Uptake of Cu, Zn, Fe and Mn by maize in the strip cropping system

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ABSTRACT

A field experiment was conducted in 2008–2010 at the Experimental Station of the Faculty of Agricultural Sciences in Zamość (50°42'N, 23°16'E), University of Life Sciences in Lublin. The aim of the study was to assess the impact of cropping method and weed control methods on the content of Cu, Zn, Fe and Mn in maize and on their uptake. Two cropping methods were studied – sole cropping and strip cropping (common bean, dent maize and spring barley in adjacent strips) and two weed control methods – mechanical and chemical. Strip cropping reduced Mn content in maize, did not significantly affect Zn content, and increased accumulation of Cu and Fe. The content and uptake of the elements by maize depended on the position of the row in the strip and on the adjacent plant species. Placement next to beans resulted in higher Fe and Zn content, while placement next to barley increased Cu content. The highest Mn content was noted in maize from the centre row. In general, micronutrient uptake by maize was lowest in the middle row. These results indicate that strip cropping can be an effective agricultural practise for plant biofortification.

Keywords: cropping method; interspecific facilitation; micronutrients; weed control

Strip cropping is a form of intercropping used in different climate zones. It protects soil from water and wind erosion and reduces nutrient leaching (Rogobete and Grozav 2011). In the intercropping system root interaction could increase the root activity and microbial quantity in the rhizosphere (Zhang et al. 2013). Interspecific interaction between species in the rhizosphere can also affect nutrient availability and uptake in intercropping (Hauggard-Nielsen et al. 2001, Li et al. 2010). In strip cropping, placing plants in separate strips enables more efficient use of light, water and minerals, which can also affect the chemical composition of plants. Few studies confirm the impact of this system on N, P, K, Ca and Mg content in plants, and the direction of change depends on the nutrient and on the neighboring plants (Li et al. 2001, Głowacka et al. 2011). Little information is available on the possible impact of strip cropping on micronutrient content in plants, especially in field conditions. Therefore, this study was aimed at assessing the impact of strip cropping of common beans/dent maize/spring barley and various weed control methods on Cu, Zn, Fe and Mn content and uptake by maize.

MATERIAL AND METHODS

A field experiment was conducted 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 Cambisols, slightly acidic (pH_{KCl} – 6.2), with medium organic matter content (19 g/kg according to Tiurin) and average content of available forms of zinc (9.5–12.7 mg Zn/kg), copper (3.9–5.7 mg Cu/kg), manganese (160.8–221.2 mg Mn/kg) and iron (942–961 mg Fe/kg). The content of micronutrients in the soil was determined by extraction with 1 mol/L HCl. The experiment had a split-plot design with four replications. Mineral fertilization was applied uniformly in the amounts of N – 140, P – 35 and K – 100 kg/ha (N in the form of ammonium nitrate, P – triple superphosphate, K – potassium salt). Phosphorus and potassium fertilization was introduced once before spring pre-sowing treatments, and nitrogen was applied in split applications (half before sowing, and the rest for top dressing in the 4–5 leaf stage – BBCH 14–15). The factors analyzed were: I. Cropping method (CM): (1) sole cropping of a single species, in which the plot size was 26.0 m^2 with 10 rows of maize per plot and 65 cm spacing between rows; (2) strip cropping, in which three species – common bean (*Phaseolus vulgaris* L.), dent maize (*Zea mays* L.), and spring barley (*Hordeum vulgare* L.) – were grown side-by-side in adjacent strips 3.3 m wide, with 5 rows of maize in each strip, spaced at 65 cm. The plot size for the maize was 11.75 m^2. II. Weed control method (WC): A – Mechanical – weeding of interrows twice (first at the 5–6 leafs growth stage BBCH 15/16, and again 2 weeks later – BBCH 16/17); B – chemical – herbicide with a.i. bromoxynil + terbuthylazine at 144 g/ha + 400 g/ha at the 4–6 leafs growth stage BBCH 14/16. Two weed control methods were also used in the barley and common bean crop. A detailed description of the conditions of the study and the agricultural techniques used is presented in an earlier paper (Głowacka 2013a).

In sole cropping and in strip cropping maize hybrid Celio was grown for silage on a site where the previous crop was barley. Determinate types of common bean Aura variety was grown for dry seeds on a site where the previous crop was maize. Spring barley Start variety was grown at a site where the previous crop was common bean. In the successive years of the study the maize and common bean was sown on 28th April and 2nd and 5th May, and barley was sown on 12th, 15th and 19th April. Maize was harvested at the milky wax stage BBCH 79/83, common bean in the third week of August or first week of September, spring barley in the first or second third of August (BBCH 89).

