Article

Production and nutritional quality of corn under rainfed conditions in Aguascalientes, Mexico

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Abstract

In Aguascalientes, during 2014-2016, the production of grain and stubble and the nutritional quality of maize during 2014-2015 was evaluated, cultivated under dry conditions in the municipalities of El Llano (LL) and Rincón de Romos (RR). The production (grain + stubble) was 2 413, 1 072 and 2 059 kg ha^{-1} and 699, 318 and 483 kg ha^{-1} for El Llano and Rincón de Romos, during 2104, 2015, and 2016 respectively. The stubble in LL resulted with 2 113, 969 and 1 856 kg ha^{-1}, against 419, 191 and 290 kg ha^{-1} obtained in RR for the years 2014, 2015, and 2016 correspondingly. The grain production was 299, 103, and 201 kg ha^{-1}, against 280, 127 and 193 kg ha^{-1} for the same municipalities and years reciprocally. The crude protein was similar ($p\geq 0.05$) in 2014 with 6.7 and 6.2% and different ($p\leq 0.05$) in 2015 with 5.3 and 2.9%, for the same municipalities. Neutral detergent fiber was similar ($p\geq 0.05$) with 55.8 and 56.6%, and 61.4, 65.2%, for RR and LL during 2014 and 2015 respectively. The acid detergent fiber differed ($p\leq 0.05$) from 30.9 and 30.2% and 34.6 and 38.3% during the years 2014 and 2015 in RR and LL respectively. The adjusted in situ digestibility curves of the dry matter were similar ($p\geq 0.05$) in the two RR and LL locations, and the 2014 and 2015 evaluation periods.

Keywords: *Zea mays* L., grain, nutritional quality, stubble, temporal.

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Introduction

Mexico and the Mesoamerican region are the center of origin of the maize *Zea mays* L. and its diversification in the more than 50 recognized native races in our territory (Kato, 2005). Corn represents, together with the bean *Phaseolus vulgaris* L., the base of the diet of the majority of Mexican families, and each year they are cultivated from 7 to 8.5 and from 1.8 to 2.1 million hectares of corn and beans, respectively (CEFP/054/2004; CEFP/004/2007), of which 85% are grown under rainfed conditions (Miramontes, 2011), which contribute 65% of the total corn grain produced in Mexico. The country is deficient in yellow corn, which has various uses, mainly livestock, so that there are import requirements of more than five million tons annually (SAGARPA-SIAP, 2015).

The yield potential of the corn crop for grain under irrigation conditions is higher than 20 t ha^{-1}. However, in Mexico, the national average for irrigation is 5.2 t ha^{-1} and 2 t ha^{-1} for temporary (Miramontes, 2011). In Aguascalientes, an area of around 122 000 ha is cultivated annually under rainfed conditions, mainly corn, with disastrous productive results, and the erosive effect of the mechanical and rustic activities carried out (fallowing and tracing) in the preparation of the sowing bed for the establishment of the crop, weeds, damage by lagomorphs and rodents, poor quality of seed, but above all the effect of climate, among others (INIFAP, 1998).

There is a lot of scientifically documented information about maize production with data collected mainly from irrigated areas or with favorable climates for the development of this crop, but not for maize producing areas, but under seasonal conditions (Hernández, 1993). Therefore, the objectives of this work were to determine the production of corn grain and stubble in two municipalities of the state of Aguascalientes Rincón de Romos (RR) and Llano (LL), and quantify the nutritional quality of the stubble under dry conditions during three years of evaluation.

Materials and methods

The work was carried out during the years 2014 to 2016 in two municipalities in the state of Aguascalientes, Mexico, RR and LL. During 2014, three parcels were located and geo-located in each municipality (n= 6), with the position for the RR site being the UTM coordinates (region 13Q): X= 774852, Y= 2465212, 2 021 masl, and for the LL the UTM coordinates (region 13 Q): X= 801162, Y= 2415962, 2 031 masl. The climate of the region is temperate (García, 1988; Medina *et al*., 1998), with an average annual temperature of 20 °C and with shallow, stony soils and poor in organic matter of the Regosol and Feozem type (INIFAP, 1998). Rainfall affects mainly between the months of June to September, which, in 2014, 2015 and 2016, accumulated 342.8, 775.4 and 529.8 mm, and 466.6, 651.8, and 389 mm for RR and LL respectively (Figure 1).

