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Nutrient removal and yield of different maize hybrids

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ABSTRACT

Objective: to determine the macro and micronutrient removal values and potential yield of different hybrids, and, also to determine the relationship between grain nutrient removal and grain yield.

Design/methodology/approach: to assess correlations and determine the association degree between the nutrient removal values and grain yield.

Results: the total nutrient removal values were in N>K>Ca>Mg>P, and Mn>Fe>Zn>B>Cu order, which are higher values when compared to another research. Also, these provide the mineral content in grains, which is a nutritional quality-related parameter. Limitations on study/implications: increasing the number of hybrids, different fertilization rates, different soil conditions, and crop management practices should be evaluated to assess whether these influence/inhibit the final nutrient concentration and total removal in grain.

Findings/conclusions: The total grain nutrient removal values varied as a function of hybrids, yield goal, and nutrient concentration in tissues.

These values allow the adjustment of current fertilization rates. The same hybrids under different management practices (fertilization dose), or soil types, substantially influence the grain nutrient concentration and therefore total nutrient removal.

Keywords: nutritional extraction, fertilization, yield.

INTRODUCTION

Agriculture is associated with environmental variables such as temperature, precipitation, and solar radiation. These variables, especially temperature increase, affect crop development, water, and nutrient uptake rate, yield, and grain nutrient concentration. Maize (*Zea mays* L.) cultivation in the state of Sinaloa, Mexico, is one of the most important, not only for its planted area in each growing season but also for its nutritional value (SIAP 2023). According to several reports, maize's yield potential has been maximized due to (breeding) and the implementation of increasingly efficient agronomic practices, but nutrient management is also essential. In that sense (Ma *et al.*, 2006; Ciampitti and Vyn, 2013; Caires and Milla, 2016) showed that climatic variables and agronomic management directly impact grain nutrient removal; while the uptake and extraction processes associated

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with optimal yield help to improve fertilization management considering climate variability (Ciampitti and Vyn, 2011; Hill and Clérici, 2013). Currently, there is limited information on grain nutrient removal in maize seeds grown in semi-arid climate conditions of northern Sinaloa. Much of the existing information is outdated, from hybrids grown in other regions, and not useful for current hybrids, agronomic management practices, and climatic or edaphic conditions. Therefore, the objective of this research was to determine the nutrient removal values of macro and micronutrients, the yield potential of different maize hybrids, and determining the relationship between nutrient removal and grain yield.

MATERIALS AND METHODS

Description of the study area

The research was carried out during the autumn-winter growing season 2020-2021 agricultural cycle in three different lots. The soils in the region are classified as clay loam (50% clay, 30% silt, and 20% sand), low organic matter content ($<1\%$), 1.15 g cm^{-3} bulk density, 48% field capacity, and 33% permanent wilting point.

Crop establishment

Planting was carried out in 90,000 plants per hectare density moist soil. The hybrids, Dekalb 4055®, P3230W®, Asgrow Hipopótamo®, and P3274W® were planted from November 10 to 30, 2021, corresponding to the optimal planting window, according to the recommendation by the technical guide for maize production of the Instituto Nacional de Investigaciones Agrícolas y Pecuarias through the Valle del Fuerte Experimental Field (INIFAP-CEVAF).

Crop fertilization

Fertilization was applied in the following stages: 400 kg ha^{-1} of bulk blend (30-10-12), pre-plant applied. the second fertilization event was done when the plant attained the V6 growth stage with 300 kg ha^{-1} of urea or anhydrous ammonia (NH_3), and a last application was done during the flowering stage (R1) with 100 kg ha^{-1} of NH_3.

Seed sampling nutrient

Seed samples were collected from each hybrid (100 g of seeds) at physiological maturity to determine nutrient concentration.

Grain drying

The 100 g of grain were dried in a forced air oven at 70 °C temperature for 24 hours, once dried, 20 g were taken for nutrient determination.

