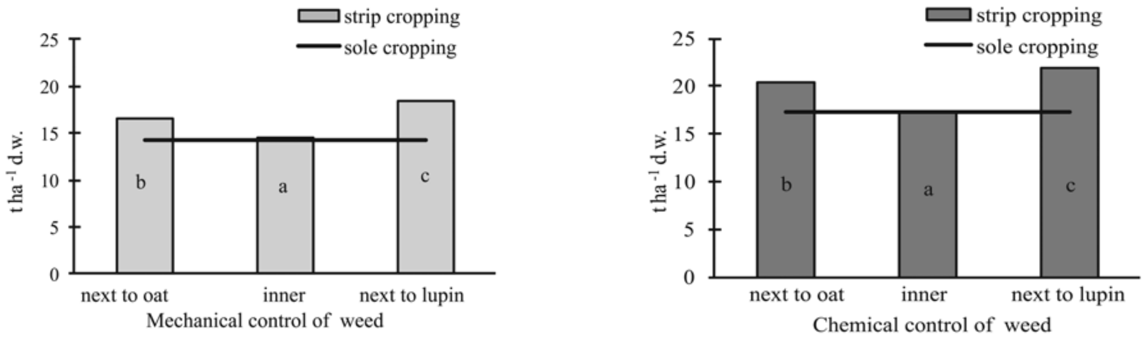
Maize yield. Maize yield was significantly higher in the strip cropping than in the sole cropping, only in the first and third years of the study (Table 1).

Table 1. Maize yield (t ha^{-1} dry weight)

Cropping method	Weed control	Years 2008	2009	2010	Average
Sole cropping	mechanical	14.9	13.1	13.3	13.8
	chemical	17.5	16.0	16.7	16.7
Strip cropping	mechanical	17.3	13.9	16.3	15.8
	chemical	19.5	17.1	19.4	18.7
$LSD_{0.05}$ for cropping method × weed control		n.s.	n.s.	n.s.	n.s.
Average for factors					
Cropping method	sole cropping	16.2	14.6	15.0	15.3
	strip cropping	18.4	15.5	17.9	17.3
$LSD_{0.05}$ for cropping method		0.9	n.s.	0.6	n.s.
Weed control	mechanical	16.1	13.5	14.8	14.8
	chemical	18.5	16.6	18.1	17.7
$LSD_{0.05}$ for weed control		0.4	0.6	0.8	0.4
Years		17.3	15.1	16.5	–
$LSD_{0.05}$		0.9			

n.s. – not significant

The maize yield in the strip cropping changed depending on the position of the row 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 oat (Fig. 1).



Note. d.w. – dry weight; values marked by the same letters do not differ significantly at $P < 0.05$ levels.

Figure 1. Effect of row position in the strip on maize yield

Content of micronutrients. Strip cropping significantly reduced Cu content in the maize only in the third year of the study. In the first and second year, as well as on average for the experiment, the impact of the cropping systems was not significant (Table 2). There was a significant interaction between cropping systems and weed control methods. Where mechanical weed control had been used, strip cropping reduced the Cu content in the maize, while in the case of the chemical weed control it was conducive to greater Cu accumulation. Zn content was significantly higher in the maize in the strip cropping, by an average of 36% compared with the sole cropping (Table 2).

Table 2. Content of copper (Cu) and zinc (Zn) in maize (mg kg^{-1} dry weight)

