MICRONUTRIENTS ACCUMULATION AT DIFFERENT MAIZE DEVELOPMENT STAGES[1]

Acúmulo de micronutrientes em híbridos de milho em diferentes estádios de desenvolvimento

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ABSTRACT

The study of micronutrients accumulation as a function of plant development stage is of fundamental importance to subsidize strategies for fertilizer application and minimum amount to maintain soil fertility. This study evaluated micronutrient accumulation in two maize cultivars at different development stages. The experimental design was randomized blocks with four replications in split-plots, with two maize hybrids as the plots and sampling time according to development stages as sub-plots. Maize accumulated minimum amounts of B, Cu, Mn, and Zn in the initial stages of development, and the maximum accumulated values were observed after 100 days seedling emergency. The evaluated hybrids accumulated maximum of Zn and Cu close to physiological maturity. Maize plants accumulate nutrients in the above ground parts as follows: Zn > Mn > Cu > B. The total amount of nutrients required to produce one ton of corn is: 0.0009 kg B; 0.019 to 0.02 kg Cu; 0.042 to 0.046 kg Mn; 0.100 to 0.194 kg Zn.

Index terms: *Zea mays*, accumulation, nutrients, cultivars.

RESUMO

Estudar o acúmulo de micronutrientes em função dos estádios fenológicos da cultura é de fundamental importância para subsidiar estratégias de definição das quantidades e das épocas de realização de adubações na cultura, e das quantidades mínimas que devem ser restituídas ao solo para fins de manutenção da fertilidade. Neste trabalho, objetivou-se avaliar o acúmulo de micronutrientes em função dos estádios fenológicos da cultura, considerando dois híbridos de milho. O delineamento utilizado foi o DBC com quatro repetições, em esquema de parcelas subdivididas, sendo os dois híbridos de milho dispostos nas parcelas e, nas sub-parcelas, as épocas de coleta das plantas, considerando os estádios fenológicos da cultura do milho. Híbridos de milho acumulam quantidades mínimas de B, Cu, Mn e Zn nos estádios iniciais de desenvolvimento da cultura, sendo os valores máximos acumulados obtidos a partir de 100 dias após a emergência. Os híbridos de milho avaliados acumulam zinco e cobre até próximo à maturidade fisiológica, quando são obtidos os acúmulos máximos. Híbridos de milho acumulam micronutrientes em sua parte aérea na seguinte ordem decrescente: Zn>Mn>Cu>B. As quantidades de micronutrientes necessárias para produzir uma tonelada de grãos de milho são: 0,0009 kg de B; 0,019 a 0,020 kg de Cu; 0,042 a 0,046 kg de Mn; 0,100 a 0,194 kg de Zn.

Termos para indexação: *Zea mays*, acúmulo, nutrientes, híbridos.

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INTRODUCTION

Nutrient requirement of a plant is determined by the total amount of nutrients absorbed. Knowledge about these amounts allows the estimation of the exported amounts through grain harvest and what will be returned to the soil by the litter (BULL, 1993). The major Brazilian studies with maize were done more than 20 years ago, with hybrids that are no longer used by the farmers (ANDRADE et al., 1975; VASCONCELOS et al., 1983). The study of macro and micronutrients accumulation in maize as a function of plant development stage is of fundamental importance to subsidize strategies determining the amount of fertilizer and the time of application and minimum amount that should be reapplied to maintain soil fertility (BULL, 1993; BRASIL et al., 2007; DEUNER, et al., 2008).

Micronutrient fertilization will depend on the yield and nutrient accumulation by the grain and in other plant parts. It is necessary to make available for the plant the amount of nutrients extracted, which are supplied by the soil and by fertilizations. After defining the doses to be applied on the culture, next step is to know nutrient absorption and accumulation during the different plant development stages, identifying the times of greater demand for each element. Among the official fertilization recommendation for maize in Brazil, those proposed by

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Cantarella et al. (1996) and CFSEMG (1999), include micronutrient doses based on expected yield for a given management type. However, these recommendations, presented as tables, report average values for a root system exploring a predetermined soil volume.

