ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 15 Number 1, 2013

http://dx.doi.org/10.11118/actaun201361010123

EFFECT OF NITROGEN AND POTASSIUM FERTILIZATION ON MICRONUTRIENT CONTENT IN GRAIN MAIZE (*ZEA MAYS* L.)

Josef Maňásek, Tomáš Lošák, Karel Prokeš, Jaroslav Hlušek, Monika Vítězová, Petr Škarpa, Radek Filipčík

Received: July 12, 2012

Abstract

MAŇÁSEK JOSEF, LOŠÁK TOMÁŠ, PROKEŠ KAREL, HLUŠEK JAROSLAV, VÍTĚZOVÁ MONIKA, ŠKARPA PETR, FILIPČÍK RADEK: *Effect of nitrogen and potassium fertilization on micronutrient content in grain maize (Zea mays L.).* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 1, pp. 123–128

A two-year small-plot field experiment with the grain maize hybrid KWS 2376 was conducted on heavy soil with a low supply of available nutrients incl. potassium (K) at Otrokovice, Czech Republic, during 2010–2011. The experiment included 4 treatments: unfertilized control; nitrogen (N) fertilisation with urea (120 kg N/ha) alone or combined with two forms of K fertiliser (potassium chloride (KCl) or potassium sulphate (K_2SO_4); 125 kg K_2O/ha).
Biomass samples for determination of Zn, Mn, Cu and Fe were taken as the whole aboveground biomass in the DC 32 (first node stage), the ear-leaf in the DC 61 (flowering stage) and grain during the harvest.
Between the two years the content of micronutrients in the individual treatments varied irregularly. In DC 32 and DC 61 the order of the content of micronutrients was as follows: Fe > Mn > Zn > Cu. The Fe content was significantly the highest in the unfertilised control and the Mn content after the application of N + K_2SO_4 in both samplings. In the grain the order was as follows: Zn > Fe > Mn > Cu (mg/kg DM): at the following contents: Zn: 19.20–23.19; Fe: 15.12–19.87; Mn: 0.85–3.60; Cu: 0.19–1.34. We can recommend fertilisation of maize with urea and with both potassium mineral fertilisers without any negative effects on the content of the micronutrients in the maize biomass.

zinc, manganese, copper, iron, leaf, plant

Maize (*Zea mays* L.) is a crop of worldwide importance whose grain is used primarily in the food and feed industries or as silage for feeding animals or as a substrate for biogas stations. The current situation in the Czech Republic is that maize is grown for grain and silage on about 98,000 and 192,000 ha, respectively, of the country's total arable land of about 3.2 million ha (Lošák *et al.*, 2010). However the maize acreage is continuing to increase.

Cultivation of high yielding quality crops including corn is dependent on adequate and balanced nutrient fertilization (Sahrawat *et al.*, 2008; Prokeš, 2008). In this respect nitrogen is of crucial importance (Berenguer *et al.*, 2009; Gallais *et al.*, 2008) particularly in raising yields and fodder production. Indeed under conditions in the Czech Republic, nitrogen is often the only nutrient which is supplied as a fertiliser, crops in many cases being dependent on the natural fertility of the soil as a source of other macronutrients – P, K, Ca, Mg, S (Lošák *et al.*, 2006, 2011).

In terms of micronutrient supply, maize is usually fertilised with zinc (Potarzycki and Grzebisz, 2009; Hossain *et al.*, 2008; Fecenko and Ložek, 1996), the other micronutrients considered here (Mn, Cu, Fe) not normally being supplied. The importance the micronutrients in plant nutrition should not be underestimated. As pointed out by Marschner (1995), even though micronutrients are present in the plant in only minute concentrations, plant and crop growth is crucially dependent on an adequate supply of all essential elements regardless of the amounts in which they are required. Interactions between macro- and micronutrients (ions) may result in their increased (synergism) or reduced (antagonism) uptake by the plant and in this way they may have a fundamental effect on the entire metabolism of the plant.

The aim of the work reported here, a two-year field small-plot experiments with grain maize, was to assess the impact of nitrogen and potassium on the content of four micronutrients (Zn, Mn, Cu, Fe) in maize biomass at the DC 32 (1st node), DC 61 (flowering stages) and in the grain at harvest.

