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Research Article

Influence of Corn (*Zea mays* L.) Cultivar Development on Grain Nutrient Concentration

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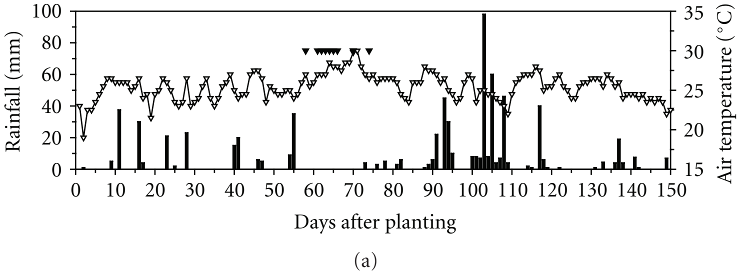
While corn productivity has been increased by the adoption of high-yield hybrids, there are concerns that increased grain potential may be associated with diminished grain nutrient concentration. Ten corn (*Zea mays* L.) cultivars representing five technological levels (landrace variety, commercial variety, and double, triple, and single cross-hybrids) were cropped on a Rhodic Ferralsol Eutric soil with high fertility in 2006 (dry year) and 2007 (normal year) in Rolândia County, Brazil. At maturity, grain was evaluated for concentrations of P, K, Ca, Mg, Fe, Mn, Zn, and Cu. In general, differences among cultivars were noted for all nutrients in both years. Concentrations of P, K, Fe, and Mn were lower in the dry year, while Ca, Mg, Cu, and Zn were higher. Soil water availability appeared to exert more influence on grain nutrient concentration than did cultivar development; nutrient removal due to grain harvest was also greatly influenced by rainfall patterns and their impact on corn productivity. Even though genetic differences were noted, which may be useful to breeding programs, long-term testing in subtropical environments will be required to clarify the interaction between genetics and climate events on grain nutrient quality and exportation.

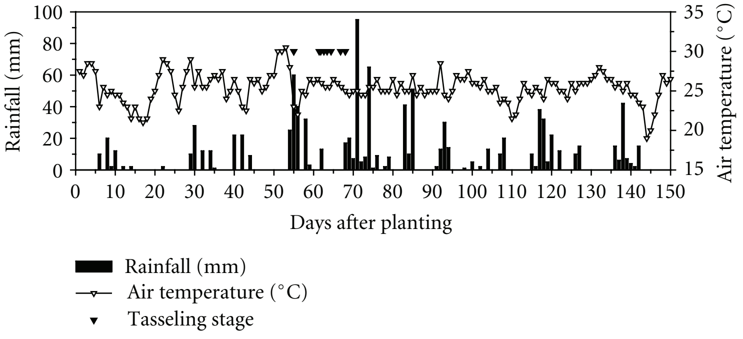
1. Introduction

Grain nutrient concentration plays a key role in seed quality as it relates to seed reserves required to germination and nutritional feed value [1]. Grain nutrient concentration can also provide information related to nutrient exportation (i.e., removal from the field) and the necessity for soil nutrient replenishment through fertilization [2, 3]. Despite these important issues, tissue analysis has traditionally focused on leaf, rather than grain, nutrient levels to diagnose whole-plant nutritional status.

Recently, it has been suggested that genetic selection in wheat (*Triticum aestivum* L.) has contributed to reduced levels of some micronutrients in grain [1]. Concerns regarding diminished grain quality have spread to other crops such as corn (*Zea mays* L.). In a study evaluating six corn hybrids released between 1959 and 1988, lower values of micronutrients were found in the newer hybrids [4]. A study of four tropical corn cultivars released between 1970 and 1990 noted some differences among cultivars; however, it was not clear whether new cultivars designed for higher yields would result in decreased grain nutrient concentration [5]. Similar variation in grain nutrient concentrations among corn hybrids have also been reported in different field studies [3].

Other factors, such as soil type and climate, may also influence crop nutrient status. For example, soil type influenced selenium grain concentration among 14 wheat cultivars, while smaller variation was seen for Fe, Zn, and Cu [1]. Long-term Cu and Zn application increased soil





(b)

Figure 1: Daily rainfall and average air temperature after planting in 2005 and harvesting in 2006 (a) and planting in 2006 and harvesting in 2007 (b). Dark arrows indicate tasseling stage dates for the ten corn cultivars.

availability as reflected by corn leaf concentrations; however, grain Cu was unaffected and increases in grain Zn were lower than observed in leaves [6]. Furthermore, water shortage showed little effect on grain nutrient concentrations of P, K, Mg, Ca, Zn, Mn, and Cu [5]. Nonetheless, decreased corn grain P concentration has been observed when water was not limiting [2]. These differences may help explain the variation in grain nutrients among years and the difficulty of correlating grain nutrient concentration with corn yields [3, 7].