Cropping method	Weed control	Cu				Zn			
		2008	2009	2010	mean	2008	2009	2010	mean
Sole cropping	mechanical	12.1	5.2	11.9	9.7	41.6	28.1	39.3	36.3
	chemical	8.5	4.9	7.9	7.1	40.9	22.4	36.2	33.2
Strip cropping	mechanical	9.2	5.8	8.7	7.9	54.3	30.4	46.3	43.7
	chemical	10.1	4.6	9.3	8.0	60.9	34.3	57.9	51.0
$LSD_{0.05}$ for cropping method × weed control		1.20	n.s.	0.54	0.66	3.75	0.63	3.95	0.93
Average for factors									
Cropping method	sole cropping	10.3	5.0	9.9	8.4	41.2	25.3	37.8	34.8
	strip cropping	9.6	5.2	9.0	7.9	57.6	32.3	52.1	47.4
$LSD_{0.05}$ for cropping method		n.s.	n.s.	0.50	n.s.	3.45	0.6	3.60	0.90
Weed control	mechanical	10.6	5.5	10.3	8.8	47.9	29.3	42.8	40.0
	chemical	9.3	4.7	8.6	7.6	50.9	28.4	47.0	42.1
$LSD_{0.05}$ for weed control		1.06	0.55	0.40	0.56	2.65	0.44	2.79	0.66
Average for years		10.0	5.1	9.4	–	49.4	28.8	44.9	–
$LSD_{0.05}$ for years		1.6				4.6			

Explanation under Table 1

The experimental factors analyzed affected the content of Fe in maize. There was a significant interaction between cropping systems and weed control methods. Strip cropping significantly increased the content of Fe in the maize, but only in combination with chemical weed control (Table 3). Chemical weed control led to higher content of Fe in the maize biomass than mechanical weed control. In each year of the research, Mn content in the maize was significantly higher, on average by 42%, in strip cropping than in sole cropping (Table 3).

Uptake of micronutrients. The cropping systems and weed control methods did not significantly affect the total uptake of Cu by maize (Table 4). There was a significant interaction between the factors analysed. The highest uptake of Cu was noted on the sites with strip cropping and chemical weed control. In mechanical weed control conditions, greater accumulation of Cu was observed in the sole cropping.

Differences in Cu uptake were mainly due to differences in its content in the maize, which is confirmed by a significant correlation coefficient (Table 5). Total uptake of Zn by the aboveground biomass of maize was 26% and 62% higher in the strip cropping than in the sole cropping, for the mechanical and chemical weed control

Table 3. Content of iron (Fe) and manganese (Mn) in maize (mg kg^{-1} dry weight)

Cropping method	Weed control	Fe				Mn			
		2008	2009	2010	mean	2008	2009	2010	mean
Sole cropping	mechanical	82.8	63.5	76.8	74.4	16.7	17.3	18.1	17.4
	chemical	64.6	81.7	59.7	68.7	22.4	23.1	23.7	23.1
Strip cropping	mechanical	74.9	70.7	69.9	71.8	22.6	23.0	25.8	25.1
	chemical	99.1	60.4	89.6	84.3	38.7	21.9	35.9	32.2
$LSD_{0.05}$ for cropping method × weed control		2.71	6.63	8.34	0.93	2.7	4.77	1.65	n.s.
Average for factors									
Cropping method	sole cropping	73.7	72.6	68.2	71.5	19.5	20.2	21.0	20.2
	strip cropping	87.0	67.4	79.7	78.0	32.6	22.5	30.9	28.7
$LSD_{0.05}$ for cropping method		2.5	n.s.	7.7	2.80	2.5	n.s.	1.5	1.3
Weed control	mechanical	78.8	67.1	73.3	73.1	21.6	20.1	22.0	21.2
	chemical	81.9	72.9	74.6	76.5	30.5	22.5	29.8	27.6
$LSD_{0.05}$ for weed control		1.92	4.69	n.s.	2.14	1.91	n.s.	1.17	0.99
Average for years		80.4	70.0	74.0	–	1.91	n.s.	1.17	–
$LSD_{0.05}$ for years		7.80				2.43			

Explanation under Table 1

Table 4. Uptake of micronutrients by maize (g ha^{-1}) (means for 2008–2010)