Nutrient concentration in grain

Nutrient levels were estimated following the methodology described in the Official Mexican Standard (NOM-021-RECNAT-2000).

Total grain nutrient removal was estimated with Equation (1).

$$\text{Nutrients in grain}\left(\text{kg ha}^{-1}\right)=\left[\ \text{yield}\left(\text{kg ha}^{-1}\right)*\%\ \text{nutrient}/100\right] \qquad (1)$$

Yield evaluation

For yield evaluation, sampling of each hybrid was assessed in a 3 m^2 area, considering the two central rows where cobs were collected. Subsequently, the moisture content in grains was measured with a humidity tester —(Agratronix Mt-pro). The humidity adjustment to 14% of the grain was carried out with the following Equation (2):

$$HG(14\%)=WG\ \text{kg}*(100-\%HG)/86 \qquad (2)$$

Where: *HG* is the humidity of grain adjusted to 14%; *WG* is the weight of the grain sampled in kg; %*HG* is the grain moisture percentage; 86 is the factor to standardize the yield at 14% humidity.

To estimate the yield components, cob length, number of rows, number of grains per row, cob weight (including its core), grain weight per cob, and weight of 100 grains were quantified. Finally, grain yield was calculated with Equation (3).

$$Y\left(\text{t ha}^{-1}\right)=\left(WG\ 14\%\ \text{kg}\right)*\left(HA\ \text{m}^2/SHA\ \text{m}^2\right)/1000 \qquad (3)$$

Where: *Y* is the grain yield t ha^{-1}; *WG* 14%: grain weight adjusted to 14% moisture; *SH* is the area of 1 hectare (m^2); SHA is the surface area of sampling (m^2).

Statistical analysis

Data of yield and its components were analyzed with one way anova. Regression models were fitted and tested on significance levels ($\alpha=0.05$) and R^2 values using the data of nutrient concentration (Minitab, 2017).

RESULTS AND DISCUSSION

Yield and its components

Table 1 shows the values of yield and total yield components for each of the evaluated hybrids. No statistical differences were found between cob length and the number of rows among the hybrids. However, numerically the P3230W® and P3274W® hybrids reported higher cob weight and number of grains per cob.

Statistical differences were found regarding the weight of 100 grains, since the highest weight was obtained from the hybrid P3274W® and the lowest from Asgrow Hipopótamo®, with the average 55 g concentration.

Duarte *et al.* (2019) reported average values of 33.2 and 34.6 g in different hybrids. It is worth mentioning that all the yield component values represent the average of the hybrids grown in the same area and the same growing season.

The highest yield was found on P3274W® while the lowest yield on Dekalb 4055® (Figure 1). In this sense, Machado-Silva *et al.* (2018) reported similar yield values on hybrids DKB

Table 1. Yield components in maize varieties.

Hybrid	EL	RN	G/R	EW (kg)	GW/E (kg)	Weight of 100 grains (gr)
DK 4055	16.81 (±1.78) a	16.19 (±0.95) a	32 (±2.44) b	0.197 (±0.004) b	0.182 (±0.017) b	51 (±0.003) c
P3230W	16.73 (±2.08) a	16.02 (±0.24) a	33 (±2.22) ab	0.211 (±0.008) a	0.183 (±0.033) a	60 (±0.005) b
Hipopótamo	16.50 (±1.90) a	15.59 (±1.71) a	35 (±5.34) a	0.198 (±0.016) b	0.195 (±0.019) b	38 (±0.003) d
P3274W	16.43 (±1.75) a	14.90 (±0.82) a	34 (±2.46) a	0.215 (±0.004) a	0.200 (±0.014) a	72 (±0.003) a
Mean	16.6	15.6	33.5	0.205	0.19	55
($P \leq 0.05$)	0.554	<0.0001	<0.0001	0.016	0.021	<0.0001

EL: ear length, RN: row number, G/R: grains per row, EW: ear weight, GW/E: grain weight per ear. Means with distinct letters within a column are statistically different (Fisher LSD $P \leq 0.05$), ±standard deviation.