Hitherto, few experiments have studied grain nutrient concentration of corn cropped under tropical or subtropical conditions or the impact of genetic selection (varying from old cultivars to new hybrids) on variation in grain nutrient concentration. The objective of this study was to evaluate ten corn cultivars representing five degrees of breeding development (landrace variety, commercial variety, double, triple and single cross hybrids) to determine whether selection altered grain nutrient concentration in a Brazilian cropping system.

2. Materials and Methods

The study was conducted at the Monsanto Experiment Station at Rolandia City, Paraná State, Brazil, located at 23°16′ S latitude, 51°28′ W longitude, and 645 m altitude. The local climate is characterized as Cfa, Subtropical Humid with uniform precipitation distribution [8]. Temperature (°C) and rainfall (mm) were measured daily (Figure 1). The soil was formed from basalt and classified as a Clay Loam Rhodic Ferralsol Eutric [9]. Seeds were sown in November 2005 and October 2006. Before planting, soil samples were collected (10 cm) for chemical analyses. After drying, samples were analyzed for pH, Ca, Mg, Al, K, P, Mn, Fe, Cu, Zn, and organic matter following procedures of Embrapa [10] (Table 1).

The experiment had ten treatments, corresponding to ten cultivars represented by five pairs of corn technological levels. The experimental design was a complete randomized block with five replications. The selected cultivars ranged from highly developed hybrids to farmer selection (landrace), as represented by (a) single cross-hybrids (AG9010 and DKB950) (b), triple cross hybrids (DKB566 and AG5020); (c) double cross hybrids (AG2040 and DKB979), (d) commercial varieties (BRS4157 and BR106), and (e) landrace cultivars (Palotina and GIO45). Detailed information concerning these cultivars has been previously reported [11].

For both years, soil was moldboard plow and disk harrow twice before planting. Plots were 4 × 10 m with 6 rows of which the two central were used for data collection. Plots were hand-planted at two seeds per burrow and thinned to achieve desired plant population at the V_2 stage. Row width was 0.8 m with plant spacing within rows of 0.2 m for an established plant population of 62,500 plants ha^{-1}.

During sowing, N, P_2O_5, and K_2O were applied at 28, 70, and 70 kg ha^{-1}, respectively. The used fertilizers were MAP, ammonium sulfate, potassium chloride, and superphosphate at proportion of 34.4, 11.0, 33.4, and 21.2%, respectively. Additionally, a side dress application of 135 kg N ha^{-1} was made using urea at the V_4 stage. Seed treatment, weed control, and other management practices were similar for both years.

The harvests in 2006 and 2007 were conducted approximately 150 days after planting. Fifteen plants per plot were

Table 1: Study site soil chemical characteristics (0–10 cm layer) at Rolandia County, Parana State, Brazil.

	pH	O.M.	P	Ca	Mg	K	H + Al	Mn	Fe	Cu	Zn
	$CaCl_2$	$g\ kg^{-1}$	$mg\ kg^{-1}$		g/kg		$cmol_c\ kg^{-1}$		$mg\ kg^{-1}$		
Year 1	6.0	28.4	24.5	0.21	0.04	0.04	3.2	268	86	33	13
Year 2	5.9	29.1	40.3	0.13	0.03	0.03	3.1	308	67	24	12

Table 2: Grain macronutrient concentration in ten corn cultivars representing five different technological levels in 2006 and 2007, at Rolandia County, Parana State, Brazil.