Each year prior to harvest, 3 plants were collected from the middle row of the sole cropping plots. From each strip of cropping plot 3 plants were taken from the border rows adjacent to the bean and barley and from the middle row. The plants were crushed, dried and the content of Cu, Zn, Fe and Mn was determined (after wet mineralization in extra pure HNO_3) by atomic adsorption spectroscopy (AAS, Sydney, Australia) according to PN-EN ISO 6869:2002. The results were converted to dry weight, and uptake of each element was calculated per hectare. The results were analyzed statistically by ANOVA using STATISTICA PL (Tulsa, USA). Differences between averages were determined using the Tukey's test, at $P < 0.05$.

RESULTS AND DISCUSSION

The weather conditions in each year of the study significantly influenced the content of the micro-

Table 1. Content of microelements in maize, depending on year, cropping and weed control methods (mg/kg DW)

I. Cropping method (CM)	II. Weed control (WC)	Nutrient			
		Cu	Zn	Fe	Mn
Years	2008	8.8	55.2	122.1	39.1
	2009	2.9	32.8	67.5	30.7
	2010	7.9	50.0	112.9	34.0
$LSD_{(0.05)}$ for years		0.6	3.6	6.8	3.4
Average for factors					
CM	sole cropping	6.2	46.1	94.6	36.9
	strip cropping (mean for strip)	7.1	45.9	107.0	32.3
$LSD_{(0.05)}$ for CM		0.3	ns	5.7	2.3
WC	A	6.9	52.7	95.7	30.8
	B	6.4	39.3	106.0	38.5
$LSD_{(0.05)}$ for WC		0.3	2.5	2.1	1.4
Interaction CM × WC					
Sole cropping	A	6.5	55.0	88.5	31.2
	B	5.9	37.2	100.7	42.7
Strip cropping (mean for strip)	A	7.2	50.4	102.9	30.4
	B	6.9	41.4	111.2	34.3
$LSD_{(0.05)}$ for CM × WC		ns	1.7	ns	1.9

Weed control: A – mechanical; B – chemical; ns – not significant; DW – dry weight

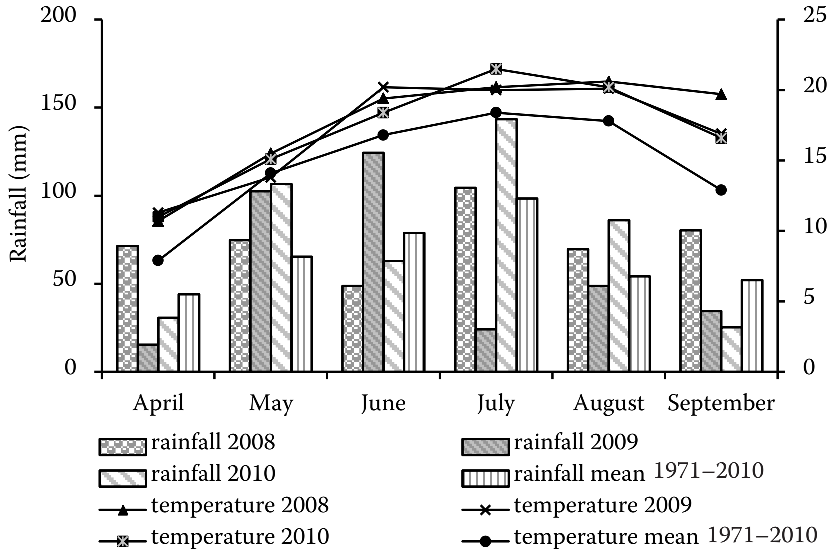

Figure 1. Rainfall and air temperature in months IV–IX as compared to the long-term means (1971–2010), according to the Meteorological Station in Zamość, Poland

elements. The least Cu, Zn and Fe were noted in the maize in 2009 (Table 1). This growing season had the lowest rainfall, and it was very unevenly distributed (Figure 1).

