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Article

# N, P and K demand in corn lines in the High Valleys of Mexico

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## Abstract

The commercial production of improved corn seed has different limitations, among which the few studies of mineral nutrition of parent lines that form commercial hybrids stand out. This work aimed to determine the demand for N, P and K of corn lines that are parents of hybrids adapted to the conditions of the High Valleys of Mexico and to estimate their fertilization doses with N-P-K. The study was carried out at INIFAP’s Valle de México Experimental Field. The experimental design used was randomized complete blocks in a factorial arrangement with two factors: 1) year of evaluation (2014, 2015 and 2016) and (2) corn lines M-18 (♂-S2), M-55 (♀-S4), M-45 (♂-S3), M-48 (♂-S3) and CML-456 (♂-S4). In physiological maturity, the variables measured were dry matter, grain yield, harvest index and the extraction of N, P and K. The demand and fertilization dose of N, P ($P_2O_5$) and K ($K_2O$) (kg $ha^{-1}$) in the lines were 70 to 115, 0 to 44, 42 to 80; 0, 120 to 249, 0; respectively. The corn lines differed in extractions and the demand for N, P, and K according to the level of inbreeding, plant dry matter production, and grain yield, and consequently in fertilization doses, an aspect that should be considered in a fertilization program for seed production.

## Keywords:

dry matter, fertilization doses, grain yield, phenological stages.

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# Introduction

Corn is the most important agricultural crop in Mexico, with a grown area of 7 472 356.82 ha and an annual production of 27 424 527.55 Mg (SIAP, 2020). Of this area, 55.3% of the production comes from improved corn seed (CEDRSSA, 2018); however, the commercial production of improved corn seeds presents limitations such as the development of inappropriate production technology; climatic factors that determine seed productivity and quality (Vallejo *et al*., 2008; Virgen-Vargas *et al*., 2016; Chassaigne-Ricciulli *et al*., 2021); high production costs (Ruiz and Hernández, 2017) and lack of national companies that have the technical and physical infrastructure to conduct research and implement seed production technology for the country (Chassaigne-Ricciulli *et al*., 2021).

The agronomic practices that are carried out in the lines in a corn seed production lot, which include the fertilization dose, are generally the same as those practiced for the production of commercial hybrid corn (Ruiz and Hernández, 2017; Vallejo *et al*., 2008; Chassaigne-Ricciulli *et al*., 2021), even though it is known that in a seed production lot, the inbred lines that are used, unlike hybrids, lose vigor and productivity more quickly throughout their development (Virgen-Vargas *et al*., 2014), they are more vulnerable to deficiencies and imbalances of mineral nutrients due to their lower rooting capacity (Wych, 1988) and in general, they tend to be weak and more susceptible to environmental stress, diseases, herbicides and insecticides (Ruiz and Hernández, 2017).

The seed technology programs of the Valle de México (CEVAMEX), for its acronym in Spanish and Bajío (CEBAJ), for its acronym in Spanish experimental fields of INIFAP has carried out different works to strengthen seed production technology (Virgen-Vargas *et al*., 2016). However, studies on mineral nutrition in corn parent lines are still scarce. Currently, nutrient management is developed and promoted through four requirements: a) applying the right source and dose at the right time and in the right way (IAH, 2017) to ensure efficient fertilization; b) reducing production costs; c) increasing production and d) preventing negative impacts on the environment (Souza and Chaves, 2017).

To achieve this, a methodology with a scientific approach to generate fertilization formulas or doses is the simplified rational method proposed by Rodríguez (1993), who indicates that the fertilization dose depends on the nutritional demand based on the maximum achievable yield of the area of interest, the nutritional requirement, and the supply of the nutrient through the soil; the latter obtained from the chemical analysis of soil and the efficiency in the recovery of the fertilizer applied.

This work aimed to determine the demand for N, P, and K of corn lines that are parents of three-way cross hybrids adapted to the climatic conditions of the High Valleys of Mexico and to estimate their N-P-K fertilization doses.

