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Impact of nutrient omission technique on the formation of a simple hybrid of corn (*Zea mays* L.)

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Impacto de la técnica de omisión de nutrientes en la formación de un híbrido simple de maíz (*Zea mays* L.)

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ABSTRACT

Due to the scarcity of information in Ecuador on the effect of nutrient omission in the fertilization of parents for the formation of a new maize hybrid, this research aimed to evaluate the impact of nutrient omission on the formation of a maize hybrid and its seed yield. The study was carried out at the Estación Experimental Tropical Pichilingue (EETP) del Instituto Nacional de Investigaciones Agropecuarias (INIAP), Los Ríos province, Ecuador. Six omission treatments were established -N, -P, -K, -Mg, -S, -B, complete fertilization (N, P, K, Mg, S, B), a treatment based on the application of a farmer and control. A randomized complete block design was used and the averages were differentiated using Tukey's test. The variables evaluated were: plant height (m), ear height (m), days to flowering, cob length (cm), cob diameter (mm), 100-seed weight (g), percentage of rotten ears, stem diameter (mm), stem and root lodging, chlorophyll levels, yield, partial productivity factor, agronomic efficiency and nutrient harvest index. The results obtained showed that the highest yield was obtained with the omission of the B (2,093 kg ha^{-1}) fertilization plan causing a decrease of up to 42.02% in the partial productivity factor (PPF) and 425.14% of agronomic efficiency (AE) of the studied elements. Since the nutritional priorities of the parents of the corn hybrid had the sequence Mg>N>K=P>S>>B.

Keywords:
Crop management
Fertilizers
Plant nutrition
Production
Soil

RESUMEN

Debido a la escasa información en el Ecuador sobre el efecto de la omisión de nutrientes en la fertilización de los progenitores para la formación de un nuevo híbrido de maíz, el objetivo de esta investigación fue evaluar el impacto de la omisión de nutrientes en la formación de un híbrido de maíz y su rendimiento de semilla. El estudio se realizó en la Estación Experimental Tropical Pichilingue (EETP) del Instituto Nacional de Investigaciones Agropecuarias (INIAP), provincia de Los Ríos, Ecuador. Se establecieron seis tratamientos de omisión de -N, -P, -K, -Mg, -S, -B, fertilización completa (N, P, K, Mg, S, B), un tratamiento basado en la aplicación de un agricultor (N, P, K) y un testigo. Se utilizó un diseño de bloques completos al azar y los promedios diferenciados mediante la prueba de Tukey. Las variables evaluadas fueron: altura de planta (m), altura de mazorca (m), días de floración, longitud de mazorca (cm), diámetro de mazorca (mm), peso de 100 semillas (g), porcentaje de mazorcas podridas, diámetro de tallo (mm), acame de tallo y de raíz; niveles de clorofila, rendimiento, factor parcial de productividad, eficiencia agronómica e índice de cosecha de nutrientes. Los resultados obtenidos mostraron que el mayor rendimiento se consiguió con la omisión de B (2.093 kg ha^{-1}), esto debido a que su presencia en el plan de fertilización provoca disminución de hasta el 42,02% en el factor parcial de productividad (FPP) y 425,14% de eficiencia agronómica (EA) de los elementos estudiados. Siendo que las prioridades de nutrición de los parentales del híbrido de maíz, tuvieron la secuencia Mg>N>K=P>S>>B.

Palabras clave:
Manejo de cultivos
Fertilizantes
Nutrición vegetal
Producción
Suelo

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Worldwide, corn (*Zea mays* L.) is one of the most versatile crops and adapts to different environmental conditions. Its uses range from human food, to animal feed and as raw material for a large number of industrial products (Ayyar et al. 2019). In Ecuador, corn production and productivity in the Coast and Amazon regions have increased in recent years due to greater technification, which has made it possible to reduce corn imports. These increases were made possible by innovations in genetic improvement, with the development of varieties and hybrids with high yield potential (Caviedes-Cepeda et al. 2022).

Hybrid corn is a unique and highly specialized crop, its production requires time, money and experience. Obtaining hybrid corn seeds involves crossing two inbred lines, one of which is called "male", which is responsible for the production of pollen and 'female' the plant that creates the hybrid seed, the purpose is to create a variety that shows some important characteristic, for example, resistance to pathogen (Mirsam et al. 2021).