Strip cropping significantly increased Cu content in maize (Table 1). Total Cu uptake by the maize was significantly higher, by about 18%, in strip cropping than in sole cropping. Wasaki et al. (2003) argue that the interaction of plant species in intercropping can affect the availability of nutrients in the rhizosphere and their uptake by the plants. In the present study Cu content and uptake by maize in strip cropping depended on the row position in the strip and on the adjacent plant species (Figure 2). The lowest Cu content was noted in maize from the middle row and the

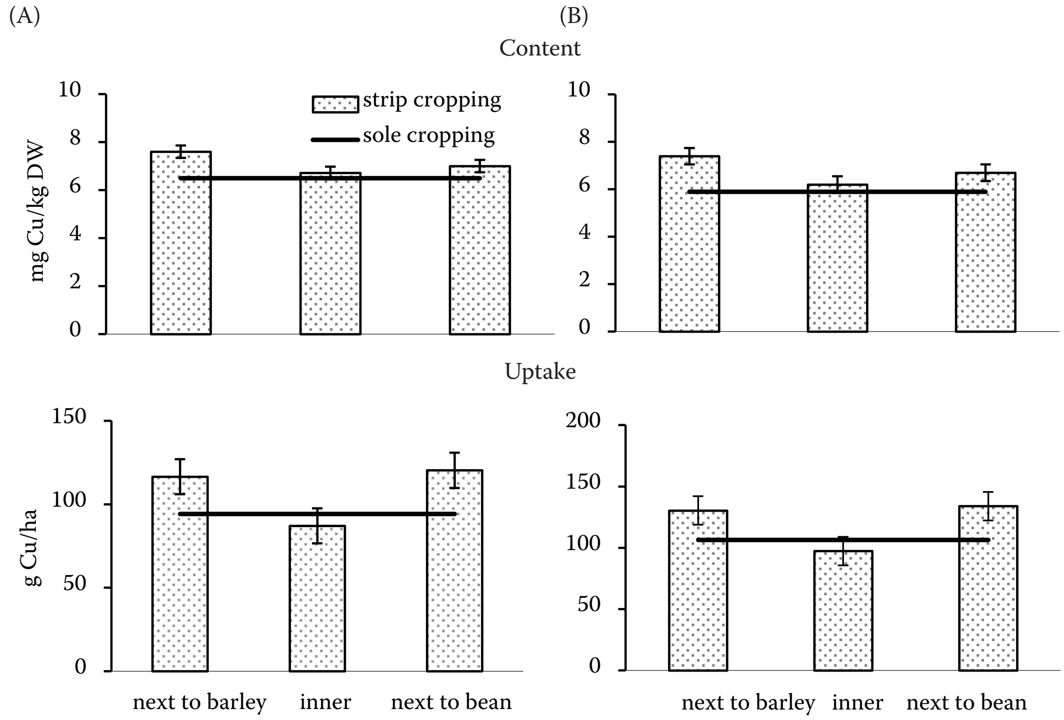

Figure 2. Effect of row position in the strip on Cu content and uptake by maize; A – mechanical weed control; B – chemical weed control; bars represent the standard errors. DW – dry weight

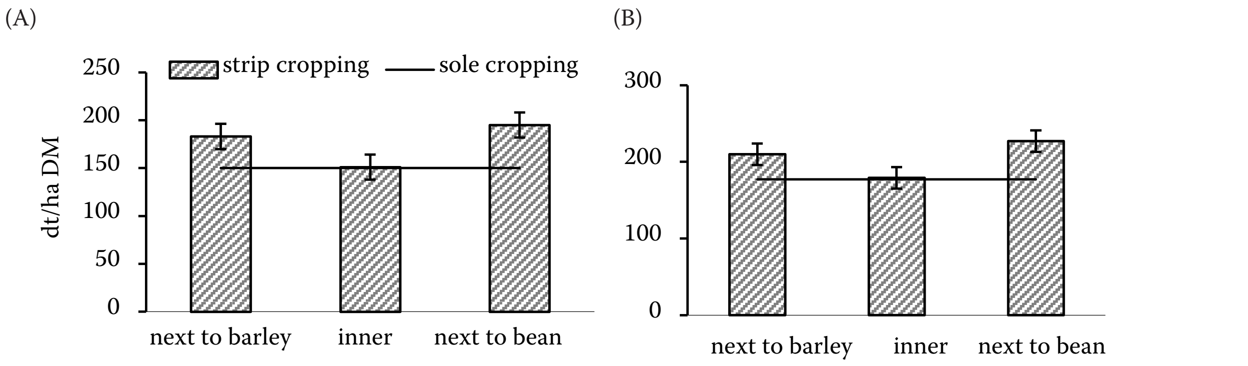

Figure 3. Effect of row position in the strip on the yield of maize biomass; A – mechanical weed control; B – chemical weed control; bars represent the standard errors. DW – dry weight