No specific function for the micronutrient boron has been identified, and its metabolism in the plant is not well understood. It is known that its functions are related to some basic processes, such as carbohydrate metabolism and sugar transport through membranes, synthesis of nucleic acids (RNA and DNA) and plant hormones, the formation of cell walls, cell division and tissue development. Some authors have observed a lack of correlation between B leaf contents and corn yield in experiments done in different locations (GALLO et al., 1976).

Zinc is the micronutrient with the most significant effects on maize, affecting plant growth, number of leaves, forage and grain production, as well as the increase in nitrogen and protein total contents in the grains (DECARO et al., 1983). Areas with known zinc deficiency turn maize rooting shallow and with no ear production. Its effects on grain yield are due to the generalized deficiency of this micronutrient in Brazilian soils, especially in the savannah (BULL, 1993).

Copper has an important role on physiologic processes such as photosynthesis, respiration, carbohydrate distribution, nitrogen reduction and fixation, and metabolism of proteins and of cell walls (DECHEN, 1988). It controls water relations in the plant and production of RNA and DNA, and its deficiency significantly reduces seed production due to the increase in pollen sterility (GALLO et al., 1975).

Iron is the component of hemeproteins and of other non heme proteins and is involved in the mechanism of electron transfer in photosynthesis, in the reduction of nitrites and sulphates, in the metabolism of nucleic acids and in the formation of chlorophyll. Also, its catalyzer function for Fe^{2+} and Fe^{3+} are known (DECHEN, 1988).

Manganese takes part on nitrogen metabolism and forms bridges between ATP and transfer enzymes of the phosphate group (BARBOSA FILHO, 1987). It is an important activator of enzymes acting in the Krebs cycle and, together with chlorine, acts on breaking the water molecule in the photosystem II.

The absorption peak of micronutrients Mn and Zn occurs 80 days after germination and the amounts required are 656 and 332 g ha^{-1}, respectively. In contrast, the absorption peak for Fe and Cu occurs later, at 100 days, and the requirement for Fe is 1,610 g ha^{-1} and for Cu 150 g ha^{-1}.

Considering that the studies done in Brazilian tropical conditions (ANDRADE et al., 1975; VASCONCELLOS et al., 1983) are quite old and that plant breeding has come a long way, that is, more productive and early hybrids are being released, new studies about micronutrient absorption in maize can indicate other times and amounts required of each nutrient that could be different from those previously determined.

MATERIALS AND METHODS

Two single cross hybrids (P30F33 and GNZ2004), with different plant architecture, cycle, kernel consistency, height, stay green and use, with high yield potential for the conditions of southern Minas Gerais, were used. The study was done at the Department of Agriculture of Universidade Federal de Lavras, in Lavras, MG, at 21º14’ S and 45º 00' W, 910 m above sea level.

A split plot randomized block design with four replication was used, with two maize hybrids (GNZ2004 and P30F33) in the plots, and the plant collection dates as sub-plots, considering the eleven phenological stages of maize, as described by Fancelli (1986), adapted from Nell & Smit (1978), and described as: Stage 0, from sowing to emergence; Stage 1, plant with four fully expanded leaves; Stage 2, plant with eight leaves; Stage 3, plant with 12 fully unfolded leaves; Stage 4, tasseling; Stage 5, flowering and pollination; Stage 6, milky kernels; Stage 7, dough stage with pasty consistency kernels; Stage 8, beginning of denting; Stage 9, “hard” kernels; Stage 10, physiologically mature kernels. The plants were collected at the end of each stage.

The experimental units consisted of four 5-m rows spaced by 0.80 meters, and the two middle rows were used for data collection. The density of 60,000 pl ha^{-1} was used in all plots, i.e., the plants were spaced by 20.83 centimeters or 24 plants per 5 meters of row.