The corn program of the Estación Experimental Tropical Pichilingue (EETP) del Instituto Nacional de Investigaciones Agropecuarias (INIAP), is constantly seeking to generate new promising genetic materials to improve the economic income of producers, mainly small and medium-sized ones (Zambrano et al. 2018). However, the optimal yield of genetic materials in corn can be compromised by inadequate fertilization, as sometimes the nutrient reserves in the soil are not sufficient to meet the crop's demands. Therefore, balanced fertilization is necessary to achieve quality corn production. The incorporation of nutrients such as magnesium, phosphorus, nitrogen and potassium in adequate form is necessary for the growth, development and yield of the crop, considering that potassium improves the productivity of irrigation water (Ul-Allah et al. 2020).

The nutrient omission or missing element technique allows for determining the impact of not applying a specific nutrient on crop yields. This method involves supplementing the soil with nutrients while excluding one specific nutrient, while maintaining adequate levels of the others. This helps identify which nutrient has the greatest effect on both crop yield and the absorption of other nutrients (Shankar et al. 2021). Additionally, this technique can be used to evaluate the synergism or antagonism in the absorption of heavy metals, which may affect the safety of the resulting products(Valarezo et al. 2022).

To achieve high conversion efficiency of intercepted radiation into biomass and achieve high yields in corn it is necessary to know the nutritional requirements of the crop and the contribution of the soil to estimate its fertilization needs, research conducted by Hasang et al. (2018) in evaluating maize hybrid seed production with two homozygous lines in response to the missing element technique in maize, determined that the best yield potential, 2,134 kg ha^{-1}, was obtained with the sulfur omission treatment; furthermore, it was estimated that the fertilization priorities were P>N=Mg=K>>Zn>B>>S. It was also found that ear length and diameter were reduced when the K application was omitted. Due to the little information in the country on the effect of nutrient omission in the fertilization of parents for the formation of a new maize hybrid, this research aimed to evaluate the impact of nutrient omission on the formation of a maize hybrid and its seed yield.

MATERIALS AND METHODS

Location of the trial

The study was carried out at the Estación Experimental Tropical Pichilingue (EETP) del Instituto Nacional de Investigaciones Agropecuarias (INIAP), located in the province of Los Ríos, canton Mocache, 5 km from the Quevedo - El Empalme road. It is located at 79°280' W longitude and 01°060' S latitude, at 75 meters above sea level (masl), with an average temperature of 24.5 °C, average annual rainfall of 1,723 mm and relative humidity of 84.33%.

Edaphic characteristics and genetic material.

The edaphic characteristics of the experimental area were determined using the methodologies described by Quezada et al. (2017), which resulted in a pH=5.9, nutrient content of NH_4+ (8 mg kg^{-1}), 34 mg kg^{-1} (P), 0.97 meq 100 mL^{-1} (K), 11 meq 100 mL^{-1} (Ca), 2 meq 100 mL^{-1} (Mg), 7 mg kg^{-1} (S), 6.3 mg kg^{-1} (Zn) and 0.97 mg kg^{-1} (B), 5.4% organic carbon and silt loam texture**.** The trial was conducted during the rainy season of 2019; 36 experimental units were established with a planting density of 62,500 plants per hectare, the seeds of homozygous parents; male (CML-172) and female (L-21-3-1-1-1-1-1-1-1 COM 2), provided by the Program de maize of the EETP of INIAP.

Treatments

The study factor was the omission of nutrients to the progenitors, for this purpose six omission treatments (N, P, K, Mg, S and B), a complete fertilization treatment one based on fertilization by a farmer and an absolute control were evaluated (Table 1), the area of each experimental unit was 24 m^2, with a useful area of 9.6 m^2.

Table 1. Treatments evaluated in the nutrient omission experiment in breeding a new simple hybrid of durum corn (*Zea mays* L.). rainy season.

Treatments	N	P_2O_5	K_2O	S	Mg	B
	Kg ha^{-1}					
-N	-	46	60	44	55	1.5
-P_2O_5	140	-	60	44	55	1.5
-K_2O	140	46	-	44	55	1.5
-S	140	46	60	-	55	1.5
-Mg	140	46	60	44	-	1.5
-B	140	46	60	44	55	-
Complete	140	46	60	44	55	1.5
PFP*	140	46	60	-	-	-
Witness	-		-	-	-	-

***PFP:** Producer's fertilizer plot.

Variables evaluated

The chlorophyll levels were recorded with a portable chlorophyll meter atLEAF chlorophyll meter, USA (atLEAF units) at 25, 30 and 35 days after sowing (DAS). The days to flowering were estimated from the day of sowing until 50% of the panicles and cobs emerged. The morphological variables were plant and ear height (cm), stem diameter (mm) at the first inter-node, percentage of stem lodging in plants with more than 45% inclination at the first inter-node and root in plants with more than 30% inclination from the soil surface, were recorded at 107 DAS. At 116 DAS, ear rot (%), ear diameter and length (mm), and hundred-seed weight (g) were evaluated.

