

Forage yield and morphological composition of native maize under semi-arid conditions

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Abstract

Environmental conditions in semi-arid areas limit the productivity of forage species used in animal feed; however, corn (*Zea mays* L.) has a wide adaptation to different environmental conditions of temperature, precipitation, altitude, soil, among others. The objective of the present study was to evaluate the yield and morphological composition of ten native corn genotypes, a hybrid and a synthetic variety, during the cycle Spring-Summer 2017. A randomized complete block experimental design was used, and an analysis of variance was performed; the means of the treatments were compared with the Tukey test. The variables evaluated were: yield of total dry matter (TDM), and by morphological component: leaf (IDM), stem (sDM), ear (eDM), panicle (pDM) and dead matter (dmDM), plant height (PH), number of leaves (NL), leaf length (LL), leaf width (LW) and the leaf/stem ratio (L/S). The highest and lowest TDM yield was obtained by the Raton×Tuxpeño Norteño genotype and the A6-069-B hybrid, with 8 888 and 3 113 kg DM ha⁻¹, respectively. The highest height (180 cm) was obtained by the genotypes Raton×Tuxpeño Norteño and Olotillo×Tuxpeño. The largest number of leaves number was presented by the genotype Tuxpeño Norteño×Olotillo with 11.6. The largest leaf:stem ratio (2.1) was in the synthetic variety Breve Padilla. More research is needed on the improvement by recurrent selection of the Raton×Tuxpeño Norteño genotype to obtain a higher yield and nutritional value in corn fodder.

Keywords: *Zea mays*, forage potential, genotypes.

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Introduction

Maize (*Zea mays* L.) due to its wide range of adaptation to different climates and soil types has been cultivated in different regions of Mexico, in 2017 the planted area was 6.4 million hectares (SIAP, 2018), the maize produced is mainly destined for human consumption and for animal feed. In Mexico, the area cultivated with native corn ranges between 70 and 80% of the planted area, its establishment is done with a dual purpose (for human consumption and animal feed); therefore, the improvement has focused on grain production mainly, leaving aside the nutritional value of forage (Franco *et al.*, 2015), which is considered an important aspect in animal nutrition.

In this regard, forage maize are considered as genotypes with considerable profitability in the different production systems, due to their nutritional value and high yields of green or dry matter, which favors being a food source commonly used in livestock systems (Franco *et al.*, 2015; Nuñez *et al.*, 2015).

However, when corn is destined for silage, the grain filling stage must be considered at the time of harvest, which should be $\frac{1}{2}$ or $\frac{1}{3}$ of the milk line, since this influences the nutritional value of the forage (González *et al.*, 2006; Ruiz *et al.*, 2006).

Therefore, harvesting the plant in a milky or doughy grain reduces the yield of dry matter per hectare, nutritional value and digestibility of the forage (Nuñez *et al.*, 2005). In this sense, in 2016, 425 thousand hectares of forage maize were planted with a yield of 43 t ha⁻¹ of green matter (SIAP, 2017), which is around 9.5 t DM ha⁻¹, considered a low yield, by this, in several production systems makes it an expensive input.

In the state of Tamaulipas, there is a great diversity of native germplasm unexplored in its entirety (Castro-Nava *et al.*, 2014), so evaluating forage yield is a viable option to identify genotypes with higher forage characteristics.

For this, it is important to carry out previous studies of the materials to be established in a given area and, based on the results, carry out improvements to increase their yield and nutritional value of the forage (Reynoso *et al.*, 2014). Therefore, the objective of the present study was to evaluate the yield and morphological composition of ten native maize genotypes, one hybrid and one synthetic variety under semi-arid conditions in the state of Tamaulipas.

Materials and methods

This study was carried out during the spring-summer cycle of 2017, in the Common San Lorencito, Municipality of Jaumave, Tamaulipas. Located at the coordinates 23° 22' 56" north latitude and 99° 24' 56" west longitude, at 735 masl. The climate is classified as BS₁ hw (Vargas *et al.*, 2007). The average annual temperature ranges between 21 and 23 °C and the average annual precipitation is 473 mm. The soil texture is clayey with alkaline pH (8.0). The genetic material evaluated was 10 native genotypes from the municipalities of Jaumave, Tula and Ocampo, Tamaulipas (Table 1).

Table 1. Genetic material evaluated (native and hybrid maize) and provenance origin.