Cropping method	Weed control	Micronutrient			
		Cu	Zn	Fe	Mn
Sole cropping	mechanical	160.6	559.9	1101	248.2
	chemical	119.0	586.7	1262	417.6
Strip cropping	mechanical	121.6	640.0	1064	376.9
	chemical	148.2	999.0	1607	635.1
$LSD_{0.05}$ for cropping method × weed control		13.2	15.2	45.3	38.4
Average for factors					
Cropping method	sole cropping	140.3	573.0	1182	332.9
	strip cropping	138.9	819.3	1336	506.0
$LSD_{0.05}$ for cropping method		n.s.	14.0	41.7	35.3
Weed control	mechanical	141.1	600.0	1082	312.6
	chemical	134.0	793.0	1435	526.4
$LSD_{0.05}$ for weed control		n.s.	10.7	32.1	27.2
Years	2008	174.8	885.8	1433	472.2
	2009	78.2	436.1	1086	330.7
	2010	159.7	767.0	1256	455.0
$LSD_{0.05}$		16.2	27.3	57.9	45.7

Explanation under Table 1

methods, respectively. Maize in the strip cropping took up 1161 and 1603 g ha^{-1} Fe, for the mechanical and chemical weed control methods, respectively, and uptake was 5.4% and 27% higher than in the sole cropping. Total uptake of Mn by maize in the strip cropping was much higher than in the sole cropping, by 61% and 46% for the mechanical and chemical weed control.

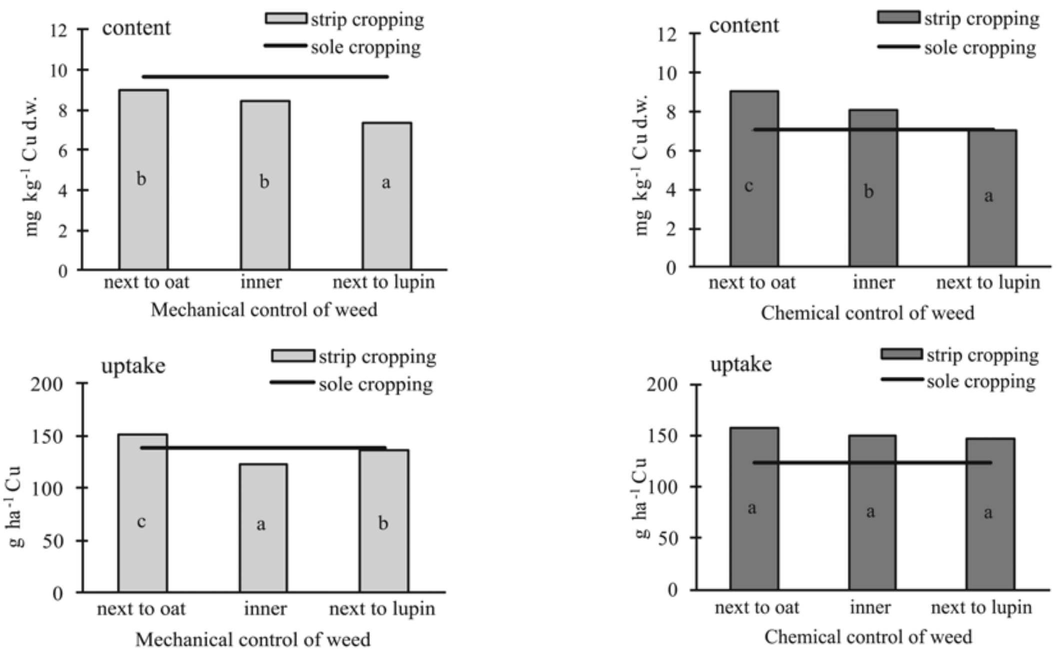
Table 5. Correlation coefficient between yield and content and uptake of elements

		Yield	Micronutrients content			
			Cu	Zn	Fe	Mn
Content	Cu	0.18	–			
	Zn	0.35*	0.58***	–		
	Fe	0.32*	0.42**	0.50***	–	
	Mn	0.59***	0.06	0.67***	0.58***	–
Uptake	Cu	0.27	0.92***	0.66***	0.45**	0.22
	Zn	0.63***	0.46**	0.94***	0.55***	0.78**
	Fe	0.75***	0.28	0.55**	0.86***	0.74***
	Mn	0.77***	0.08	0.65***	0.58***	0.96***