Sowing fertilization was done with 500 kg ha^{-1} of the formulation 08-28-16 + 0.3% Zn. Three side dressing fertilizations were done: at 18 days (90 kg ha^{-1} N and 60 kg ha^{-1} K_2O), at 22 days (60 kg ha^{-1} N) and at 31 days (60 kg ha^{-1} N). Sowing and side dressing fertilizations were done based on the results of a soil analysis (Table 1) and yield prevision above 12 t ha^{-1} of grain (CANTARELLA et al., 1996).

Sowing occurred on 22/11/2004. Weed control was done by hoeing at 15 and 25 days after emergence. Thinning was done with 3 to 4 fully expanded leaves. Disease control was not needed, and the control of armyworm was done when the plants had 4 to 5 leaves, and again at 8 to 9 leaves, using the insecticide Decis at 200 ml ha^{-1}.

Table 1 – Results of the soil sample analysis (0 – 20 cm) from the experimental area, before the treatments were applied. UFLA, Lavras, 2006.

Chemical attributes		Chemical attributes		Chemical attributes	
pH in H_2O	5.8	P-rem (mg/L)	16.4	Org. Mat. (g/kg)	31
H + Al ($cmol_c/dm^3$)	2.3	Zn (mg/dm^3)	3.4	SB ($cmol_c/dm^3$)	3.0
Al ($cmol_c/dm^3$)	0.0	Fe (mg/dm^3)	98.8	T ($cmol_c/dm^3$)	5.3
Ca ($cmol_c/dm^3$)	2.2	Mn (mg/dm^3)	12.7	t ($cmol_c/dm^3$)	3.0
Mg ($cmol_c/dm^3$)	0.7	Cu (mg/dm^3)	2.4	V (%)	56
K (mg/dm^3)	20	B (mg/dm^3)	0.6	m (%)	0
P (mg/dm^3)	4.3	S (mg/dm^3)	9.8		
Physical attributes					
Sand (g/kg)	330				
Silt (g/kg)	230				
Clay (g/kg)	440				
Texture class textural	Clay				

Extractors used: P,K,Cu, Mn and Zn → Mehlich (HCl 0.05 N + H_2SO_4 0.025 N); Ca, Mg and Al → KCl 1 N; B → Hot water (HCl 1:1); S → Calcium biphosphate 0.01 N; Al + H → FMP pH 7.5.

Data collection was done considering the maize phenological stages classifications system proposed by Fancelli (1986), adapted from Nell & Smit (1978), with eleven stages numbered from 0 (zero) to 10 (ten). The following characteristics were evaluated: zinc, copper, boron and manganese contents in the total plant dry matter.

The plant material collected from each plot (six competitive plants) was separated into stalk, leaves, corn husk, corncob and kernels. Subsequently, the plant parts were rinsed in tap water, placed in a forced air oven at 70ºC for drying, and were weighed periodically until constant mass was obtained. The dried samples of each plot was ground and sent to the Leaf Analysis Laboratory at the Department of Soil Sciences of UFLA for the determination of the micronutrient contents in the dry matter.

The results were submitted to the analysis of variance, and regression analyses were done using the software SISVAR (FERREIRA, 2000), considering micronutrient and dry matter accumulation as dependent variables, and the times of plant collection, according to the phenological stages described by Fancelli (1986), adapted from Nell & Smit (1978), as the independent variable. The models for adjusting the equations were selected based on the determination coefficient and its significance.

RESULTS AND DISCUSSION

The summary of the analyses of variance for the micronutrients is presented in Table 2. Significant effects ($P<0.01$) were observed for boron and zinc for the hybrids (H), phenological stages (EF) and for the interaction H x EF. Significant effect ($P<0.01$) was observed for copper for phenological stages (EF) and for the interaction H x EF. Significant effects were observed for manganese for the phenological stages (EF) and for the hybrids (H).

The experimental precision, evaluated by the coefficient of variation (CV%), had high values for zinc and boron accumulation. Probably, it was due to the nil values of Zn and B accumulation values obtained at the early development stages of the plants.