Treatment		P	K	Ca	Mg	P	K	Ca	Mg
		2006				2007			
		$g\ kg^{-1}$							
Single	AG9010	3.0^{a*}	3.7^{a}	0.30^{b}	1.37^{cd}	4.1^{b}	7.7^{b}	0.12^{ab}	0.92^{ab}
Hybrids	DKB950	2.9^{a}	4.0^{a}	0.32^{b}	1.32^{d}	5.1^{a}	10.3^{a}	0.13^{ab}	1.12^{a}
Triple	DKB566	2.8^{a}	3.6^{a}	0.31^{b}	1.59^{abc}	3.8^{b}	7.4^{b}	0.10^{b}	0.90^{ab}
Hybrids	AG5020	3.0^{a}	3.4^{b}	0.38^{b}	1.45^{bcd}	3.5^{b}	6.6^{b}	0.15^{ab}	0.94^{ab}
Double	AG2040	3.4^{a}	3.7^{a}	0.49^{ab}	1.71^{a}	4.0^{b}	7.7^{b}	0.14^{ab}	1.00^{ab}
Hybrids	DKB979	2.9^{a}	3.5^{ab}	0.66^{a}	1.39^{cd}	4.1^{b}	7.3^{b}	0.13^{ab}	0.77^{b}
Commercial	BRS4157	3.4^{a}	3.9^{a}	0.46^{ab}	1.64^{ab}	4.0^{b}	7.5^{b}	0.13^{ab}	0.91^{ab}
Varieties	BR106	3.5^{a}	3.9^{a}	0.39^{b}	1.56^{abcd}	4.1^{b}	8.1^{b}	0.18^{a}	1.09^{ab}
Landrace	GI045	3.3^{a}	3.8^{ab}	0.29^{b}	1.55^{abcd}	3.4^{b}	6.8^{b}	0.10^{b}	0.89^{ab}
Cultivars	Palotina	3.1^{a}	3.9^{ab}	0.36^{b}	1.32^{d}	3.8^{b}	7.7^{b}	0.13^{ab}	0.84^{ab}
Coefficient of variation		14	11	46	11	18	18	33	24

[*] Averages followed by the same letter in a column did not differ according to Duncan's multiple range test ($P \leq 0.05$).

sampled for grain nutrient evaluation. Grain was separated and subjected to dry digestion in porcelain crucibles. Phosphorus was determined colorimetrically using an UV/VIS Spectrophotometer. Calcium, Mg, Fe, Mn, Zn, and Cu were determined by Atomic Absorption Spectrophotometry while K was determined by Flame Spectrophotometry [12]. Nutrient exportation (removed from the field) was calculated by multiplying grain dry weight by nutrient concentration. Data were analyzed by analysis of variance (ANOVA) and Duncan's test ($P \leq 0.05$) was performed to compare means. The yield, nutrients concentration and exportation data were submitted to correlation and regression analysis, using the Statistical Analysis System software.

3. Results and Discussion

There were differences among grain macronutrient concentrations for the tested cultivars in both years, excepting for P in the first year (Table 2) when plants experienced less rainfall (Figure 1), particularly during tasseling [11]. Observed grain P concentration fell within the range reported by others [3, 7, 13–15], but were above the 2.3 $g\ kg^{-1}$ mean reported by Altmann and Pavinato [16] for corn produced in the Cerrado Region of Brazil, where soil normally has low available P. Grain P concentration was higher in the second year (more rainfall) compared to the first year across all cultivars. In the second year, single hybrid DKB950 grain P was higher than all other cultivars. The fact that the remaining nine cultivars showed no differences suggests that grain P had undergone small variation due to crop technological level. Similarly, others have reported little variation among corn cultivars [4, 5]. However, Eghball et al. [2] reported greater grain P concentration among 12 hybrids grown under water shortage, suggesting the possibility of selecting hybrids with high soil P extraction capacity.

Similarly to P, K was higher in the second, wetter year. The range in grain K concentration in the first year (Table 2) was comparable to previously reported values [4, 5, 7]; however, values in the second year were much higher than other studies [3, 13–15]. Both P and K are dependent on diffusion as an uptake mechanism and, therefore, are influenced by soil water status. It is noteworthy that our soil P and K levels were high. Once again and like P, the single hybrid DKB950 had the highest K concentration in both years (Table 2) and was significantly higher than other cultivars in the second year. Grain K concentration varied somewhat among cultivars, independently of technological level, supporting the observations made by Vyn and Tollenaar [4] and Feil et al. [5].

