Article

# Statistical model for predicting corn grain yield

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## Abstract

The growth of the world population leads to the demand for food, and these must be obtained through the efficient use of resources, this could be achieved by planning and prioritizing the factors that involved in production processes. Simulation models are a tool with which it can visualize scenarios and quantify the inputs to use. In this work, with data on maximum maize yields (RG) from 1943 to 2017 obtained from global field experiments and predominantly data from the United States of America (80%), a statistical model was generated to estimate grain yield in maize ($RG_E$) and to support the decision-making of those involved in the grain maize production process. The most important variables to express the model were: population density ($D_P$), potassium dose (K), irrigation sheet ($L_R$), nitrogen dose (N) and phosphorus dose (P) and were used to generate the model with the *stepwise* multiple regression method and expressed as: $RG_E$= 3.158205 + 0.693319 ($D_P$) - 0.022246 (K) + 0.005990 ($L_R$)+ 0.010687 (N) + 0.013794 (P), had an $R^2$= 0.73 and a standard error of 0.964 Mg $ha^{-1}$. $D_P$ was the variable that explained in greater proportion the value of $RG_E$, with the analysis of RG data the increase in the planting rate over time was observed to achieve a higher $D_P$ and increase the RG, which generated the demand for inputs.

**Keywords:** *Zea mays* L., nitrogen, population density.

Reception date: January 2021
Acceptance date: March 2021

# Introduction

The highest rate of yield increase in maize hybrids from 1950 to 1999 in east Nebraska, for dry conditions was 0.05 Mg ha$^{-1}$ year$^{-1}$ in soils with high water retention capacity, followed by irrigation with 0.028 Mg ha$^{-1}$ year $^{-1}$ (Mason *et al*., 2008). Yield trends from 1987 to 2015 indicated a comparable increase according to latitudes (108, 97 and 117 kg ha$^{-1}$ year$^{-1}$ for 35-40°, 40-45° and 45-50° north latitude, respectively) and there was an improvement in high environments (AR) and extremely high yield (MAR) at the average maximum rate of 50 kg ha$^{-1}$ year$^{-1}$ (Assefa *et al*., 2017).

Optimizing agrotechnical elements reduces harmful climate effects (Sárvári and Pepó, 2014). The contribution to factors yields (transgenic resistance to insects, strobilurin fungicide, P-sulfur phosphorus fertilization, S-zinc Zn and nitrogen fertilization N) was greater when applied as part of a complete supplement of inputs than when added individually (Ruffo *et al*., 2015). Technology and management were the most limiting factors, followed by precipitation and soil in maicera regions of China (Zhao *et al*., 2018). The challenge is to untangle the interaction of factors that can be manipulated by farmers to increase yields (Van Loon *et al*., 2019).

Reduced yield in the long rainy season in 2000 and 2001 was attributed to poor precipitation distribution (Shisanya *et al*., 2009). Precipitation was the limiting factor for water-limited yield potential to reach potential level in four maicera regions in China (Liu *et al*., 2017). In dry maize by correlation, seasonal precipitation explained to grain yield by 66% (Limón-Ortega *et al*., 2016).

The effect of moisture stored in the soil and available to the plant plus adequate fertility and a high level of management indicated that the potential to produce maize is determined by such soil capacities (Leeper *et al*., 1974). Soil texture should be an important criterion on which to make recommendations of the static dose of N to optimize yield and prevent the accumulation of residual nitrate in the soil (Alotaibi *et al*., 2018).

Problems persist, such as specifying the dose of fertilizer to be applied to increase the efficiency of the use of nutrition and the profitability of production, without deterioration of natural resources (Bugarín-Montoya *et al*., 2002) and those related to the relative content of nutriments in a crop are connected with problems related to fertilization techniques (Alcántar-González *et al*., 2016). The consumption of N necessary for a maximum growth rate depends in part on the growth rate when it is not limited by the lack of water or nutrients; the percentage of N in widely different crops seem to be determined not so much by the species but by the total weight of dry matter per unit area (Greenwood, 1983).

Maize requires between 20 to 25 kg N ha$^{-1}$ for each ton of grain produced (Melgar and Torres-Duggan, 2004). The design of an integrated crop and N management system is an alternative approach to maximizing the use of solar radiation and favorable temperature periods, to achieve high yield and new efficiency in the use of N (Guo *et al*., 2016). The residual effect of the broadcast application of P in maize and caupi (*Vigna unguiculata* L.) production, as a measurement of soil yield and P, was greater than high applied doses (Smyth and Cravo, 1990).

The balanced application of N, P and S resulted in an increase in yields compared to treatments with unbalanced or no application, the maximum absorption of nutrients was related to higher yields (Ciampitti *et al*., 2010). The concentrations in the cob leaf of N-P-S-copper (Cu) and Fe explained the variation in grain yield by more than 50% and 40%, respectively (Kovács and Vyn, 2017). K represents the cation that is absorbed in greater quantity by plants, grasses are known as accumulators of K (Alcántar-González *et al*., 2016). Under drought stress, the spraying of K and iron (Fe) could reduce such stress in maize (Zare *et al*., 2014). Foliar application of 1-3% and 0.1-0.2% K and Zn respectively, was more beneficial under limited irrigation conditions and in vegetative stage resulted in better growth and higher yield (Amanullah *et al*., 2016).

