Article

Production of corn hybrids with stabilized urea and foliar nutrition

Benjamín Zamudio González[1]
Amelia Félix Reyes[1]
Aarón Martínez Gutiérrez[2§]
João Carlos Cardoso Galvão[2]
Alejandro Espinosa Calderón[3]
Margarita Tadeo Robledo[4]

[1]Valle de Toluca Experimental Field-INIFAP. Road Toluca-Zitacuaro km 4.5, Zinacantepec, State of Mexico, Mexico. CP. 51350. Tel. 01(722) 4582109. (bzamudiog@yahoo.com.mx; Ame-1307@hotmail.com). [2]Federal University of Viçosa-*Campus* Viçosa. Peter Henry Rolfs Avenue, Viçosa, Minas Gerais, Brazil. CP. 36 570 000. (jgalvao@ufv.br). [3]Valley of México Experimental Field-INIFAP. Highway Los Reyes-Texcoco km 13.5, Coatlinchán, Texcoco, State of Mexico, Mexico. CP. 56250. (espinoale@yahoo.com.mx). [4]School of Higher Studies Cuautitlán-UNAM. (tadeorobledo@yahoo.com).

[§]Corresponding author: aaron_0715@hotmail.com.

Abstract

Six corn hybrids were evaluated in Ixtlahuaca, Villa Victoria and Temascalcingo, State of Mexico, in factorial arrangement, with conventional urea, Urea NitroXtend with Agrotain and Urea NitroXtend with Agrotain + S at a rate of 250 kg ha^{-1} of N and four foliar fertilization treatments (Control, Quimcasa, Disagro and Bios). The combination of factors 3∗6∗3∗4 with four repetitions. The foliar treatments were applied in stage V_{4-6} and V_{9-10}. A sub-subdivided plot design was used, with the larger plot for hybrids, medium plot for urea types and smaller plot for foliar fertilization treatments. The Tukey test at 5% was used for the comparison of means. For grain yield, the averages were Ixtlahuaca 13.6, Temascalcingo with 11.7 and Villa Victoria 10.8 t ha^{-1}, for hybrids it was for the BG1304 of 14.24, BG1384 with 13.79, Syn1806 with 12.28, Albatros with 11.60, H-51AE with 10.25 and H-57AE with 10.24 t ha^{-1}, no response was found to the types of urea, while for foliar fertilization the control (11.13 t ha^{-1}) was surpassed by the Quimcasa treatments (12.36 t ha^{-1}), Disagro (12.49 t ha^{-1}) and Bios (12.30 t ha^{-1}). Positive interactions of hybrids (H) by types of ureas (U) and hybrids x foliar fertilization (F) were found. The high yields obtained are due to the use of new hybrids and the adoption of the best agricultural practices (MPAs), among which soil fertilization and foliar nutrition stand out.

Keywords: *Zea mays* L., microelements, nitrification inhibitors, plant nutrition.

Reception date: June 2018
Acceptance date: August 2018

Introduction

In the State of Mexico, maize grain is produced in an area of 540 632 ha, 84% under rainfed conditions and the rest with irrigation tips. The production of the State of Mexico is 2 036 772 tons with an average yield of 3.62 t ha^{-1} (SIAP, 2015). Even with the growing government support for corn production in the State of Mexico, the growth rate is negative, both in the condition of seasonal and irrigation (Trueba, 2012). To meet the corn grain demand in the State of Mexico, we import grain from states such as Sinaloa or from outside the country (Ramírez and García, 2014), so to achieve self-sufficiency, integrated measures must be implemented to its solution (Ortiz *et al*., 2007).

The use of certified maize seeds in Mexico is 26%, in contrast in the High Valleys of Mexico, of 6% (Espinosa *et al*., 2004). The creole maizes, although they are rustic and adapted in adverse weather conditions in the occurrence of cold-cloudiness-hail-drought-frosts and torrential rains, such as clay-acid soils and irregular sowing practices, have low grain production potential (Espinosa *et al*., 2008). The use of hybrids or improved seeds with high grain production potential is a viable economic alternative (Virgen *et al*., 2010; Virgen *et al*., 2016). Therefore, the increase in corn grain yield is associated 60% by the quality of the seed and the rest 40% is due to the agronomic management of the crop (Espinosa *et al*., 2008).

On the other hand, the nutrition and management of soil fertility is essential to obtain profitable corn production. The fertilization to the soil with nitrogen is a priority, followed by the use of phosphorus and potassium in the soil (Kibet *et al*., 2009) therefore, a balanced dose of NPK has a significant influence on the growth and yield of corn (Redman *et al*., 2011). Nitrogen fertilizers in the soil have losses of 20 to 80%, mainly due to nitrate leaching processes that contribute to the eutrophication of surface waters and volatilization as ammonia or denitrification processes (Bianchini *et al*., 2008; Ferraris *et al*., 2009). An effective agronomic practice to increase the efficient use of nitrogen fertilizers directed to the soil is to split the applications (Cassman *et al*., 2002) according to the nutritional requirement and times of greater demand of the crop (Ciampitti and Vyn, 2014).

In maize it is recommended to apply one third of the total dose of N sowing and the rest in one or two applications in the stage of rapid vegetative growth (V_{4-10}) (Guohua *et al*., 2008; Yu-kui *et al*., 2009; Ciampitti and Vyn, 2014). In this sense, based on industrial technology, nitrogen fertilizers are offered with inhibitors that reduce the rate of urea transformation such as hydrolysis, blocking of enzymatic activities, and even physical barriers such as waxy covers, and the potential losses of N (Gambaudo and López, 2005; Ferraris *et al*., 2009; Linares *et al*., 2012). The use of nitrogen stabilization technologies represents an alternative due to the high prices of nitrogen fertilizers, since nitrogen stabilizers inhibit nitrification (nitrapyrin, DCD [dicyandiamide]) by reducing the conversion of nitrogen to nitrate and nitrate activity. Urease (NBPT) avoiding losses due to volatilization in the form of ammonia (Havlin *et al*., 2005).