While larger concentrations of P and K were seen in 2007, greater concentrations of Ca and Mg were observed in 2006 which received less rainfall; however, values in both years fell within reported ranges [3–5, 7]. Differences among cultivars were observed in both years for Ca and Mg; however, patterns among cultivars greatly differed between years (Table 2). The variation in Ca and Mg concentrations cannot be explained by soil availability, since their soil levels were high in both years (Table 1). Arnon [17] indicated that a common antagonistic nutrient interaction occurs between K and Ca and/or Mg in leaves, which might help explain the inverse relationship observed between years. Nevertheless, the same

Table 3: Grain micronutrient concentrations for 10 corn cultivars representing five different technological levels in 2006 and 2007, at Rolandia County, Parana State, Brazil.

Treatment		Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn
		2006				2007			
		g kg^{-1}							
Single	AG9010	7.3^{ab}	21^{ab}	6^{bc}	36^{ab}	1.1^{a}	38^{a}	10^{a}	24^{a}
Hybrids	DKB950	5.7^{ab}	19^{ab}	5^{c}	30^{bc}	0.8^{a}	39^{a}	11^{a}	26^{a}
Triple	DKB566	4.7^{b}	18^{ab}	7^{bc}	32^{abc}	0.7^{a}	33^{a}	12^{a}	24^{a}
Hybrids	AG5020	4.8^{ab}	17^{b}	5^{bc}	31^{bc}	1.0^{a}	37^{a}	11^{a}	23^{a}
Double	AG2040	9.6^{a}	29^{ab}	11^{a}	39^{a}	1.1^{a}	37^{a}	13^{a}	27^{a}
Hybrids	DKB979	5.2^{ab}	20^{ab}	7^{bc}	31^{bc}	1.1^{a}	33^{a}	10^{a}	24^{a}
Commercial	BRS4157	5.6^{ab}	34^{a}	8^{ab}	32^{abc}	0.9^{a}	37^{a}	13^{a}	31^{a}
Varieties	BR106	2.8^{b}	18^{ab}	8^{ab}	27^{c}	0.7^{a}	38^{a}	11^{a}	24^{a}
Landraces	GI045	3.6^{b}	18^{b}	7^{abc}	28^{c}	1.3^{a}	40^{a}	11^{a}	22^{a}
Cultivars	Palotina	6.4^{ab}	17^{b}	6^{bc}	29^{bc}	0.9^{a}	41^{a}	12^{a}	22^{a}
Coefficient of variation		59	54	33	17	87	18	29	27

*Averages followed by the same letter in a column did not differ according to Duncan's multiple range test ($P \leq 0.05$).

Table 4: Macronutrients exportation of maize cultivars in 2006 and 2007, at Rolandia County, Parana State, Brazil.

Treatment		P	K	Ca	Mg	P	K	Ca	Mg
		2006				2007			
		kg ha^{-1}							
Single	AG9010	7.0^{ab}	8.6^{abc}	0.74^{bc}	3.2^{bc}	38.0^{ab}	70.8^{b}	1.09^{abcd}	8.6^{ab}
Hybrids	DKB950	7.0^{ab}	9.5^{abc}	0.76^{bc}	3.2^{bc}	45.8^{a}	91.8^{a}	1.16^{abc}	10.1^{a}
Triple	DKB566	9.1^{a}	11.6^{a}	0.98^{b}	5.1^{a}	32.8^{b}	63.0^{b}	0.85^{bcd}	7.5^{abc}
Hybrids	AG5020	8.5^{ab}	9.5^{abc}	1.06^{b}	4.1^{ab}	35.2^{b}	66.9^{b}	1.55^{a}	9.6^{ab}
Double	AG2040	7.4^{ab}	8.2^{abc}	1.09^{b}	3.7^{bc}	37.5^{ab}	72.1^{b}	1.26^{ab}	9.4^{ab}
Hybrids	DKB979	8.7^{a}	10.5^{ab}	1.83^{a}	4.2^{ab}	38.0^{ab}	68.0^{b}	1.28^{ab}	7.2^{bc}
Commercial	BRS4157	6.9^{ab}	7.9^{bc}	0.92^{b}	3.3^{bc}	22.6^{cd}	42.7^{cd}	0.75^{bcd}	5.1^{cd}
Varieties	BR106	5.7^{b}	6.5^{c}	0.60^{bcd}	2.6^{c}	29.7^{bc}	57.8^{bc}	1.28^{ab}	7.8^{abc}
Landrace	GI045	2.3^{c}	2.7^{d}	0.21^{cd}	1.1^{d}	16.6^{d}	32.9^{d}	0.51^{d}	4.3^{d}
Cultivars	Palotina	0.7^{c}	0.8^{d}	0.09^{d}	0.3^{d}	17.8^{d}	35.5^{d}	0.64^{cd}	3.9^{d}
Coefficient of variation		18	11	10	11	11	20	22	44

*Averages followed by the same letter in a column did not differ according to Duncan's multiple range test ($P \leq 0.05$).

author indicated that increased water supply would favor absorption of Ca and Mg over K. In our study, this behavior was observed for leaves, while stalks (data not shown) behaved similarly to grain, suggesting that this antagonistic relationship can vary among plant components [18]. Overall, soil water availability exerted a greater influence on grain macronutrient concentration than did genetics.