highest in the border row next to spring barley. The differences may be also due to the earlier harvest of barley, which meant that it competed with maize for a shorter time. According to Skowrońska and Filipek (2009), the most intensive uptake of micronutrients by maize, especially Cu, occurs between 109 and 132 days after sowing. In the present study, this was just after the barley harvest. On the other hand, pulses (i.e. beans) consume nutrients uniformly until blooming, after which the dynamics of the process increases, especially during pod setting and seed filling. In maize strip higher Cu uptake was noted in the edge rows, irrespective of the adjacent plant. This was both due to differences in Cu content and greater maize yield (Figure 3). Mechanical weed control led to higher content of Cu in the maize than chemical weed control (Table 1).

The influence of cropping methods on zinc content was not significant (Table 1). Changes in Zn content depending on the row position in the strip were also observed. In mechanically weeded plots, maize from the edge rows contained less zinc than maize from the middle row. In plots

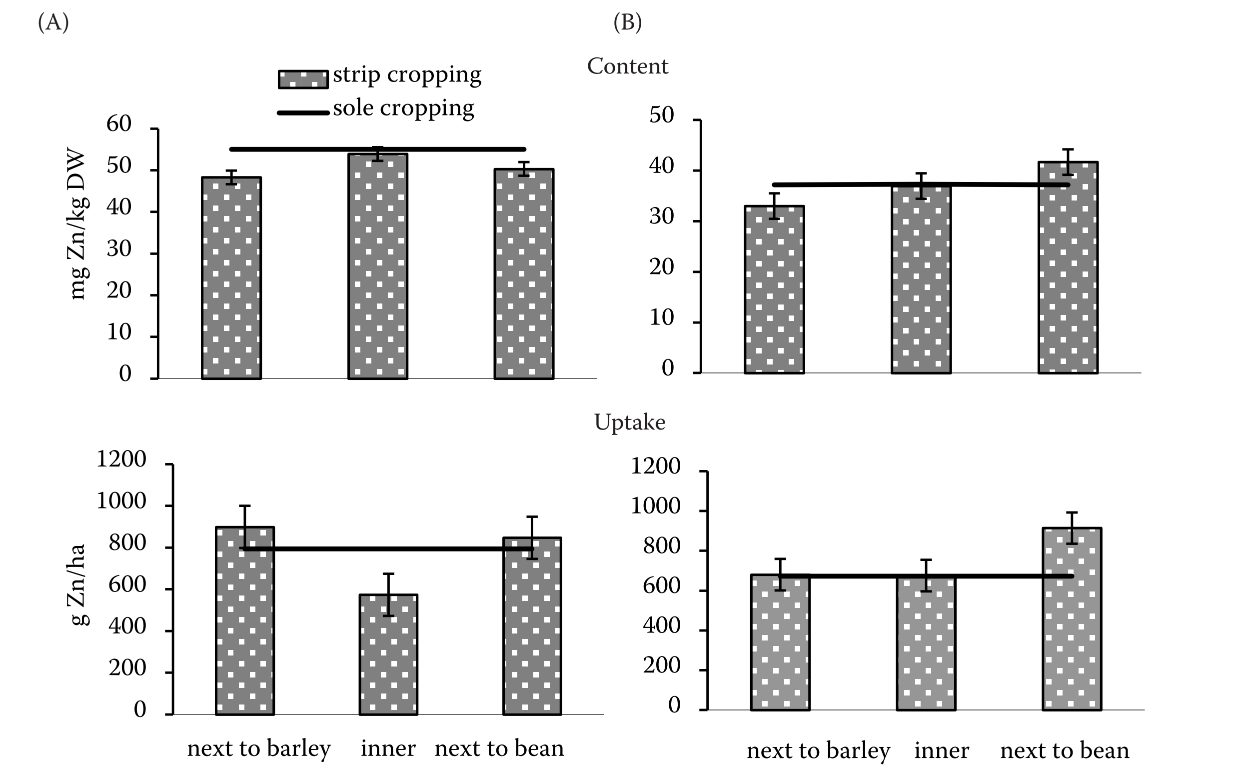

Figure 4. Effect of row position in the strip on Zn content and uptake by maize; A – mechanical weed control; B – chemical weed control; bars represent the standard errors. DW – dry weight