With the incorporation of Agrotain® whose active ingredient is N-(n-butyl) triamide thiophosphoric acid, which blocks the activity of the urease enzyme and consequently retards the hydrolysis and volatilization of ammonia to form compounds with NH_4^+ and the second urea with the same active ingredient Agrotain® plus sulfur (S) as a nutritional complement under the principle of the N-S binomial is accompanied by various plant physiological processes (Barbieri *et al*., 2010; Linares *et al*., 2012; Franzen, 2013).

The use of hybrids and nitrogen fertilization are tools to aspire high yields of corn grain; when combined with the best agronomic practices or MPAs, such as the amendment of organic matter and the liming of acid soils, the retention of water in periods of drought and drainage when excess rainfall occurs, an effective control of weeds and soil pests and foliage (Moreno *et al*., 2004; Bruulsema *et al*., 2008; Kibet *et al*., 2009; Álvarez *et al*., 2010; Tadeo *et al*., 2012).

In order to achieve high agricultural yields, the diagnosis and correction is focused on fine points of weaker production links, among which the foliar fertilization with micronutrients has a high impact (Ling and Silberbush, 2002) and the application of phyto-hormones (Ferraris and Lucrecia, 2008). On the other hand, several authors confirm that foliar fertilization is effective when it is complementary to soil fertilization (Melendez *et al*., 2006; Girma *et al*., 2007). This must be oriented based on chemical diagnosis and there must be certain conditions that allow good results in crops (Santos and Aguilar, 1999). Other references on foliar nutrition have obtained positive results when there are adverse conditions, for example: droughts, floods, frosts, aluminum toxicity and excess carbonates (Yuncai *et al*., 2008) that hinder the absorption of nutrients in the roots of the plants. Therefore, the objective of this study was to evaluate the response of maize hybrids with the application of two types of stabilized urea and foliar fertilization in the High Valleys of the State of Mexico.

Materials and methods

The three experiments were established in the spring-summer agricultural cycle 2013. In the first site is located in Ixtlahuaca in the coordinates (longitude 19° 36.937’, latitude 99° 51.023’ and altitude of 2 535 m) the date of planting was the April 18, with precipitation of 839 mm; the second site was located in Villa Victoria (longitude 19° 25’ 39”, latitude 99° 55’ 12” and altitude of 2519 m) was planted on May 10 and with precipitation of 885 mm; and the third site in Temascalcingo (longitude 19° 55.459’¸ latitude 100 00.613’ and altitude 2 377 m) was planted on May 18, with precipitation 1 181 mm during the crop cycle. The plantings in Ixtlahuaca and Temascalcingo were carried out with ‘irrigation tip’ once the soil reached a moisture point and in Villa Victoria the planting was dry and the germination and emergence occurred at the end of May after rains occurred between on the 13^{th} and 20^{th} of that month.

The physical-chemical conditions of the soils of Ixtlahuaca, Villa Victoria and Temascalcingo, respectively, were: pH 6.48, 4.98 and 6.52 units, organic matter 2.95, 3.2 and 1.74%, textures of clay, clay loam and clay; bulk density of 1.71, 1.42 and 1.53 g cm^{-3}, CIC of 20.2, 10.6 and 12.2 me 100 g^{-1} SS, CE of 0.98, 1 and 2.12 dSm^{-1}, CC of 35, 27.6 and 25%, PMP of 18.9, 14.9 and 12.4%, porosity of 25, 34 and 35%, Mg of 0.37, 0.63 and 1.64 me 100 g^{-1} SS, K of 0.63, 0.15 and 1.19 me 100 g^{-1} SS. The interpretation of the soils is considered to be of low fertility, due to the low content of organic matter, low cation exchange capacity and poor nutrients.

The design of the treatments was formed by combining a complete factorial of three sites, six hybrids, with three types of urea and four foliar treatments, with four repetitions, in a sub sub divided plots design, where the large plot were the hybrids of white grain corn (Albatros, H-51AE, BG1384, Syn1806, H-57AE and BG1304), the average plot for the urea sources (conventional, NitroXtend with Agrotain and NitroXtend with Agrotain + S), and the small plot for the foliar fertilization treatments with commercial products (Control, Quimcasa, Disagro and Bios).

The precision planter was calibrated for 95 thousand seeds per hectare in rows at 0.8 cm. At the time of planting, the soil was fertilized with the formula 80-60-40 of NPK. The rest of nitrogen (170N) was applied in the weeding between stage V_{4-8}, at two different times, which was incorporated into the soil.

The foliar treatments were carried out in two moments: in V_{4-6} and V_{9-10} and the contents of the products were: for the first treatment, the control was considered with application of water to the foliage. In the second treatment of the Quimcasa company, three products were used: in the first application, it was with Q2000 (selective germicidal iodophide with nitrogen-fixing bacteria, mycorrhizae, entomopathogenic fungi, iodine is free at 0.84%) and the second application was with QCyan (organic product containing nitrogen-fixing bacteria) and QEnergy (humic and fulvic acids, carbohydrates, free amino acids, biostimulants, macro and micronutrients).

The third foliar treatment of the company Disagro was in combination of three products: MaxiStart + Nano Max Fierro + Nano Max Zinc. The MaxiStart (extract of the seaweed Ascophyllum nodosum and micronutrients chelated with EDTA). Nano Max Fierro (chelated iron associated with complex carbohydrate derivatives of vegetable origin). Nano Max Zinc (chelated zinc and boron). And the fourth foliar treatment was from the BIOS company, two products were used sequentially: BIO Esperanza and BIO Cosecha. Both products contain organic nutrients of vegetable origin enriched with minerals.