When the number of plants per area goes beyond optimal there are detrimental consequences for the ontogenia of the cob, and it results in infertility (Sangoi, 2000). Increasing plant density can improve biomass and yield and also increases competition for resources between plants, in high density, changes in the structure and functions of the individual and population plant affect the morphogenesis of plants, the accumulation of carbohydrates in the stem, bark tissue and mechanical resistance of the stem, the structure and functioning of the root and are more susceptible to acame (Jun *et al*., 2017).

Organic farmers can improve the suppression of weeds in maize by interspersing with hedge crops and optimizing yields by sowing maize at a lower rate than is typically used with hedging cultivation (Youngerman *et al*., 2018).

The availability of precocious hybrids with lower height, fewer leaves, vertical leaves, smaller styles and synchrony between male and female flowering has improved resistance to high densities without showing excessive infertility and has allowed it to intercept and use solar radiation more efficiently, contributing to the potential increase in yield (Sangoi, 2000).

Utilizing genetic diversity has been a pillar of production improvements prior to high-throughput DNA sequencing; related bioinformatics and genetic technologies can be used to detect hidden genetic variability and understand the functions of genes (Phillips, 2010). The cultivation of new genetic materials is important to increase yield potential and meet the growing demand for food (Tao *et al*., 2015).

A model can be a conceptual, numerical, or graphical representation of an object, system, process, activity, or thought; highlights the characteristics that the modeler considers important of the phenomenon in question (García, 2008), can integrate climatic, soil and genetic variables into the diagnosis of N fertilization of crops (García, 2005), the information generated is the basis for improving the synchronization of pesticide applications, fertilization, irrigation and harvesting (Verdugo-Vásquez *et al*., 2016). The APSIM-Maize model calibrated in the Northern China Plain (PNC) explained >63% variations in maize yield (Wang *et al*., 2014).

The yield gap determined with the MCWLA-Maize model decreased by approximately 2% per year in the main corn regions in China (Tao *et al*., 2015). In different locations and regardless of the reporting method, estimate data in V7 predicted the yield ($R^2$ >0.7) and can be used to predict yields in drought-free conditions in New York (Tagarakis and Ketterings, 2017).

The objective of this work was to discern between different environmental and management conditions, those variables that most influence the RG. Based on this, create a mathematical model to determine the $RG_E$, applicable under different production conditions.

The working hypotheses were: the RG is a function of environmental and agronomic management conditions, climate variables have a more significant influence on the RG, compared to those that make up agronomic management and the RG is a consequence of the incidence of multiple variables, for this the multiple regression model makes it possible to more appropriately determine the $RG_E$ for different environmental and management conditions.

## Materials and methods

The database of maximum maize grain yields (RG) was generated with information sought in 2019 in the databases: Science Direct and ASCESS DL with the keywords ‘high yield’ ‘corn’ ‘maize’ from the period 1943 to 1946 and from 1948 to 2017, about ten representative RG values were selected per year, studies covering more than a year of research represented RG of more than one year. Within the RG recorded in the literature by essays, no one from Mexico was considered because there were higher records in the rest of the world.

From each study, the location, year(s) studied, genetic material, agronomic management, properties and characteristics of the soil were captured, in addition of climatic conditions and response from experimentation. The RG was adjusted to 13.5% grain moisture and expressed in Mg $ha^{-1}$. Because of the diversity of the trials, the variables it is reported were not always the same. The classification of variables was: study, other variables reported, and site. The dependent variable studied was the RG, as the main maize product, and which depends on various factors.

The data analysis was: identification and classification of the independent variables of each experiment; general trend of RG; over the years by linear regression (RL), trend of RG over the years by the water regime reported, by RL; trend of RG over the years for each independent variable identified interchangeably of the reported water regime, by RL, trend of RG; over theyears for each independent variable identified, according to the reported water regime, by RL, filtration of independent variables for the creation of the model in the following order: irrigation sheet, doses of N, dose of P, dose of K and population density, selection and ordering of independent variables for analysis using the *stepwise* multiple regression method, generation of equations: general, by water regime and according to soil texture, by tillage system and by irrigation system and validation of the model: observed RG *vs* RG estimated by RL.

The factor analysis methodology was carried out using a ‘stepwise’ calculation program, which includes or eliminates predictor variables based on the impact that this causes in the statistic used to assess the significance of the relationship (De la Casa, 1992), the statistical analyses was carried out with the R program (R Core Team, 2017).

# Results and discussion

## Spatial and temporal distribution of data

The studies analyzed represented eighty different locations and 80% were located in the United States of America (Table 1), the rest was located in Romania, Lebanon, Canada, Spain, Slovenia, France, China and Argentina, a representativeness of different production environments and management schemes was achieved. Over the years, population density, the use of fertilizers and improved varieties in production systems increased, in order to achieve the highest yields. Future research could continue to focus on improving yield and reducing low-yield and medium-yield environments with improved technologies for growing and using hybrids (Assefa *et al*., 2017).