Treatment	Genotype	Municipality
1	Olotillo	Jaumave
2	Bolita × Raton	Jaumave
3	Tuxpeño I	Tula
4	Olotillo × Raton	Tula
5	Tuxpeño Norteño × Olotillo	Tula
6	Raton × Tuxpeño Norteño	Jaumave
7	Tuxpeño × Elotes Occidentales	Tula
8	Tuxpeño Norteño	Ocampo
9	Olotillo × Tuxpeño	Tula
10	Tuxpeño II	Ocampo
11	Synthetic variety Breve Padilla	
12	Hibrido A6-069-B	

The preparation of the land was carried out with agricultural machinery (plow and harrow). Before planting, a rolling irrigation was applied and it was cultivated with animal traction. Weed control was performed manually and Emamectin Benzoate (1 mL L⁻¹) was applied with a spray backpack for the control of the armyworm (*Spodoptera frugiperda*). It was fertilized with 46 kg ha⁻¹ of N (Urea) at the time of planting. The sowing was carried out manually by punch, depositing three seeds per blow, with a distance of 80 cm between rows and a separation between plants of 50 cm. To obtain a density of 50 000 plants ha⁻¹, a thinning was carried out eliminating one of the three emerged plants, if applicable.

Each parcel was made up of two furrows 5 m long. The days to male flowering (DMF) and female (DFF) were determined, recorded when 50% of the population was in each of the above stages of flowering. Days to harvest were determined to classify the genotypes as early, intermediate or late, as well as days to harvest after female flowering.

At 113, 116 and 119 days after planting (DDS), the plant height (AH; cm) was measured with a standard, from the ground level to the last upper node (insertion of the panicle) of the plant. In each experimental plot, all the forage present in two linear meters was harvested (20 cm above the ground), weighed and then a sample of approximately 4 kg was taken. Subsequently, the sample was separated into the morphological components of the plant (leaf: IDM, stem: sDM, ear: eDM, panicle: pDM and dead matter: dmDM), then the samples were dried in a forced air stove (OMS60, Thermo Scientific®, USA) at 65 °C for up to 72 h.

Each sample was weighed before and after drying to determine the total dry matter yield (TDM kg ha⁻¹). The number of leaves present in each plant was counted without considering the senescent ones, later the length (LH; cm) and width (AH; cm) of the leaf were measured, where the ear was inserted, which was taken as the basis for Take this measurement and the width was measured at half the length of the sheet. Based on the dry matter yields, the leaf: stem ratio (H:T) was determined.

A randomized complete block design with four replications was used. The data were analyzed using the PROC GLM SAS (SAS, 2003) and when statistical difference was found, the Tukey mean comparison test ($\alpha=0.05$) was applied.

Results and discussion

Statistical analysis indicated significant differences ($p < 0.05$) for the DMF and DFF variables (Table 2). The genotype that reached the fastest flowering time for males (FM) and females (FF) was Olotillo, with 71.5 and 77 d, respectively, and the one that took the longest was Tuxpeño II, with 91.5 and 100.5 d, for FM and FF, respectively. The difference between both genotypes was 20 days. This is attributed to the fact that most of the genotypes were not established in their environment, temperature, precipitation and altitude; environmental factors considered essential for the vegetative development of the plant.

In this regard, it has been mentioned that the absence of precipitation during the stages of vegetative development and changes in the altitude at which the corn crop is established, induce delayed flowering and, therefore, floral asynchrony occurs (Avendaño-Arrazate *et al.*, 2008; Pecina-Martínez *et al.*, 2009).

For the variable days to harvest after sowing, significant differences were found ($p < 0.05$), because the genotypes were harvested on different dates, classifying them as early, intermediate and late when harvested at 113, 117 and 119 DDS, respectively (Table 2).

For the variable days to harvest after female flowering, significant differences were found ($p < 0.05$). It was observed that the greatest number of days elapsed from the female flowering to the harvest was presented by the breve Padilla genotype, with 41 days being earlier compared to the Tuxpeño II and Tuxpeño Norteño \times Olotillo genotypes, which presented fewer numbers with 18.5 and 16.5 days, respectively (Table 2).

Table 2. Time elapsed to male and female flowering, to harvest after planting and harvest after female flowering in maize evaluated in Jaumave, Tamaulipas.