# Materials and methods

## Experimental site conditions

The research was conducted at the Valle de México Experimental Field of INIFAP in Coatlinchán, State of Mexico (19° 17’ north latitude, 98° 53’ west longitude and 2 250 masl). The soil had a sandy loam texture, with pH of 6.2, organic matter of 2.1% and EC of 0.16 dS $m^{-1}$. The mineral content of the soil (mg $kg^{-1}$) and degree of sufficiency, according to Castellanos *et al*. (2000), were N (31, medium), P (47, high), K (222, medium), Ca (2116, medium), Mg (615, moderately high), Fe (15, moderately high), Cu (0.7, moderately low), Zn (1.3, medium) and Mn (12, medium).

## Genetic material and experiment management

The experiment was carried out from May to November in 2014, 2015 and 2016, during the spring-summer crop cycle. The accumulated precipitation and average monthly temperature were 834, 755 and 543 mm; 19, 19 and 20 °C, respectively (SMN, 2017). Five corn lines were evaluated: M-18 (♂-S2), M-55 (♀-S4), M-45 (♂-S3), M-48 (♂-S3), and CML-456 (♂-S49), all adapted to the conditions

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of the High Valleys of Mexico, which are used as parents in the formation of high-yielding three-way cross hybrids.

Line M-18 comes from Mich 21 CompI-7-2; M-55: Tlax 151 SFC1-11-2-2-2; M-43: Mich 21-181-14-1-16-5; M-45: T58Pob86/1-5-3; M-48: Pob87xSIB/-1-4-3; and CML-456: [(INIFAP simple cross) x (Batán 8585-6)]-B-1-1-1-2-B-TL-B. The experimental design was randomized complete blocks in a factorial arrangement with three replications. The factors were: (1) evaluation year: 2014, 2015, and 2016, and (2) corn lines: M-18 (♂-S2), M-55 (♀-S4), M-45 (♂-S3), M-48 (♂-S3) and CML-456 (♂-S49) and experimental unit of two 5 m long rows 0.8 m apart.

The population density was 62 500 plants ha$^{-1}$. A fertilization dose of 150-00-00 was used, with urea (46% N) as a nitrogen source; half of the N was applied at the time of sowing and the rest in the second weeding. Five gravity irrigations were carried out with a 12 cm sheet in different phenological stages as described by Schütte and Meier (1981): at the time of sowing, third leaf neck visible (V3), tenth leaf neck visible (V10), last branch of the panicle fully visible (VT) and visible stigmas (R1).

The following was applied to control weeds: Atrazine + S-metolachlor at a dose of 1.5 L ha$^{-1}$ in pre-emergence and Dicamba + Atrazine with a dose of 2 L ha$^{-1}$ in post-emergence when the weed was 5 cm high.

## Study variables

The variables measured in the $R_6$ stage (physiological maturity) were plant dry matter, grain yield, harvest index and N, P and K extractions. The dry matter (DM) in g was calculated as follows: i) two plants were cut at ground level and placed in a paper bag; ii) the fresh weight (g) (W1) was obtained; iii) a subsample of 100-200 g (W2) was taken and iv) the dry weight of the subsample was obtained with the help of a drying oven at a temperature of 70 °C for 72 h (W3), then the following expression was used for its calculation: DM (g)= [(100 - ( ( (W2 - W3) / W2) x 100)] / 100 x W1) / 2.

Grain yield (kg ha$^{-1}$ at 14% moisture) was calculated with the equation: YIE= [FW x % DM x % G x CF] /8600. Where: FW= field weight of the mature ear of corn in kilograms per useful plot; (%) DM= percentage of dry matter, by the difference, 100 minus the percentage of moisture; (%) G= percentage of grain, as an average of the ratio of grain weight to the weight of the ear without bracts, of five ears, multiplied by 100; CF= correction factor, obtained by dividing 10 000 m$^2$ (1 ha) by the useful area of the plot (8 m$^2$ ); 8 600= a constant value that allows estimating the yield with a uniform moisture of 14%, which is the one at which seeds are handled commercially in Mexico.