The management of the crop was carried out with a strict control of pests of soil and foliage, as well as of weeds with weed and herbicides. The climate during the cycle was favorable for the vegetative and reproductive development of corn; the cycle lengthened by late rains that allowed a full grain filling, however, delayed the date of the harvest because the cobs were kept with high humidity until December.

The variables that were measured with four repetitions were: height of insertion of spike and cob, number of plants and cob harvested, weight of straw, weight of cob, weight of grain, weight of corn for the calculation of grain index of the cob, number of large cobs, medium and small. In addition, the production variables were measured; hectoliter weight of the grain and percentage of grain moisture, straw production and grain yield adjusted to 14% moisture. When continuing with the characterization of the cob, by method, the length and diameter of the large cobs were evaluated. The variables evaluated were analyzed with the statistical package SAS Ver. 9.3. The comparisons of means and interactions were separated with the Tukey test at 5% error.

Results and discussion

The factorial statistical analysis detected highly significant differences in 14 of the 16 study variables (Pr> F 0.0001) except for the length and diameter of the cob that did not present significant differences (Table 1). Regarding the field variables (from 1-4, Table 1), the average density of the harvested plant experiment was 90 600 per ha. The average height of plant and cob was 254 and 144 cm, respectively; and the total number of cobs harvested on average was 116 425 per hectare, which are qualified as 'high' in comparison to the traditional sowing practice in the region in the order of 70 000 plants ha^{-1}.

Table 1. Significance and average of 16 response variables with respect to the design of site treatments, hybrids, urea types and foliar fertilization. High Valleys of the State of Mexico, INIFAP. 2013.

Variable response	Units	R^2	CV	Average	F- Value	Pr> F
1. Density	(Plants ha^{-1})	0.51	6.13	90 600	11.4	<0.0001
2. Plant height	(cm)	0.59	6.4	254	15.8	<0.0001
3. Height of cob	(cm)	0.61	9.68	144	17	<0.0001
4. Harvested cobs	(num ha$^{-1)}$	0.47	11.13	116 425	9.9	<0.0001
5. Index of cob	(num)	0.61	44.8	1.2	17.4	<0.0001
6. Large cobs	(num)	0.41	27.07	15.5	7.7	<0.0001
7. Medium cobs	(num)	0.31	23.96	19.3	4.9	<0.0001
8. Small cobs	(num)	0.22	32.3	11.7	3.2	<0.0001
9. Grain index	(num)	0.42	4.16	0.82	8	<0.0001
10. Cob length	(cm)	0.09	44.49	17.3	1.1	0.225
11. Diameter cob	(mm)	0.11	31.89	5	1.4	0.024
12. Large cob weight	(g)	0.38	11.17	210.2	6.8	<0.0001
13. Hectolytic Weight	(g L^{-1})	0.55	2.53	770	13.6	<0.0001
14. Moisture grain	(%)	0.51	6.48	16.1	11.4	<0.0001
15. Straw	(t ha^{-1})	0.2	58.89	21.3	2.8	<0.0001
16. Yield at 14%	(t ha^{-1})	0.73	10.75	12.1	30.2	<0.0001

From the variable 5 to 12 of Table 1, the mean values of the characteristics of the cob of an area collected in 4 m^2 are presented. It is observing the number of large, medium and small cobs were 15.5, 19.3 and 11.7 respectively, this distribution resembles a normal curve. The length of the cob on average was 17.3 cm and the diameter of the cob was 5.1 cm but without observing significant difference between the factors. The grain index the average was 0.82, this is the weight of a cob 82% corresponds to the grain and the rest 18% is from the cob. This value is within the values reported in the literature (Hernández and Esquivel, 2004; Pecina *et al*., 2011). The hybrids expressed their maximum potential given the conditions of management and the favorable climate.

From the production variable from 13 to 16 (Table 1 and 2) the averages were: hectoliter weight of 770 g L^{-1}, grain moisture at the time of harvest of 16.1%, straw yield of 21.3 t ha^{-1} and grain production adjusted to 14% humidity of 12.1 t ha^{-1}. The production of straw exceeding 20 t ha^{-1} stands out, it means that it has economic value for the farmer and contrast with values from other regions such as the Bajio of Guanajuato where the average yield of straw is of the order of 10 t ha^{-1}, this direct relation of straw production is proportional to greater grain production in high potential hybrids. By site, all the evaluated variables presented significant differences (Table 2). To consider of greater relevance and economic interest, only the production variables are discussed.

Table 2. Averages[£] of four variables of corn production for three sites in the High Valleys of the State of Mexico, INIFAP. 2013.

Site	Hectoliter weight (g L^{-1})	Humidity (%)	Straw (t ha^{-1})	Grain yield (t ha^{-1})
Ixtlahuaca	780.4 a	15.6 b	25.2 a	13.6 a
Villa Victoria	747.4 b	17 a	19.7 b	10.8 c
Temascalcingo	782.3 a	15.6 b	18.8 b	11.7 b
Average	770	16.1	21.2	12
CV	2.5	6.5	58.8	10.7

[£]= the means with the same letter within the same column are statistically equal (Tukey p= 0.05); CV= coefficient of variation.

The densest grain corresponded to the sites of Temascalcingo and Ixtlahuaca with 782.3 and 780.5 g L^{-1} respectively, in contrast to the grain of Villa Victoria with a hectoliter weight of 747.4 g L^{-1}. Although Villa Victoria presented a lower value than the other sites, it is within the minimum value demanded for the process of nixtamalization and nearby value reported by Vázquez *et al*. (2015); Zamudio *et al*. (2015); Virgin *et al*. (2016). This was due to the fact that the crop had favorable conditions in the reproductive stage maturation of the cob and consequently greater grain density. Likewise, the lower density of the harvested grain in Villa Victoria was associated with a higher percentage of humidity and it was 17.03%, which allows to deduce the cycle of physiological maturation was prolonged. Of the three sites, Ixtlahuaca highlighted the higher grain yield of 13.6 t ha^{-1}, which is consistent with the high straw production of 25.2 t ha^{-1} according to what was reported by Lorenz *et al*. (2010).