The yield (kg ha^{-1}) was determined using Equation 1, with data on fresh harvested grain weight (FGW), and the percentage of grain moisture (GW) in the fertilized female plants of each treatment and the result was adjusted to 14% desired moisture (DM).

$$\text{Yield (kg ha}^{-1}) = \frac{\text{FGW} \times (100 - \text{GW})}{(100 - \text{DM})} \times \frac{\text{Density (Plants ha}^{-1})}{\text{\# Harvested plants}} \quad (1)$$

The fertilization efficiency was determined using the equations described by Dobermann (2007): partial productivity factor (PPF) is calculated as the ratio between the kilograms of seed produced and the kilograms of the applied element, allowing for the evaluation of a specific nutrient's efficiency in production, agronomic efficiency (AE) is defined as the ratio of the increase in production (kg) to the kg of the applied element, helping to understand how much additional yield is obtained per unit of nutrient and nutrient harvest index (NHI) indicates the proportion of absorbed nutrients that will be allocated to the grain, reflecting the crop's ability to transfer nutrients from the soil to the edible part of the plant.

Crop management

The seeds of the parents were treated with insecticide and fungicide before sowing. The soil was prepared by harrowing. For each experimental unit, two rows of the male parent and four rows of the female parent were planted (4:2). Insect pest control was carried out at 5, 15 and 34 DAS, and at 46 DAS a manual application of insecticide bait was made. Disease control was carried out at 35 DAS, and chemical weed control was applied at planting and post-emergence (manually at 47, 82 and 96 DAS). Fertilization was carried out according to the omission treatments, by continuous jet, in four applications: dividing

N into three applications at 15, 30 and 45 DAS, P at sowing, K at 15 DAS, S and Mg two applications at 15 and 30 DAS and B at 30 DAS, using commercial fertilizers: Urea, Triple Super Phosphate, Potassium Muriate, Ammonium Sulfate, Magnesium Sulfate, Magnesium Nitrate, Borax.

Pollination was assisted at the time of panicle emission. At the emission of the female flower from the female parent, a sheath was placed to avoid fertilization with pollen from other treatments, and each ear was pollinated with pollen from the male parent subjected to the same treatment.

To determine the nutrient content in the tissues, the methodologies used by Carrillo et al. (2019) were employed. At the end of the experiment, two plants (aerial part) were taken from each experimental unit, washed with distilled water, and dried in ovens at 70 °C until a constant weight was achieved. Nitrogen analysis was carried out by the Kjeldahl method (KjeltecTM 8400 TecatorTM Line Fost, China). The other elements were determined by wet digestion (nitric-perchloric acid) and the analyses for K, Ca and Mg were measured by an atomic absorption spectrophotometer (AA 6800) Japan, as well as S, P and B by colorimetry (Spercord 210 Plus, Germany).

Data analysis

Data were analyzed using the Randomized Complete Block Design (RCBD) with four replications and comparisons between means with Tukey's 5% test, using the statistical program InfoStat v2018 (Di Rienzo et al. 2018).

RESULTS AND DISCUSSION

Morphological characteristics of the corn plant due to the effect of treatments of nutrient omission

These results show that, although under the conditions of the experiment it was not possible to find differences in some variables, the skipping treatments significantly influenced the morphology of the maize plants. Complete fertilization favored better growth and greater grain weight, while the omission of nitrogen weakened the stems and roots. This underscores the importance of balanced nutrition to avoid structural problems in the crop.

Table 2 shows the plant height of the different treatments applied, the highest height is presented by the fertilized treatment according to the producer (194 cm), followed by the Mg omission treatment (193 cm), probably because this element is not essential for the development of the plant at height, as it is for photosynthesis, where it is an essential component of the chlorophyll molecule. The lowest height was found in the control treatment at 170 cm, these results coincide with those found by Lucero et al. (2023), who found no significant differences for the plant height variable in a trial with hard yellow corn testing different sources of magnesium and silicon.