The harvest index was obtained by dividing the grain dry matter by the total aerial dry matter. Extraction of N, P and K (g plant$^{-1}$) was obtained in the phenological stage R6. For the analytical determination, from the subsample of 100-200 g to obtain dry matter (W2), 20-30 g was taken and ground. The extraction of macronutrients was calculated as the product of: 1) dry matter or plant tissue, produced in $R_6$ and the concentration of N, P and K in plant tissue. N and P were determined by the Micro Kjeldahl and yellow molybdovanadate methods, respectively (Chapman and Pratt, 1973) and K by flammometry (Sherwood M410, Cambridge, England).

## Fertilization doses

The fertilization dose of N was estimated with Rodríguez’s (1993) simplified rational model:

$$\text{Fertilization dose}\left(\text{kg ha}^{-1}\right)=\frac{\text{Crop demand}\left(\text{kg ha}^{-1}\right)\ \text{- soil supply}\left(\text{kg ha}^{-1}\right)}{\text{Fertilizer use efficiency}\left(\text{dimensionless}\right)}$$

## Crop N, P and K demand

Nutritional demand (DEM) was based on the maximum achievable yield (MAY) of the area of interest and the nutritional requirement (NUTREQ) according to Castellanos *et al*. (2000): DEM (kg ha$^{-1}$) = MAY (kg ha$^{-1}$) x NUTREQ (kg of nutrient per Mg of grain). MAY for the present study was the average

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yield of the years of evaluation and the NUTREQ of each element (N, P and K) in physiological maturity was estimated with the following expression:

$$\text{NUTREQ (kg of nutrient per Mg of grain)} = \frac{\text{Nutrient extraction (kg}\,ha^{-1})}{\text{MAY (Mg)}}$$

To estimate the NUTREQ of P and K, the extraction of P was multiplied by the factor 2.29 and for K, it was multiplied by 1.2, to make the conversion to the chemical form $P_2O_5$ and $K_2O$, which is used in the fertilization dose.

## Supply of N by the soil

It was made up of the organic N of the soil organic matter (SOM) plus the inorganic N ($NO_3$+ $NH_4$) reported from the chemical analysis of the soil. To estimate organic nitrogen, the following considerations were made: the bulk density (Bd) of the soil corresponds to a soil with a coarse texture, 1.4 (g $cm^3$), the SOM had an average of 5% N, the N was mineralized at a rate of 2% considering the percentage of organic matter and soil texture (Castellanos *et al*., 2000).

When adding organic and inorganic nitrogen, a total of 145.9 kg $ha^{-1}$ was obtained, with an assumed plant utilization efficiency of 60%. Based on the above, the amount of inorganic nitrogen actually available was 89.1 kg $ha^{-1}$. An example of a calculation for the N dose for the M-48 line was: a) the nitrogen demand to produce 4.4 Mg $ha^{-1}$ with an extraction of 25.9 kg $ha^{-1}$ was 114 kg $ha^{-1}$; b) the soil supply is 89.1 kg $ha^{-1}$; c) the nitrogen fertilizer efficiency was 60% and d) the dose of nitrogen to be applied was: (114-89.1)/0.6= 44 kg of N $ha^{-1}$. These calculations were made according to methodology to Castellanos *et al*. (2000).

## Supply of P and K by the soil

The supply of P and K was obtained with Castellanos *et al*. (2000) methodology, which was generated from experimental information and the use of chemical soil analysis. For P, we considered the level of soil content according to the extraction method and yield goal for grain corn; for our study, we considered a high level of P (47 kg $ha^{-1}$) obtained by the Bray P1 method and a low grain yield level (< 2 to 6 Mg $ha^{-1}$). In the case of K, a medium level (222 kg $ha^{-1}$), the low response crop class, and the target yield, which was low, were considered. For both elements, the conversion to $P_2O_5$ and $K_2O$ is done as indicated above.

## Fertilizer use efficiency

According to Castellanos *et al*. (2000), it ranges from 0.25 to 0.9% for nitrogen fertilizers, 15-25% for phosphoric fertilizers and from 30-50% for potassium fertilizers.

