J. Elem. s. 605–619 DOI: 10.5601/jelem.2013.18.4.535

THE INFLUENCE OF DIFFERENT METHODS OF CROPPING AND WEED CONTROL ON THE CONTENT AND UPTAKE OF Fe AND Mn BY DENT MAIZE

Aleksandra Głowacka

University of Life Sciences in Lublin
Department of Soil and Plant Cultivation

Abstract

Strip cropping is a form of intercropping in which two or more species of plants are grown in adjacent strips. Strips should be wide enough for independent mechanical cultivation, but sufficiently narrow to allow for interaction between species. This may affect not only the size and structure of yield, but also the chemical composition of the plants.

The aim of this study was to assess the impact of strip cropping and different weed control methods on the content of iron and manganese and uptake by dent maize. The study was conducted on a private farm in the village of Frankamionka in the district of Zamość. It was run from 2004 to 2006. It consisted of a field experiment established on soil with an average Fe and Mn content. The experimental factors were two methods of cultivation: sole cropping and strip cropping (common bean, dent maize, and spring wheat in adjacent strips), and three methods of weed control: mechanical (inter-row cultivation applied twice), mechanical-chemical (the herbicide Gesaprim 90 WG 1.5 kg ha^{-1} + single inter-row cultivation), and chemical (the herbicides Gesaprim 90 WG 1.5 kg ha^{-1} + Milagro 040 SC 1.5 L ha^{-1}). Maize was grown for silage and harvested at the milky-wax stage. Iron and manganese in the dry matter of maize were determined by atomic absorption spectrometry (AAS) after digestion in HNO_3 (extra pure) in accordance with PN EN ISO 6869:2002.

On average for the experiment, strip cropping of maize with common beans and spring wheat increased the iron and manganese content in maize crop in comparison with sole cropping. The Fe and Mn content varied depending on the position of a row in strip cropping. Location adjacent to beans was more conducive to iron accumulation in maize, but reduced the manganese content. Strip cropping significantly increased the uptake of both iron and manganese by maize. The iron content was the highest where mechanical weed

Aleksandra Głowacka, PhD, Department of Soil and Plant Cultivation, University of Life Sciences in Lublin, Szczebrzeska 102, 22-400 Zamość, Poland, e-mail: aleksandra.glowacka@up.lublin.pl

control was applied, while manganese was the highest where herbicides alone were used. The uptake of iron and manganese was the highest under the chemical weed control method. The results confirm the impact of strip cropping on the uptake of these minerals by maize and their content in the maize.

Key words: maize, strip cropping, weed regulation, iron, manganese, content, uptake.

WPŁYW METOD UPRAWY I REGULACJI ZACHWASZCZENIA NA ZAWARTOŚĆ I POBRANIE Fe I Mn PRZEZ KUKURYDZĘ PASTEWNĄ

Abstrakt

Uprawa pasowa jest formą uprawy współrzędnej i polega na uprawie dwóch lub więcej gatunków roślin w sąsiadujących pasach. Szerokość pasów powinna umożliwić zarówno niezależną mechaniczną uprawę roślin, jak i wzajemne oddziaływanie. To z kolei może wpływać nie tylko na wielkość i strukturę plonu, ale również na skład chemiczny roślin.

Celem pracy była ocena wpływu uprawy pasowej i metod regulacji zachwaszczenia na zawartość oraz pobranie żelaza i manganu przez kukurydzę pastewną. Eksperyment polowy przeprowadzono w gospodarstwie indywidualnym położonym we wsi Frankamionka w powiecie zamojskim, w latach 2004-2006, na glebie o średniej zasobności w Fe i Mn. Badanymi czynnikami były dwa sposoby uprawy: siew czysty i uprawa pasowa (w sąsiadujących pasach fasola zwyczajna, kukurydza pastewna, pszenica jara) oraz trzy metody regulacji zachwaszczenia: mechaniczna (2-krotne opielanie międzyrzędzi), mechaniczno-chemiczna (herbicyd Gesaprim 90 WG 1,5 kg ha^{-1} + jednokrotne opielanie międzyrzędzi); chemiczna (herbicydy Gesaprim 90 WG 1,5 kg ha^{-1}+ Milagro 040 SC 1,5 l ha^{-1}). Kukurydzę pastewną uprawiano na zielonkę i zbierano w fazie dojrzałości mleczno-woskowej. Zawartość żelaza i manganu w suchej masie kukurydzy oznaczono metodą absorpcyjnej spektrofotometrii atomowej (ASA) po mineralizacji w HNO_3 (ekstra czystym), zgodnie z normą PN-EN ISO 6869:2002.

Średnio w doświadczeniu, uprawa pasowa kukurydzy z fasolą zwyczajną i pszenicą jarą wpłynęła na zwiększenie zawartości żelaza i manganu w kukurydzy w porównaniu z uprawą w siewie czystym. Zawartość Fe i Mn zmieniała się w zależności od położenia rzędu w uprawie pasowej. Sąsiedztwo z pasem fasoli sprzyjało gromadzeniu większej ilości żelaza w kukurydzy, zmniejszało zaś zawartość manganu. Uprawa pasowa wpłynęła na istotne zwiększenie pobrania zarówno żelaza, jak i manganu z plonem kukurydzy. Zawartość żelaza była największa w warunkach stosowania mechanicznej regulacji zachwaszczenia, zaś manganu tam, gdzie stosowano wyłącznie herbicydy.