**Table 1. Summary of grain yield data (RG) for the period (1943-2017).1**

| Parameters | General | Water regime | |
|---|---|---|---|
| | | Irrigation | Unirrigated land |
| Observations | 732 | 331 | 23 |
| Minimum (Mg ha$^{-1}$) | 1.996 | 5.801 | 5.828 |
| First quartile (Mg ha$^{-1}$) | 8.097 | 10.241 | 9.154 |
| Median (Mg ha$^{-1}$) | 10.796 | 11.701 | 10.79 |
| Average (Mg ha$^{-1}$) | 10.679 | 12.395 | 10.602 |
| Third quartile (Mg ha$^{-1}$) | 12.64 | 15.414 | 12.668 |
| Maximum (Mg ha$^{-1}$) | 19.779 | 19.779 | 13.834 |

## Corn grain yield trends 1943-2017

The RG averaged 10.679 Mg ha$^{-1}$, the maximum value was 19.779 Mg ha$^{-1}$ in 2012 and the minimum of 1.996 Mg ha$^{-1}$ and was recorded in 1959; throughout the years of study the data showed an uptrend ($p$< 0.01, $R^2$= 0.74, n= 732) (Figure 1), which verified the constant improvement in production systems to achieve greater RG. Assefa *et al*. (2017) found a comparable increase in average maize yield at latitudes (rates of 108, 97 and 117 kg ha$^{-1}$ year$^{-1}$ for latitudes 35° to 40°, 40 to 45° and 45 to 50° north latitude, respectively).

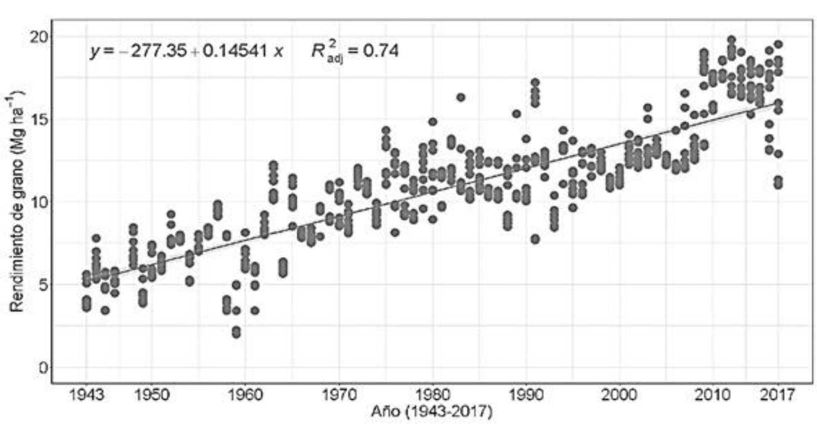


**Figure 1. Relationship between study years and RG (1*p*< 0.01).**

## Water regime

The RG averaged 12.395 Mg ha$^{-1}$ and 10.602 Mg ha$^{-1}$ for the production of 'irrigation' and 'dry' respectively, while the maximum RG reached were 19 779 Mg ha$^{-1}$ in irrigation and 13 834 Mg ha$^{-1}$ for dry, in both cases of RG and under both water irrigation regimes ($p< 0.01$, $R^2= 0.7$, n= 331) and dry ($p< 0.01$, $R^2= 0.59$, n= 23) an uptrend was observed; through the years (Figure 2). The rate of increase in yield was 0.05 Mg ha$^{-1}$ year$^{-1}$ for dry conditions in soils with high water retention capacity and 0.028 Mg ha$^{-1}$ year$^{-1}$ for cultivation under irrigation (Mason *et al*., 2008). In 2009 maize yields ranged from 9.05 Mg ha$^{-1}$ for the dry regime to 15.5 Mg ha$^{-1}$ for full irrigation, and in 2010 they were 11.7 Mg ha$^{-1}$ and 15.5 Mg ha$^{-1}$, respectively (Djaman *et al*., 2013).

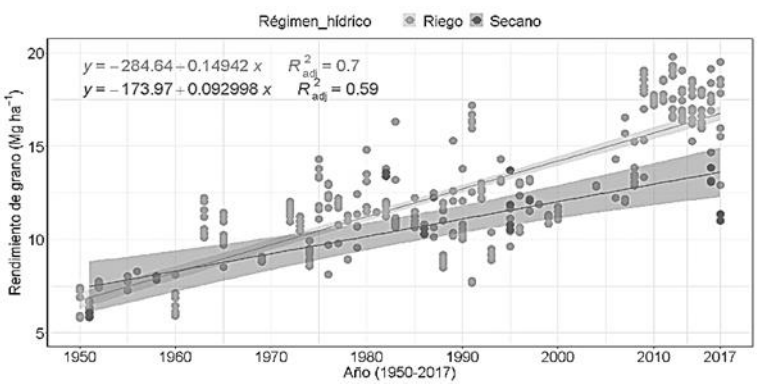


**Figure 2. Relationship between study years and RG in different water regimes 2(*p*< 0.01).**

## Analysis over time of the identified study variables

With the analysis of the dispersion of the effect in the RG for each independent quantitative variable, levels were delimited to be able to visualize the trend through the study period (Table 2).