MATERIALS AND METHODS

Two-year field small-plot experiments with grain maize were established in 2010 and 2011 in co-operation with the firm KWS OSIVA on heavy cambisol at the site Otrokovice near Zlín (South-East Moravia, Czech Republic, 49°11'23.046"N, 17°32'39.020"E, 200 m above sea level). This is a sugar beet production area, with typical spells of drought during the growing season. The average annual temperature is 8.9 °C and average annual precipitation 619 mm. For the experiment we intentionally selected a plot with a low supply of available nutrients in the soil according to Mehlich III (Tab. I).

In both years the grain maize hybrid KWS 2376 (FAO 340) was used after conventional pesticide treatments. The seed rate was 78,400 seeds/ha and sowing was carried out on 27 April 2010 and 9 April 2011 using a Kverneland Accord Optima pneumatic precision seed drill.

The experimental plots (randomised complete block Latin square design) were laid out within the normal field area. Each plot measured 6 m x 30 m (8 rows at 0.75 m spacing). Urea (46% N), muriate of potash (KCl; 60% K_2O) and potassium sulphate (K_2SO_4; 50% K_2O, 18% S) were applied manually prior to sowing and harrowed into the soil to avoid N (ammonia) losses via volatilisation (Tab. II). Each treatment included 4 replicates.

In both years weed control was carried out by conventional chemical methods. The entire aboveground biomass in DC 32 (first node stage), and ear-leaf in DC 61 (flowering stage) and grain during the harvest was taken as biomass sample for the determination of Zn, Mn, Cu and Fe. During manual harvest (7 November 2010 and 17 October 2011) at the DC 89 stage (dry straw, yellow leaves), 15 cobs from each plot were taken for sampling following yield measurements.

The soil was extracted using the Mehlich III method (CH_3COOH, NH_4NO_3, NH_4F, HNO_3 and EDTA). The content of available phosphorus (P) in the extract was determined colorimetrically and the content of available potassium (K), magnesium (Mg) and calcium (Ca) by atomic absorption spectrometry (AAS). The ion-selective electrode (ISE) method was used to determine the pH value after extraction in 0.01 M $CaCl_2$.

Plant and grain samples were dried at 60 °C to a constant weight. After wet oxidation (HNO_3+H_2O_2) of the samples in a standard laboratory microwave, micronutrient chemical analyses were carried out using atomic absorption spectrometry (AAS).

The data were statistically analysed by means of variance analysis (ANOVA) using the statistical programme Statistica. Scheffe's test ($P < 0.05$) was used to determine statistically significant differences between the factors within methods of subsequent tests.

RESULTS AND DISCUSSION

The four micronutrients in this study Zn, Mn, Cu and Fe, function in numerous ways in plant metabolism with roles that are now reasonably well established and have been reported in detail in the texts of Marschner (1995), Bergmann (1992), Mengel and Kirkby (2001) and the review paper of Kirkby and Römheld (2004). All four of these micronutrients activate particular enzyme systems and are closely involved in various plant physiological processes. A lack of availability of this micro nutrient is particularly evident on high pH, calcareous, clay soils, low in organic matter (Mengel and Kirkby, 2001).

I: *Plant-available nutrient content and soil reaction (Mehlich III) of the cambisol at the study site*

pH/ $CaCl_2$	mg/kg			
	P	K	Ca	Mg
5.61	37	86	1,888	150
slightly acid	low	low	low	low

II: *Fertilisation treatments used in the field experiment*

Treatment No.	Description	Dose of nutrients (kg/ha): N + K_2O	Treatment code
1	Control	0 + 0	N0K0
2	Urea	120 + 0	N1K0
3	Urea + KCl	120 + 125	N1K1
4	Urea + K_2SO_4	120 + 125	N1K1S

a) Content of micronutrients in whole plants in stage DC 32

The micronutrient composition of the plant mass of maize plants sampled at the stage of the 1st node (DC 32) is given in Tab. III. Maize is a zinc-intensive plant with a high zinc demand (Mengel and Kirkby, 2001). The Zn content (Tab. III) ranged between 53 and 73 mg/kg and between 51 and 65 mg/kg in 2010 and 2011, respectively. These values may be considered adequate for this crop (sufficiency range 21–70 mg/kg in maize leaves Mengel and Kirkby, 2001). In both years the Zn content was the highest in the control unfertilised treatment (treatment N0K0) and is in accordance with the findings of Camp (1945) and Ozanne (1955) that high levels of nitrogen reduce zinc content.