The coefficient of general variation of grain yield of 10.7 is similar to that published by González *et al.* (2008) who observed a value of 12.8 on the study of the genetic diversity of corn varieties and hybrids in the Toluca-Atlacomulco Valley, somewhat higher than the value of 2.6 to 6.1 of the study published by Kibet *et al*. (2009) on the effect of moisture and nitrogen in the soil on the behavior of hybrid and creole maize from High Valley of Mexico. This coefficient explains part of the effect due to the irregularity of site conditions such as the topsoil layer (Chioderoli *et al*., 2012). It is convenient to separate the sources of variation by effect of site and hybrids to know the magnitude of the source of variation by genotype and management-environment (Coutiño and Vidal, 2006).

The above, is interpreted from two approaches: the first concerning the stability and uniformity of the hybrids tested and that possibly should be formed with higher quality pressure, and the second criterion from the management itself on the site. It is affirmed according to Witt *et al*. (2006); Roberts (2007); Bruulsema, *et al*. (2008), to obtain maximum yield, the best agricultural practices should be adopted by specific site, to maximize the genetic capacity of the seed and the use of resources to increase profitability.

In relation to the hybrids evaluated in Table 3, the hybrid Albatros was visualized, the highest average grain density was 783.3 g L^{-1}. In contrast, the INIFAP materials (H-51AE and H-57AE) registered the lowest specific grain weights, but commercially acceptable from 753.1 to 756.6 g L^{-1}. The H-57AE presented the grain with the highest moisture content of 16.84% at the time of harvest, which indicates that it is a late material when compared with the other five hybrids. In contrast, the BG384 and Syn1806 materials recorded the lowest moisture values of the grain at harvest.

Table 3. Averages£ of four variables of corn grain production of six hybrids in the High Valleys of the State of Mexico, INIFAP. 2013.

Hybrids	Hectoliter weight (g L^{-1})	Humidity (%)	Straw (t ha^{-1})	Yield (t ha^{-1})
Albatros	783.3 a	16.4 b	22.6 ab	11.6 d
H-51AE	753 d	15.8 cb	19.6 b	10.2 e
BG1384	776.4 bc	15.6 d	20.1 b	13.8 b
Syn1806	780.4 ab	15.5 d	19.4 b	12.3 c
H-57AE	756.5 d	16.8 a	21.3 ab	10.2 e
BG1304	770.5 c	16.1 c	24.4 a	14.2 a
Average	770	16	21.3	12.1
CV	2.53	6.4	58.8	10.7

£= the means with the same letter within the same column are statistically equal (Tukey p= 0.05); CV= coefficient of variation.

The hybrid BG1304 produced 24.4 t ha^{-1} of straw followed by Albatros with 22.6 and H-57AE with 21.3 t ha^{-1} respectively. And the values compared against H-51AE, BG1384 and SYN1806 were significantly higher. These materials are qualified for the cycle of optimum conditions of rain and without frost, they showed their maximum potential in straw production. The grain is the variable of greatest economic interest for the farmer, therefore and under the conditions already described favorable climate and with the adoption of best agricultural practices, stood out in grain yield, the hybrids BG1304 with 14.2 t ha^{-1}, followed by BG1384 with 13.8 t ha^{-1}.

The two hybrids of the INIFAP, H-51AE and H-57AE, had the lowest grain yields with an average of 10.2 t ha^{-1}, compared to the grain yields of the BG hybrids (13.7 to 14.2 t ha^{-1}), being the difference from 3.5 to 4 t ha^{-1}. It follows that the hybrids of the brand (BG) were better adapted to the edaphoclimatic conditions and to an appropriate agronomic management. However, it is worth noting that the H-51AE and H-57AE hybrids in this study exceeded that reported by Tadeo *et al*. (2016) who evaluated these corn hybrids from High Valley of Mexico with grain yields of 7.9 and 8.3 t ha^{-1}, respectively. The materials released by INIFAP are usually formed under a wide range of agroclimatic conditions, so their grain yields tend to be consistent in different scenarios. The above is in agreement to stable gene expression found in corn hybrids evaluated under contrast conditions of moisture and soil N by Kibet *et al*. (2009), as well as that published by other groups of researchers (Gallais and Hirel, 2004; Guohua *et al*., 2008) who identified QTLs on corn chromosome 5, which explain the variation and stability of the use efficiency of N for different types of corn.

In the application of urea treatments stabilized and enriched with sulfur (NitroXtend with Agrotain and NitroXtend with Agrotain + S), they did not have significant effects for production variables such as: hectoliter weight, humidity percentage, straw and grain yield adjusted to 14% humidity (Table 4).

Table 4. Averages£ of four variables of corn grain production, due to the effect of three types of urea in the High Valleys of the State of Mexico, INIFAP. 2013.

Urea	Hectoliter weight (g L^{-1})	Humidity (%)	Straw (t ha^{-1})	Grain yield (t ha^{-1})
UC	773.6 a	15.8 b	22.4 a	12.1 a
UX	768.6 b	16.1 a	20.6 a	12 a
UXS	767.9 b	16.3 a	20.7 a	12.1 a
Average	770	16.1	21.2	12
CV	2.5	6.5	58.8	10.7

£= averages with the same letter in the column are statistically equal (Tukey *p*= 0.05); CV= coefficient of variation; UC= conventional urea; UX= Nitro Xtend with Agrotain; UXS= Nitro Xtend with Agrotain + S.

The no significant response of the urea types stabilized against conventional urea is explained first to the fractionation in three moments of the total N dose and second to the adoption of good agricultural practices such as covering the urea in the second weeding and the occurrence of rain that incorporated the urea of the third application in non-alkaline soil. Thus, the probable loss due to volatilization of conventional urea was low in this study. These results corroborate the non-significant response of urea fertilizers with urease enzyme process reductants and volatilization nitrogen losses published by Gambaudo and López (2005); Barbieri *et al*. (2010); Linares *et al*. (2012).