## Analysis of results

The data obtained were subjected to an analysis of variance and the Tukey mean comparison test ($p$= 0.05) with the SAS statistical package, version 9.0 (SAS, 2014). Additionally, the following correlations were evaluated: 1) between DM and the extraction of accumulated N, P and K and (2) the yield of each line and the nutritional requirement.

# Results and discussion

## Effect of environmental conditions and N on corn line production

Dry matter, harvest index, and grain yield showed statistically significant differences between evaluation years (Table 1). Most of the variables had the highest value in 2014, followed by those obtained in 2015 and 2016, which corresponded to the decreasing order of the average monthly rainfall: 2014 (834 mm) >2015 (755 mm) >2016 (543 mm). The differences in DM in R6, yield and HI in 2014 compared to 2015 and 2016 were 52 and 83%, 35 and 34% and 26 and 70%, respectively.

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**Table 1**

**Effect of environmental conditions (years) on the average grain production in corn lines in High Valleys (2014-2016).**

| Year of evaluation | Dry matter (kg ha$^{-1}$) | Harvest index (%) | Yield (kg ha$^{-1}$) |
|---|---|---|---|
| 2014 | 13082 a | 0.43 a | 5719 a |
| 2015 | 9281 b | 0.32 b | 2734 b |
| 2016 | 7445 c | 0.13 c | 975 c |
| HSD | 1416 | 0.05 | 524 |

Means with the same letter in each column are statistically equal (Tukey, $p \leq 0.05$). HSD= honest significant difference.

Virgen-Vargas *et al*. (2016); Zepeda *et al*. (2021) noted similar effects when studying the agronomic behavior of corn lines and hybrids. For their part, Chakwizira *et al*. (2016) reported that the HI increased when the water supply was greater, this as a consequence of better environmental conditions that, in turn, favored DM production and yield. Liu *et al*. (2020), when studying a database, indicated that DM and HI contributed to corn yield by 77.36% and 26.28%, respectively.

Significant differences were found between corn lines for the grain production variables (Table 2), which can be explained, among other factors, by genetic differences and the level of inbreeding that reduces their vigor (MacRobert *et al*., 2014). The male lines (♂) with lower inbreeding presented higher values of dry matter, HI and grain yield compared to the CML-456 (♂) line with a higher level of inbreeding.

**Table 2. Dry matter, harvest index, and average grain yield in corn lines in High Valleys (2014-2016).**

| Line | Dry matter (kg ha$^{-1}$) | Harvest index (%) | Yield (kg ha$^{-1}$) |
|---|---|---|---|
| M-48 (♂-S3) | 11316 ab | 0.42 a | 5132 a |
| M-18 (♂-S2) | 12395 a | 0.3 bc | 3684 b |
| M-45 (♂-S3) | 9614 b | 0.38 ab | 3527 b |
| M-55 (♀-$S_4$) | 9396 b | 0.23 dc | 2262 c |
| CML-456 (♂-S4) | 6960 c | 0.16 d | 1085 d |
| HSD | 2152 | 0.12 | 1103 |

Means with the same letter in each column are statistically equal (Tukey, $p \leq 0.05$). HSD= honest significant difference.

The M-55 (♀) line, despite having greater inbreeding, presented dry matter similar to the male lines with a low level of inbreeding, which is possible since the ♀ parents have this characteristic and as indicated by Ruiz and Hernández (2017), the females of the triple and double cross hybrids have a higher yield potential than those of single hybrids.

These results had the same behavior as those obtained by Arellano *et al*. (2011) and Virgen-Vargas *et al*. (2014), which include some of the lines evaluated in this study. The low grain yield and harvest index of the CML-456 line was explained by the high level of inbreeding that it has since depression due to inbreeding leads to low-yielding corn lines (Virgen *et al*., 2014).