* – $P < 0.05$, ** – $P < 0.01$, *** – $P < 0.001$

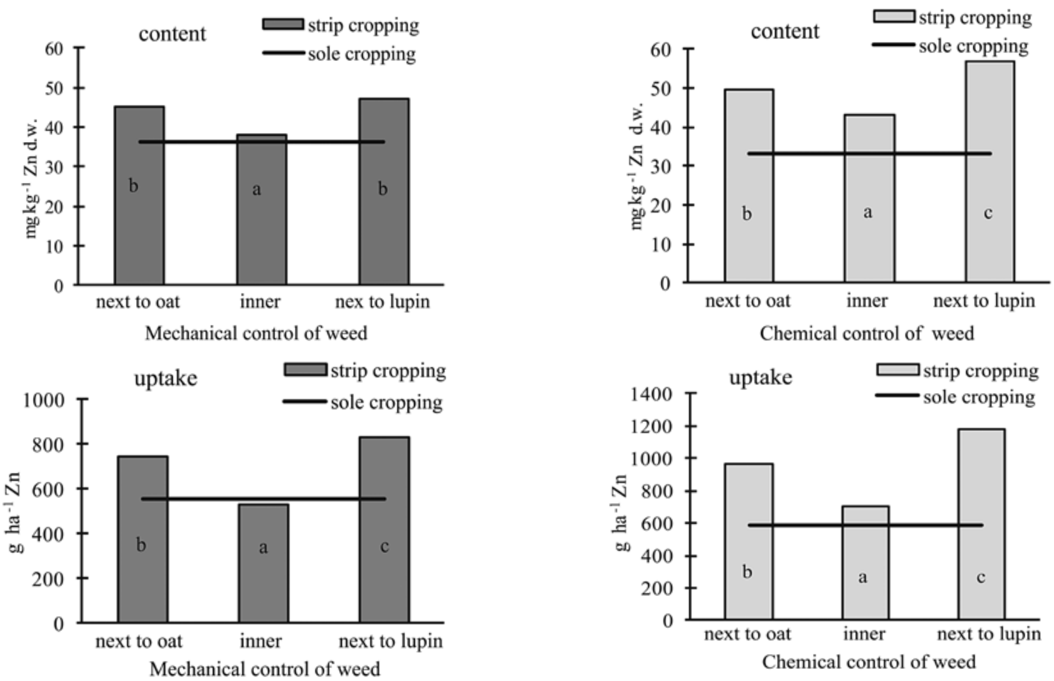
Effect of row position in the strip on the content and uptake of the micronutrients. Content and uptake of Cu by maize in the strip cropping varied depending on the position of the row in the strip and on the neighbouring plant species (Fig. 2). Irrespective of the weed control method, the highest Cu concentration was observed in maize from the border row next to the oat strip, and the lowest in the row adjacent to the lupin. Uptake of Cu was markedly higher in the edge rows of the strip, irrespective of the neighbouring plant species. This was the result of differences in Cu content and in the maize yield (Fig. 1).

The Zn content in the maize varied depending on the position of the row in the strip. Irrespective of the method of weed control, maize from borders rows, both next to lupin and to oat, contained significantly more Zn than the maize in the middle row (Fig. 3). Differences in Zn uptake between individual rows resulted from the Zn content in the maize and from the size of the yield.



Explanations under Figure 1

Figure 2. Effect of row position in the strip on copper (Cu) content and uptake by maize