Genotype	Male flowering	Female flowering	Harvest after planting	Harvest after female flowering
	(Days)			
Olot	71.5 e*	77 f	113 c	36 ab
Boli \times Rat	75 de	79 def	113 c	34 bc
Tuxp I	77 de	84 cde	113 c	29 cd
Olot \times Rat	81.5 abcde	85.5 cd	117 b	31.5 bcd
Tuxp Nort \times Olot	89.5 ab	100.5 a	117 b	16.5 e
Rat \times Tuxp Nort	80 bcde	84 cde	117 b	33 bc
Tuxp \times Elot Occi	78.5 cde	83.5 cdef	117 b	33.5 bc
Tuxp Nort	88.5 abc	93 b	119 a	26 d

Genotype	Male flowering	Female flowering	Harvest after planting	Harvest after female flowering
	(Days)			
Olot × Tuxp	83 abc	87.5 bc	119 a	31.5 bcd
Tuxp II	91.5 a	100.5 a	119 a	18.5 e
VS breve Padilla	75.5 de	78 ef	119 a	41 a
Hybrid A6-069-B	77.5 de	81.5 cdef	119 a	37.5 ab

*= means with different literals indicate significant statistical differences (Tukey, $p=0.05$). Olot: Olotillo; Boli= Bolita; Rat= Raton; Tuxp= Tuxpeño; Tuxp Nort= Tuxpeño Norteño; Elot Occi= Elotes Occidentales; SV= synthetic variety.

In the total dry matter yield (TDM) and by component: leaf, stem, ear, panicle and dead material, it was different in the evaluated genotypes ($p < 0.05$; Table 3). The highest and lowest yield of TDM was obtained by the Raton × Tuxpeño Norteño genotype and the hybrid A6-069-B, with 8 888 and 3 113 kg DM ha⁻¹, respectively.

Table 3. Yield of total dry matter, leaf, stem, ear, panicle and dead material of native and hybrid maize in Jaumave, Tamaulipas.

Genotype	IDM	sDM	eDM	pDM	dmDM	TDM
	(kg ha ⁻¹)					
Olot	1 460 b*	1 051 def	845 bc	211 abcd	299 bc	3 866 bc
Boli × Rat	1 560 b	1 510 cdef	1 046 abc	250 abc	452 bc	4 818 bc
Tuxp I	1 802 ab	1 650 cdef	1 040 abc	255 ab	422 bc	5 169 bc
Olot × Rat	2 203 ab	2 095 abcde	1 367 abc	290 ab	369 abc	6 324 abc
Tuxp Nort × Olot	2 251 ab	2 270 abcd	336 c	292 ab	496 abc	5 645 abc
Rat × Tuxp Nort	2 712 a	3 077 ab	2 627 a	270 ab	200 a	8 888 a
Tuxp × Elot Occi	1 631 ab	1 895 bcdef	830 bc	357 a	315 bc	5 028 bc
Tuxp Nort	1 478 b	2 082 abcde	422 c	233 abcd	486 bc	4 701 bc
Olot × Tuxp	2 027 ab	3 338 a	860 bc	206 bcd	467 ac	6 898 abc
Tuxp II	2 026 ab	2 605 abc	163 c	293 ab	432 ac	5 519 abc
SV breve Padilla	1 338 b	617 f	2 226 ab	101 cd	172 bc	4 454 bc
Hybrid A6-069-B	1 318 b	786 ef	793 bc	98 d	118 c	3 113 c

*= means with different literals indicate significant statistical differences (Tukey, $p=0.05$). IDM= leaf dry matter; sDM= stem dry matter; eDM = ear dry matter; pDM= panicle dry matter; dmDM= dead matter dry matter; TDM= total dry matter. Olot= olotillo; Boli= bolita; Rat= ratón; Tuxp= Tuxpeño; Tuxp Nort= Tuxpeño Norteño; Elot Occi= Elotes Occidentales; SV= synthetic variety.

The lower yield of the hybrid (A6-069-B) can be attributed to the climatic conditions where it was evaluated, which were probably not similar to the place where it was developed, since the change in environment in which any genotype is established of corn causes fluctuations in its yield, which may or may not be favorable, the most influencing environmental factors are temperature, precipitation and altitude (Pecina-Martínez *et al.*, 2009; Espinosa-Calderón *et al.*, 2012; Reynoso *et al.*, 2014).

On the other hand, Tadeo-Robledo *et al.* (2015), when evaluating two native corn, Atlacomulco and Ixtlahuaca and two hybrids H-50 and H-52, documented that the production of these genotypes was similar with 7 389, 7 955, 7 207 and 6 773 kg DM ha⁻¹ respectively. These similarities between the yields are attributed to the native germplasm that is present in the hybrids, which gives them characteristics such as adaptability to climate and soil and tolerance to pests and diseases, where they were evaluated.