Pobranie z plonem żelaza i manganu było największe w warunkach stosowania chemicznej metody regulacji zachwaszczenia. Potwierdzono wpływ uprawy pasowej na zawartość oraz pobranie składników mineralnych z plonem.

Słowa kluczowe: kukurydza, uprawa pasowa, regulacja zachwaszczenia, żelazo, mangan, zawartość, pobranie.

INTRODUCTION

Strip cropping is used in many regions of the world to protect soil against water and wind erosion and to reduce losses due to leaching of minerals (Bucur et al. 2007, Rogobete, Grozav 2011). It involves two or more crop species grown in strips wide enough to allow for independent mechanical cultivation, yet sufficiently narrow so that interaction between species occurs. This system affects not only crop yield but also nutrient content in plants, with the strength and direction of these changes depending on a nutrient and on the neighbouring crops (LI et al. 2001, GŁOWACKA 2010). Maize is often selected for strip cropping because it responds to the edge effect with significant increases in yield. It has the potential to produce large amounts of both silage and grain of high nutritional value. Maize plays an important role as animal feed, food for people and raw material for various industries (SZYMAŃSKA et al. 2009). Therefore, as with other plants, the nutritional value and composition as well as proportions of nutrients in maize are very important to the health of humans and animals (GRAHAM et al. 2007, WHITE, BROADLEY 2009).

In the Polish literature, few studies deal with the impact of strip cropping on weed infestation, yield and the content or uptake of macronutrients (BURCZYK 2003, GŁOWACKA 2008, GŁOWACKA et al. 2011). There have been no reports on the impact of strip cropping on the iron and manganese content in plants. Therefore, the aim of this study was to evaluate the impact of strip cropping and sole cropping, together with weed control methods, on the content and uptake of iron and manganese in maize.

MATERIAL AND METHODS

Field experiments were carried out in 2004-2006, on a private farm located in the village of Frankamionka in the district of Zamosc. The experiment was set up in a split-plot randomized block design in four replications. It was conducted on clayey silt soil with granulometric composition, slightly acid (pH in 1 mol KCl dm^{-3} 6.5), containing 19 g kg^{-1} organic matter and with an average content of available forms of manganese and iron (219.4--230.6 mg Mn kg^{-1}, 904-912 mg Fe kg^{-1}).

The experimental factors were as follows: 1) method of cultivation: a) sole cropping, in which the size of plots was 23.75 m^2 for sowing and 17 m^2 for harvesting, with 10 rows of maize spaced at 50 cm, and b) strip cropping, in which three crops – common bean, dent maize and spring wheat – were grown side by side in strips of the width of 2.5 m each. Five rows of maize were planted in each strip, spaced at 50 cm. The size of the maize plots was 11.75 m^2 for sowing and 10.5 m^2 for harvesting; 2) method of weed control: a) mechanical – inter-row cultivation twice; b) mechanical--chemical – the herbicide Gesaprim 90 WG 1.5 kg ha^{-1} (a.i. atrazine 135 g ha^{-1}) + inter-row cultivation; c) chemical – the herbicides Gesaprim 90 WG 1.5 kg ha^{-1} (a.i. atrazine 135 g ha^{-1}) + Milagro 040 SC 1.5 L ha^{-1} (a.i. nicosulfuron 60 g ha^{-1}). The cultivar Veritis of dent maize (FAO 230-240) was sown between 25 April and 5 May. Mineral fertilization was applied uniformly in the amount of 160 kg N ha^{-1}, 40 kg P ha^{-1} and 108 kg K ha^{-1}. Maize was harvested at the milky-wax stage (BBCH 79/83), in the second third of September. Spring wheat was harvested in the second third of August (BBCH 89), and common beans in the last third of August or first week of September (BBCH 88/89). A detailed description of the methodology of the experiment can be found in an earlier study (GŁOWACKA 2008). Meteorological conditions during the years of the research are shown in Figure 1.

Each year prior to harvest, two maize plants were randomly collected from middle rows of each plot. Additionally, from each plot with strip cropping two maize plants were collected from the border rows adjacent to the rows of common bean and spring wheat. After the plants were crushed, dried and ground, the iron and manganese content in the samples (following wet mineralization in extra pure HNO_3) was determined by atomic adsorption spectroscopy (AAS) according to PN EN ISO 6869:2002. the results were calculated on the dry weight basis. The analyses were performed at the Agroecological Central Laboratory of the University of Life Sciences in Lublin. The results were analyzed statistically using analysis of variance (KALA 2009). Differences between averages were evaluated by Tukey's test. The significance of differences was determined at a 95% confidence level.