Regarding foliar fertilization treatments, significant differences were observed for the four production variables (Table 5). Additionally, the FM fertilization treatment (Disagro) was highlighted, which impacted the corn kernel density (772.2 g L^{-1}).

Table 5. Averages£ of four variables of corn grain production by effect of four foliar fertilization treatments in the High Valleys of the State of Mexico, INIFAP. 2013.

Foliar	Hectoliter weight (g L^{-1})	Humidity (%)	Straw (t ha^{-1})	Grain yield (t ha^{-1})
FT	767.1 b	16.8 a	18.8 b	11.1 b
FQ	770.6 ab	16.1 b	21.4 b	12.4 a
FM	772.2 a	16.1 b	23.6 a	12.5 a
FB	770.4 b	15.9 b	21.1 ab	12.3 a
Average	770	16.1	21.2	12.1
CV	2.5	6.5	58.8	10.7

£= the means with the same letter within the same column are statistically equal (Tukey *p*= 0.05); CV= coefficient of variation; FT= foliar witness; FQ= Quimcasa; FM= Disagro; FB= Bios.

For straw production, it varied from 18.8 to 23.6 t ha^{-1}, the latter corresponds to the FM treatment (Disagro) that was superior to the other foliar treatments. The control showed a yield of 11.3 t ha^{-1} of grain adjusted to 14% in comparison to the treatments FB (Bios), FQ (Quimcasa) and FM (Disagro) that presented higher grain yields with 12.3, 12.36 and 12.49 t ha^{-1}, respectively. It was observed that the three treatments of foliar fertilization exceeded at least one tonne of grain against the control and to calculate the costs of these commercial products in two sprays equivalent to approximately 400 kg of corn grain, it is deduced in favorable conditions of climate the fertilization foliar is profitable.

The previous positive results coincide with numerous citations published on foliar fertilization in addition to soil fertilization, among which are noted, Santos and Aguilar (1999) who conclude that the application of foliar fertilization optimizes the production capacity of various crops; Ferraris and Lucrecia (2008) reported an increase in grain yield with foliar applications of micronutrients (Zn and B) up to 12.2 t ha^{-1} of corn kernel compared to the control of 10.2 t ha^{-1}, Potarzycki and Grzebisz (2009) measured increments in average of 18% yield of grain of corn, with foliar applications of 1 to 1.5 kg ha^{-1} of Zn, in the stage of V_5, and even the foliar fertilization of N complementary to the fertilization of N to the soil in the Wheat cultivation according to Bakht *et al*. (2010). In corn Girma *et al*. (2007) achieved the increase of the efficiency of use of P with the foliar fertilization in stage (V_8) with 4 to 8 kg ha^{-1} of P (source KH_2PO_4) in addition to the fertilization of phosphorus to the soil.

Regarding the response by interactions (Table 6), there was a highly significant difference in grain production by hybrid effect by urea (0.008**) and hybrid by foliar (0.012**), but not significant by urea x foliar and neither in the hybrid x urea x foliar interaction.

A significant difference was found for the variables, hectoliter weight and moisture percentage, straw and grain yields in the interactions (hybrids x urea) and (hybrids x leaf). For straw production, all double and triple interactions had a highly significant difference. For grain yield the interaction (urea x foliar) and (hybrid x urea x leaf) did not have significant effects, therefore, the hybrid factor in grain production is considered relevant.

Table 6. Statistical significance (Pr> F) of four variables of corn grain production due to interactions. Stockings from three experimental sites. High Valleys of the State of Mexico, INIFAP. 2013.

Interaction	Hectoliter weight (g L^{-1})	Humidity (%)	Straw (t ha^{-1})	Grain yield (t ha^{-1})
Hybrid x urea	0.031*	0.0001**	0.0161*	0.008**
Hybrid x foliar	0.007**	0.0001**	0.008**	0.012**
Urea x foliar	0.085	0.077	0.046*	0.378
Hybrid x urea x foliar	0.526	0.002**	0.001**	0.303

**= significant to 1% by the test of F; *= significant at 5%; ns= not significant.

In order to visualize and identify possible significant differences by foliar fertilization treatments in production variables of each hybrid in the particular, six hybrid blocks were formed with the interactions of the foliar fertilization treatments (Table 7). There were no significant statistical differences for treatments of foliar fertilization by hybrids for hectoliter weight and straw yield. When visualizing the contents of grain moisture percentages of the hybrid interactions per foliar, only the hybrid Albatross was observed with the treatment without foliar fertilization, the value was higher with 17.3 with respect to the treatments of FM (16.04) and FB (15.94). For this hybrid, it is affirmed the foliar fertilization advances the maturity of the grain. The rest of the hybrids and interactions with foliar fertilization treatments were not found average difference.

Table 7. Comparison of means£ of four variables to the maize crop due to the effect of the double interactions of six hybrids by four treatments of foliar fertilization.