310PRO2 (13.219 kg ha^{-1}), DKB 390PRO (10.793 kg ha^{-1}), AG 8088PROX (10,784 kg ha^{-1}) and P30F53 YH (9.299 kg ha^{-1} grown in contrasting environments of Brazil.

Nutrient concentration in grain

The nutrient concentration present in maize grain was in the following order: N>K>Ca>Mg>P with average values of 11.5, 10, 6, 5, and 3.4 g kg^{-1} of seed. The micronutrients concentration was Mn>Fe>Zn>B>Cu with mean values of 415, 436, 172, 104, and 33 mg kg^{-1} (Table 2). Duarte (2003) reported values of 13.7, 3.6, 4.7, 0.1 1.3, 1.0 g kg^{-1} of N, P, K, Ca, Mg, S, and 32.3, 8.1, 4.0, 30.1, 6.0 mg kg^{-1} Fe, Mn, Cu, Zn, and B respectively. It is worth mentioning that micronutrient values are lower than those found in this research. However, P, K, and Mg concentrations are higher than those reported by Duarte *et al.* (2019) who found nutrient concentration of N>K>P>Mg>S>Ca>Zn>Fe> Mn>B>Cu with mean values of 13.1, 3.1, 2.1, 1.1, 0.9, 52.5 g kg^{-1} and 17.5, 13.1, 4.7, 3.7, 1.8 mg kg^{-1} in different hybrids and locations. They also coincide with findings reported by Resende *et al.* (2012) who showed an approximate range of values of N (15.7 mg kg^{-1}), P (3.1 mg kg^{-1}), K (3.7 g kg^{-1}), and Oliveira Junior *et al.* (2010) who reported a slight decrease in P concentration (2.4 g kg^{-1}).

Research by Heckman *et al.* (2003) found that maize hybrids evaluated over 23 years and different sites, exhibited a wide range of macronutrient concentrations: N (10.2-15.0 g kg^{-1}), P (2.2-5.4 g kg^{-1}), K (3.1-6.2 g kg^{-1}), S (0.9-1.4 g kg^{-1}), Mg (0.88-2.18 g

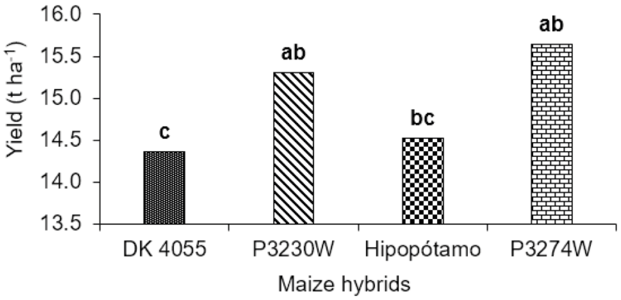

Figure 1. Yield of evaluated maize hybrids.

kg^{-1}), and Ca (0.13-0.45 g kg^{-1}) and that micronutrients had a greater variation in these concentrations, which affected the total nutrient removal. On the other hand, Bender *et al.* (2013) reported concentrations of N (13.8 g kg^{-1}), P (3.3 g kg^{-1}), K (4.4 g kg^{-1}), Mg (1.4 g kg^{-1}), Fe (21 mg kg^{-1}), Mn (6.0 mg kg^{-1}), Cu (3.4 mg kg^{-1}), Zn (26 mg kg^{-1}) and B (1.6 mg kg^{-1}) in six maize hybrids. Finally, Binford (2010) mentions that average N concentration ranges between 12 and 15 g kg^{-1}, while P and K range between 3.0 and 3.6 g kg^{-1}.

The existing variability values found in this study as compared to other research can be mainly attributed to climatic and edaphic conditions, length of growing season, and agronomic management.

In this sense, various authors such as Ciampitti and Vyn (2013) and Caires and Milla (2016) argue that nutrient content in grains is strongly influenced by the diversity of materials and agronomic management.