**Table 2. Levels of quantitative variables studied.**

| Variable | Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| $L_R$ (mm) | < 50 | 50-224 | 225-449 | 450-699 | 700-900 | > 900 | |
| N (kg ha$^{-1}$) | < 100 | 100-199 | 200-299 | 300-399 | 400-500 | > 500 | |
| P (kg ha$^{-1}$) | < 50 | 50-99 | 100-149 | 150-199 | 200-274 | 275-325 | > 325 |
| K (kg ha$^{-1}$) | 50-94 | 95-144 | 145-199 | 200-249 | 250-300 | > 300 | |
| $D_P$ (plants m$^{-2}$) | < 4 | 4-5.49 | 5.5-7.5 | > 7.5 | | | |

$L_R$= irrigation sheet; N= nitrogen dose; P= phosphorus dose; K= potassium dose; $D_P$= population density.

## Irrigation sheet

The response in the RG to irrigation was greater for rates greater than 900 mm ($p< 0.01$, $R^2= 0.74$, n= 18) and 450-699 mm ($p< 0.01$, $R^2= 0.73$, n= 26). In four irrigation regimens, there was a linear increase in real crop evapotranspiration (ETr) with increasing amounts of irrigation ($R^2 \geq 0.97$) (Djaman *et al*., 2013). In sandy soil and dry conditions, irrigation significantly increased yields and was the most important factor compared to tillage and rotation (Huynh *et al*., 2019).

## Nitrogen dose

The response in the RG to the doses of N was greater for doses greater than 500 kg N ha$^{-1}$ ($p< 0.01$, $R^2= 0.73$, n= 51) and 400-500 kg N ha$^{-1}$ ($p< 0.01$, $R^2= 0.90$, n= 31). Grain yield with a management proposal ranged from 16.1-19.1 Mg ha$^{-1}$ over four years for China Loess Plateau and reached 98 to 108% of potential yield; the optimal dose of N ranged from 207 to 222 kg ha$^{-1}$ with a ratio of 65 to 80 kg of grain per kg of N applied (Guo *et al*., 2016). When the application of N increased from 0 to 60 kg ha$^{-1}$, the yield increased 7.3% (Limón-Ortega *et al*., 2016).

## Water regimen and nitrogen dose

With this combination there was greater response in the RG for irrigation +400-500 kg N ha$^{-1}$ ($p< 0.01$, $R^2= 0.92$, n= 23) and irrigation+dose greater than 500 kg N ha$^{-1}$ ($p< 0.01$, $R^2= 0.58$, n= 42). The grain yield with a Lay Flat® hose system was 10 500 kg ha$^{-1}$, with an extraction of N by the grain of 165 kg ha$^{-1}$ and an extraction of N by the dry matter of 109 kg ha$^{-1}$ (Sifuentes-Ibarra *et al*., 2015).

## Phosphorus dosage

The largest response in RG over the years to applied P was for 275-325 kg P ha$^{-1}$ ($p< 0.01$, $R^2=$ 0.45, n= 23) and 150-199 kg P ha$^{-1}$ ($p< 0.01$, $R^2= 0.84$, n= 78). There was no response in yields beyond a dose of 22 kg P ha$^{-1}$, in equal amounts of applied P, the absence of a yield difference between the application methods (in band and broadcast) indicated that the band placement of 22 kg P ha$^{-1}$ would be the best method of application of P to maintain long-term crop production, under the manual tillage practices used in the study region (Smyth and Cravo, 1990).

## Water regime and phosphorus dose

By combining these two factors, increased response was observed in the RG for irrigation + 150-199 kg P ha$^{-1}$ ($p< 0.05$, $R^2= 0.62$, n= 59) and irrigation +100-149 kg P ha$^{-1}$ ($p< 0.01$, $R^2= 0.77$, n= 30).

## Potassium dose

The response in the RG was greater at 250-300 kg K ha$^{-1}$ ($p< 0.01$, $R^2= 0.92$, n= 34) and at 145-199 kg K ha$^{-1}$ ($p< 0.01$, $R^2= 0.72$, n= 57). The effects of K chloride (KCl) in the summer of 2005 at two different locations in Sulaimani: Kanypanka and Bazyan, (dose of 0, 75, 150, 225, 300 kg K ha$^{-1}$) were that increased KCl application increased grain yield by 30.17% and 55.45% for Kanypanka and Bazyan, respectively; K fertilizer response increased from 8.27 to 41.56% in Kanypanka, and in Bazyan it was 3 to 34.25% and the efficiency of fertilizer use ranged from 61.63 to 85.53% for Kanypanka and from 26.6 to 54.83% for Bazyan (Mam-Rasul, 2010).

## Water regime and potassium dose

In this combination, a greater response was observed in the RG for irrigation+145-199 kg K ha$^{-1}$ ($p< 0.01$, $R^2= 0.73$, n= 19) and irrigation +250-300 kg K ha$^{-1}$ ($p< 0.01$, $R^2= 0.94$, n= 20). In dry maize, yields were reduced by up to 13% in the absence of K in one year (Subedi and Ma, 2009).