Interaction	Hectoliter weight (g L^{-1})	Humidity (%)	Straw (t ha^{-1})	Yield (t ha^{-1})
H1FT	783.5 ab	17.3 ab	19.3 b	10.5 fgh
H1FQ	779.4 abc	16.6 abcd	23 b	11.7 cdefg
H1FM	783.5 ab	16 adef	23.5 b	12.2 cd
H1FB	786.7 a	15.9 defg	24.5 ab	12 cdefg
H2FT	752.4 de	15.3 efg	17.4 b	9.6 h
H2FQ	757.7 cde	16.2 bcde	21.2 b	10.5 fgh
H2FM	751 de	16.1 cdef	20.2 b	10.4 gh
H2FB	751 de	15.6 defg	19.5 b	10.4 gh
H3FT	773 abcd	15.9 defg	19.5 b	13 bc
H3FQ	781.2 abcd	15 fg	20.2 b	14.3 ab
H3FM	772.2 abcd	16 cdef	20.4 b	13.9 ab
H3FB	779.2 abcd	15.8 defg	20.2 b	14 ab
H4FT	778.1 abc	15.8 defg	17.3 b	11.3 defg
H4FQ	781.8 abc	15.4 efg	20.1 b	12.9 bc
H4FM	784.3 abc	14.8 g	19.1 b	12.8 bcd
H4FB	777.4 abc	16.1 cdef	21.1 b	12.2 cde
H5FT	748.1 c	17.4 a	19.9 b	9.6 h
H5FQ	753.1 cde	17.1 abc	22 b	10.2 gh
H5FM	762.5 bcd	16.4 abcde	22.6 b	10.5 fgh
H5FB	762.4 bcde	16.4 abcde	20.4 b	10.7 efgh
H6FT	767.6 abcde	15.8 defg	19.2 b b	12.7 bcd
H6FQ	770 abcde	16.2 bcde	21.9 b b	14.6 a
H6FM	779.2 abc	15.78 defg	35.5 b b	15 a
H6FB	765.3 abcde	16.54 abcd	20.9 b b	14.6 a

£= the means with the same letter within the same column are statistically equal (Tukey *p*= 0.05).

There were significant differences in corn grain production due to foliar fertilization treatments associated with the interaction of hybrids H_1 (Albatros), H_4 (Syn1806) and H_6 (BG1304). The above, because when comparing the means in the blocks of said hybrids, it is observed that the treatments with FT (control) showed a lower average grain yield. Corn grain yields of the H_6

interactions (BG1304) are highlighted with the three foliar fertilization treatments with 14.6, 15 and 14.6 t ha^{-1}, for FQ (Quimcasa), FM (Disagro) and FB (Bios) respectively, against the witness whose yield was 12.7 t ha^{-1}.

The results of the present study when considering positive interactions of hybrids with some other management factor such as urea types focused to increase the efficiency of N use and foliar fertilization treatments, coincide with several authors, among which Kibet *et al.* (2009) with studies of the effect of soil moisture and nitrogen on the behavior of hybrid and creole maize from the High Valleys of Mexico, to Moreno *et al*. (2004) in relation to recurrent reciprocal selection in corn populations of High Valleys in high and low nitrogen content soils in Mexico, to Reta *et al*. (2003) who evaluated yield and corn yield components in response to topological arrangements, Tadeo *et al*. (2012) with studies of population density and fertilization in sterile and fertile corn hybrids, by Barbieri *et al*. (2010) to optimize maize fertilization with slow release urea, from the Ciampitti and Vyn. (2011) group for a better understanding of the population density relationship of the corn crop and the dynamics of absorption and transport of N from the vegetative to the reproductive stage, studies by Haishum *et al*. (2006) with a model of development and production of maize hybrids with the variables of the water-soil-management system.

In this way, continuity is given to the partial solution of the problem expressed by several authors as the approaches published by Ortiz *et al*. (2007) on the national production of corn and proposals for action, from the writing by Turrent (2008) on the estimation of the productive potential of corn in the Mexican Republic; what was expressed by Ramírez and García (2014) in the study of the potential production and consumption of corn in the State of Mexico and by Trueba (2012) in their study to characterize the productive potential of corn seeds in Mexico, among other authors.

The line of investigation and technological innovation of corn does not end and suggests the adoption of new hybrids and plant nutrition, for which it is necessary to continue with studies integrating agronomic approaches with methodological evaluations of physiological and biotechnological approaches to deepen understanding and solution of the need to produce more food sustainably and with less risk to the environment and human health as proposed by Gallais and Hirel (2004).

Conclusions

In High Valleys of the State of Mexico, under a favorable climate, high yields of corn grain were obtained, with a general average of 12.07 t ha^{-1}. The best combination of factors to obtain maximum corn grain yields per specific site in t ha^{-1}, were: for Ixtlahuaca the hybrid BG1384 yielded 15.08 with conventional urea to the soil and foliar fertilization of the product Disagro, for Villa Victoria with the hybrid BG 1304 yielded 13.8 with urea Urea Xtend to the soil and with foliar fertilization of the product Quimcasa and for Temascalcingo; corn hybrid BG 1304 yielded 14.4 with urea Urea Xtend + S to the soil and with foliar fertilization of the product Disagro. On average for the variables hectolitre weight, humidity and straw were 770.06 g L^{-1}, 16.08% and 21.25 t ha^{-1}, respectively, these are due to the adoption of new hybrids and best agricultural practices (MPAs) as the foliar fertilization of this study.

Cited literature

Álvarez, S. J. D.; Gómez, D. A. V. N.; León, M. S. y Gutiérrez, M. F. A. 2010. Manejo integrado de fertilizantes y abonos orgánicos en el cultivo de maíz. Agrociencia. 44(5):575-586.

Bakht, J.; Shafi, M.; Zubair, M.; Aman, M.; Shah, K. and Shah, Z. 2010. Effect of foliar vs. soil application of nitrogen on yield and yield components of wheat varieties. Pakistan. J. Bot. 42(4):2737-2745.

Barbieri, P. A.; Echeverría, H. E.; Sainz, R. H. R. y Maringolo, M. 2010. Fertilización de maíz con urea de liberación lenta: pérdida por volatilización y eficiencia de uso de nitrógeno. Argentina. Ciencias del Suelo. 28(1):57-66.

Bianchini, A.; Garcia, F. and Melchiori. R. 2008. Nitrogen in the environment: sources, problems, and management. *In*: Hatfield, J. and Follet, R. (Eds.). Elsevier-Academic Press, San Diego, CA. USA. 105-124 pp.