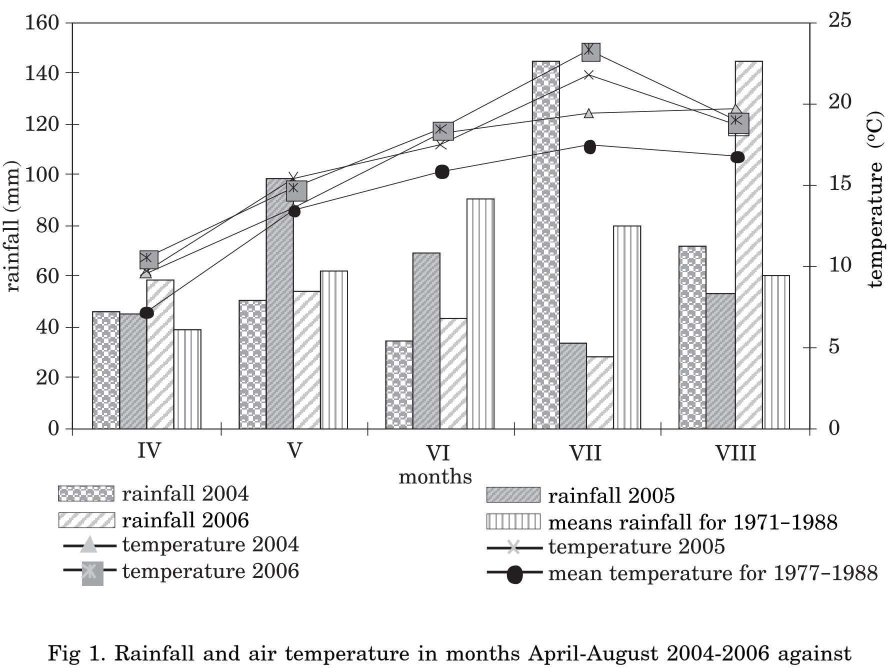

Fig 1. Rainfall and air temperature in months April-August 2004-2006 against the background of long-term means (1971-1988), according to the Meteorological Station in Zamość

RESULTS AND DISCUSSION

In the first year of the study, maize yield in the sole cropping was significantly higher than in the strip cropping (Table 1). On average for the study, however, maize yield was not significantly affected by the cropping methods. Of the three methods of weed control, the mechanical method had the least favourable effect on yield. The low maize biomass in this series was probably due to the inadequate efectiveness of the mechanical weed control treatments (ABDIN et al. 2000). The differences between the mechanical-chemical and chemical methods were small and statistically insignificant. Some significant differences in the maize yield in successive years of the study could be due to the weather conditions in the growing season.

Table 1

Yield of maize depending on the method of cropping and weed control (Mg d.m. ha^{-1})

Method of cultivation	Weed control	Years			Average
		2004	2005	2006	
Sole cropping	A* B C	20.6 22.9 23.2	14.6 15.9 18.7	12.3 16.7 16.1	15.8 18.5 19.3
Strip cropping – mean for plot	A B C	18.8 19.8 20.9	14.0 17.9 18.4	11.6 15.3 15.2	14.8 17.7 18.2
LSD (α = 0.05)		n.s.	n.s.	n.s.	n.s.
Average for factors					
Sole cropping	–	22.2*b*	16.4	15.4	17.9
Strip cropping – mean for plot	–	19.9*a*	16.8	14.0	16.9
LSD (α = 0.05)		0.94	n.s	n.s.	n.s.
–	A	19.7*a*	14.3*a*	11.9*a*	15.3*a*
–	B	21.3*b*	16.2*b*	16.0*b*	18.1*b*
–	C	22.0*b*	18.5*c*	15.7*b*	18.8*b*
LSD (α = 0.05)		1.45	1.81	3.05	1.59
Years	2004 2005 2006	21.0*c* 16.6*b* 14.5*a*			
LSD (α = 0.05)		1.65			

* weed control: A – mechanical, B – mechanical-chemical, C – chemical
a, b, c – means in columns marked with the same letter do not differ significantly

There was much less rainfall in 2005 and 2006 than in 2004 or than the long-term average. Moreover in 2006 it was very unevenly distributed.

The iron content in plants is relatively high in comparison with other micronutrients. It also varies markedly depending on the organ and the developmental stage of the plant. In a study by SKOWROŃSKA and FILIPEK (2009), the iron content was 15.5-29.0 mg kg^{-1} d.w. in the grain of maize, 47.5--77.0 mg kg^{-1} d.w. in leaves, and as high as 1,137.0-1,482.0 mg kg^{-1} d.w. in roots. In the present study, the Fe content in the aboveground biomass of maize ranged from 50.8 to 124.4 mg kg^{-1} d.w.; it varied significantly depending on weather conditions in different years of the study, method of cultivation and weed control method (Table 2). The iron content in the maize grown in strip cropping with common bean and spring wheat was substantially higher, by an average of 32%, than in sole cropping. ZANGH and LI

Table 2

Content of iron in maize depending on the method of cropping and weed control (mg Fe kg^{-1} d.w.)