The hybrids GNZ2004 and P30F33 accumulated greater amounts of B, Zn, Mn and Cu than those used in other studies (ANDRADE et al., 1975; PHILLIPS & LESSMAN, 1972, cited by GAMBOA, 1980). However, the hybrids GNZ2004 and P30F33 differed from each other on the accumulation of these micronutrients, which is contrasting with the results obtained by Brown & Clark (1974), who observed identical performance for maize hybrids accumulation of B, Zn, Mn and Cu.

Micronutrient accumulation on the aboveground matter of maize plants was practically nil until 29 days after emergence. Maximum accumulation always was obtained after 100 days of emergence, i.e., in the second half of grain filling period (Figures 1, 2, 3, e 4). Total micronutrient accumulation by the hybrids followed the decreasing order: Zn (2.05 kg ha^{-1}), Mn (0.70 kg ha^{-1}), Cu (0.30 kg ha^{-1}) and B (0.13 kg ha^{-1}).

Significant differences were observed between the hybrids GNZ2004 and P30F33 for boron accumulation. Accumulation in both hybrids was quadratic during the plant cycle (Figure 1). The results presented in Figure 1 highlights that the hybrid GNZ2004 accumulates greater boron amounts than cultivar P30F33 during the plant cycle. The superiority of hybrid GNZ2004 on B accumulation, in comparison with hybrid P30F33, is due to the greater amount of this micronutrient accumulated in the period between 85 and 138 days after emergence (end of the cycle).

Both hybrids had boron accumulation values near zero at the early stages of plant development, with an increase at 44 days after emergence and stabilization at 0.07 kg ha^{-1} until the end of flowering (71 days); at 85 days after emergence another increase in boron accumulation was observed, and total accumulation until maturity was near 0.13 kg ha^{-1} for GNZ2004 and 0.11 kg ha^{-1} for P30F33. These results highlight the superiority of GNZ2004 for B absorption during this period of the culture cycle (Figure 1).

Maximum values of boron accumulated obtained by the maize hybrids were observed 102 days after emergence, 0.16 kg ha^{-1} for GNZ2004 and 0.10 kg ha^{-1} for P30F33 (Figure 1). These values were greater than those observed by Andrade et al. (1975) and by Hiroce et al. (1989) who obtained 0.071 kg ha^{-1} and 0.083 kg ha^{-1}, respectively. There is a lack of published information on the total B accumulated by maize plants as a function of plant age, and most of the research is directed to

Table 2 – Summary of the analyses of variance for the accumulation of manganese, zinc, boron and copper, in kg ha^{-1}, of the aboveground matter of two maize hybrids as a function of the plant's phenological stages. UFLA, Lavras, MG, 2006.

SV	FD	Mean square			
		Manganese	Zinc	Boron	Copper
Blocks	3	0.00051^{NS}	0.0108^{NS}	0.00006^{NS}	0.00005^{NS}
Hybrids (H)	1	0.0328*	0.5239**	0.0057**	0.0005^{NS}
Phenological stages (EF)	10	0.4699**	3.2070**	0.0151**	0.0750**
H x EF	10	0.0144^{NS}	0.3136**	0.0020**	0.0005*
Error	63	0.0080	0.0739	0.0004	0.00027
CV (%)		22.08	42.93	28.33	14.51
LSD		0.0382	0.1158	0.0090	0.0069