## N, P and K extraction

The comparison of means of nutrient extraction of N, P, and K between corn lines indicated statistically significant differences ($p \leq 0.05$). The extractions of N, P and K in all lines were higher than those of the CML-456 (♂-S4) line with a lower level of inbreeding (Table 3).

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**Table 3. Comparison of N, P and K extraction means between corn lines in High Valleys on average for the 2014-2016 evaluation years.**

| Line | Nutrient extraction per plant (g) | | |
|---|---|---|---|
| | Nitrogen | Phosphorus | Potassium |
| M-48 (♂-S3) | 1.83 a | 0.52 a | 3.31 a |
| M-18 (♂-S2) | 1.78 a | 0.56 a | 3.25 a |
| M-45 (♂-S3) | 1.5 ab | 0.48 a | 2.66 ab |
| M-55 (♀-$S_4$) | 1.59 ab | 0.46 a | 2.22 bc |
| CML-456 (♂-S4) | 1.11 b | 0.29 b | 1.6 c |
| HSD[†] | 0.5055 | 0.1056 | 0.7145 |

Means with the same letter in each column are statistically equal (Tukey, $p\leq$ 0.05). HSD= honest significant difference.

Extractions for the M-55 (♀-S4) line were higher only compared to the male line with the highest level of inbreeding, CML-456 (♂-S4), which can be explained by the fact that the more inbred lines have less vigor and less developed root system than the hybrids (Vallejo *et al*., 2008), which decreases their ability to absorb nutrients. In the case of the female lines of triple and double cross hybrids, they have a higher yield potential and extract greater amounts of nutrients than the females of the single cross hybrids and the male lines of the triple and single cross hybrids (Ruiz and Hernández, 2017).

## Extraction and demand for N, P, and K

The average total extractions of N, P and K (kg ha$^{-1}$) in three years of evaluation had a direct relationship with DM production in the $R_6$ stage, grain yield and an inverse relationship with the level of inbreeding of the lines (Figure 1, Table 4). The order of extraction from highest to lowest was as follows, for N: M-48 >M-18 >M-55 >M-45 >CML-456; for P: M-18 >M-48 >M-45 >M-55 >CML-456 and for K: M-48 >M-18 >M-45 >M-55 >CML-456.

**Figure 1. Correlation between dry matter and nutrient extraction at physiological maturity in corn lines in the years 2014, 2015 and 2016.**

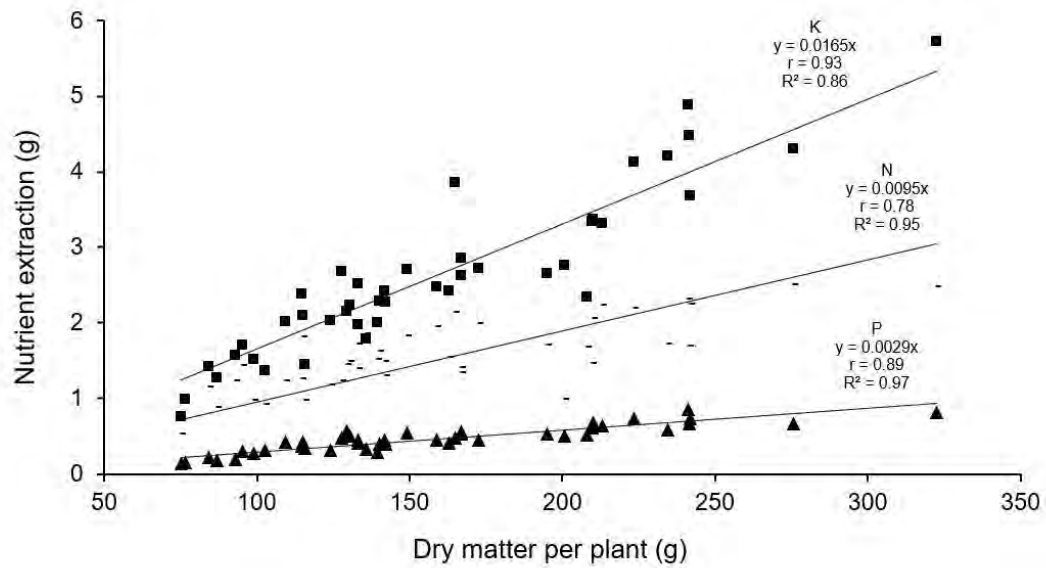

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**Table 4. Extraction, nutritional requirements and demand for N, P, K in corn lines, on average of three years of evaluation.**