There were no differences in grain micronutrients in year 2 (Table 3), which experienced normal rainfall. Grain Cu and Zn tended to be higher, while Mn and Fe tended to be lower in the first year (Table 3). Concentrations of all micronutrients were close to those reported by others [3–5, 7, 13, 16]. Like Cu, the experimental area had high levels of Fe and Mn which were derived from basalt parent material (Table 1). However, unlike Cu, both Fe and Mn are normally affected by oxidation-reduction reactions which can be influenced by water soil water status. Although the Rhodic Ferralsol has good permeability, it is plausible to assume that the temporary water logging could have favored reduction reactions thereby increasing plant available Fe and Mn in the second year. Lack of Zn is a wide-spread nutritional problem under tropical conditions, thus supplemental applications are common practice. Grain Zn concentrations observed in our study suggest that soil Zn was adequate (Table 3). The double hybrid AG2040 had the highest concentration of Cu, Mn, and Zn, while the triple hybrid AG5020 and both landraces had the lowest micronutrient concentrations. Despite differences in micronutrient grain concentrations among cultivars, it remains difficult to determine the association between grain quality and cultivar development. This differs from Garvin et al. [1], who reported an inverse relationship between genetic improvement and micronutrients in wheat grain. Our results showed larger difference within the same technological level than among the five groups studied. Similar results were observed by Vyn and Tollenaar [4]. In the same way as macronutrients, soil water availability in our study appeared to exert more influence on grain micronutrient concentration than did cultivar development;

Table 5: Micronutrients exportation of maize cultivars 2006 and 2007, at Rolandia County, Parana State, Brazil.

Treatment		Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn
		2006				2007			
		$g\ ha^{-1}$							
Single	AG9010	17.9^{a}	51^{ab}	16.1^{abc}	90^{a}	10.6^{a}	348^{ab}	88.5^{bc}	222^{abc}
Hybrids	DKB950	13.8^{abc}	44^{ab}	10.9^{bcd}	73^{ab}	7.3^{a}	354^{ab}	98.2^{abc}	233^{ab}
Triple	DKB566	14.6^{abc}	60^{ab}	23.0^{a}	101^{a}	5.7^{a}	278^{bc}	98.5^{abc}	205^{abc}
Hybrids	AG5020	13.1^{abc}	48^{ab}	15.4^{abc}	87^{a}	10.4^{a}	381^{a}	110.9^{ab}	235^{ab}
Double	AG2040	21.3^{a}	66^{a}	23.4^{a}	86^{a}	10.0^{a}	352^{ab}	123.0^{a}	241^{a}
Hybrids	DKB979	15.3^{ab}	61^{ab}	20.5^{ab}	93^{a}	9.9^{a}	304^{ab}	96.9^{abc}	227^{abc}
Commercial	BRS4157	11.1^{abcd}	63^{ab}	16.5^{abc}	65^{ab}	5.3^{a}	211^{cd}	70.8^{cde}	175^{bc}
Varieties	BR106	4.6^{bcd}	29^{bc}	13.4^{abc}	44^{bc}	4.8^{a}	277^{bc}	82.5^{bcd}	169^{c}
Landraces	GI045	2.7^{cd}	12^{c}	5.3^{cd}	19^{cd}	6.0^{a}	189^{d}	54.9^{de}	109^{d}
Cultivars	Palotina	1.2^{d}	3^{c}	1.4^{d}	6^{d}	4.2^{a}	181^{d}	52.6^{e}	104^{d}
Coefficient of variation		73	53	55	39	92	22	25	23

*Averages followed by the same letter in a column did not differ according to duncan's multiple range test ($P \leq 0.05$).

Table 6: Correlation between nutrients (macro and micro) concentration and yield for ten corn cultivars representing five different technological levels, harvesting in 2006 and 2007, at Rolandia County, Paraná State, Brazil.