Total nutrient removal

According to Table 2, P3274W® hybrid reported the highest total nitrogen removal (219 kg ha^{-1}) compared to DK4055®, which had the lowest removal (130 kg ha^{-1}). P3230W® and Asgrow Hipopótamo® showed similar removal values of 179 and 161 kg ha^{-1}. The average N removal among the evaluated hybrids was 172 kg ha^{-1}. Phosphates $\left(\mathrm{PO}_4^-\right)$ removal showed a similar trend to that of nitrogen, where the highest removal occurred in P3274W® and the lowest in DK4055® and Asgrow Hipopótamo® with 36 and 34 kg ha^{-1}.

In the same manner, P3274W® and P3230W® showed the highest removal as compared to DK4055® and Asgrow Hipopótamo® with 120 and 124 kg ha^{-1}. The average PO_4^- removal was 52 kg ha^{-1}. K^+ and Mg removal had a very similar trend in the evaluated hybrids. P3274W® and P3230W® showed the highest removal with 184-172 kg ha^{-1} of K and 109-194 kg ha^{-1} of Mg. While DK4055® and Asgrow Hipopótamo® extracted approximately 124-120 kg ha^{-1} of K and 47-54 kg ha^{-1} of Mg. The average K removal was 150 kg ha^{-1} and 76 kg ha^{-1} for Mg.

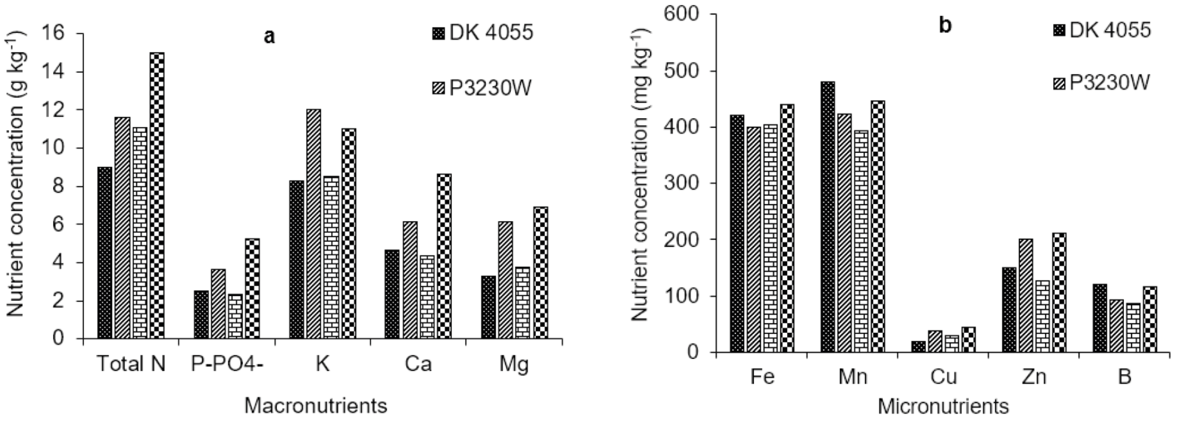

Figure 2. Grain nutrient concentration of different maize hybrids, Macronutrients (a), Micronutrients (b).

Calcium removal was greater in P3274W® with 135 kg ha^{-1} but numerically different than DK4055® and Asgrow Hipopótamo® with 67 and 63 kg ha^{-1} respectively. The average removal was 89.5 kg ha^{-1}. Iron and manganese removal in the evaluated hybrids was similar. However, P3274W® and P3230W® had numerically higher removal values compared to the other hybrids. The highest copper removal was observed in P3274W® with 69.4 g ha^{-1}, followed by P3230W® with 59 g ha^{-1}, Asgrow Hipopótamo® with 43.5 g ha^{-1} and finally DK4055® with 29 g ha^{-1}.