Method of cultivation	Weed control	Years			Average
		2004	2005	2006	
Sole cropping	A*	93.3*c*	53.2*c*	68.7*c*	71.8*b*
	B	88.2*b*	55.3*d*	47.9*a*	63.8*a*
	C	80.0*a*	55.8*d*	58.3*b*	64.7*a*
Strip cropping – mean for plot	A	111.5*d*	50.8*a*	109.3*f*	90.5*d*
	B	124.4*e*	58.2*f*	78.4*d*	87.0*c*
	C	112.1*d*	52.2*b*	92.9*e*	85.7*c*
LSD (α = 0.05)		1.42	1.22	3.32	1.77
Average for factors					
Sole cropping	–	87.2*a*	54.8*a*	58.3*a*	66.7*a*
Strip cropping – mean for plot	–	116.0*b*	53.7*a*	93.5*b*	87.8*b*
LSD (α = 0.05)		1.15	n.s.	2.47	2.27
–	A	102.4*b*	52.0*a*	89.0*c*	81.1*b*
–	B	106.3*c*	56.8*c*	63.2*a*	75.4*a*
–	C	96.0*a*	54.0*b*	75.6*b*	75.2*a*
LSD (α = 0.05)		1.23	1.66	2.72	1.42
Years	2004	101.6*c*			
	2005	54.3*a*			
	2006	75.9*b*			
LSD (α = 0.05)		3.78			

* weed control: A – mechanical, B – mechanical-chemical, C – chemical
a, b, c, d, e, f – means in columns marked with the same letter do not differ significantly

(2003) also indicate that strip cropping affects not only crop yield, but also the uptake and use of nutrients. Research by GŁOWACKA (2011) shows that the neighbouring plants in strip cropping affect the content of macronutrients 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. LI et al. (2001) reported that wheat is more competitive in the uptake of macronutrients such as N, P, and K than maize and soy accompanying it in strip cropping. In the present study, too, the iron content in maize varied depending on the position of a row in a strip and the adjacent plant. (Figure 2). On average, irrespective of the method of weed

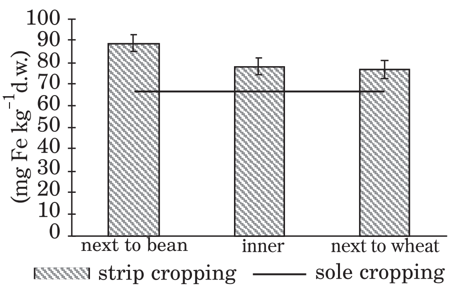

Fig. 2. The influence of row position in a strip on the iron content in maize plants

control, the iron content in maize growing in rows adjacent to beans was higher than in maize from middle rows or rows growing adjacent to wheat, between which there was no pronounced difference. Changes in the iron content in plants from individual rows were similar, irrespective of the method of weed control (Figure 3).

The manganese content in the aerial parts of a plant to some extent depends on the properties of a species (SZTEKE et al. 2004, BOWSZYS et al. 2006, ROGÓŻ, NIEMIEC 2010, RACHOŃ et al. 2012) and can range widely from 20 to 500 mg kg^{-1} d.m. In our study, the manganese content in the maize ranged from 8.4 to 28.3 mg kg^{-1} d.w. and was similar to that noted by RABIKOWSKA and PISZCZ (2004), but much lower than what is reported to be optimal in animal feed (GORLACH, 1991, FALKOWSKI et al. 2000).

Strip cropping decreased the manganese content in maize only in the first year of the experiment. In the following years and on average for the experiment, the manganese content was significantly higher in strip cropping, by an average of 16.4%, than in sole cropping (Table 3). Differences in the manganese content in maize depending on the crop adjacent to the row of maize in a strip were different than in the case of iron. The lowest manganese content was noted in rows adjacent to common bean, while the highest content was observed in middle rows (Figure 4). GŁOWACKA et al. (2011) reported that maize grown in a row adjacent to wheat contained more calcium than maize grown adjacent to beans. The ability of different plant spe-

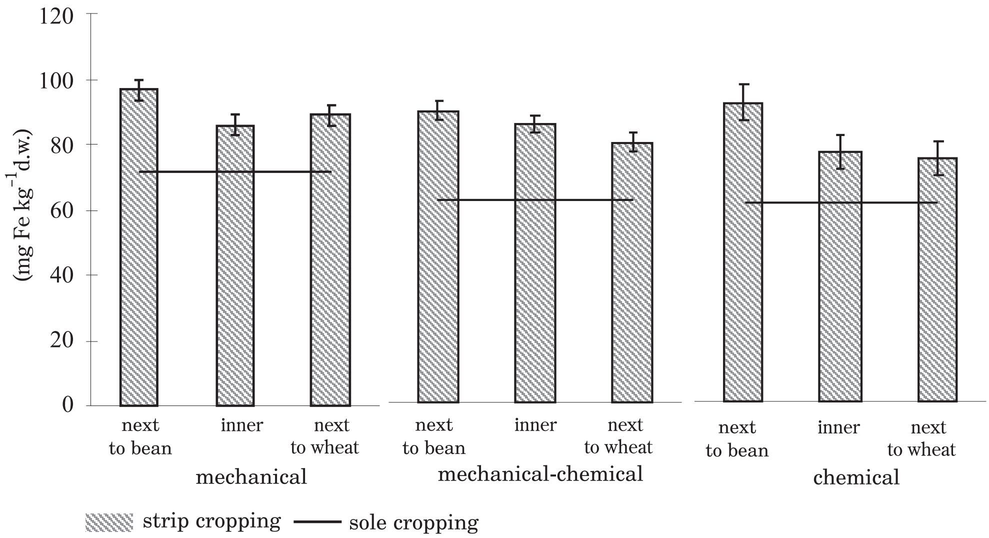

Fig. 3. The influence of a row position in a strip and weed control method on the iron content in maize plants