2005/06	Yield	C	N	P	K	Ca	Mg	Cu	Fe	Mn
C	−0.18									
N	−0.28	0.10								
P	−0.14	0.07	0.18							
K	−0.26	0.05	0.02	0.76**						
Ca	0.12	0.11	0.28	0.13	−0.03					
Mg	0.08	0.04	0.11	0.85**	0.55**	0.21				
Cu	0.12	0.23	0.13	−0.05	−0.18	0.27	0.01			
Fe	0.11	0.14	0.12	0.21	0.06	0.53**	0.32	0.38		
Mn	0.15	0.10	0.28	0.27	0.02	0.37	0.43*	0.54**	0.55**	
Zn	0.37	0.04	0.02	0.25	0.09	0.27	0.32	0.66**	0.44*	0.68**
2007	Yield	C	N	P	K	Ca	Mg	Cu	Fe	Mn
C	0.04									
N	−0.69**	0.29								
P	0.19	0.32	0.08							
K	0.09	0.30	0.10	0.87**						
Ca	0.05	−0.05	0.19	0.13	0.17					
Mg	0.06	0.04	−0.01	0.58**	0.51**	0.28				
Cu	0.04	−0.08	−0.09	−0.03	−0.07	−0.11	0.33			
Fe	−0.12	0.11	−0.01	0.30	0.21	0.52**	0.35	0.29		
Mn	−0.15	0.21	0.15	0.16	0.08	−0.30	0.30	0.09	0.58**	
Zn	0.03	0.02	0.24	0.21	0.26	0.51**	0.14	−0.01	−0.39	−0.15

$^{*}P < 0.05$; $^{**}P < 0.01$.

Table 7: Correlation between yield and amount of nutrients for the grain in ten corn cultivars representing five different technological levels in harvesting in 2006 and 2007, at Rolandia County, Paraná State, Brazil.

	C	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
2006	0.87**	0.88**	0.86**	0.85**	0.62**	0.84**	0.61**	0.69**	0.72**	0.85**
2007	0.99**	0.98**	0.79**	0.75**	0.43*	0.68**	0.34*	0.63**	0.68**	0.70**

$^{*}P < 0.05$; $^{**}P < 0.01$.