Higher zinc removal, (331 g ha^{-1}) occurred in P3274W®; while the Asgrow Hipopótamo® extracted the least amount (182 g ha^{-1}). Finally, no variability was observed on boron removal values for P3274W® and DK4055® with 183 and 172 g ha^{-1} compared to Asgrow Hipopótamo® with 126 g ha^{-1}.

Overall, the average macronutrient removal among the evaluated hybrids in this research was comparable to those found in other studies, except for some that exceeded the accumulation range, such as K removal with 150 kg ha^{-1}, Mg with 76 kg ha^{-1} and Ca with 89.5 kg ha^{-1}.

According to Bender *et al.* (2012), the average nutrient removal values found in six transgenic hybrids grown in two locations were 166, 90, 66, and 17 kg ha^{-1} of N, P_2O_5, K_2O, and Mg for macronutrients and 248, 72, 41, 166 and 19 g ha^{-1} of Fe, Mn, Cu, Zn, and B for micronutrients, respectively. However, the same authors emphasize that environmental conditions of the sites where crops are grown strongly influence the total nutrient removal.

In other research, Heckman *et al.* (2003) found macronutrient removal range of 145-188, 73-108, and 57-78 kg ha^{-1} of N-P-K respectively. While, Duarte *et al.* (2019) reported removal values of 157-232, 50-80, 40-55, 12-16, 0.3, and 0.4 kg ha^{-1} for N-P-K-Mg-Ca for different hybrids. Finally, Sifuentes *et al.* (2015) evaluated Pioneer P3245W® hybrid under two low-pressure irrigation systems (PVC pipe - lay flat hose) and surface irrigation (furrows) at Valle del Fuerte reporting the following nutrient removal values: N (165, 173, and 138 kg ha^{-1}), P (4.4 and 6 kg ha^{-1}), K (11, 10 and 9 kg ha^{-1}), Ca (9, 11 and 7 kg ha^{-1}), Mg (19, 13 and 7 kg ha^{-1}) for each of the evaluated systems.

Nutrient removal based on performance (as a function of yield)

The analyzed nutrients were correlated with yield, finding significant differences. In all cases, the correlation coefficients were in ranges above $R^2=0.80$, except for Ca removal ($R^2=0.45$). Hence, nutrient removal strongly varies with respect to yield, even when the coefficient of determination (R^2) is low.

Nitrogen removal values were in the range of 126 to 240 kg ha^{-1} for yields of 14 and 16 t ha^{-1} (Figure 3a). These concentrations significantly impact the protein content in grains, which represents a good quality parameter. PO_4^- removal was in the range of 30 to 50 kg ha^{-1} with yields between 14 and 15 t ha^{-1} (Figure 3b). The same trend was observed in K removal (133 and 180 kg ha^{-1}) with an average yield of 14.5 t ha^{-1}, up to 190 kg ha^{-1} when the yield approached to 16 t ha^{-1} (Figure 3c).

Calcium extraction was in the range of 78 to 119 kg ha^{-1} (Figure 3d); while Mg ranged between 50 and 118 kg ha^{-1} for the same yields (Figure 3e). Different studies mention that

Table 2. Total nutrient removal of different maize hybrids.

Hybrid	Macronutrients						Micronutrients			
	N	P - PO_4^-	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cu^{2+}	Zn^{2+}	B
	kg ha^{-1}						g ha^{-1}			
DK 4055	130	36.0	120	67	47	602	689	29	216	173
P3230W	179	55.5	184	93	94	616	650	59	309	143
Hipopótamo	161	34.0	124	63 b	54	586	570	43.5	182	126
P3274W	219	82.5	172	135	109	691	699	69.4	331	183
Mean	172	52.0	150	89.5	76	623	652	50	259.5	156