Bruulsema, T. W.; Witt, C.; Garcia, F.; Li, S.; Rao, N.; Chen, F. and Ivanova, S. 2008. A global framework for fertilizer BMPs. USA. Better Crops. 92(2):13-15.

Cassman, K. G.; Dobermann, A. and Walters, D. T. 2002. Agroecosystems, nitrogen use efficiency, and nitrogen management. USA. Agron. Hortic. 31(2):132-140.

Chioderoli, C. A.; Mello, L. M. M.; Noronha, R. H. D. F.; Pariz, C. M. and Lima, R. C. 2012. Spatial and linear correlations between soil and corn. Brasil. Revista Brasileira de Ciência do Solo. 36(3):765-774.

Ciampitti, I. A. and Vyn, T. J. 2011. A comprehensive study of plant density consequences on N uptake dynamics of maize plants from vegetative to reproductive stages. USA. Field Crops Research. 121(1):2-18.

Ciampitti, I. A. and Vyn T. J. 2014. Understanding global and historical nutrient use efficiencies for closing maize yield gaps. USA. Agron. J. 106(6):1-11.

Coutiño, B. E. y Vidal, M. V. A. 2006. Componentes de varianza de híbridos de maíz evaluados en la faja maicera de los Estados Unidos. México. Agrociencia. 40(1):89-98.

Espinosa, C. A.; Tadeo, R. M.; Martínez M. R.; Lothrop, J.; Azpiroz, R. S.; Tut, y C. C.; Bonilla, B, J.; María, R. A.; Pérez, C. J. P.; Ávila, P. M. A.; Gámez, V. J. y Salinas, M. Y. 2004. H-50 nuevo híbrido de maíz para los Valles Altos de México-INIFAP. Folleto técnico núm. 17. 20 p

Espinosa C., A., Tadeo, R. M.; Turrent, F. N.; Gómez, M. O.; Sierra, M. M.; Palafox, C. F.; Caballero, R. V. y Flavio, R. M. 2009. El potencial de las variedades nativas y mejoradas de maíz. Ciencias. 92(92):118-125.

Ferraris, N. G. y Lucrecia, L. A. 2008. Respuesta del maíz a la fertilización complementaria con nitrógeno y zinc por vía foliar. *In*: experiencias en fertilización y protección del cultivo de maíz. Proyecto Agrícola, CERBAN, EEA Pergamino y General Villegas. 116-122 pp.

Ferraris, N. G.; Coureto A. L. y Toribio, M. 2009. Pérdidas de nitrógeno por volatilización y su implicancia en el rendimiento del cultivo de maíz en Pergamino (bs as). Efectos de fuente, dosis y uso de inhibidores. *In*: Proyecto Regional Agrícola, Instituto Nacional de Tecnología Agropecuaria (INTA). Informaciones Agronómicas. 10-13 p.

Franzen, D. W. 2013. Volatilization losses from urea. *In*: Wisconsin Crop Management Conference. 52(1):139-155.

Gallais, A. and Hirel, B. 2004. An approach to the genetics of nitrogen use efficiency in maize. J. Exp. Bot. 55(396):295-306.

Gambaudo, S. y López, O. 2005. Eficiencia en el uso de los fertilizantes: efecto del inhibidor de la enzima ureasa. Estación Experimental Agropecuaria Rafaela. Información técnica cultivos de verano. Publicación Miscelánea. 104(1):14-17.

Girma, K.; Martin, K. L. and Freeman, K. W. 2007. Determination of optimum rate and growth stage for foliar-applied phosphorus in corn com. USA. Soil Sciences and Plant Analysis. 38(9):1137-1154.

González, H. A.; Vázquez, G. L. M.; Sahagún, C. J. y Rodríguez, P. J. E. 2008. Diversidad fenotípica de variedades e híbridos de maíz en el valle Toluca-Atlacomulco, México. Rev. Fitotec. 31(1):67-76.

Guohua, M.; Fanjun, C. and Fusuo, Z. 2008. Physiological and genetic mechanisms for nitrogen use efficiency in maize. J. Crop Sci. Biotechnol. 10(2):57-63.

Haishun, Y.; Dobermann, A.; Cassman, K. G.; and Walters, D. T. 2006. Features, Applications, and Limitations of the Hybrid-Maize Simulation Model. Agronomy Journal. 98(1):737-748.

Havlin, J. L.; Beaton, J. D.; Tisdale, S. L. and Nelson, W. L. 2005. Soil fertility and fertilizers. An introduction to nutrient management. Pearson Education, Inc. Upper Saddle River, New Jersey. 7th (Ed.). 153-157 pp.

Hernández, C. J. M. y Esquivel, E. G. 2004. Rendimiento de grano y características agronómicas en germoplasma de maíz de Valles Altos de México. Rev. Fitotec. Mex. 27(1):27-31.

Kibet, S. C.; López, C. C. y Kohashi, S. J. 2009. Efecto del nivel de humedad y nitrógeno en el suelo en el comportamiento de maíces híbridos y criollos de los Valles Altos de México. Agron. Costarric. 1(33):103-120.

Linares, M.; Barrios, M. y Solórzano, P. 2012. Efecto de la fertilización con urea tratada con inhibidor de la nitrificación sobre el rendimiento y la nutrición del maíz. Rev. Facultad de Agronomía. 38(2):41-48.

Ling, F. and Silberbush, M. 2002. Response of maize to foliar vs soil application of nitrogen-phosphorus-potassium fertilizers. USA. J. Plant Nutr. 25(11):2333-2342.

Lorenz, A. J.; Gustafson, T. J.; Coors, J. G. and De Leon, N. 2010. Breeding maize for a bioeconomy: a literature survey examining harvest indexand stover yield and their relationship to grain yield. Crop Sci. 50(1):1-12.

Meléndez, L.; Hernández, A. y Fernández, S. 2006. Efecto de la fertilización foliar y edáfica sobre el crecimiento de plantas de maíz sometidas a exceso de humedad en el suelo. Bioagro 18(2):107-114.