** (P<0.01); * (P<0.05); ^{NS} non significant

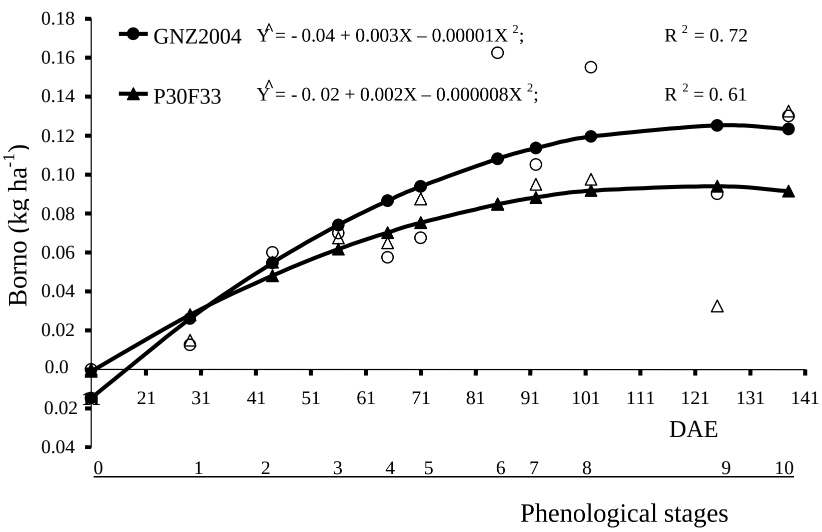

Figure 1 – Total boron accumulation, in kg ha^{-1}, by two maize hybrids, as a function of phenological stages (days after emergence – DAE). UFLA, Lavras, MG, 2006.

fertilization responses to this micronutrient. Probably, this is due to the difficulty of laboratory analyses for B, leading to inconsistent results.

The hybrids GNZ2004 and P30F33 were significantly different for zinc accumulation. Zinc accumulation during the plant cycle in both hybrids had quadratic performance (Figure 2). This performance was similar to that observed by Andrade et al. (1975). In both hybrids the total accumulated at the early stages was very small, with an increase at 44 days for an average value of 0.32 kg ha^{-1}, which maintained stable until the end of flowering. After kernel filling started (85 days after emergence) another significant increase was observed in Zn accumulation, and it increased linearly until the end of the cycle (Figure 2).

Maximum values of accumulated Zn by the hybrids were observed at physiological maturity (138 days after emergence), with 2.63 kg ha^{-1} for GNZ2004 and 1.47 kg ha^{-1} for P30F33. Vasconcellos et al. (1983), using the double cross hybrid BR105, also obtained maximum Zn accumulation at the end of the culture cycle. This decline in total Zn accumulated also was observed by Vasconcellos et al. (1983) using the forage maize cultivar BR126. However, Vasconcellos et al. (1983) always obtained lower total Zn accumulated than those found in this study, i.e., between 0.15 kg ha^{-1} and 0.20 kg ha^{-1}.

The hybrids accumulated similar amounts of Zn during most of the plant cycle. However, at the late stages, after 125 days, the hybrid GNZ2004 accumulated greater amounts than the hybrid P30F33 (Figure 2), which significantly determined the greater Zn absorption ability of this hybrid.

Manganese accumulation was similar for both hybrids, and its absorption was linear during the plant cycle for both hybrids (Figure 3). Each day, after emergence, Mn accumulation in the dry matter increased 0.006 kg ha^{-1}, and the regression equation explains 87% of the total data variation. Significant differences were observed between the hybrids GNZ2004 and P30F33 for Mn accumulation (Figure 3).

The hybrid GNZ2004 accumulated greater manganese amounts during the plant cycle (0.77 kg ha^{-1}) than the hybrid P30F33 (0.65 kg ha^{-1}). 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. Thus, the results obtained are valid for the conditions where the experiment was done, and only with more studies in different environments the probable superiority of hybrid GNZ2004 for Mn absorption in relation to hybrid P30F33 could be stated.

There was little Mn accumulation at the early plant development stages, increasing the total accumulated by the hybrids at 44 days after emergence and thereafter increased linearly until the late stages (Figure 3).