Lockman (1969) discovered that the content of manganese in the maize plants 30–45 days after emergence was adequate, i.e. 50–160 mg/kg. In our experiment the content of manganese (Tab. III) varied among the years and treatments and ranged between 62 and 76 mg/kg and between 88–108 mg/kg in 2010 and 2011, respectively. The contents of Mn were adequate for this growth stage and ranged between 40 and 100 mg/kg, as reported by Bergmann (1992). After the application of potassium sulphate (treatment N1K1S) the content of manganese was the highest in both years.

In our experiments (Table III) the copper content ranged closely within 2.6–4.6 (2010) and 3.9–6.9 (2011) (mg/kg), however no evident two-year dependence between the treatments was seen. Nan and Cheng (2001) reported that the average content of Cu in stems in the mature stage was 5.40 mg/kg.

Maize is very susceptible to iron chlorosis (Wirén *et al.*, 1994). For the micronutrients and for iron in particular, this is likely to be of special relevance on high pH calcareous soils, which are renowned for so called "lime induced chlorosis" (Marschner, 1995). In the fertilised treatments the Fe contents were relatively balanced in both years; nevertheless in the two years the contents were the highest in the unfertilised control (266 and 490 mg/kg, respectively). These results are not in accordance with the findings of Mengel and Kirkby (2001) who discovered that the uptake of ammonium N results in acidification of the rhizosphere which in turn increases the solubility and uptake of micronutrients.

III: *Content of micronutrients in mg/kg DM (1st sampling in DC 32)*

	Nutrients			
	Zn	**Mn**	**Cu**	**Fe**
Year 2010				
N0K0	73 b	62 a	4.6 a	266 b
N1K0	57 a	64 a	4.6 a	216 a
N1K1	58 a	71 ab	3.7 ab	225 a
N1K1S	53 a	76 b	2.6 b	242 ab
Year 2011				
N0K0	65 a	91 a	3.9 a	490 c
N1K0	55 a	88 a	6.2 b	355 b
N1K1	51 b	92 a	5.9 b	301 a
N1K1S	53 ab	108 b	6.9 b	280 a

Values in the same column with different letters are significantly different in each year extra at ($P < 0.05$)
DM = dry matter

IV: *Content of micronutrients in mg/kg DM (2nd sampling in DC 61)*

	Nutrients			
	Zn	**Mn**	**Cu**	**Fe**
Year 2010				
N0K0	41 a	61 a	4.24 a	136 b
N1K0	42 a	64 a	3.67 a	107 b
N1K1	41 a	63 a	3.67 a	82 a
N1K1S	43 a	74 b	4.47 a	93 a
Year 2011				
N0K0	40 a	82 a	1.84 a	190 b
N1K0	46 a	104 b	2.73 b	127 a
N1K1	53 b	108 b	3.12 b	104 a
N1K1S	53 b	109 b	2.58 b	116 a

Values in the same column with different letters are significantly different in each year extra at ($P < 0.05$)

b) Content of micronutrients in the ear-leaf in stage DC 61

At the flowering stage (DC 61), only the ear-leaf was sampled and not the entire aboveground biomass.

It has earlier been shown that the maximum accumulation of Cu, Mn and Zn is obtained 100 days after emergence, i.e. in the second half of the grain filling period (Borges *et al.*, 2009) which well corresponds with our results with the Cu contents at the 2nd sampling (Tab. IV). The Zn and Fe uptake was however reduced in both years as compared with the first sampling, probably on the basis of the so-called dilution effect (Mengel and Kirkby, 2001). In the first year there were no differences in the zinc contents, while in the second year its content increased significantly after the application of both potassium fertilisers. In both years the Mn content was the highest after the application of potassium sulphate (N1K1S), Tab. IV. In 2010 the Cu content did not change, while in 2011 it increased after the application of nitrogen and potassium. Just like the first sampling (Tab. III) in the second sampling (Tab. IV) the highest Fe content was also seen in the unfertilised control treatment. Our results do not quite confirm the studies by Ogundela *et al.* (1988) that increased N supply had no influence on the concentrations of Cu, Fe, Mn and Zn in the ear leaf of maize (*Zea mays* L.)

c) Content of micronutrients in grain

The contents of micronutrients in grain (Tab. V) fluctuated in both years mostly within close ranges. The year-on-year differences in Mn and Cu were more marked.