In drought stress, the application of K compared to control caused increased grain yield, the weight of 1 000 grains and the number of grains per cob at 16.5, 9 and 5.5%, respectively (Zare *et al*., 2014). The plots K-treated performed better than the control in terms of better growth, higher yield, and improvement in yield components; by increasing the dose of K applied up to 90 kg of K $ha^{-1}$ in two equal fractions, it improved maize growth and productivity in semi-arid climates (Amanullah *et al*., 2016).

**Population density**

The response in the RG was higher for densities greater than 7.5 plants $m^{-2}$ ($p< 0.01$, $R^2= 0.2$, n= 74) and for 5.5-7.5 plants $m^{-2}$ ($p< 0.01$, $R^2= 0.29$, n= 126). In the maize-soy rotation, increasing population narrowed the yield gap (high technology vs standard technology TE) when all other inputs were applied at the supplementary level to TE (Ruffo *et al*., 2015). The increase in density had a negative effecton the biomass of the coverage crop, in two places, the yield in low density (3.71 plants $m^{-2}$) did not differ from the standard (7.41 plants $m^{-2}$) (Youngerman *et al*., 2018).

**Water regime and population density**

The largest response in the RG was obtained in irrigation + densities greater than 7.5 plants $m^{-2}$ ($p< 0.01$, $R^2= 0.21$, n= 47) and irrigation+5.5-7.5 plants $m^{-2}$ ($p< 0.01$, $R^2= 0.11$, n= 101). Under dry conditions, yields were reduced by 8-13% with low plant density (PPD) (60 000 plants $ha^{-1}$) in all years, and the increase from PPD to 90 000 plants $ha^{-1}$ did not improve yield (Subedi and Ma, 2009). In arid environments, yield at all densities was low (2 448 kg $ha^{-1}$), yield variation was high in semi-arid environments, the polynomial regression ($p< 0.001$, n= 951) had its maximum point with 140 000 plants $ha^{-1}$ and yield of 9 000 kg $ha^{-1}$, in sub-humid environments the yield had a positive response to density, the yield increased both for conventional tillage and no-tillage systems as the population increased, in systems with a high contribution of N ($R^2= 0.19$, $p< 0.001$, n= 2 018) the response to the population to applied N was weaker than in medium contribution systems ($R^2= 0.49$, $p< 0.001$, n= 680) (Haarhoff *et al*., 2018).

**Crop**

The materials used in the studies were hybrids of seed-producing companies and crossbreeds tested by research centres, the generality of the data indicated the predominance of yellow corn, on those of sweet and white type, due to missing data no analysis was performed; however, it is known that the introduction of new crops contributes significantly to the increase in maize yield (Qian and Zhao, 2017).

**Tillage system**

There was response over time and an uptrend in the RG obtained in conventional tillage ($p< 0.01$, $R^2= 0.69$, n= 397) and zero tillage ($p< 0.01$, $R^2= 0.56$, n= 14). Huynh *et al*. (2019), found a negative influence of zero tillage that was noted after 3 years, leading to significantly lower yield compared to conventional tillage; however, the authors note that the results are likely due to the specific characteristics of the soil and the site where their study was conducted.

## Water regime and tillage system

In this interaction there was a significant response over time and an uptrend in the RG obtained in irrigation + tillage conventional ($p< 0.01$, $R^2= 0.7$, n= 164) and dry + tillage conventional ($p< 0.01$, $R^2= 0.87$, n= 11). The loss of N due to runoff and deep filtration, denitrification caused by higher soil water content and a low rate of N mineralization caused by lower soil temperatures under zero tillage potentially contributed to the observed decrease in grain yield under this system (Anapalli *et al*., 2018).

## Irrigation system

When analyzing the response in the RG to the system used it was found that the drip irrigation ($p< 0.01$, $R^2= 0.74$, n= 57) was superior to the other systems over time.

## Cultivation system

There was a higher response in the RG for monoculture ($p< 0.01$, $R^2= 0.50$, n= 92) and rotation ($p< 0.01$, $R^2= 0.73$, n= 157). The most favorable rotation of maize was with winter wheat, with the addition of NPK from 60-120, 60-70 and 90-110 kg ha$^{-1}$ respectively and density of 75 000-90 000 plants ha$^{-1}$, yields ranged from 2 to 11 t ha$^{-1}$ in extensive systems and from 10 to 15 t ha$^{-1}$ in intensive, respectively (Sárvári and Pepó 2014). Crop rotation significantly increases and maintains yield as much as the use of conventional tillage and irrigation (Huynh *et al*., 2019).

## Water regime and cultivation system

The effect on the RG was greater for irrigation + monoculture ($p< 0.01$, $R^2= 0.51$, n= 68) and irrigation + rotation ($p< 0.01$, $R^2= 0.81$, n= 30).