cies to take up minerals from soil is affected by the unequal valency and cation exchange capacity of their roots (DRAKE et al. 1951). This exchange capacity in dicotyledonous plants such as beans is twice that of monocots. Moreover, the accumulation of available forms of manganese in soil can be depressed by magnesium and calcium ions (SIENKIEWICZ et al. 2009). Our analysis of changes in the manganese content in plants from each row under different methods of weed control reveals that wherever the mechanical-chemical and chemical methods were used, the manganese content was the lowest in maize from rows adjacent to common beans. When mechanical treatments alone were applied, the highest Mn content was in maize from the center row, with insignificant differences between the rows bordering with beans and with spring wheat (Figure 5).

High-yielding crops contain smaller quantities of micronutrients per unit weight in relation to their availability in soil than crops that produce less biomass, because theformer are unable to take up from soil sufficiently large amounts of nutrients, which in turn are ‘diluted’ in the high biomass of the plant (CAKMAK 2004). This was confirmed in the present study with respect to iron. The highest iron content was noted in the maize from sites where mechanical weed control alone was used. Significantly less iron was accumulated by plants when the mechanical-chemical or chemical method was used. However, the differences between these methods were not significant (Table 2). These methods were conducive to the production of large quantities of biomass by maize (Table 1). The negative correlation between the volume of maize yield and the iron content in biomass is confirmed by the

Table 3

Content of manganese in maize depending on the method of cropping and weed control (mg Mn kg^{-1} d.w.)

Method of cultivation	Weed control	Years			Average
		2004	2005	2006	
Sole cropping	A* B C	15.3*a* 15.7*ab* 25.3*e*	8.4*a* 8.9*b* 10.7*d*	13.2*a* 19.6*b* 19.5*b*	12.3*a* 14.7*b* 18.4*e*
Strip cropping – mean for plot	A B C	16.2*b* 17.2*c* 20.0*d*	9.3*c* 127*e* 9.5*c*	20.2*d* 25.5*c* 28.3*e*	15.9*c* 17.8*d* 19.3*f*
LSD (α = 0.05)		0.63	0.04	0.38	0.21
Average for factors					
Sole cropping	–	18.7*b*	9.3*a*	17.4*a*	15.2*a*
Strip cropping – mean for plot	–	17.8*a*	10.5*b*	24.7*b*	17.7*b*
LSD (α = 0.05)		0.22	0.02	0.14	0.07
–	A	15.7*a*	8.9*a*	17.7*a*	13.8*a*
–	B	16.5*b*	10.8*c*	22.6*b*	16.6*b*
–	C	18.3*c*	10.1*b*	23.7*c*	18.9*c*
LSD (α = 0.05)		0.34	0.02	0.21	0.11
Years	2004 2005 2006	18.3*b* 9.9*a* 21.5*c*			
LSD (α = 0.05)		0.32			

* weed control: A – mechanical, B – mechanical-chemical, C – chemical
a, b, c, d, e, f – means in columns marked with the same letter do not differ significantly

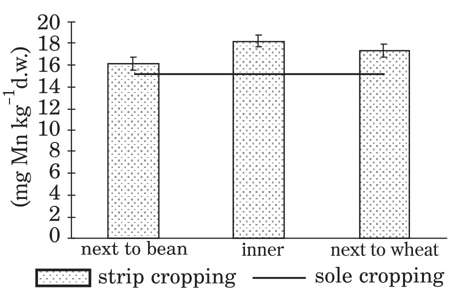

Fig. 4. The influence of a row position in a strip on the manganese content in maize plants

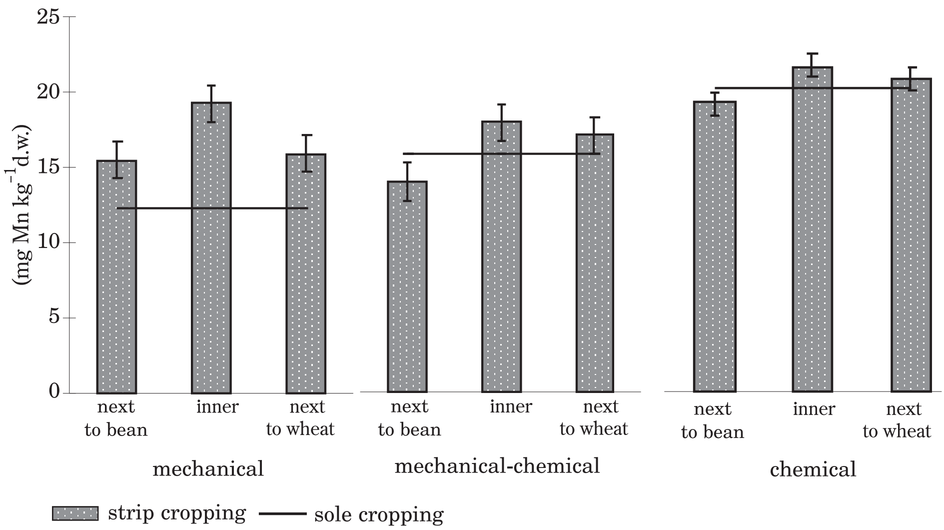

Fig. 5. The influence of a row position in a strip and weed control method on the manganese content in maize plants