The Zn content varied in both years in a range between 19.20 and 23.19 mg/kg and corresponds with the results of 3-year experiments of Hossain *et al.* (2008) with maize; they reported 16.5–27 mg/kg as the average content of zinc in grain. Orosz *et al.* (2009) reported that the average content of Mn in sweet corn (*Zea mays conv. saccharata*) was 1.2 mg/kg and this datum corresponds with our results only for the first year. In the second year the contents of Mn were higher (2.82–3.60 mg/kg, Tab. V). According to Gorsline *et al.* (1964), Mn accumulation is genetically controlled; however, it is probable that the interaction genotype-environment also plays an important role. The Cu content in both years fluctuated within a range of 0.19–1.34 mg/kg (Tab. V). Nan and Cheng (2001) found that the Cu content in grain in the mature stage ranged between 3.60 and 4.53 mg/kg. Mantovi *et al.* (2003) reported a lower content of Cu in grain. Lošák *et al.* (2011) reported that the average content of Cu in maize grain ranged between 0.3 and 0.6 mg/kg. The Fe content in grain fluctuated between 15.12 and 19.87 mg/kg and is in accordance with the results of Lošák *et al.* (2011). According to Orosz *et al.* (2009), the average content of Fe in grain was 2.4 mg/kg, and this is considerably lower than our results, however, these were in sweet corn (*Zea mays conv. saccharata*).

V: *Content of micronutrients in mg/kg DM (3rd sampling in corn grain)*

	Nutrients			
	Zn	**Mn**	**Cu**	**Fe**
Year 2010				
N0K0	19.20 a	0.85 a	0.19 a	19.87 b
N1K0	21.36 a	1.24 b	0.33 ab	17.98 b
N1K1	21.09 a	1.51 b	0.32 ab	15.47 a
N1K1S	19.37 a	0.95 a	0.64 b	15.12 a
Year 2011				
N0K0	23.19 b	3.14 a	1.04 a	16.17 a
N1K0	22.28 ab	3.60 b	1.34 a	15.36 a
N1K1	21.77 ab	3.52 b	0.98 a	15.99 a
N1K1S	19.34 a	2.82 a	1.00 a	15.42 a

Values in the same column with different letters are significantly different in each year extra at ($P < 0.05$)

SUMMARY

The application of nitrogen (N) in combination with the chloride (KCl) and sulphate (K_2SO_4) form of potassium was reflected in irregular contents of Zn, Mn, Cu and Fe in the monitored parts of the plants. At the same time we detected year-on-year differences in the nutrients. We can recommend fertilisation of maize with urea and both potassium mineral fertilisers without any negative effects on the content of the micronutrients in the maize biomass.

Acknowledgement

This study was supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6215648905 'Biological and technological aspects of sustainability of controlled ecosystems and their adaptability to climate change', by KWS OSIVA, s. r. o.

REFERENCES

BERENGUER, P., SANTIVERI, F., BOIXADERA, J. and LLOVERAS, J., 2009: Nitrogen fertilisation of irrigated maize under Mediterranean conditions. *European Journal of Agronomy,* 30: 163–171.

BERGMANN, W. E., 1992: *Nutritional Disorders of Plants: Development, Visual and Analytical Diagnosis.* Gustav Fischer, Jena, Stuttgart, New York.

BORGES, I. D., PINHO, R. G. V. and PEREIRA, J. L. A. R., 2009: Micronutrients accumulation at different maize development stages. *Ciência e Agrotecnologia*, 33: 1018–1025.

CAMP, A. F., 1945: Zinc as a nutrient in plant growth. *Soil Science*, 60: 157–164.

FECENKO, J. and LOŽEK, O., 1996: Agronomical efficiency of Nitrogen – Zinc Fertilizer. *Zeszyty problemove postepów nauk rolniczych*, 434: 129–132.

GALLAIIS, A., COGUE, M. and BERTIN, P., 2008: Response to selection of a maize population for adaptation to high or low nitrogen fertilization. *Maydica*, 53: 21–28.

GORSLINE, G. W., THOMAS, W. I. and BAKER, D. E., 1964: Inheritance of P, K, Mg, Cu, B, Zn, Mn, Al, Fe concentration by corn (*Zea mays* L.) leaves and grain. *Crop Science*, 4: 207–210.

HOSSAIN, M. A., JAHIRUDDIN, M., ISLAM, M. R. and MIAN, M. H., 2008: The requirement of zinc for improvement of crop yield and mineral nutrition in the maize-mungbean-rice system. *Plant and Soil*, 306: 13–22.

KIRKBY, E. A. and RÖMHELD, V., 2004: *Micronutrients in plant physiology: functions, uptake and mobility*. pp. 1–52 *In*: Proceedings 543, The International Fertiliser Society, York, UK.

LOCKMAN, R. B., 1969: *Relationship between corn yields and nutrient concentration in seedling whole-plant samples*. Agronomy abstracts. Madison, WI: American Society of Agronomy.