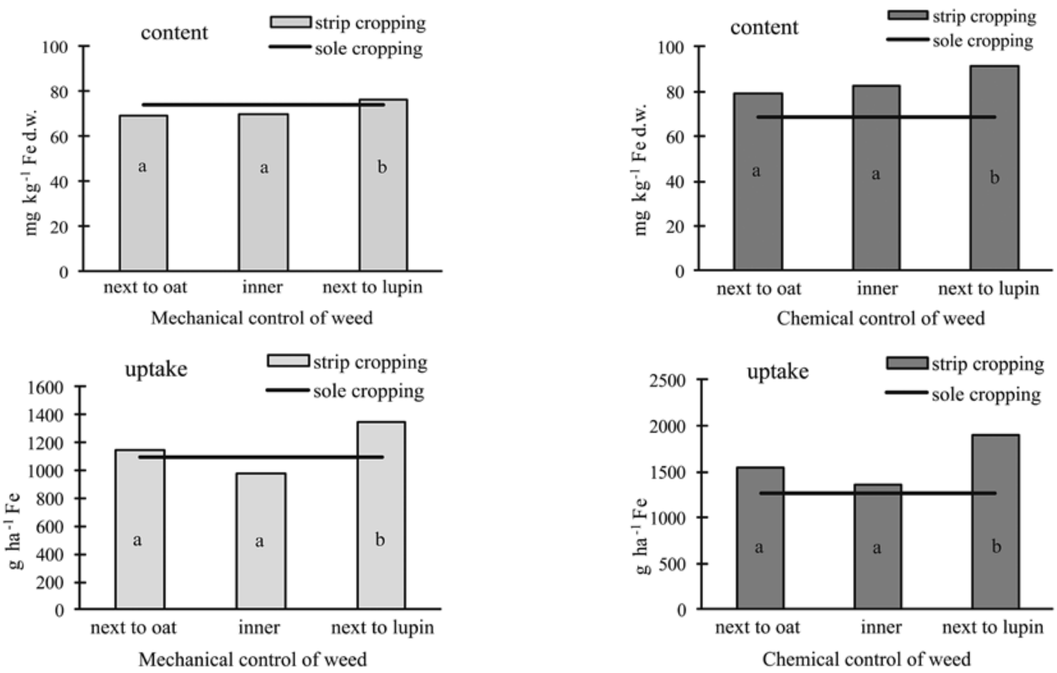


Explanations under Figure 1

Figure 3. Effect of row position in the strip on zinc (Zn) content and uptake by maize

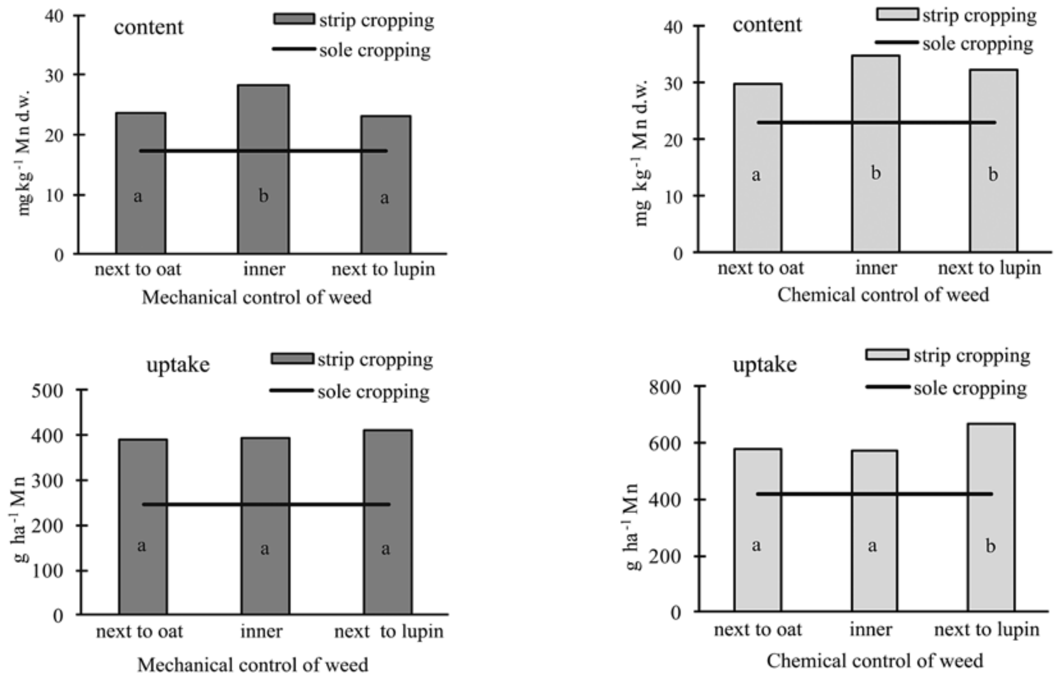
Row position in the strip also affected Fe content. Irrespective of the weed control method, proximity to the lupin strip was conducive to higher Fe content (Fig. 4). The differences between the middle row and the edge row next to oat were small. Maize grown in the row adjacent to lupin took up significantly more Fe than maize from the middle row and the row adjacent to the oat. This was due to different Fe content and higher maize yield in the edge rows of the strip, especially the row adjacent to lupin (Fig. 1).