Pearson's correlation coefficient (r = -0.471, $p < 0.05$). The manganese content, however, was the lowest in mechanically-weeded maize (Table 3). Inter-row cultivation repeated twice did not completely eliminate weeds from maize rows; the dominant species of weeds, i.e. Echinochloa crus-galli, Chenopodium album, and Galinsoga parviflora, are much more competitive than maize in the uptake of manganese, containing 7-10-fold more of this element, which could have resulted in its limited availability for maize.

The weather conditions substantially affected the iron and manganese content in maize. The smallest amounts of Fe and Mn in the dry matter of the maize were noted in 2005, which was characterized by low rainfall in July and August. The highest iron content was observed in 2004, and the highest manganese content appeared in 2006, the last year of the study (Tables 2 and 3). The impact of weather conditions on the absorption of micronutrients and their higher content in plants in years with more rainfall is also confirmed by the results of other experiments (RAJCAN, SWANTON 2001, SZTEKE et al. 2004, KLIKOCKA 2011).

The uptake of manganese and iron by plants is competitive, with Mn activity greater than that of Fe, especially where pH is acidic (ROGÓŻ 2009). In our study, the manganese content in maize was positively correlated with the iron content – r = 0.410 ($p < 0.05$). According to FALKOWSKI et al. (2000), an optimal Fe/Mn ratio in maize for animal feed should be 1.5-2.5:1. When the value is less than 1.5, symptoms of Mn toxicity and Fe deficiency appear, and when it is above 2.5 there is harmful excess of iron and symptoms of Mn deficiency. Therefore, it is important to maintain an appropriate balance between these two elements. However, the value of this ratio in different species of plants has a much broader range, which appears to be a taxonomic characteristic. In plants of the families Solanaceae, Brassicaceae, and Chenopodiaceae, the ratio is greater than 4, while for the families Fabaceae and Poaceae the optimum Fe/Mn ratio is 2.5-4. In our experiment, the Fe/Mn ratio was 4.9 in strip cropping and 4.6 in sole cropping, which was close to that characteristic of the Poaceae family, but well above the limit proposed for animal feed. The lowest Fe/Mn ratio was found in maize grown with chemical weed control, while the highest was noted in maize weeded mechanically (Table 4).

In a study by Rabikowska and Piszcz (2004), the uptake of manganese by maize ranged from 128 to 375 g from 1 ha. The manganese uptake by maize was similar in the present study: an average of 289 g per 1 ha (123-430.8 g

Table 4

Proportion of the Fe/Mn in maize depending on the method of cropping and weed control

Method of cultivation	Weed control	Years			Average
		2004	2005	2006	
Sole cropping	A* B C	6.1*c* 5.6*b* 3.2*a*	6.3*c* 6.2*c* 5.2*b*	5.2*e* 2.5*a* 3.3*b*	5.8*e* 4.3*b* 3.5*a*
Strip cropping – mean for plot	A B C	6.9*d* 7.2*e* 5.6*b*	5.5*b* 4.6*a* 5.5*b*	4.0*d* 3.3*c* 3.0*c*	5.4*d* 4.9*c* 4.4*b*
LSD (α = 0.05)		0.5	0.6	0.6	0.3
Average for factors					
Sole cropping	–	5.0*a*	5.9*b*	3.5*a*	4.6*a*
Strip cropping – mean for plot	–	6.6*b*	5.2*a*	3.6*a*	4.9*b*
LSD (α = 0.05)		0.15	0.16	0.12	0.21
–	A	6.5*b*	5.9*b*	4.8*b*	5.4*c*
–	B	6.4*b*	5.4*a*	2.9*a*	4.6*b*
–	C	4.4*a*	5.4*a*	3.1*a*	4.0*a*
LSD (α = 0.05)		0.18	0.19	0.24	0.31
Years	2004 2005 2006	5.8*b* 5.5*b* 3.6*a*			
LSD (α = 0.05)		0.36			

* weed control: A – mechanical, B – mechanical-chemical, C – chemical
a, b, c, d, e – means in columns marked with the same letter do not differ significantly

from 1 ha). On average for the experiment, significantly more manganese was taken up by maize grown in strip cropping with spring wheat and common beans than in sole cropping (Table 5). The least manganese was taken up by maize from plots weeded mechanically, significantly more from plots where the mechanical-chemical weed control was applied, and the most in the case of chemical weed control. Pearson's correlation coefficients confirm a close relationship between the uptake and micronutrient content, r = 0.831 (p < 0.001), and between the uptake and yield, r = 0.819 (p < 0.001). On average in the experiment, strip cropping significantly increased the uptake of iron by maize compared to sole cropping (Table 6). The total uptake of iron was the lowest when the mechanical weed control method was used. A significantly higher uptake of micronutrients was noted for the mechani-