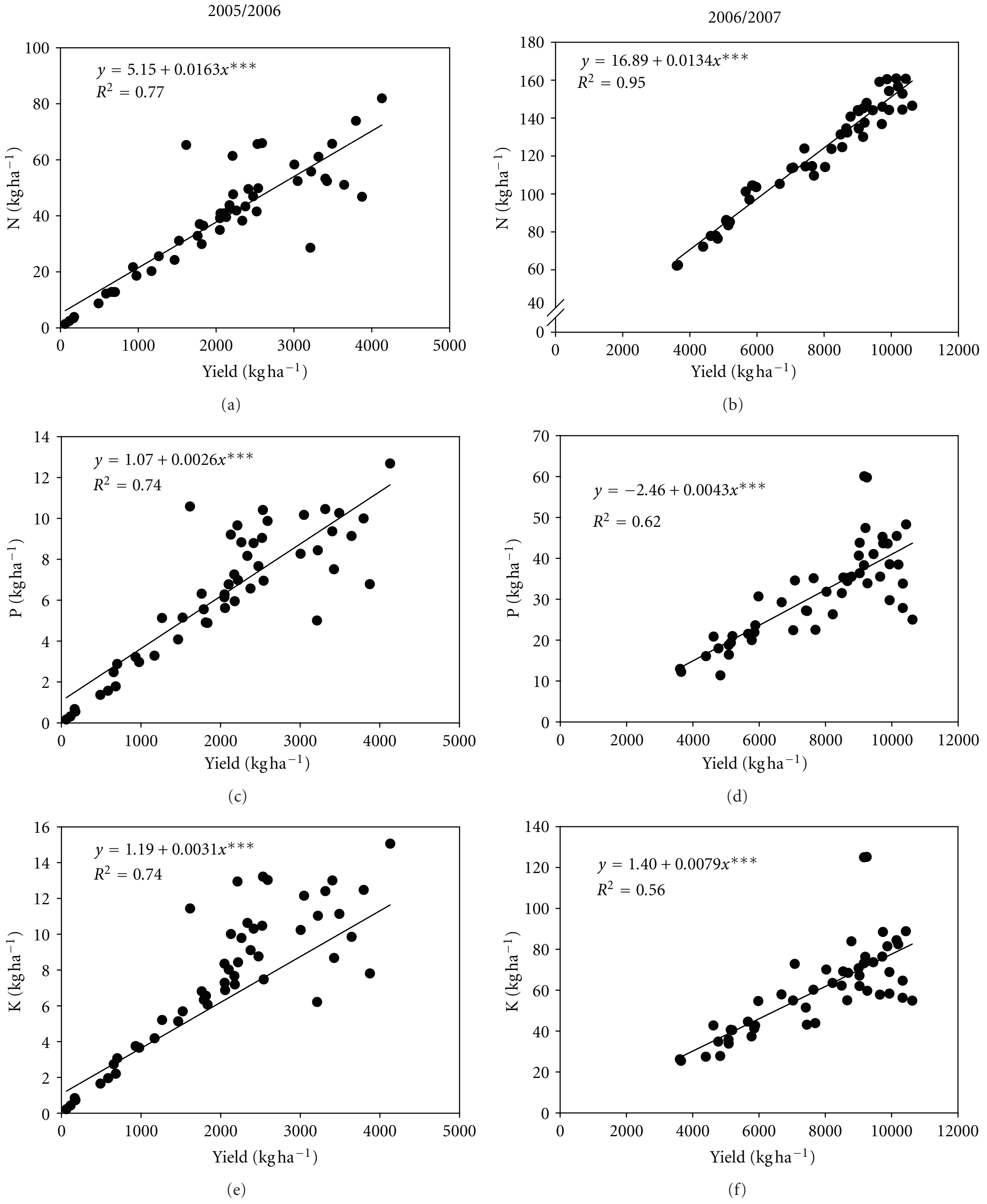


FIGURE 2: Regression between yield (kg ha^{-1}) and exportation of N, P, and K (kg ha^{-1}) in the grain in ten corn cultivars representing five different technological levels harvesting in 2006 and 2007, at Rolandia County, Paraná State, Brazil. $^{***}P < 0.001$.

however, some genetic differences exist, which may be useful in breeding programs.

Nutrient exportation or removal from the field by grain harvest was different among cultivars in both years, with the exception of Cu in the second year (Tables 4 and 5). The amount of nutrient removal was controlled by corn productivity, which was greatly influenced by rainfall patterns [11, 18]. The hybrids and commercial varieties showed a 4-fold decrease in grain production due to lower rainfall in the first year; however, the landraces were much more affected

(10-fold decrease) by rainfall patterns. In general, the single, double, and triple hybrids showed higher nutrient exportation, for both macro- and micronutrients than commercial varieties and landrace cultivars. Again, this was due to greater grain biomass production for the hybrids [11]. Similar results for other corn cultivars were noted by Feil et al. [5]. Although few differences were observed among hybrids, it was interesting to note that DKB hybrids tended to have the highest grain biomass (and thus nutrient removal) in the dry year, while AG hybrids were highest in nondried year.

The results from yield [11] and nutrient concentration correlation indicated that there was an inverse relationship between yield and N concentration for 2006/2007 growing season (Table 6). This fact could be indication of dilution as result of yield increment and suggest a decrease on nutritional values of grain.

There was a consistent relationship between concentrations of P × K and P × Mg for both year's crops (Table 6). Our results confirm earlier observation that there is a synergic interaction between P, and Mg on plant absorption [17].

The amount of nutrients exported by grain was well associated with yield, especially for C [11], N [11], P and K (Table 7). The results indicated an exportation and necessity of soil reposition of 13.4, 4.3, and 7.9 in 2005/2006 and 16.3, 3.1, and 2.6 in 2006/2007 for N, P, and K in each 1000 kg grain (Figure 2), respectively.

4. Conclusions

Evaluation of various corn cultivars commonly used in Brazilian cropping systems did not indicate an obvious association between grain quality and cultivar development. In this study, soil water availability appeared to exert more influence on grain nutrient concentration than did cultivar development. Similarly, nutrient removal due to grain harvest was also greatly influenced by the impact of rainfall patterns on corn productivity. Genetic differences were noted which might be useful for breeding programs. However, long-term studies covering multiple years and, accordingly, varying rainfall patterns would be helpful for elucidating the influence of genetics (and their interaction with weather) on grain nutrient quality and exportation.

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