In the variable days to male and female flowering, ranging between 62-64 and 60-61 days respectively, this two-day variation indicates that this characteristic of the plant is more influenced by its genetics than by nutrition, at least in the soil evaluated, these results differ from those found by Romero-Cortes et al. (2022), because it was made with other genetic material and 2,426 masl, who report significant differences between the different fertilization schemes evaluated ($P \leq 0.05$) 98.67 and 100.67 days for male flowering; 103.33 and 106.33 days for female flowering, in Kculli Purple maize under different fertilization schemes.

Regarding the variable weight of 100 grains, the treatment that obtained the highest weight per 100 grains was the complete fertilization (27 g), while the lowest value was the treatment where the element obtained the omission of P (21 g), these results coincide with what was stated by Marchiori et al. (2020), who affirms that the application of P_2O_5 increases the weight of corn grains.

The variables insertion height, length and cob diameter, the highest cob height was presented in the treatment with the omission of phosphorus (112 cm) and the lowest height was presented by the treatment with the omission of nitrogen and the control (85 cm), these differ from those obtained by Vera et al. (2020) where the effect of three forms of fertilization via edaphic fertilization was evaluated in corn variety DAS 3383, where the ear at 70 days showed significant differences ($P<0.05$), being the treatment where the conventional fertilization plan was applied the one that showed the highest average with 89.05 cm.

With respect to cob length, there are no differences, probably due to lines with a high degree of homozygosity, used for seed multiplication (Gutiérrez et al. 2016), the values among treatments are very similar, with the lowest values (14 cm) observed in the control treatment and in the omission of B, the highest values are observed in the omission of K and Mg, with 16 cm, these values differ from those obtained by Romero-Cortes et al. (2022), who report significant differences between the different fertilization schemes evaluated for ear length ($P \leq 0.05$), with the best results observed in the treatments where Chemical fertilizer + Bioinoculants + Organic fertilizer were applied, with cob lengths of 18.95 cm.

The cobs diameter did not show differences in the treatments applied, obtaining the highest values in the complete fertilization treatment (39 mm) and the lowest value was reported by the omission of N (34 mm), these are below the data reported by Guamán et al. (2020), where they report a cob diameter of 45 mm for the hybrid INIAP H-551.

The percentage of rotten cobs did not show differences; however, the highest values were observed with the S omission treatment (56%) and the lowest value with the Mg omission treatment (49%).

Table 2. Average plant height, ear height, days to flowering, cob length, cob diameter, 100-seed weight, and percentage of rotten ears, affected by nutrient omission in breeding a new simple hybrid of durum corn (*Zea mays* L.). Rainy season.

Treatment	Plant height (cm)	Ear height (cm)	Flowering ♂	Flowering ♀	Cob length (cm)	Cob diameter (mm)	Weight 100 seeds (g)	Rotten cob (%)
PKSMgB (-N)	173	85	64	61	15	34	23	38
NKSMgB (-P)	182	112	64	60	15	35	21	38
NPSMgB (-K)	183	101	63	60	16	36	22	37
NPKMgB (-S)	190	96	64	60	15	36	23	56
NPKSB (-Mg)	193	102	63	60	16	35	24	34
NPKSMg (-B)	185	102	63	61	14	36	26	49
NPKSMgB	183	92	62	60	15	39	27	42
PFP*	194	97	63	60	15	36	23	44
Witness	170	85	62	60	14	37	23	40
Average	184	97	63	60	15	36	23	42
Significance	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	5.86	13.31	1.76	2.43	8.53	7.04	11.5	25.94

* PFP= Producer's fertilization plot; NS: Not significant; CV= Coefficient of variation.

The variables stem diameter, stem lodging and root, presented highly significant statistical differences ($P<0.05$) (Table 3). The greatest stem diameter reduction was found with the N omission treatment (19 mm); however, the omission of Mg obtained the greatest diameter (22 mm), these values are similar to those reported by Remache et al. (2017), indicating that with N omission a stem diameter of 17 mm was obtained.

Regarding the stem and root lodging variables, the highest percentages were observed with the N omission treatment at 28.71 and 5.86%, respectively, with the lowest percentages of root lodging observed with the omission of 13.55% (K) and with the absence of 1.68% (B). These results were corroborated by Mateus et al. (2020), who state that high N application rates in no-tillage promote higher nutrient concentrations in leaves (mainly N and P), corn yield and production because it favors stalk development; whereas, with a limitation in this nutrient, it can result in weak stalks and roots.