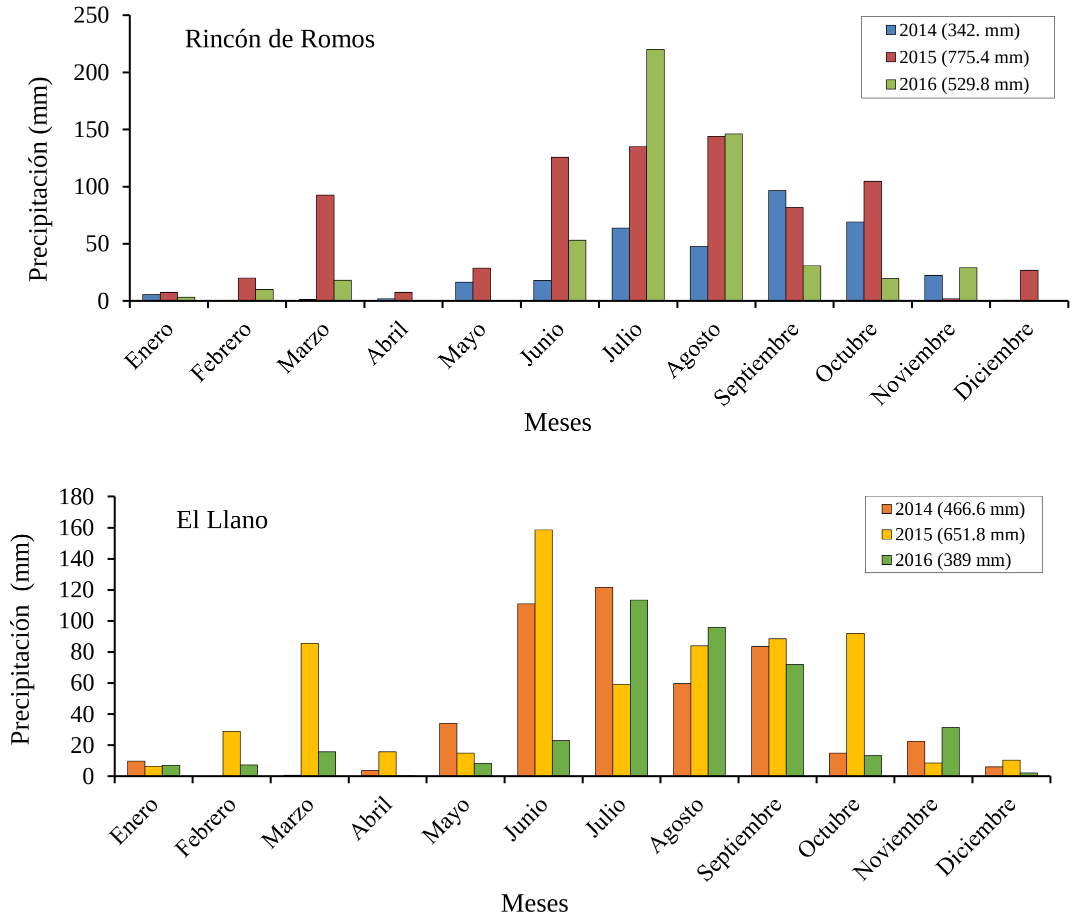

Figure 1. Annual rainfall and monthly distribution in Rincón de Romos and El Llano, Aguascalientes, during 2014-2016.

Soil analysis

The soils were sampled with a 92 cm long LS type soil auger and its 28 cm long sample tube at an average depth of 20 cm. Five samples were collected per plot (n= 30), fifteen samples in the three plots of RR and fifteen in the three plots of LL. Subsequently, the samples were dried at room temperature, ground with a wooden roller and sieved with a 10 mesh (2 mm). They were then cooled to a temperature of 7 °C. The pH (1:2, soil:water) was determined by means of a potentiometer. Organic matter was obtained by the Walkley and Black method, nitrogen was determined by the Kjeldahl method, phosphorus was measured by the Olsen method. The determination of Ca and Mg soluble cations was done by means of an atomic absorption spectrophotometer in the saturation extract. These analyzes were carried out in the Laboratory of Analysis of Soil, Water and Plant Nutrients of the Center of Agricultural Sciences of the Autonomous University of Aguascalientes, in accordance with the procedures established in the Official Mexican Standard (SEMARNAT, 2000). The corresponding results are shown in Table 1.