Moreno, P. E. C.; Beck, L. D.; Cervantes. T. y Torres, F. J. L. 2004. Selección reciproca recurrente en poblaciones de maíz de Valles Altos en suelos con alto y bajo contenido de nitrógeno en México. Agrociencia. 38(1):305-311.

Ortiz, C. J.; Ortega, P. R.; Molina, G. J.; Mendoza, R. M.; Mendoza, C. M. C.; Castillo, G. F.; Muñoz, O. A.; Turrent, F. A. y Kato, Y. T. A. 2007. Análisis de la problemática de la producción nacional de maíz y propuestas de acción. UACH-CP-INIFAP. 29 p.

Pecina, M. A.; Mendoza, C. M. C.; López, S. J. A.; Castillo, G. F.; Mendoza, R. M. y Ortiz, C. J. 2011. Rendimiento de grano y sus componentes en maíces nativos de Tamaulipas evaluados en ambientes contrastantes. Rev. Fitotec. Mex. 34(2):85-92.

Potarzycki, J. and Grzebisz, W. 2009. Effect of zinc foliar application on grain yield of maize and its yielding components. Czech Republic. Plant, Soil Environ. 55(12):519-527.

Ramírez, J. R. y García, S. J. A. 2014. Producción potencial y consumo de maíz en el Estado de México. Agroproductividad. 7(1):1-13.

Redman, A.; Farrukh, S. M.; Hussain, S. and Akhtar, N. 2011. Grain quality, nutrient use efficiency, and bioeconomics of maize under diferent sowing methods end NPK levels. Pakistán. Chilean J. Agric. Res. 71(4):586-593.

Reta, S. D. G.; Gaytán, M. A. y Carrillo, A. J. S. 2003. Rendimiento y componentes del rendimiento de maíz en respuesta a arreglos topológicos. México. Rev. Fitotec. Mex. 26(2):75-80.

Roberts, T.L. 2007. Right product, right rate, right time, right place. The foundation of BMPs for fertilizer. IFA Workshop on Fertilizer Best Management Practices (FBMPs). Brussels, Belgium. Better Crops. 91(4):14-15.

SIAP-SAGARPA. 2015. Servicio de Información Agroalimentaria y Pesquera-Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Información básica. www.siap.sagarpa.gob.mx/index.php?option=com_content&view=article&id=10&Itemid =15F.

Santos, A. T. y Aguilar, M. D. 1999. Fertilización foliar, un respaldo importante en el rendimiento de los cultivos. Terra Latinoam. 17(3):247-255.

Tadeo, R. M.; Espinosa, C. A.; Chimal, N.; Arteaga, E. I.; Trejo, P. V.; Canales, I. E.; Sierra, M. M.; Valdivia, B. R.; Gómez, M. N.; Palafox, C. A. y Zamudio, G. B. 2012. Densidad de población y fertilización en híbridos de maíz androestériles y fértiles. Terra Latinoam. 30(2):157-164.

Tadeo, R. M.; Zaragoza, E. J.; Espinosa, C. A.; Turrent, F. A.; Zamudio, G. B.; Virgen, V. J.; Mora, G. K. Y. y Valdivia, B. R. 2016. Productividad de la generación F1 y F2 de híbridos de maíz (*Zea mays* L.) de Valles Altos de México. Agrociencia. 50(1):33-41.

Trueba, C. A. J. 2012. Estudio para caracterizar el potencial productivo de las semillas de maíz en México. Secretaría de Agricultura, Ganadería Desarrollo Rural, Pesca y Alimentación (SAGARPA). 211 p.

Turrent, F. A. 2008. Estimación del potencial productivo de maíz en la República Mexicana. *In*: reserva estratégica de alimentos, una alternativa para el desarrollo del campo mexicano y la soberanía alimentaria. (Ed.). Franco, C. y Álvarez, M. UACH. 111-118. pp.

Vázquez, C. M. G.; Arellano, V. J. L. y Santiago, R. D. 2015. Rendimiento y calidad de grano y tortilla de maíces híbridos de Valles Altos de México crecidos en riego y temporal. México. Rev. Fitotec. 38(1):229-237.

Virgen, V. J.; Arellano, V. J. L.; Rojas, M. I.: Ávila, P. M. A. y Gutiérrez, H. G. F. 2010. Rendimiento y calidad de semilla en cruzas simples de híbridos de maíz (*Zea mays* L.) para Valles Altos, bajo dos densidades de población de Tlaxcala. Rev. Fitotec. Mex. 33(4):247-255.

Virgen, V. J.; Zepeda, B. R.; Ávila, P. M. A.; Espinosa, C. A.; Arellano, V. J. L. y Gámez, V. A. 2016. Producción y calidad de semillas de maíz en Valles Altos de México. Agron. Mesoam. 1(27):191-206.

Witt, C.; Pasaquim, J. M. and Dobermann, A. 2006. Toward a site specific nutrient management approach for maize in Asia. USA. Better crops with plant food. 90(2):28-31.

Yu, K. R.; Shi, L. J.; Fu, S. Z.; and Jian, B. S. 2009. Effects of nitrogen fertilizer input on the composition of mineral elements in corn grain. Agrociencia. 43(1):21-27.

Yuncai, H.; Burucs, Z. and Schmidhalter, U. 2008. Effect of foliar fertilization application on the growth and mineral nutrient content of maize seedlings under drought and salinity. USA. Soil Sci. Plant Nutr. 54(1):133-141.

Zamudio, G. B.; Tadeo, R. M.; Espinosa, C. A.; Martínez, R. J. N.; Celis, E. D. I. y Valdivia, B. R. 2015. Eficiencia agronómica de fertilización al suelo de macro nutrimentos en híbridos de Maíz. México. Rev. Mex. Cienc. Agríc. 7(6):1557-1569.