## Soil

According to was reported in the studies consulted, the highest RG was achieved in soils with sandy loam texture ($p< 0.01$, $R^2= 0.62$, n= 73) and loam ($p< 0.01$, $R^2= 81$, n= 61). The effect of the interaction between soil quality and fallow on maize yield was negative, this suggested the influence of the quality of leaf litter and the immobilization of N in soils (Braimoh and Vlek, 2006). The optimal economic dose of fertilizer N (DOEN) was higher in the soil Gleysol (Sg) (173 kg ha$^{-1}$) and lower in the soil Podzol (Sp) (123 kg ha$^{-1}$) with a grain yield in Sp of almost 60% lower than expected in other textural groups of the soil, DOEN in clay and loam soils was 144 and 164 kg ha$^{-1}$ with an estimated grain yield of 12.7 and 12 Mg ha$^{-1}$, respectively, the content of residual soil nitrate (NRS) was higher in Sg and Sp soils, and the NRS estimated by the DOEN was lower than that observed in the Sp soil, which indicates possible losses of N in this soil (Alotaibi *et al*., 2018).

## Water regime and soil

It was observed that the higher values of RG were found in irrigation + sandy loam soil ($p< 0.01$, $R^2= 0.69$, n= 48) and irrigation + loam soil ($p< 0.01$, $R^2= 0.96$, n= 13).

## Proposed models

The variables used in model generation were irrigation sheet, nitrogen dose, phosphorus dose, potassium dose and population density, with which five model proposals were generated using *stepwise* multiple regression method (Table 3).

**Table 3. Obtained models and their parameters for maize yield prediction ($RG3_E$).**

| No. | Model | n | EE | $R^2$ |
|---|---|---|---|---|
| 1 | $RG_E$= 3.158205+0.693319 ($D_P$)-0.022246 (K)+0.005990 ($L_R$)+0.010687 (N)+0.013794 (P) | 45 | 0.964 | 0.73 |
| 2 | $RG_E$= 8.4373743+0.0095280 ($L_R$)-0.0166342 (K)+0.0226333 (P) | 70 | 1.341 | 0.88 |
| 3 | $RG_E$= 7.9784939+0.0085484 ($L_R$)+0.0084006 (P) | 97 | 1.708 | 0.75 |
| 4 | $RG_E$= 3.798942+1.082989 ($D_P$)-0.002505 (K) | 187 | 1.742 | 0.63 |
| 5 | $RG_E$= 8.3668051+0.5422341($D_P$)-0.0071137(N)+0.0026075($L_R$) | 81 | 1.624 | 0.35 |

$RG_E$= estimated grain yield; n= number of observations; EE= standard error; $D_P$= population density (plants $m^{-2}$); K= potassium dose (kg $ha^{-1}$); $L_R$= irrigation sheet (mm); P= phosphorus dose (kg $ha^{-1}$); N= nitrogen dose (kg $ha^{-1}$); $p< 0.01$ value.

According to the first analysis by joining the five identified variables of the studies, which pointed to population density as the most significant variable in the *stepwise* procedure, the combinations revolved around this variable, and were considered as a demanding input (water and fertilizers), model 1 was chosen for the results report and its discussion because it considered the five variables of the study and because it presented the lowest value of the standard error.

## Model 1

$RG_E$ is a function of the five variables identified and studied in this research, the statistical parameters of the model ($p< 0.01$, $R^2$= 73, n= 45) indicated an error of 964 kg grain $ha^{-1}$; in Figure 3 the RG and $RG_E$ were related through a linear regression, whose equation was highly significant ($p< 0.01$, $R^2$= 73); likewise, the tendency to underestimate the values by the generated model was observed.

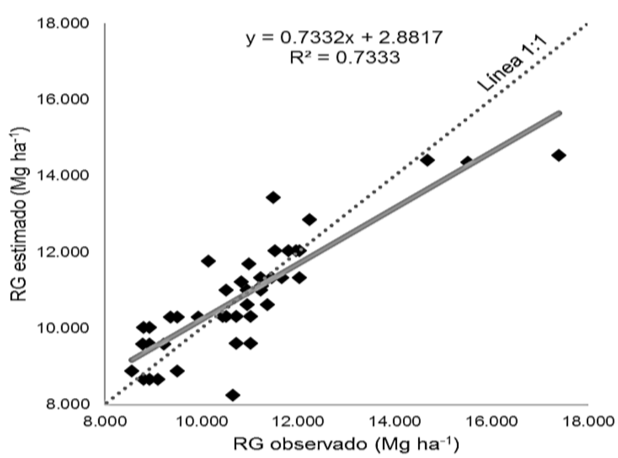


**Figure 3. Relationship between observed and estimated data with model 1.** The dotted line 3 indicates the 1:1 ratio between the observed value (RG) and the estimated value ($RG_E$).

In this regard, De la Casa (1992) founds a multiple regression equation ($R^2$= 0.8, EE= 407.1 kg $ha^{-1}$), based on precipitation data, when using the stepwise method to predict maize yield in Argentina, accounted for three components, one technological or temporary, one rainfall, and one geographical, that equation achieved an average percentage error between 17 and 18% with respect to witness data. Monteiro *et al*. (2017) estimated by a model the yield of maize for the 2000-2001 to 2007-2008 in Brazil based on the technological level of production systems and meteorological conditions, there was a high correlation between estimated and observed yield ($0.76 > R^2 \geq 0.92$, $p< 0.01$) with model efficiency between 0.45 and 0.73, relative mean error (MAE) between -0.9 and 2.4, and absolute mean error (MAE) less than 70 kg $ha^{-1}$ depending on the technological level.