Table 5

Uptake of manganese with maize yield depending on the method of cropping and weed control (g ha^{-1})

Method of cultivation	Weed control	Years			Average
		2004	2005	2006	
Sole cropping	A* B C	315*a* 359*ab* 585*c*	123*a* 142*a* 199*b*	162 328 314	199*a* 277*b* 366*d*
Strip cropping – mean for plot	A B C	304*a* 342*a* 421*b*	130*a* 228*b* 175*ab*	292 360 431	242*ab* 310*c* 342*cd*
LSD (α = 0.05)		62.9	53.3	n.s.	46.4
Average for factors					
Sole cropping	–	420*b*	156*a*	268*b*	281*a*
Strip cropping – mean for plot	–	355*a*	178*b*	361*b*	298*b*
LSD (α = 0.05)		22.3	19.0	39.1	16.5
–	A	309*a*	127*a*	227*b*	221*b*
–	B	351*b*	185*b*	344*b*	293*b*
–	C	503*c*	187*b*	372*b*	354*c*
LSD (α = 0.05)		34.3	29.0	60.1	25.3
Years	2004 2005 2006	387*c* 166*a* 314*b*			
LSD (α = 0.05)		37.8			

* weed control: A – mechanical, B – mechanical-chemical, C – chemical

a, b, c, d – means in columns marked with the same letter do not differ significantly

Table 6

Uptake of iron with maize yield depending on the method of cropping and weed control (g ha^{-1})

Method of cultivation	Weed control	Years			Average
		2004	2005	2006	
Sole cropping	A* B C	1920 2016 1851	779 881 1041	842 800 941	1180 1233 1278
Strip cropping – mean for plot	A B C	2100 2466 2345	709 1041 963	1263 1198 1415	1357 1568 1574
LSD (α = 0.05)		n.s.	n.s.	n.s.	n.s.
Average for factors					
Sole cropping	–	1929*a*	900*a*	861*a*	1230*a*
Strip cropping – mean for plot	–	2303*b*	905*a*	1292*b*	1500*b*
LSD (α = 0.05)		110.1	n.s.	125.4	58.9
–	A	2010*a*	744*a*	1052*a*	1269*a*
–	B	2241*b*	961*b*	999*a*	1401*b*
–	C	2098*b*	1002	1178*a*	1426*b*
LSD (α = 0.05)		169.1	151.4	n.s.	90.4
Years	2004 2005 2006	2116*c* 902*a* 1077*b*			
LSD (α = 0.05)		98.7			

* weed control: A – mechanical, B – mechanical-chemical, C – chemical
a, b – means in columns marked with the same letter do not differ significantly

cal-chemical and chemical methods of weed control. However, the differences between these two methods were not significant. The correlation analysis confirmed no significant relationship between the iron uptake and maize yield. Instead, it confirmed the close relationship between uptake of this micronutrient and its content in the biomass of the maize, $r = 0.691$ ($p < 0.001$), which is consistent with results obtained by MAZUR and SIENKIEWICZ (2009).

CONCLUSIONS

1. Strip cropping of maize with common beans and spring wheat significantly increased both the content and uptake of iron and manganese by maize in comparison with sole cropping.

2. The iron content was highest in the maize where the mechanical method of weed control was used, while manganese content and iron and manganese uptake was highest in the case of the chemical weed control.

3. The study confirms the influence of neighbouring plant species in strip cropping on the uptake of different amounts of iron and manganese by maize. Location next to common beans was more conducive to the accumulation of iron in maize, but reduced the manganese content.

REFERENCES

Abdin O.A., Zhou X.M., Cloutier D., Coulman D.C., Faris M.A., Smith D.L. 2000. *Cover crops and interrow tillage for weed control in short season maize* (*Zea mays*). Eur. J. Agron., 12: 93-102.

Bowszys T., Ruszkowski K., Wierzbowska J., Wojciechowski T. 2006. *Effect of liming on manganese content and removal with winter rye harvest*. J. Elementol., 11(4): 421-430.

Bucur D., Jitareanu G., Ailincai C., Tsadilas C., Ailincai D., Mercus A. 2007. *Influence of soil erosion on water, soil, humus and nutrient losses in different crop systems in the Moldavian Plateau, Romania.* J. Food, Agric. Environ., 5 (2): 261-264.

Burczyk P. 2003. *Advantages of strip cropping undersown with legumes plants and the possibility of reducing the loss of nitrogen*. Post. Nauk Rol., 2(296): 16-21. (in Polish)

Cakmak I. 2004. *Plant nutrition research: Priorities to meet human needs for food in sustainable ways*. Plant Soil, 247: 3-24.

Drake M., Vengris J., Colby W.G. 1951. *Cation exchange capacity of plant roots*. Soil Sci., 72: 138-147.