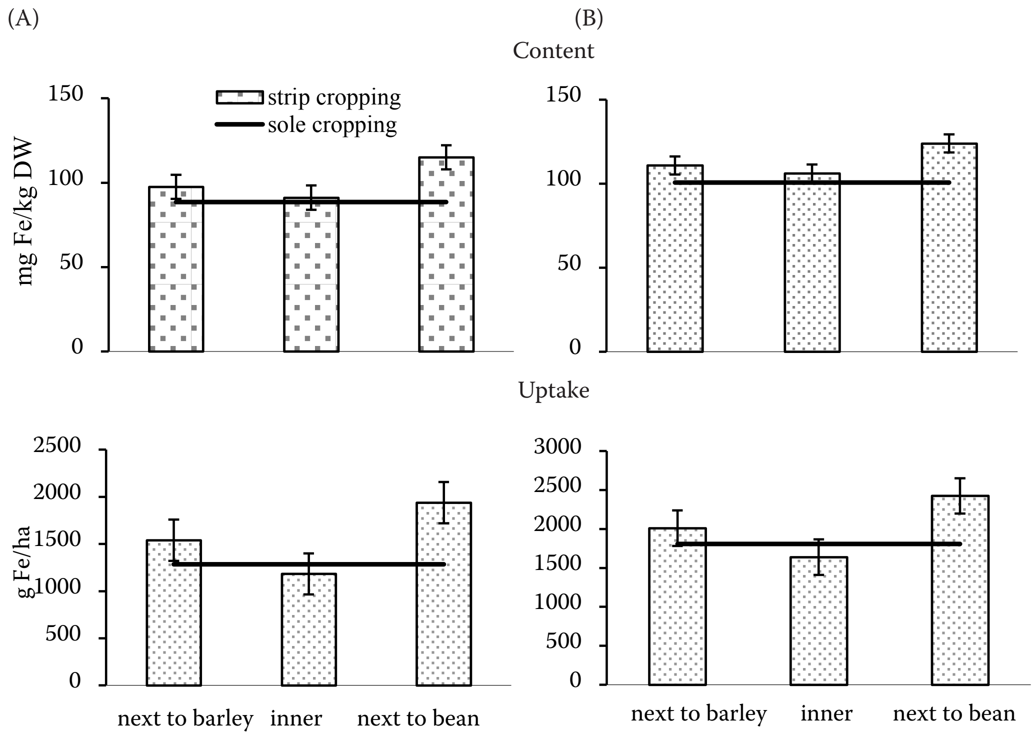

Figure 5. Effect of row position in the strip on Fe content and uptake by maize; A – mechanical weed control; B – chemical weed control; bars represent the standard errors. DW – dry weight

with chemical weed control, markedly more Zn was noted in the row adjacent to beans (Figure 4). A similar direction of change in Zn content in maize depending on row position was found in strip cropping of common bean/maize/spring wheat (Głowacka 2013b). In a greenhouse study, Li et al. (2004) also noted an increase of Zn in wheat intercropping with chickpea. The differences in Zn uptake by maize between cropping systems were negligible. Significant differences were observed between rows of maize in the strip cropping (Figure 4).

Strip cropping significantly increased Fe content in maize (Table 1). Irrespective of the weed control, placement next to beans facilitated iron accumulation by the maize (Figure 5). The differences between the middle row and the edge row next to barley were not significant. Zuo et al. (2000) report that interaction in the rhizosphere between maize and peanut in intercropping clearly increased Fe availability and reduced symptoms of Fe deficiency in peanut plants. However, Gunes et al. (2007) showed that chickpea/wheat intercropping increased Fe content in both species. Our findings indicate that beans can facilitate Fe accumulation by maize. Veneklaas et al. (2003) and Zuo and Zhang (2009) argue that some plants, can release greater amounts of carboxylates through their roots, which may increase utilization of Fe, Zn and Ca by plants, even from less available compounds. Significantly more Fe was taken up by maize in the row adjacent to beans than in the middle row and the row next to barley (Figure 5). This was due to different Fe content and to increased maize yield in the edge rows, especially next to common bean (unpublished data).