## Conclusions

The factors that influenced the obtaining of $RG_E$ in maize were population density, K dose, irrigation sheet, N dose and P dose and all of them belonged to the group of agronomic factors. According to the analysis of studies related to the production of maize grain yield and the diversity of environments in which they were developed, the influence of agronomic factors was significantly associated with the crop response, so only these variables were chosen to determine the $RG_E$. The regression model (N= 45, $R^2$= 0.73, EE.= 0.964 Mg $ha^{-1}$) represented the effect of agronomic factors on the RG, while environmental variables did not have a significant impact on the crop response.

## Cited literature


Alcántar-González, G.; Trejo-Téllez, L. I. y Gómez-Merino, F. C. 2016. Nutrición de cultivos. 2ª. (Ed.). Biblioteca Básica de Agricultura, México, DF. 443 p.

Alotaibi, K. D.; Cambouris, A. N.; Luce, M. S.; Ziadi, N. and Tremblay, N. 2018. Economic optimum nitrogen fertilizer rate and residual soil nitrate as influenced by soil texture in corn production. Agron. J. 110(6):2233-2242.

Amanullah, I. A.; Irfanullah. and Hidayat, Z. 2016. Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition. Sci. Rep. 6:1-12.

Anapalli, S. S.; Reddy, K. N. and Jagadamma, S. 2018. Conservation tillage impacts and adaptations in irrigated corn production in a humid climate. Agron. J. 110(6):2673-2686.

Assefa, Y.; Vara-Prasad, P. V.; Carter, P.; Hinds, M.; Bhalla, G.; Schon, R.; Jeschke, M.; Paszkiewicz, S. and Ciampitti, I. A. 2017. A new insight into corn yield: trends from 1987 through 2015. Crop Sci. 57(5):2799-2811.

Braimoh, A. K. and Vlek, P. L. G. 2006. Soil quality and other factors influencing maize yield in northern Ghana. Soil Use and Management. 22(2):165-171.

Bugarín-Montoya, R.; Galvis-Spinola, A.; Sánchez-García, P. y García-Paredes, D. 2002. Acumulación diaria de materia seca y de potasio en la biomasa aérea total del tomate. Terra. 20(4):401-409.

Ciampitti, I. A.; Boxler, M. y García, F. O. 2010. Nutrición de maíz: requerimientos y absorción de nutrientes. Informaciones Agronómicas del Cono Sur. 48:14-18.

De la Casa, A. 1992. Modelo estadístico de pronóstico de rendimiento de maíz para la región semiárida de Córdoba basado en datos pluviométricos areales. Agriscientia. 9(2):87-96.

Djaman, K.; Irmak, S.; Rathje, W. R.; Martin, D. L. and Eisenhauer, D. E. 2013. Maize evapotranspiration, yield production functions, biomass, grain yield, harvest index, and yield response factors under full and limited irrigation. Am. Society Agric. Biol. Eng. 56(2):273-293.

García, F. 2005. Criterios para el manejo de la fertilización del cultivo de maíz. *In*: La jornada “Maíz 2005” organizada por Capacitación Agropecuaria. Córdoba, Argentina. 1-19 pp.

García, J. M. 2008. Teoría y ejercicios prácticos de dinámica de sistemas. Fundación Universitat Politécnica de Catalunya (UPC). Cataluña, España. 84 p.

Greenwood, D. J. 1983. Quantitative theory and the control of soil fertility. New Phytol. 94(1):1-18.

Guo, J.; Wang, Y.; Fan, T.; Chen, X. and Cui, Z. 2016. Designing corn management strategies for high yield and high nitrogen use efficiency. Agron. J. 108(2):922-929.

Haarhoff, S. and Swanepoel, P. A. 2018. Plant population and maize grain yield: a global systematic review of rainfed trials. Crop Sci. 58(5):1819-1829.

Huynh, H. T.; Hufnagel, J.; Wurbsa, A. and Bellingrath-Kimura, S. D. 2019. Influences of soil tillage, irrigation and crop rotation on maize biomass yield in a 9-year field study in Müncheberg, Germany. Field Crops Res. 241:1-9.

Jun, X.; Rui-Zhi, X.; Wang-Feng, Z.; Ke-Ru, W.; Peng, H.; Bo, M.; Ling, G. and Shao-Kun, L. 2017. Research progress on reduced lodging of high-yield and -density maize. J. Integrative Agric. 16(12):2717-2725.

Kovács, P. and Vyn, T. J. 2017. Relationships between ear-leaf nutrient concentrations at silking and corn biomass and grain yields at maturity. Agron. J. 109(6):2898-2906.

Leeper, R. A.; Runge, E. C. A. and Walker, D. M. 1974. Effect of plant-available stored soil moisture on corn yields. I. Constant Climatic Conditions. Agron. J. 66(6):723-727.

Limón-Ortega, A.; Ruiz-Torres, N. A.; Vázquez-Carrillo, G. and Báez-Pérez, A. 2016. Environment and nitrogen influence on rainfed maize yield and quality. Crop Sci. 56(3):1257-1264.