Effect of Nutrient Omission on Chlorophyll Levels

Table 4 shows the chlorophyll levels at 25, 30 and 35 DAS, highly significant differences were found, registering the lowest values in the omission of N (36.68, 39.55 and 39 atLEAF units), respectively. These findings align with Ontiveros-Capurata et al. (2022), stated, that atLEAF meters can be used to

Table 3. Average stalk diameter, stalk and root lodging affected by nutrient omission in breeding a new simple hybrid of durum maize (*Zea mays* L.). Rainy season.

Treatment	Stem diameter (mm)	Stem stalks (%)	Root lodging (%)
PKSMgB (-N)	19.00 C	28.71 A	5.86 A
NKSMgB (-P)	21.00 AB	18.54 AB	1.95 C
NPSMgB (-K)	22.00 A	13.55 B	2.51 BC
NPKMgB (-S)	22.00 A	14.91 B	1.72 C
NPKSB (-Mg)	22.00 A	20.00 AB	2.20 C
NPKSMg (-B)	20.00 ABC	20.62 AB	1.68 C
NPKSMgB	21.00 BC	17.27 B	3.66 BC
PFP*	21.00 ABC	22.92 AB	2.17 C
Witness	19.00 BC	21.69 AB	4.49 AB
Average	21.00	19.80	2.92
Significance	**	**	**
CV (%)	5.34	22.12	30.52

*PFP= Producer's fertilization plot; CV= Coefficient of variation; Means with the same letter do not differ statistically according to Tukey's test at 1%.

estimate N levels in plants in a non-destructive, fast and reliable way. The observed reduction in chlorophyll content due to N omission is consistent with Toor et al. (2021), who state that N is an important component of chlorophyll, proteins, nucleic acids and other plant components. These findings underscore this importance and highlight the need to consider nitrogen as a key element in plant nutrition.

Table 4. Chlorophyll levels in atLEAF units as affected by nutrient omission in breeding a new simple hybrid of durum maize (*Zea mays* L.). Rainy season.

Treatments	atLEAF units		
	25 DAS	30 DAS	35 DAS
PKSMgB (-N)	36.68 B	39.55 B	39.00 B
NKSMgB (-P)	47.68 A	44.54 AB	46.81 A
NPSMgB (-K)	47.09 A	47.06 A	46.86 A
NPKMgB (-S)	44.85 A	47.29 A	45.55 A
NPKSB (-Mg)	44.04 A	47.06 A	45.29 A
NPKSMg (-B)	46.07 A	47.44 A	44.70 A
NPKSMgB	46.56 A	46.59 A	46.72 A
PFP*: NPK	48.05 A	46.39 A	45.86 A
Witness	45.25 A	43.69 AB	45.48 A
Average	45.14	45.51	45.14
Significance	**	**	**
CV (%)	6.06	5.05	4.97

* PFP= Producer's fertilization plot; CV= Coefficient of variation; Means with the same letter do not differ statistically according to Tukey's test at 1%.

Seed yield due to nutrient omission plot

The yield obtained in this research showed significant statistical differences, due to the effect of nutrient omissions (Figure 1). The treatment with the omission of B (2,093 kg ha^{-1}) was the highest, and the lowest due to the effect of omissions with Mg with 1,126 kg ha^{-1}; these values are lower than those reported by Barrios-Sánchez et al. (2019), since they worked with the commercial hybrid DK-5277, yields of 10,274 kg ha^{-1} were obtained by applying nitrogen fertilization, which is typical for commercial materials. However, this is not the case for genetic materials with a high degree of homozygosity, which tends to produce very little dry matter (Gutiérrez et al 2016). Therefore, these results align with those found by Hernández et al. (2010), who, when evaluating 17 homozygous lines of maize parent lines in Venezuela, obtained yields ranging from 1,707 to 3,199 kg ha^{-1}.