| NUT | Line | YIE (Mg·ha$^{-1}$) | Extraction | | NUTREQ (kg Mg$^{-1}$) | DEM (kg ha$^{-1}$) | FD (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | Plant (g) | ha (kg) | | | |
| N | M-48 (♂-S3) | 4.4 | 1.83 | 114.5 | 26 | 115 | 44 |
| N | M-18 (♂-S2) | 3.2 | 1.78 | 111.5 | 35 | 112 | 42 |
| N | M-45 (♂-S3) | 1.9 | 1.59 | 99.5 | 51 | 100 | 16 |
| N | M-55 (♀-$S_4$) | 3 | 1.5 | 93.6 | 31 | 94 | 9 |
| N | CML-456 (♂-S4) | 0.9 | 1.11 | 69.5 | 75 | 70 | 0 |
| P | M-48 (♂-S3) | 4.4 | 0.52 | 32.6 | 17$^{§}$ | 75$^{§}$ | 0 |
| P | M-18 (♂-S2) | 3.2 | 0.56 | 35.1 | 25 | 80 | 0 |
| P | M-45 (♂-S3) | 1.9 | 0.48 | 30 | 35 | 69 | 0 |
| P | M-55 (♀-$S_4$) | 3 | 0.46 | 29 | 22 | 66 | 0 |
| P | CML-456 (♂-S4) | 0.9 | 0.29 | 18.2 | 45 | 42 | 0 |
| K | M-48 (♂-S3) | 4.4 | 3.31 | 207.1 | 56$^{¥}$ | 249$^{¥}$ | 0 |
| K | M-18 (♂-S2) | 3.2 | 3.25 | 203 | 77 | 244 | 0 |
| K | M-45 (♂-S3) | 1.9 | 2.66 | 166.5 | 103 | 200 | 0 |
| K | M-55 (♀-$S_4$) | 3 | 2.22 | 139 | 55 | 167 | 0 |
| K | CML-456 (♂-S4) | 0.9 | 1.6 | 100.2 | 129 | 120 | 0 |

NUT= nutrient; YIE= dry basis yield; NUTREQ= nutritional requirement (kg per Mg of grain); FD= fertilization dose; DEM= demand; $^{§}$= P in the chemical form $P_2O_5$; $^{¥}$= K in the chemical form $K_2O$.

The average total requirement of N, P and K in the lines to produce one megagram (1x10$^{6}$ g) of grain increased as extraction decreased; the order from highest to lowest was: CML-456 >M-55 >M-18 >M-45 >M-48. For example, the CML-456 line with a lower level of inbreeding and an average yield of 0.99 t ha$^{-1}$ of grain required 74.5 kg of nitrogen, 44.6 kg of phosphorus and 128.8 kg of potassium to produce 1 t ha$^{-1}$; that is, 65% of N, 62% of P and 57% of K more than those required by the M-18 line (Table 4), values that are below the international average reported by Bertsch (2009): 17.9 to 34.9 kg of N, 3.3 to 7.3 kg of P and 11.3 to 25 kg of K and that, according to Castellanos *et al*. (2005), the unit extraction of the nutrient is a function of the potential yield and is not a fixed value.

The requirements for one megagram of grain of the CML-456 line, when multiplied by the average yield, give the demand during the crop cycle (kg ha$^{-1}$): N, 70; P, 42 and K, 120, results that agree with Cervantes *et al*. (2013), who also indicated that the level of inbreeding of a line influences its response to nitrogen fertilization.