Maize in the middle row contained the most Mn (Fig. 5). Plants in the edge rows of the maize strip, bordering with lupin and oat, accumulated less Mn. Significant differences in Mn uptake between rows in the strip were observed only under chemical weed control conditions.



Explanations under Figure 1

Figure 4. Effect of row position in the strip on iron (Fe) content and uptake by maize



Explanations under Figure 1

Figure 5. Effect of row position in the strip on manganese (Mn) content and uptake by maize

Effect of weed control methods on the content and uptake of the micronutrients. The weed control methods significantly affected the content of micronutrients in the maize. Much higher content of Zn (36.2%), Fe (4.7%) and Mn (30.2%) was noted in the maize weeded chemically (Tables 3–5). However, significantly higher content of Cu was observed in maize weeded mechanically (Table 2).

Correlations between yield and micronutrients content and uptake. Pearson correlation coefficients confirm the significant relationship between yield and the content and uptake of some micronutrients (Table 5). Both the content and the total uptake of Zn, Fe and Mn by the maize were significantly positively correlated with the size of the yield. No significant correlation between yield and the content and uptake of Cu by maize was observed.

A positive relationship between uptake and content of all the micronutrients in the maize was also confirmed.

Discussion

Numerous studies have demonstrated an increase in maize biomass yield (of about 10–30%) in strip cropping compared to cultivation of a single species (Lesoing, Francis, 1999; Borghi et al., 2012; Głowacka, 2013 a). This is mainly due to the strong response of maize to the edge effect and better use of the greater amount of available light. As a result, increased yield has been observed in the border rows of the strip (up to 50%), and overall yield was higher (Cruse, Gilley, 1996). In the present study, the positive effect of strip cropping on maize yield was significant in the first and third years of the experiment. Maize yield in the strip cropping was on average 10% higher than in the sole cropping. This resulted from increased maize yield in the edge rows of the strip – by 27–29% on average in the row adjacent to lupin, and by 16–19% in the row adjacent to oat. The differences in yield between rows of the strip were due to the adjacent plant species, and row position of the strip. In strips running north to south there is a tendency for higher yield in the east border rows compared to those on the west side. This is due to a faster rate of photosynthesis in the cooler mornings, when the sunlight reaches the eastern edge of the strip, than in the hot afternoons, when it falls on the western edge and cannot be fully utilized by maize plants due to water stress and wilting.