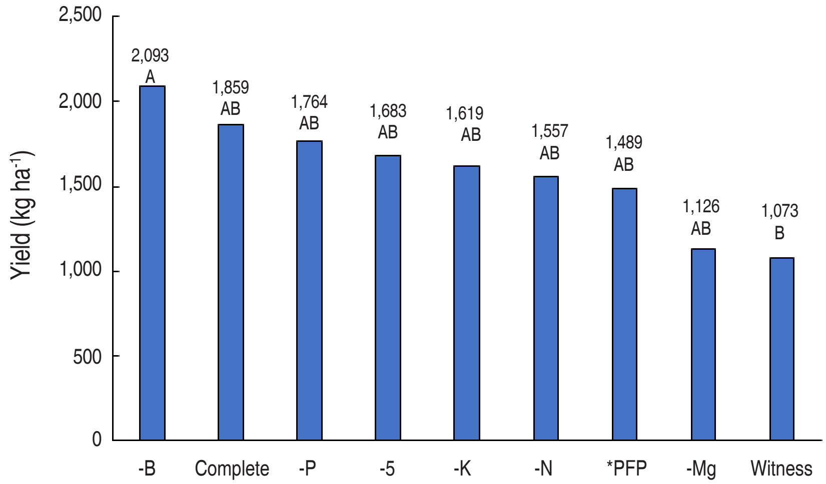

Figure 1. Yield of durum corn (*Zea mays* L.) affected by nutrient omission for breeding a new single hybrid. rainy season; * PFP= Producer's fertilization plot.

Effect of nutrient omission on fertilization efficiencies

The partial productivity factor (PPF) is given by the relationship between the kg of seed produced and the kg of element applied, as described in Table 5. The results indicate that the omission of key nutrients such as N, B and Mg affects the partial productivity factor (PPF). The omission of B generally increased the PPF, while the omission of Mg had the greatest negative impact, especially on the productivity of N and K, this is discussed below.

In the partial factor of N productivity, the highest effect was found with the omission of B (14.95 kg kg^{-1}) and the lowest with the omission of Mg (7.95 kg kg^{-1}), which means that for each kg of B, the yield decreases by 11.17% the PPF of N in relation to the FC treatment. For P, the PPF, with the omission of B was achieved 45.50 kg kg^{-1} P, indicating that the effect of the application of the element, reduces by 11.02% the PPF of P, in relation to the FC treatment. The application of Mg caused an increase in P PPF of 41.03%. The PPF of K was found that, with the omission of B, the highest PPF was achieved (34.89 kg kg^{-1} of K), indicating a reduction of 12.62% of harvested grain per kg of K applied with the addition of B, in relation to the FC. The lowest FPP of K resulted from the omission of Mg (18.27 kg kg^{-1}), being that with its application there is an increase in FPP of K of 41.02%, these results coincide with the reported by Hasang et al. (2018). For S, the PPF, the omission of B with 47.57 kg kg^{-1} of S applied, resulted in the highest PPF value; this implies that with the application of B the PPF of S will be reduced by 42.02%, as a function of FC.

For Mg, it was found that the treatment with omission of B (38.06 kg kg^{-1}), had the highest Mg PPF, showing a 12.63% decrease in Mg PPF due to the application of B, when compared to the complete fertilization treatment. Also, it can be seen that the omission of N affected the Mg PPF, presenting the lowest value (24.75 kg kg^{-1} of Mg).

Therefore, the application of N increased the PPF of Mg by 26.75% in relation to the CF treatment.

It is observed that the PPF of B, which with complete fertilization 1,239 kg kg^{-1} of B was achieved and proved to be the highest; on the other hand, the omission of Mg presented the lowest value of PPF of B with 730 kg kg^{-1}, this indicates that if Mg is applied the PPF of B is increased by 41.08%. These results do not agree with that found by Kumar et al. (2020) who found that the omission of N, P and B nutrients in wheat crops significantly reduced yield, achieving an increase in the dose of nutrients applied based on soil sampling resulted in an increase of about 14-17% in wheat grain yield as compared to farmers.

Table 5. Partial productivity factor (kg kg^{-1}) as affected by nutrient omission in the breeding of a new simple hybrid of durum corn (*Zea mays* L.). Rainy season.