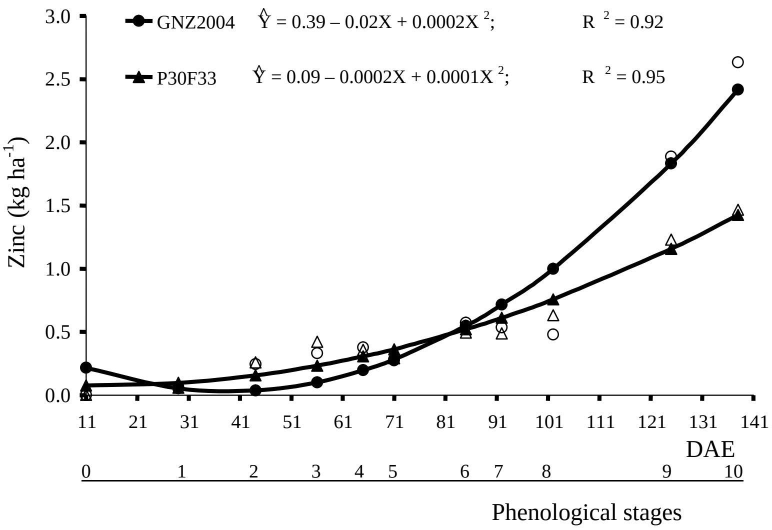

Figure 2 – Total zinc accumulated, in kg ha^{-1}, by two maize hybrids, as a function of phenological stages (days after emergence – DAE). UFLA, Lavras, MG, 2006.

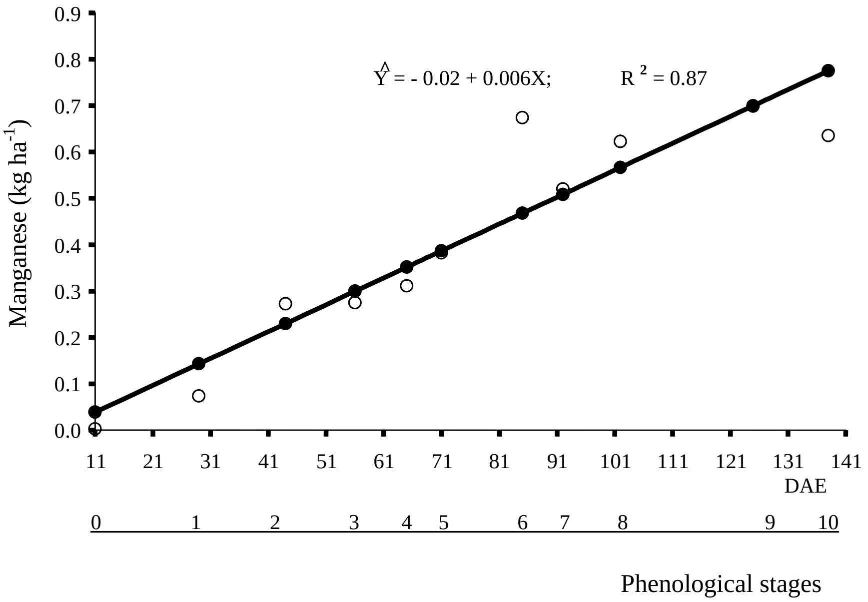

Figure 3 – Total manganese accumulation, in kg ha^{-1}, considering the average of two maize hybrids, as a function of phenological stages (days after emergence – DAE). UFLA, Lavras, MG, 2006.

It was found that, immediately after kernel filling started (at 85 days after emergence), there was an absorption peak of Mn, highlighting that this is critical period for this micronutrient in maize. However, after this peak, the hybrids had a reduction in the total Mn accumulated. Subsequently, there was an increase in total Mn accumulated until the maximum, which was observed near the end of the cycle (125 days after emergence), with average values around 0.70 kg ha^{-1}. After the maximum accumulation point, losses of total Mn accumulated were observed until physiologic maturity.

The small Mn accumulation at the early plant cycle (0.07 kg ha^{-1}, until 29 days after emergence), followed by a linear increase until a maximum point, with subsequent reduction in the total accumulated at the late stages of the cycle also was observed by Andrade et al. (1975). However, those authors observed a quadratic model for Mn accumulation, where the maximum accumulation point occurred between 82 and 94 days after emergence, with average values around 0.61 kg ha^{-1}.