The content of the micronutrients analysed in the maize varied significantly in successive years of the study. This confirms the major impact of climatic conditions demonstrated in other studies, not only on the effect of strip cropping on yield (Lesoing, Francis, 1999), but also on the chemical composition of the plants. The interaction between plants in intercropping can affect the mobility and availability of nutrients in the rhizosphere and their uptake by plants (Wasaki et al., 2003). According to Zuo and Zhang (2009), intercropping dicots and monocots, which have different strategies for responding to Fe deficiency, may increase its accessibility for dicots, especially in alkaline soils. A study by Zuo et al. (2000) found that the interaction in the root zone between maize and peanut grown in intercropping increased the availability of Fe and reduced symptoms of Fe deficiency in the peanut plants. In strip cropping, the distance between plants in adjacent strips is greater, which may reduce the strength of the interaction between them. However, this study also found significantly higher Fe content in the maize in strip cropping with lupin and oat than in sole cropping. Moreover, it was observed that placement next to lupin was conducive to Fe accumulation in the strip cropping. Similar, Musa et al. (2012) reported that cowpea and sorghum intercropping significantly increased the Fe content of sorghum seeds. According to Veneklaas et al. (2003) and Nuruzzman et al. (2005), some plants, such as lupin and chickpeas, can release substantial quantities of carboxylates through their roots, increasing utilization by plants of Fe, Zn and Ca – even of forms less accessible to plants. Furthermore, legumes (*Fabaceae*) may release more carboxylates than species of the *Poaceae* family (Pearse et al., 2006), which could explain the differences in Fe content depending on the adjacent plant species. Gunes et al. (2007) also observed an increase in the Fe content of intercropped wheat and chickpeas.

In the literature, different effects of intercropping on the content of Zn have been reported. Musa et al. (2012) found that cowpea and sorghum intercropping did not affect the content of Zn in the seeds of sorghum plant, whereas Gunes et al. (2007) reported that intercropping enhanced Zn contents of intercropped wheat/chickpea under field conditions. In the present study, strip cropping significantly increased the Zn content of the maize in comparison with the sole cropping. This was due to significantly higher Zn content in the maize from the edge rows, both adjacent to the oat and to the blue lupin. A similar direction of changes in Zn content was observed in maize strip-cropped with common beans and spring wheat (Głowacka, 2013 b). Li et al. (2004) also observed an increase in Zn content in wheat/chickpea intercropping.

In the study by Zuo and Zhang (2008) intercropping peanut with maize, barley, oat and wheat generally increased the Cu content in the shoot of peanut in the field conditions. Similar, Musa et al. (2012) found that intercropping cowpea and sorghum slightly increased the Cu content of sorghum seeds. In our experiment strip cropping did not significantly affect the Cu content of the maize. This divergence of result might be due to different plants species, locations and agronomic practices. However, as in the case of Fe and Zn, the row position in the strip affected uptake of Cu by the maize. Proximity to oat was more conducive to Cu accumulation, while placement next to lupin led to lower content. This may be because the plants accompanying maize in the strip cropping were harvested at different times. Oat was harvested earlier and thus competed with maize for minerals for a shorter time. The most intensive accumulation of micronutrients, especially Cu, is between 109 and 132 days after maize sowing. In the present study, this was just after the oat harvest. On the other hand, the dynamics of nutrient uptake by leguminous plants increases after blooming, especially during pod setting and seed filling. This could result in greater competition from lupin and reduced availability of Cu for maize. In addition, maize in the row adjacent to the lupin produced significantly higher yield, which could also contribute to the lower Cu content in the biomass due to the "dilution" effect (Cakmak, 2004).

According to Gunes et al. (2007), intercropping of wheat and chickpea increased concentration of Mn in both plant species. In our previous research, an increase in Mn content in maize strip-cropped with common beans and wheat was observed in comparison to sole cropping (unpublished data). In addition, placement next to common bean in strip cropping was found to reduce Mn accumulation by maize. Similarly, in the present study, strip cropping led to a pronounced increase in Mn content in maize. However, the maize from the edge rows of the strip contained less Mn than maize from the middle rows. This shows that in the strip cropping the plants adjacent to maize competed with it for Mn or reduced its availability. Similarly, Inal et al. (2007) observed a reduction in Mn content in maize in intercropping with peanut. The lower Mn content may also be associated with the higher maize yield noted in the edge rows of the strip, both next to common bean and next to oat.

Effect of strip cropping and weed control methods on weed infestation in maize and accompanying plants will be discussed in other paper (Głowacka, 2013 a). Double interrow weeding used in the mechanical weed control did not completely eliminate weeds in the row of maize; they may have competed with the crop plant and limited the availability of micronutrients for it, especially as the dominant species in maize in south-east Poland, i.e. *Echinochloa crus-galli*, *Chenopodium album* and *Galinsoga parviflora*, are more competitive than maize in the accumulation of Zn, Fe and Mn. This may explain the lower Zn, Fe and Mn content observed in the present study in the maize weeded mechanically.