The lines, due to their level of inbreeding, plant dry matter production and grain yield, differ in the extractions of N, P and K and consequently in the fertilization requirements, aspects that must be considered in the fertilization program in a seed production lot. Figure 1 shows that, in general, there was a high correlation between dry matter and K, P and N extraction, of 0.93, 0.89 and 0.78, respectively.

The $R^2$ values were high: K (0.97), N (0.95) and P (0.97), indicating that extractions can be estimated based on the total dry matter production of the lines. Grageda (1999) points out that the amount of nutrients is correlated with the production of dry matter and that, in turn, it is influenced by the environmental conditions and genetic constitution of the plant.

The estimated fertilization dose of N was different between lines, from 0 to 44 kg ha$^{-1}$. In P and K, there was no need for fertilization, probably because the reserves in the soil were sufficient to cover the demand of the plants, as also pointed out by Castellanos *et al*. (2005) for most soils in Mexico where cereals are grown, except for tropical soils, where the response to K application is low (critical level). For P obtained with the Bray 1 method, 30 ppm can be considered as a critical

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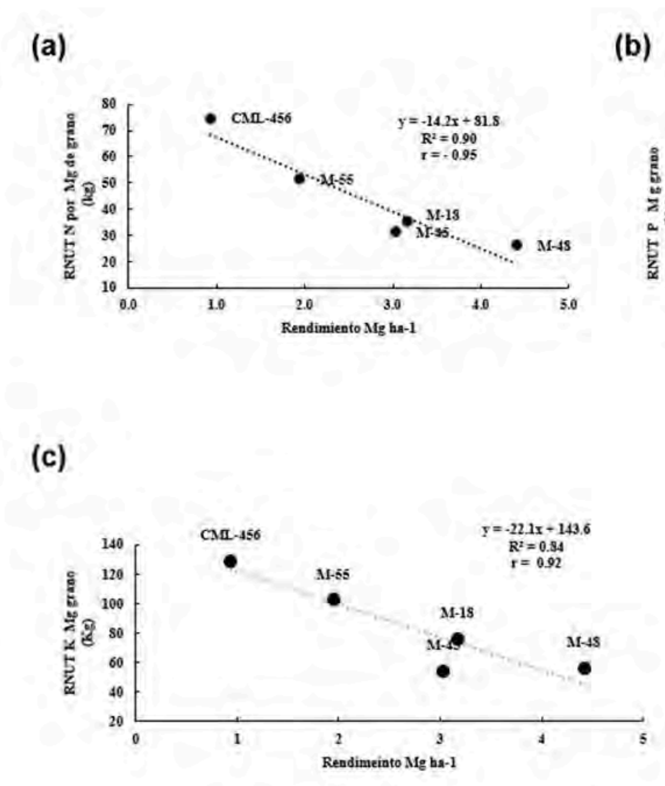
value; in the present study, the concentration was 47 ppm P, which is sufficient for corn lines and for most crops (Castellanos *et al*., 2005).

The requirement of N, P and K by the lines had a high and negative correlation with the yield of the lines, which was related to their level of inbreeding. Rodríguez (1993) indicated that it is possible to estimate the nutritional requirement from the maximum achievable yield, which in our study, corresponded to the average of three years of evaluation. The results also indicate that the lines have different nutritional needs (Figure 2).

**Figure 2. Correlation between dry basis yield and N, P and K requirement in physiological maturity in corn lines in the years 2014, 2015 and 2016.**




## Conclusions

The results allow us to conclude that the corn lines that are parents of three-way cross hybrids adapted to the conditions of the High Valleys of Mexico differ in the demand and extractions of N, P and K according to the level of inbreeding, plant dry matter production and grain yield and consequently differ in the total fertilization requirements, an aspect that must be considered in a seed production fertilization program for the formation of commercial hybrids. The nutrient demand (kg $ha^{-1}$) in the corn lines was 70 to 115 for N, 42 to 80 for $P_2O_5$ and 120 to 249 for $K_2O$. The estimated fertilization dose of N was 0 to 44 kg $ha^{-1}$ and for P and K the fertilization needs were zero.

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# N, P and K demand in corn lines in the High Valleys of Mexico

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