In this regard, Kibet *et al.* (2009) when evaluating native and hybrid maize under dry and humid conditions, they obtained higher biomass and grain yields in the hybrids compared to native maize. The higher yield in the Raton × Tuxpeño Norteño genotype is due to the fact that it was evaluated in its place of origin and the climatic conditions were favorable for its development; these results could be taken into account for future work mainly on the genetic improvement of this genotype, to achieve higher biomass yields and to be used as forage for animal feed.

In addition, the Raton × Tuxpeño Norteño genotype had the highest leaf yield (2 712 kg DM ha⁻¹), surpassing the Olotillo, Bolita × Raton, Tuxpeño Norteño, breve Padilla and the A6-069-B hybrid genotypes; which obtained a yield of 1 460, 1 560, 1 478, 1 338 and 1 318 kg DM ha⁻¹, respectively.

The dry matter yields of leaf obtained in this investigation are lower than those reported by Elizondo-Salazar (2011), who, when evaluating the effect of cutting height on forage yield of a creole genotype and a hybrid, obtained for the creole harvested at 15 and 45 cm in height, yields of 5 176 and 3 306 kg DM ha⁻¹, respectively. While for the hybrid they were 3 345 and 3 142 kg DM ha⁻¹, respectively. These higher yields obtained can be attributed mainly to the environmental conditions of precipitation, which was 2 050 mm, and to the management provided, such as the height of cut at which the forage was harvested.

Stem accumulation was higher in the Olotillo × Tuxpeño genotype, which obtained a yield of 3 338 kg DM ha⁻¹, while the lowest yield was obtained by a breve Padilla with 617 kg DM ha⁻¹. However, the latter did not present statistical differences with the hybrid A6-069-B, which obtained a yield of 786 kg DM ha⁻¹. These differences between the yields are attributed to the height of the plant, which was lower for Padilla and the hybrid A6-069-B in comparison with the creole genotype Olotillo × Tuxpeño (119-124 vs. 180 cm).

The above is consistent with that documented by Muñoz-Tlahuiz *et al.* (2013), who obtained higher stem yields in corn genotypes with higher plant height. Ear yield showed differences between genotypes ($p < 0.05$); The highest yield was obtained by the genotype in the Raton × Tuxpeño Norteño genotype with 2 627 kg DM ha⁻¹ and the lowest values, the Tuxpeño Norteño × Olotillo, Tuxpeño Norteño and Tuxpeño II genotypes with 336, 422 and 163 kg DM ha⁻¹ respectively. These yields are attributed to the time elapsed from the female flowering to the harvest, which was less in the latter genotypes and therefore presented less development and filling of grain.

The ear is an important component, since it increases protein and digestibility, providing forage with higher nutritional value, which increases animal production (Corral *et al.*, 2010; Elizondo-Salazar, 2011) a characteristic that genotypes presented. They are mainly made up of the

Tuxpeño breed. The greatest and least accumulation of dead matter was obtained by the Tuxpeño Norteño × Olotillo genotype and the A6-069-B hybrid with 496 and 118 kg DM ha⁻¹.

Leaf senescence is a process that decreases the yield and nutritional value of the forage, because the nitrogen content is reduced. One way to decrease the content of dead matter in corn forage is to increase the cutting height, although with this practice there will be a considerable reduction in the yield of total dry matter.

The highest plant height (AP) was obtained by the Raton × Tuxpeño Norteño and Olotillo × Tuxpeño genotypes, both with 180 cm (Table 4). In contrast, the lowest AP was presented by the hybrid A6-069-B with 119 cm. The behavior observed in the hybrid (A6-069-B) is attributed to the improvement that has been made to it, which was in order to reduce the AP to avoid plant collapse; as well as semi-arid climatic conditions, which were not favorable for its adequate growth. In this regard Sánchez *et al.* (2013) when evaluating maize genotypes in humid tropic conditions, they obtained the highest height in the creole genotype with 247 cm, surpassing hybrids and varieties H520, HE1A17, HE2A15, A7573, V556AC and VS536 that obtained heights of 184, 190, 185, 166, 173 and 195 cm, respectively.