Manganese content in the maize was significantly lower in the strip cropping, by an average of 14%, than in the sole cropping (Table 1). Although the impact of strip cropping to reduce Mn content was significant only in plots with chemical weed control, it determined the averages for the cropping systems. Similarly, Inal et al. (2007) observed a reduction in manganese in maize intercropped with peanuts. The differences between cropping systems resulted from the lower Mn content in maize from the edge rows bordering with bean or barley (Figure 6). This shows that the plants in the adjacent strips competed with maize for Mn or decreased its availability. Moreover, the accumulation of manganese and iron by plants is competitive, and increasing Fe content in maize from edge rows can decrease Mn accumulation. However, Losak et al. (2011) stated that Fe did not

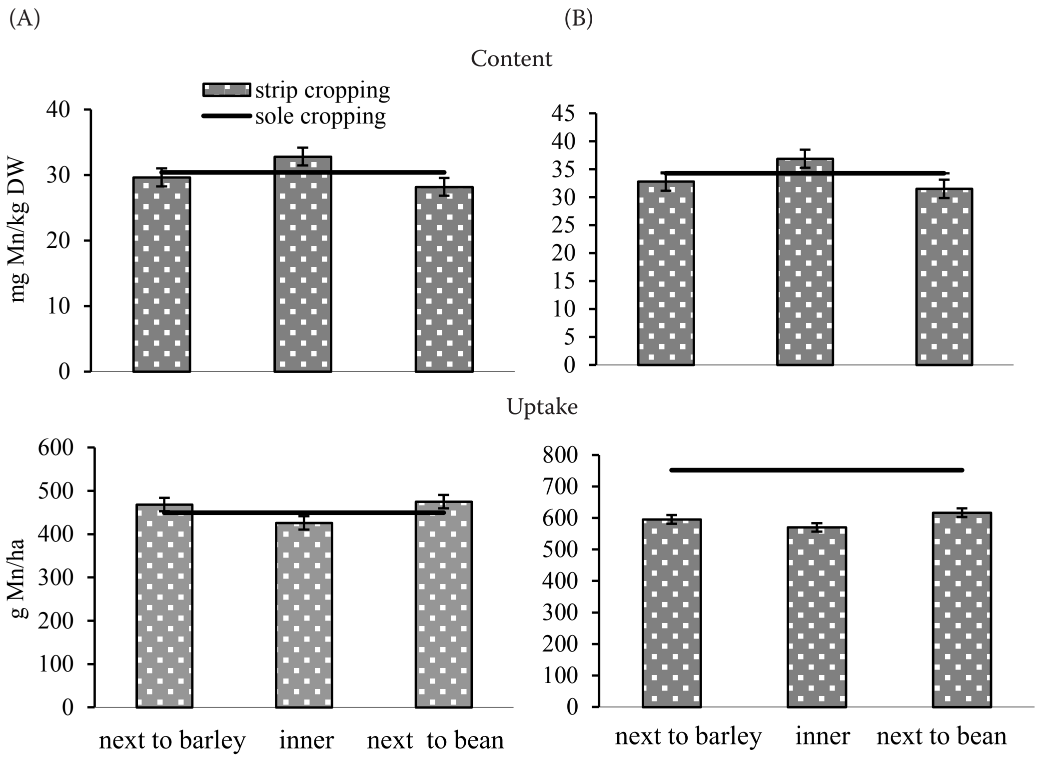

Figure 6. Effect of row position in the strip on Mn content and uptake by maize; A – mechanical weed control; B – chemical weed control; bars represent the standard errors. DW – dry weight

inhibit the uptake of Mn by maize biomass at the flowering stage. According to Chakraborty et al. (2011), the nature of interaction between Fe and Mn depended on the plant concerned and the ratio of the two metals. Manganese uptake in sole cropping was higher than in strip cropping, but only in plots with chemical weed control (Figure 6). However, differences in Mn uptake between rows of the maize strip were observed only in mechanically weeded plots.

The weed control methods significantly affected micronutrient content in the maize. Maize weeded mechanically contained significantly less Fe and Mn. Weeding of interrows did not completely eliminate weeds, which are often much more competitive in nutrients uptake than maize and reduced its availability for the maize. On the other hand, in plants producing a large amount of biomass, content of trace elements per unit weight may be lower than in those producing less biomass, since they are unable to take up enough nutrients (Cakmak 2004, Orosz et al. 2009). This was confirmed in this study with respect to Cu and Zn (Table 1).

In conclusion, strip cropping increased Cu and Fe content in maize, but reduced Mn content. Content of these micronutrients in maize in strip cropping was affected by the position of the row and the neighbouring plant species. These results suggest that appropriate selection of species for strip cropping can affect the content of some nutrients in plants, and can be cost-effective way for plant biofortification.

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