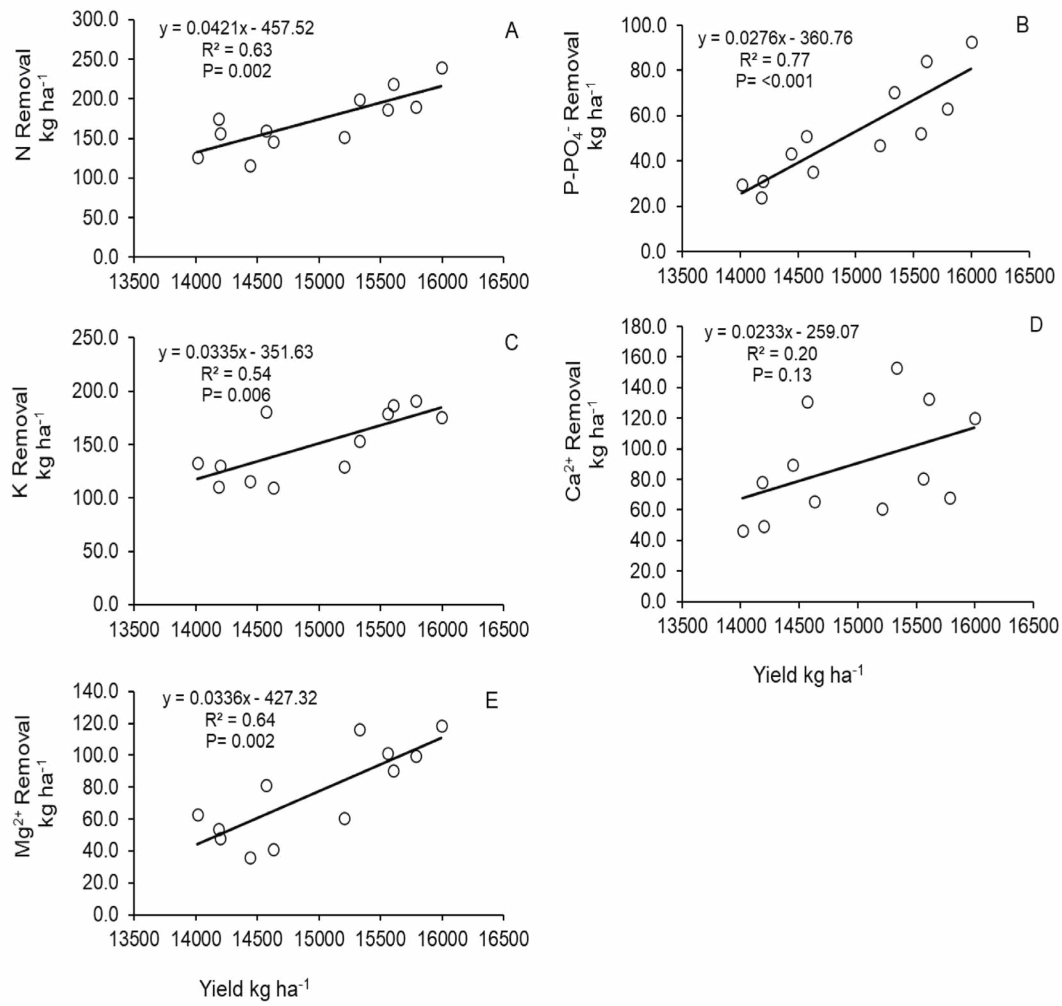

Figure 3. Total nutrient removal of N (a), P (b), K (c), Ca (d), and Mg (e) as a function of yield.