No significant differences were observed between the hybrids for copper accumulation. Accumulation of this micronutrient by the hybrids GNZ2004 and P30F33 was linear during the whole plant cycle (Figure 4). Each day after emergence copper accumulation increased 0.0024 kg ha^{-1} for GNZ2004 and 0.0022 kg ha^{-1} for P30F33, and the regression equations explained 82% and 84% of the total data variation, respectively. However, at physiologic maturity (138 days after emergence) the hybrid GNZ2004 accumulated greater amount of copper than hybrid P30F33.

The values of total Cu accumulated were small, and until 102 days after emergence presented a very small increase (0.11 kg ha^{-1}). A significant increase in total Cu accumulated was observed at 125 days after emergence, which was maintained until the end of the cycle, with values near 0.30 kg ha^{-1} (Figure 4). During this period, maximum values accumulated by the hybrids were 0.31 kg ha^{-1} for GNZ2004 and 0.29 kg ha^{-1} for P30F33, demonstrating that this was the time of greatest demand of copper by the maize hybrids.

Maximum observed copper accumulation, in maize, by Andrade et al. (1975) occurred earlier and with lower values than those found in this study. It is important to note that significant losses in the total accumulated from the maximum point until maturity, as observed earlier, were not recorded for the hybrids GNZ2004 and P30F33.

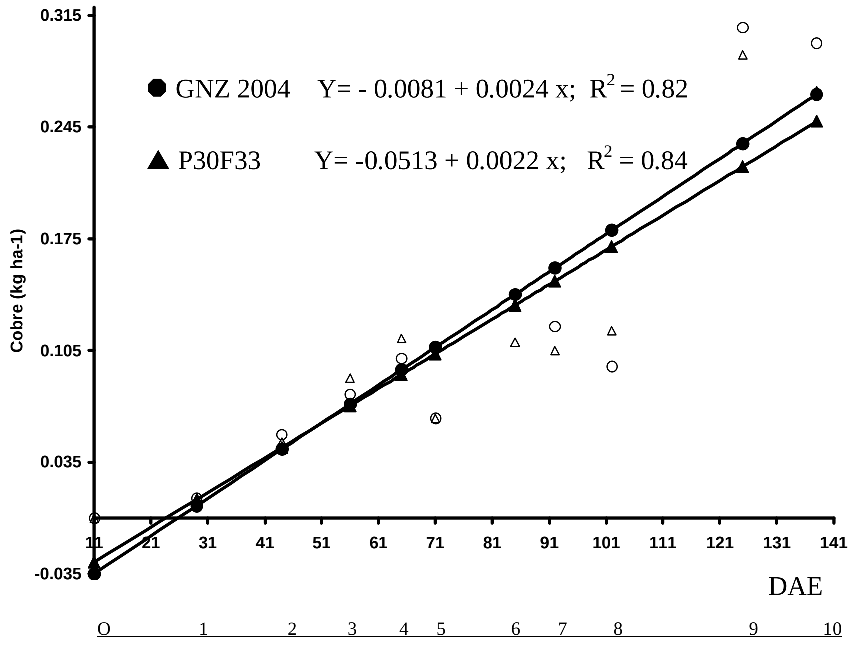

Figure 4 – Total copper accumulation, in kg ha^{-1}, considering the average of two maize hybrids, as a function of phenological stages (days after emergence – DAE). UFLA, Lavras, MG, 2006.

CONCLUSIONS

Zinc is the most accumulated micronutrient in the aboveground matter of the maize hybrids studied, followed by manganese, copper and boron, which is the least absorbed micronutrient.

The maize hybrids GNZ2004 and P30F33 accumulated minimum amounts of B, Cu, Mn and Zn at the plant's early development stages, and the maximum values were obtained after 100 days of emergence.

The hybrids GNZ2004 and P30F33, in general, accumulated greater amounts of B, Cu, Mn and Zn during their cycle the the hybrids used in other studies.

The maize hybrids used accumulated Zn and Cu until near plant physiologic maturity, the time when maximum accumulation is obtained.

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