Furthermore, the results of this investigation differ from those reported by Tadeo-Robledo *et al.* (2015), who when evaluating native and hybrid maize obtained similar heights between the two native genotypes, Ixtlahuaca and Atlacomulco, compared with those obtained by the H-50 and H-52 creoles of 271, 241 and 262, 245 cm respectively, this attributed to the improvement made in the hybrids and to the native germplasm that they possess, which allows their adaptation to the climatic conditions of High Valleys of the site where they were evaluated.

The leaf length was different between the evaluated genotypes ($p < 0.05$), the Raton × Tuxpeño Norteño genotype obtained the greatest length with 93 cm and the smallest the Tuxpeño I genotype with 61 cm. In the leaf width variable, no significant differences were observed ($p > 0.05$), whose values ranged from 7 to 8 cm. However, in the average number of leaves between the genotypes, statistical differences were obtained ($p < 0.05$; Table 4).

Table 4. Plant height, leaf length, leaf width, number of leaves and leaf/stem ratio of native and hybrid maize in Jaumave, Tamaulipas.

Genotype	AP	LH	AH	NH	H/T
	(cm)				
Olot	133 cde*	79 abc	8 a	8.5 bc	1.5 bc
Boli × Rat	146 bcde	79 abc	8 a	8 c	1 cd
Tuxp I	167 ab	61 c	8 a	9.8 abc	1.1 cd
Olot × Rat	167 ab	75 abc	8 a	10 abc	1.1 cd
Tuxp Nort × Olot	153 abcd	85 ab	8 a	11.5 a	1.1 cd
Rat × Tuxp Nort	180 a	93 a	8 a	9.8 abc	0.9 d

Genotype	AP	LH	AH	NH	H/T
	(cm)				
Tuxp × Elot Occi	150 abcd	75 bc	7 a	10 abc	0.9 d
Tuxp Nort	164 ab	74 bc	8 a	10 abc	0.7 d
Olot × Tuxp	180 a	82 ab	8 a	9.5 ab	0.6 d
Tuxp II	160 abc	81 ab	8 a	11 ab	0.8 d
SV breve Padilla	124 de	82 ab	7 a	8 c	2.1 a
Hybrid A6-069-B	119 e	68 bc	8 a	9.3 abc	1.8 ab

* = means with different literals indicate significant statistical differences (Tukey, $p=0.05$). AP= plant height; LH= leaf length; AH= leaf width; NH= number of leaf; H/T= leaf/stem ratio; Olot= Olotillo; Boli= Bolita; Rat= Raton; Tuxp= Tuxpeño; Tuxp Nort= Tuxpeño Norteño; Elot Occi= Elotes Occidentales; SV= synthetic variety.

The greatest number of leaves was presented by the Tuxpeño Norteño × Olotillo genotype with 11.5, while the Bolita × Raton and breve Padilla genotypes presented the lowest values, with 8 leaves on average for both. It is worth mentioning that senescent leaves were not considered, therefore, lower averages were obtained in the number of leaves compared to that documented by Castro-Nava *et al.* (2014), who obtained averages of 18.6 to 20.3 in commercial hybrids and 18.7 to 19.8 in native genotypes, but similar to those reported by Sánchez-Hernández *et al.* (2019) which ranged from 9.1 to 10.8 when evaluating a synthetic variety, VS536 and four hybrids, DK357, H520, H564 C, NH5 and HE1A17.

The nutritional value of forage is important, since the productivity of the animals depends on it. One way to assess this nutritional value is through the leaf/stem ratio. It has been documented that, at higher values in this variable, the protein content and digestibility in forage is higher (Elizondo-Salazar, 2011).

In this sense, the breve Padilla genotype had the highest value (2.1) compared to native genotypes; but it was similar to the hybrid A6-069-B (1.8), this due to the lower stem thickness and lower plant height, which these materials presented compared to the native genotypes (Sanchez *et al.*, 2013) or the height at which were harvested (Elizondo-Salazar, 2011).

Conclusions

The evaluated materials presented great genetic variability, since they showed differences in most of the variables (dry matter of leaf, stem, ear, plant height, number of leaves and the leaf/stem ratio). The Raton × Tuxpeño Norteño genotype can be used in animal feed to increase productivity in livestock systems, because it presented the highest yield of total dry matter, leaf DM and ear DM; likewise a leaf/stem ratio close to one, which is considered adequate for a forage maize. The results obtained in this research can serve as a reference for future works that have a focus on the genetic improvement of corn for forage production.

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