Liu, B.; Chen, X.; Meng, Q.; Yang, H. and Van Wart, J. 2017. Estimating maize yield potential and yield gap with agro-climatic zones in China-Distinguish irrigated and rainfed conditions. Agric. Forest Meteorol. 239:108-117.

Mam-Rasul, G. A. 2010. Effect of potassium fertilizer on growth and yield of corn plants in some soils at Sulaimani governorate. Mesopotamia J. Agric. 38(1):35-43.

Mason, S. C.; Kent, D. K.; Eskridge, M. and Galusha, T. D. 2008. Yield increase has been more rapid for maize than for grain sorghum. Crop Sci. 48(4):1560-1568.

Melgar, R. y Torres-Duggan, M. 2004. Manejo de la fertilización en maíz. IDIA XXI. Revista de Información sobre Investigación y Desarrollo Agropecuario. 4(6):114-121.

Monteiro, J. E. B. de A.; Assad, E. D.; Sentelhas, P. C. and Azevedo, L. da C. 2017. Modeling of corn yield in Brazil as a function of meteorological conditions and technological level. Pesq. Agropec. Bras. 52(3):137-148.

Phillips, R. L. 2010. Mobilizing science to break yield barriers. Crop Sci. 50(1):99-108.

Qian, J. and Zhao, Z. 2017. Estimating the contribution of new seed cultivars to increases in crop yields: a case study for corn. Sustainability. 9(7):1-11.

R Core Team. 2017. R: a language and environment for statistical computing. https://www.r-project.org/.

Ruffo, M. L.; Gentry, L. F.; Henninger, A. S.; Seebauer, J. R. and Below, F. E. 2015. Evaluating management factor contributions to reduce corn yield gaps. Agron. J. 107(2):495-505.

Sangoi, L. 2000. Understanding plant density effects on maize growth and development: an important issue to maximize grain yield. Ciência Rural. 31(1):159-168.

Sárvári, M. and Pepó, P. 2014. Effect of production factors on maize yield and yield stability. Cereal Res. Comm. 42(4):710-720.

Shisanya, C. A.; Mucheru, M. W.; Mugendi, D. N. and Kung'u, J. B. 2009. Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in central highlands of Kenya. Soil Tillage Res. 103(2):239-246.

Sifuentes-Ibarra, E.; Macías-Cervantes, J.; Ruelas-Islas, J. R.; Preciado-Rangel, P.; Ojeda-Bustamante, W.; Inzunza-Ibarra, M. A. y Samaniego-Gaxiola, J. A. 2015. Mejoramiento del grado de uso del nitrógeno en maíz mediante técnicas parcelarias de riego por superficie. Rev. Mex. Cienc. Agríc. 6(8):1903-1914.

Smyth, T. J. and Cravo, M. S. 1990. Phosphorus management for continuous corn-cowpea production in a Brazilian Amazon Oxisol. Agron. J. 82(2):305-309.

Subedi, K. D. and Ma, B. L. 2009. Assessment of some major yield-limiting factors on maize production in a humid temperate environment. Field Crops Res. 110(1):21-26.

Tagarakis, A. C. and Ketterings, Q. M. 2017. In-season estimation of corn yield potential using proximal sensing. Agron. J. 109(4):1323-1330.

Tao, F.; Zhang, S.; Zhang, Z. and Rötter, R. P. 2015. Temporal and spatial changes of maize yield potentials and yield gaps in the past three decades in China. Agric. Ecosystems Environ. 208:12-20.

Van Loon, M. P.; Adjei-Nsiah, S.; Descheemaeker, K.; Akotsen-Mensah, C.; Van Dijk, M.; Morley, T.; Van Ittersum, M. K. and Reidsma, P. 2019. Can yield variability be explained? Integrated assessment of maize yield gaps across smallholders in Ghana. Field Crops Res. 236:132-144.

Verdugo-Vásquez, N.; Acevedo-Opazo, C.; Valdés-Gómez, H.; Araya-Alman, M.; Ingram, B.; García de Cortázar-Atauri, I. and Tisseyre, B. 2016. Spatial variability of phenology in two irrigated grapevine cultivar growing under semi-arid conditions. Precis. Agric. 17(2):218-245.

Wang, J.; Wang, E.; Yin, H.; Feng, L. and Zhang, J. 2014. Declining yield potential and shrinking yield gaps of maize in the North China Plain. Agric. Forest Meteorol. 195-196:89-101.

Youngerman, C. Z.; DiTommaso, A.; Curran, W. S.; Mirsky, S. B. and Ryan, M. R. 2018. Corn Density Effect on Interseeded Cover Crops, Weeds, and Grain Yield. Agron. J. 110(6):2478-2487.

Zare, K.; Vazin, F. and Hassanzadehdelouei, M. 2014. Effects of potassium and iron on yield of corn (*Zea mays* L.) in drought stress. Cercetări Agronomice în Moldova. 47(1):39-47.

Zhao, J.; Yang, X. and Sun, S. 2018. Constraints on maize yield and yield stability in the main cropping regions in China. Eur. J. Agron. 99:106-115.