LOŠÁK, T., PROKEŠ, K. and HLUŠEK, J., 2006: The effect of local applications of the amofos fertiliser when growing maize (*Zea mays*, L.). *Agrochemistry*, 46: 20–23 (in Czech with English summary).

LOŠÁK, T., MAŇÁSEK, J., HLUŠEK, J., PROKEŠ, K., FILIPČÍK, R. and VARGA, L., 2010: The effect of nitrogen fertilisation of grain maize at a very high supply of P, K, Ca and Mg in soil. *Agrochemistry*, 50: 13–16 (in Czech with English summary).

LOŠÁK, T., HLUŠEK, J., MARTINEC, J., JANDÁK, J., SZOSTKOVÁ, M., FILIPČÍK, R., MAŇÁSEK, J., PROKEŠ, K., PETERKA, J., VARGA, L., DUCSAY, L., OROSZ, F., MARTENSSON, A., 2011: Nitrogen fertilization does not affect micronutrient uptake in grain maize (*Zea mays* L.). *Acta Agriculturae Scandinavica Section B: Soil and Plant Science*, 61: 543–550.

MARSCHNER, H., 2002: *Mineral nutrition of higher plants*. 2nd edition. London: Academic Press, 889 p.

MANTOVI, P., BONAZZI, G., MAESTRI, E. and MARMIROLI, N., 2003: Accumulation of copper and zinc from liquid manure in agricultural soils and crop plants. *Plant and Soil*, 250: 249–257.

MENGEL, K. and KIRKBY, E. A., 2001: *Principles of Plant Nutrition*. 5th Edition, Kluwer Academic Publishers, Dordrecht / Boston / London. 849 p.

NAN, Z. and CHENG, G., 2001: Copper and zinc uptake by spring wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.) grown in Baiyin region. *Bulletion of Environmental Contamination and Toxicology,* 67: 83–90.

OGUNLELA, V. B., AMORUWA, G. M. and OLOGUNDE, O. O., 1988: Growth, yield components and micronutrient nutrition of field-grown maize (*Zea mays* L.) as affected by nitrogen fertilization and plant density. *Nutrient Cycling in Agroecosystems,* 17: 189–196.

OROSZ F., JAKAB, S., LOSAK, T. and SLEZAK, K., 2009: Effect of fertilizer application to sweet corn (*Zea mays*.) grown on sandy soil. *Journal of Environmental Biology*, 30: 933–938.

OZANNE, P. G., 1955: The effect of nitrogen on zinc deficiency in subterranean clover. *Australian Journal of Biological Sciences,* 8: 47–55.

POTARZYCKI, J. and GRZEBISZ, W., 2009: Effect of zinc foliar application on grain yield of maize and its yielding compone. *Plant, Soil and Environment,* 55: 519–527.

PROKEŠ, K., 2008: *The nutrition of maize in a potato-growing region*. Dissertation thesis. Mendel University of Agriculture and Forestry in Brno. Brno (in Czech with English summary).

SAHRAWAT, K. L., REGO, T. J., WANI, S. P. and PARDHASARADHI, G., 2008: Sulfur, Boron, and Zinc Fertilization Effects on Grain and Straw Quality of Maize and Sorghum Grown in Semi-Arid Tropical Region of India. *Journal of Plant Nutrition,* 31: 1578–1584.

WIRÉN, N., MORI, S., MARSCHNER, H. and RÖMHELD, V., 1994: Iron inefficiency in maize mutant "*ys1*" ("*Zea mays*" L. cv Yellow-Stripe) is caused by a defect in uptake of iron phytosiderophores. *Plant Physiology*, 106: 71–77.

Address

doc. Ing. Tomáš Lošák, Ph.D., prof. Ing. Jaroslav Hlušek, CSc., dr.h.c., Mgr. Monika Vítězová, Ph.D., Ing. Petr Škarpa, Ph.D., Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Ing. Radek Filipčík, Ph.D., Department of Animal Breeding, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, Ing. Josef Maňásek, Ing. Karel Prokeš, Ph.D., KWS OSIVA, s. r. o., Pod Hradbami 2004/5, 594 01 Velké Meziříčí, Czech Republic, e-mail: losak@mendelu.cz, hlusek@mendelu.cz, szostkov@mendelu.cz, petr.skarpa@mendelu.cz, radek.filipcik@mendelu.cz, josef.manasek@kws.com, karel.prokes@kws.com