Treatment	N	P	K	S	Mg	B
	(kg of grain harvested / kg of element applied)					
PKSMgZnB (-N)	0.00	29.59	22.69	30.94	24.75	907.00
NKSMgZnB (-P)	10.49	0.00	24.49	33.39	26.71	979.00
NPSMgZnB (-K)	10.40	31.64	0.00	33.08	26.46	970,00
NPKMgZnB (-S)	12.02	36.58	28.05	0.00	30.60	1,121.00
NPKSZnB (-Mg)	7.83	23.83	18.27	24.91	0.00	730.00
NPKSMgZn (-B)	14.95	45.50	34.89	47.57	38.06	0.00
NPKSMgZnB (FC)	13.28	40.40	30.98	42.24	33.79	1,239.00
PFP*	8.04	24.48	18.77	0.00	0.00	0.00
Witness	0.00	0.00	0.00	0.00	0.00	0.00
Average	8.56	25.78	19.79	23.57	20.04	661.01
Maximum	14.95	45.50	34.89	47.57	38,06	1,239.00
Minimum	7.83	23.83	18.27	24.91	24.75	730.00

* PFP= Producer's fertilization plot.

The agronomic efficiency (AE) is given by the ratio between the kg increase in production and the kg of element applied, as described in Table 6. The agronomic efficiency of all the elements analyzed was negatively affected by nutrient omissions, with Mg having the most significant adverse impact, particularly on AE S and AE P. These findings are detailed below.

The highest N AE (3.55 kg grain increases kg^{-1} of N applied) was achieved with the FC treatment, followed by the omission of B with (1.68 kg kg^{-1} of N), being negatively affected to a greater degree with the omission of Mg which presented an N AE of -5.45 kg kg^{-1}, which means a loss of 9 kg kg^{-1} of N AE, corresponding to 253.52%. The results are lower than those reported by Snyder and Bruulsema (2007), who report averages between 10 and 30 units of corn grain per unit of applied N, on the other hand, Zamudio et al. (2015), obtained EA of 20.9 kg of corn grain kg^{-1} of N applied to the soil; considering that homozygous lines were used in this research.

The P as well as N resulting in the FC treatment showed the highest AE value (8.46 kg kg^{-1} of P), followed by the omission of B with 5.10 kg kg^{-1} of P, which is mostly reduced by 25.03 kg kg^{-1} (295.86%) with the omission of Mg which presented AE of P of -16.57 kg kg^{-1}.

The maximum K AE was found in the complete fertilization treatment with a 6.72 kg yield increase per kg K applied, while with the omission of Mg was the lowest with -12.71 kg kg^{-1} of K; reducing by 19.43 kg kg^{-1} of K (289.13%). These results coincide with the values reported by Hasang et al. (2018) with a decrease in EA of 10.39 kg kg^{-1} of K in the Mg omission treatment.

The B omission treatment showed an S AE of 5.33 kg kg^{-1} of S, which was the highest; on the other hand, the lowest AE was obtained with the omission of Mg (-17.33 kg kg^{-1} of S), which indicates that it tends to decrease by 22.66 kg kg^{-1} of S (425.14%), followed by the (-N) treatment with a decrease of 16.66 kg kg^{-1} of S (312.57%).

The highest agronomic efficiency of Mg was found with the FC treatment with 13.86 kg kg^{-1} of Mg; on the other hand, the treatment with the omission of N reduced the EA of S the most, presenting -9.04 kg kg^{-1} of Mg; therefore, it showed a reduction of 22.9 kg for every kilo of S applied, equivalent to 165.22, these results are similar to those found by Hasang et al. (2018) who report that with the omission of N there was a decrease in the EA of Mg of 10.6 kg kg^{-1}.

For B, the efficiencies were negative for all the omitted elements. The lowest decrease was observed with the S omission treatment with values of -117.14 kg kg^{-1} and a reduction in efficiency was observed with the omission of Mg with -508.24 kg kg^{-1}. These values do not coincide with those obtained by Hasang et al. (2018) who reported that with the omission of N there was a reduction of 300 kg kg^{-1} of B.

Table 6. Agronomic efficiency (kg kg^{-1}). affected by nutrient omission in the breeding of a new simple hybrid of durum corn (*Zea mays* L.). Rainy season.