Falkowski M., Kukułka I., Kozłowski S. 2000. *The chemical properties of grassland plants*. Wyd. AR Poznań, pp. 132. (in Polish)

Głowacka A. 2008. *The effect of strip cropping on dimension and structure of maize yield cultivated for silage*. Fragm. Agron., 25(3): 52-60. (in Polish)

Głowacka A. 2010. *Changes of nitrogen contents in soil and maize as a result of different methods of cropping and weeding control*. Zesz. Probl. Post. Nauk Rol., 556: 85-91. (in Polish)

Głowacka A. 2011. *Changes of phosphorus and potassium content and intake in maize as result of different methods of cropping and weed control*. Fragm. Agron., 28(3): 26-34. (in Polish)

Głowacka A., Klikocka H., Juszczak D. 2011. *The influence of cropping and weed control methods of maize on magnesium and calcium content and intake*. Fragm. Agron., 28(4): 25-32. (in Polish)

Gorlach E. 1991. *The content of trace elements in fodder plants as a measure of their values*. Zesz. Nauk. AR w Krakowie, 262: 13-21. (in Polish)

Graham R.D., Welch R.M., Saunders D.A., Ortiz-Monasterio I., Bouis H.E. et al. 2007. *Nutritious subsistence food system.* Adv. Agron., 92: 1-74.

GRZYŚ E. 2004. *The role and importance of micronutrients in plants' nutrition*. Zesz. Probl. Post. Nauk Rol., 502: 89-99. (in Polish)

KALA R. 2009. *Statistic for naturalist*. Wyd. UP w Poznaniu, 1-234. (in Polish)

KLIKOCKA H. 2011. *The effect of sulphur kind and dose on content and uptake of micronutrients by potato tubers* (*Solanum tuberosum* L.). Acta Sci. Pol., Hort. Cult., 10(2): 137-151.

LI L., SUN J., ZHANG F., LI X., RENGEL Z., YANG S. 2001. *Wheat/maize or wheat/soybean strip intercropping* II. *Recovery or compensation of maize and soybean after wheat harvesting*. Field Crops Res., 71: 173-181.

MAZUR Z., SIENKIEWICZ S. 2009. *Effect of urea applied with composts on concentration of Cu, Zn and Mn in corn fresh matter*. J. Elementol., 14(2): 323-330.

PN-EN ISO 6869. 2002. Forage – *Determine the content of calcium, copper, iron, magnesium, manganese and zinc – method by atomic absorption spectrometry*. PKN Warszawa, ss. 18. (in Polish)

RABIKOWSKA B., PISZCZ U. 2004. *Effect of differentiated nitrogen fertilization on utilization of copper, manganese and zinc of FYM in 4 year crop rotation.* Part II. *Manganese*. Zesz. Probl. Post. Nauk Rol., 502: 277-286. (in Polish)

RACHOŃ L., PAŁYS E., SZUMIŁO G. 2012. *Comparison of the chemical composition of spring durum wheat grain (Triticum durum) and common wheat grain (Triticum aestivum ssp. vulgare)*. J. Elem., 17(1): 104-114. DOI:10.5601/jelem.2012.17.1.10

RAJCAN I., SWANTON C.J. 2001. *Understanding maize-weed competition: resource competition, light quality and the whole plant*. Field Crops Res., 71: 139-150.

ROGOBETE G., GROZAV A. 2011. *Methods for assessment of soil erosion*. Res. J. Agric. Sci., 43: 174-179.

ROGÓŻ A. 2009. *Trace elements content in soils and in selected root crops.* Part II. *Manganese and iron*. Zesz. Probl. Post. Nauk Rol., 541(2): 365–373. (in Polish)

ROGÓŻ A., NIEMIEC M. 2010. *Contents of the trace elements in weeds of cereal crops against the background of their contents in soil*. Zesz. Probl. Post. Nauk Rol., 556: 907-922. (in Polish)

SIENKIEWICZ S., WOJNOWSKA T., KRZEBIETKE S., WIERZBOWSKA J., ŻARCZYŃSKI P. 2009. *Content of available forms of some micronutrients in soil after long-term differentiated fertilization*. J. Elementol., 14(4): 787-794.

SKOWROŃSKA M., FILIPEK T. 2009. *The content and uptake of micronutrients by maize under the conditions of differentiated mineral fertilization*. Zesz. Probl. Post. Nauk Rol., 541: 383-389. (in Polish)

SZTEKE B., JĘDRZEJCZAK R., RĘCZAJSKA W. 2004. *Iron and manganese in selected edible plants*. Rocz. PZH, 55: 21-27. (in Polish)

SZYMAŃSKA G., SULEWSKA H., PANASIEWICZ K. 2009. *The content of microelements in grain of six maize cultivars depending on the harvest date.* Zesz. Probl. Post. Nauk Rol., 541: 433-439.

WHITE P.J., BROADLEY M.R. 2009. *Biofortification of crops with seven mineral elements often lacking in human diets – iron, zinc, copper, calcium, magnesium, selenium and iodine*. New Phytol., 182, 49-84.

ZHANG F., LI L. 2003. *Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency*. Plant Soil, 248: 305-312.