The results of our study indicate that strip cropping can affect the chemical composition of the plants. It is difficult to answer directly the question of what mechanisms play an important role in the improvement of microelement nutrition in maize. According to Wu et al. (2012), in intercropping system two or more species differ in growth habit and physiological parameters. Thus, resources are used in a complementary fashion, in both time and space, due to niche partitioning. A more likely explanation for enhanced micronutrient nutrition is root interaction in the rhizosphere between maize and neighbouring plant species. This may result from the release or activation of enzymes by the roots. But it is not technically easy to determine in the field conditions the rates of synthesis and release of enzymes of those species, mostly because they cannot be recovered after release into the rhizosphere in soil conditions (Zuo, Zhang, 2009). The explanation of these mechanisms requires further study, preferably in a greenhouse experiment.

Conclusions

1. Strip cropping increased zinc (Zn) , iron (Fe) and manganese (Mn) content in the maize but did not affect significantly the content of copper (Cu).

2. The content of trace elements in maize in strip cropping was affected by the row position in the strip and the neighbouring plant species.

3. Placement adjacent to oat was conducive to Cu accumulation by the maize, while placement next to blue lupin increased Fe and Zn content. Irrespective of the neighbouring plants, maize from the edge rows contained less Mn than maize in the middle row.

4. These results suggest that an appropriate choice of species for strip cropping can affect the concentration of some micronutrients in plants and their quality. However, this requires further detailed study.

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Dantinių kukurūzų įsisavinamų Cu, Zn, Fe bei Mn kiekių pokyčiai, juos auginant juostiniu būdu su siauralapiais lubinais ir vasarinėmis avižomis

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Santrauka

Juostinio auginimo būdas yra viena iš augalų auginimo tarpueiliuose formų, naudojamų tropinio ir vidutinio klimato zonose. Paprastasis kukurūzas (*Zea mays* L.) yra augalų rūšis, kurie dažnai auginami juostiniu būdu, nes auginant kraštinėse eilėse jų derlius smarkiai padidėja. Eksperimento metu lygintas kukurūzų juostinis auginimas su siauralapiais lubinais bei avižomis ir jų auginimas vienanariame pasėlyje, taikant mechaninį ir cheminį piktžolių naikinimo būdus. Lauko eksperimentas atliktas 2008–2010 m. Liublino gyvybės mokslų universiteto Zamosčės bandymų stotyje (50°42′ N, 23°6′ E). Tirta kukurūzų auginimo ir piktžolių naikinimo būdų įtaka vario (Cu), cinko (Zn), geležies (Fe) bei mangano (Mn) kiekiui ir šių elementų įsisavinimui augaluose. Taip pat tirta eilės vietos juostoje ir šalia augančio augalo rūšies įtaka šių mikroelementų kiekiui bei įsisavinimui. Auginant juostomis kukurūzuose smarkiai padidėjo Zn bei Fe ir sumažėjo Mn kiekiai, tačiau šis auginimo būdas neturėjo didelės įtakos Cu kiekiui. Augalus auginant juostomis taip pat buvo nustatyta tarprūšinė šalia augančių augalų sąveika. Kukurūzus auginant šalia avižų, juose padidėjo Cu kiekis, o šalia siauralapių lubinų – Fe ir Zn kiekiai. Didžiausias Mn kiekis nustatytas kukurūzuose, augintuose vidurinėje eilėje. Eksperimento rezultatai rodo, kad tinkamai parinkus augalų rūšis ir juos auginant juostomis, galima daryti įtaką augalų cheminei sudėčiai. Šis auginimo būdas leidžia panaikinti arba sumažinti mineralinių maisto medžiagų trūkumą augaluose.

Reikšminiai žodžiai: auginimo būdai, mikroelementai, piktžolių kontrolė, tarprūšinė sąveika.