Treatment	N	P	K	S	Mg	B
	(kg increase in production/kg element applied)					
PKSMgZnB (-N)	0.00	-10.81	-8.29	-11.30	-9.04	-331.55
NKSMgZnB (-P)	-2.78	0.00	-6.49	-8.85	-7.08	-259.55
NPSMgZnB (-K)	-2.88	-8.77	0.00	-9.16	-7.33	-268.84
NPKMgZnB (-S)	-1.26	-3.82	-2.93	0.00	-3.19	-117.14
NPKSZnB (-Mg)	-5.45	-16.57	-12.71	-17.33	0.00	-508.24
NPKSMgZn (-B)	1.68	5.10	3.91	5.33	4.27	0.00
NPKSMgZnB (FC)	3.55	8.46	6.72	3.99	13.86	-156.39
PFP*	-5.23	-15.92	-12.21	0.00	0.00	0.00
Witness	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.49	5.64	0.77	4.59	2.49	192.40
Maximum	3.55	8.46	6.72	5.33	13.86	-508.24
Minimum	-5.23	-16.57	-12.71	-17.33	-9.04	-117.14

* PFP= Producer's fertilizer plot.

The nutrient harvest index (NHI) indicates the proportion of nutrients that are absorbed that will be exported to the grain (Table 7). The HI of N in the omission of nitrogen registered the highest HI with 0.36, followed by the omission of B (0.29). For P, the highest HI was observed with the treatment with omission of B with values of 0.44, with the lowest HI being seen with the -S treatment with 0.17. Conversely, the HI of K showed that the treatment with omission of B had the most significant impact on its HI, presenting a value of 0.14. The omission of sulfur negatively affected the HI of Mg (0.10); however, the omission of N, P and B obtained the highest HI of sulfur.

The HI of B obtained the lowest value with the omission of S (0.5); in contrast, the omission of nitrogen obtained the highest average of 0.20. These harvest indices are lower than those found by Zamudio et al. (2016), who, when evaluating the hybrid H-51 under different densities and doses of nitrogen fertilization, reported IHN=0.45, IHP=0.75, IHK=0.21, IHMg=0.45, and IHS=0.43. The omission of nutrients, especially nitrogen and boron, impacts the translocation of essential elements to the grain. The greater capacity of nitrogen to be transported under deficiency conditions suggests a prioritization of this nutrient to optimize grain production, while the negative influence of sulfur omission on the magnesium

Table 7. Nutrient harvest index affected by the omission of nutrients in the breeding of a new simple hybrid of durum corn (*Zea mays* L.). Rainy season.

Treatment	N	P	K	Mg	S	B
	Harvest index					
PKSMgZnB (-N)	0.36	0.37	0.09	0.24	0.14	0.20
NKSMgZnB (-P)	0.22	0.32	0.06	0.18	0.14	0.10
NPSMgZnB (-K)	0.21	0.34	0.09	0.17	0.10	0.08
NPKMgZnB (-S)	0.10	0.17	0.05	0.10	0.05	0.05
NPKSZnB (-Mg)	0.16	0.27	0.06	0.12	0.07	0.11
NPKSMgZn (-B)	0.29	0.44	0.14	0.26	0.14	0.11
NPKSMgZnB (FC)	0.14	0.33	0.06	0.15	0.07	0.13
PFP*	0.22	0.30	0.06	0.17	0.08	0.13
Witness	0.23	0.33	0.13	0.22	0.13	0.09
Average	0.21	0.32	0.08	0.18	0.10	0.11
Maximum	0.36	0.44	0.14	0.26	0.14	0.20
Minimum	0.10	0.17	0.05	0.10	0.05	0.05

* PFP= Producer's fertilization plot.

harvest index highlights the interdependence of these nutrients.

CONCLUSION

The potential seed yield of the newly developed simple corn hybrid was 2,093 kg ha^{-1}, which is understandable given the high homozygosity of the genetic materials. However, this yield was affected by the omission of Mg, resulting in a 46.20% reduction, making it the most limiting nutrient for seed production in the Mocache area. Additionally, nitrogen (N) was the element that most impacted the agronomic traits of corn. On the other hand, the omission of boron (B) resulted in the highest seed yield, as its inclusion in the fertilization plan led to a reduction in the PPF and AE of the studied elements. In these soils, the natural levels of boron are sufficient, and its excess negatively affects the efficiencies. The fertilization priorities for the soils in Mocache follow the sequence Mg>N>K=P>S>>B. These results highlight the importance of proper Mg and N management in fertilization programs to maximize corn seed yield, suggesting that future research should focus on the interaction of these nutrients under different agroecological conditions and their impact on agronomic efficiency. Thus, optimizing corn fertilization is crucial, not only to enhance production but also to reduce costs and mitigate contamination risks. Given that corn is a strategic crop for food security, efficient nutrient management will play a vital role in ensuring sustainable agricultural practices and maximizing yields while protecting the environment.

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