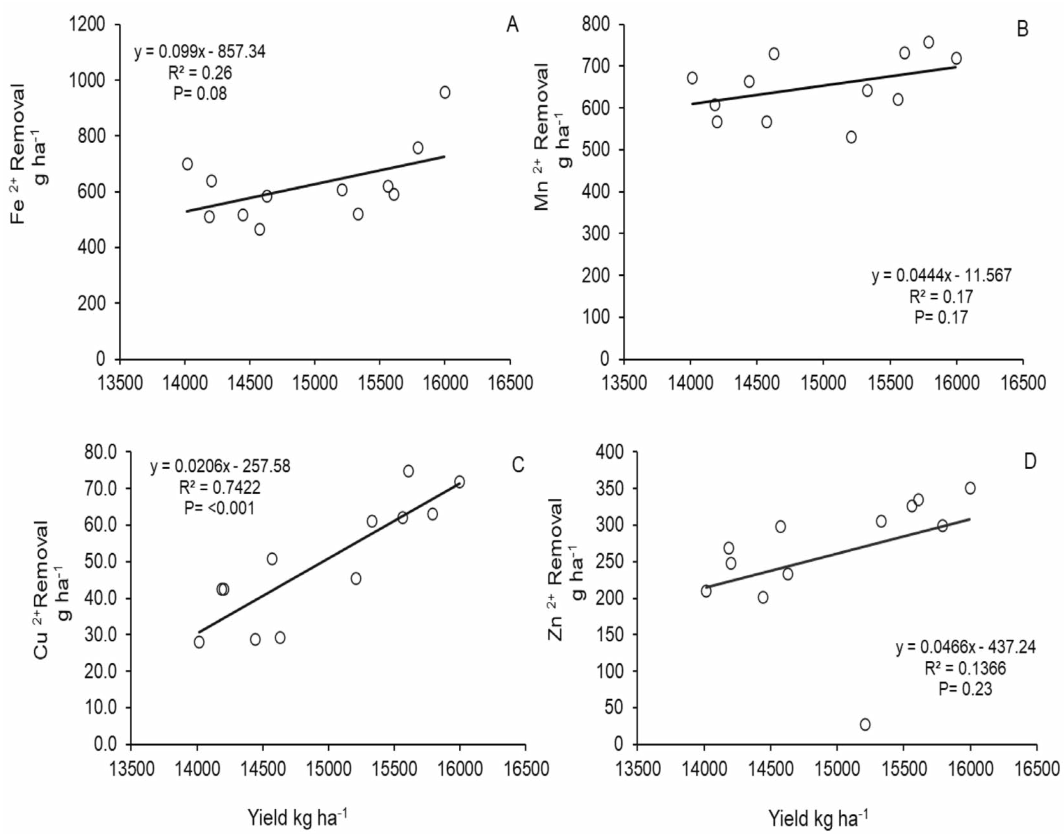

Figure 4. Total nutrient removal of micronutrients Fe (a), Mn (b), Cu (c), and Zn (d) as a function of yield.

nutrient removal in grain is the product of their concentration in that organ, as well as the yield, and agronomic practices (plant density, hybrid).

In that sense, findings reported by Below *et al.* (2010) mention that transgenic hybrids (with insect protection against cutworms and maize borers) increased the nutrient removal of N, P, K, S, and Zn, arguing that a greater influence was observed on the immobile nutrient uptake than on mobile ones. Similarly, Bender *et al.* (2012) found a removal range of N (145-188 kg ha^{-1}), P (73-108 kg ha^{-1}), K (57-78 kg ha^{-1}), Mg (15-20 kg ha^{-1}), Fe (218-285 g ha^{-1}), Mn (62-87 g ha^{-1}), Cu (30-49 g ha^{-1}), Zn (269-353 g ha^{-1}) and B (13 -32 g ha^{-1}) for an average yield of 12 t ha^{-1} in transgenic hybrids.

Finally, Raymond *et al.* (2009) mention that nutrient uptake and grain concentration decrease by increasing plant density, despite yield increase.

CONCLUSIONS

This research found that nutrient removal in grain varies as a function of hybrids, yield goal, and nutrient concentration in tissues. The removal values are higher as compared to other studies. Therefore, they are useful for making adjustments in fertilizer rates and application times. This research demonstrates that planting the same hybrids under different agronomic management conditions (fertilization rates) or soil types can substantially influence the nutrient concentration in grain and, consequently the total nutrient removal values.

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