Table 1. Results of the physical-chemical soil analysis in Rincón de Romos and El Llano, Aguascalientes, 2014.

Variable	Methodology	Rincón de Romos	El Llano
Sand (%)	Bouyoucos	54	38
Slime (%)	Bouyoucos	21.3	37.3
Clay (%)	Bouyoucos	24.7	24.7
Textural class		Sandy clay loam	loam
pH	(1:2 water)	6.4	6.4
Electric conductivity	(1:2 water)	0.1	0.3
Organic material (%)	Walkley y Black	1.4	1.2
Inorganic nitrogen (mg/kg)	Micro Kjeldahl	14.1	7.9
Phosphorus (mg kg)	BrayKurtz 1	6.2	6.9
Potassium (mg kg)	Ammonium acetate	188.1	242.6
Calcium (mg kg)	Ammonium acetate	476.8	447.2
Magnesium (mg kg)	Ammonium acetate	58.9	58.2
Sodium (mg kg)	Ammonium acetate	24.8	24

Grain and stubble production

The sowing was carried out chronologically differently during the three years of evaluation due to the establishment of the rainy season of each year, which for 2014 was in the month of June, for the year 2015 and 2016 it was at the end of July in the two municipalities. The corn seed used in both municipalities for planting was an acrylic variety called SR Pipitillo. Given the different harvesting conditions of corn by the owners of the properties, it was necessary to adapt the evaluation methods to this situation.

On the LL site, producers usually harvest corn when the plants are completely dry, using a chopper-type combine harvester; then this chopped material submits it to the hammer mill to obtain the ground stubble that is the way it is used and marketed. In this site, the sampling consisted of harvesting the standing corn, when it was mature and dry, in five rows at random in each plot and in 20 linear meters at random in each furrow. The total harvested material was weighed first, then the ears were extracted and shelled, weighing the extracted grain. Then, by difference, the stubble weight was calculated. With the distance between rows, production data were calculated per hectare.

On the Rincón de Romos site, producers harvest manually by cutting the corn plants still green, allowing them to dehydrate completely in the monkey. It is harvested with rozadera forming ‘monkeys’. Here, a random sampling was carried out, choosing in each plot a total of five monkeys of the maize already harvested, and to which fifty maize plants were extracted (n= 50). Said plants were weighed individually in three ways: complete plant (stubble and cob), plant without ear (stubble only) and grain. Here the average number of corn canes per monkey and per plot was obtained. With the above data and with the surface data of each plot, the production per hectare was calculated.

The sampling was carried out in the month of December of the years 2014, 2015, 2016, when the plants and the grain of corn were ripe and ready to be harvested. With the above data, production was calculated per hectare on a dry basis: total production (grain and stubble), stubble production and grain production.

Nutritious quality

The dry stubble was harvested in the month of December 2014 and 2015, with three samplings per plot of approximately 1.5 kg, forming a composite sample for the bromatological analysis. The samples were processed in the Animal Nutrition Laboratory of the Agricultural Sciences Center of the Autonomous University of Aguascalientes.

The samples were dried in a forced air oven at a temperature of 60 °C for 24 h and processed using a Wiley® mill with a 1 mm mesh. The crude protein (PC) was analyzed according to the Dumas technique (AOAC, 1990), using a Leco FP-528 nitrogen detector. The fractions of neutral detergent fiber (FDN) and acid detergent fiber (FDA) were analyzed with the method of Van Soest and Robertson (1991). The *in situ* ruminal digestibility of the dry matter (DISMS) was developed based on the nylon bag method (Mehrez and Orskov, 1977) with measurements at 0, 6, 12, 18, 24, 36 48, 72 and 96 hours, to obtain complete digestibility curves and analyze the parameters of degradation kinetics using the mathematical model of Orskov and McDonald (1979).

$$Y = a + b\ (1 - exp^{-c*t})$$

Where: a= is the soluble portion of the forage, measured at 0 h of fermentation (30 min in a water bath at 39 °C); b= is the potentially degradable fraction; c= is the degradation rate per hour, t= is the fermentation time. The sum of the fractions a+b is the total of degradable material. From these parameters, the expected degradability (DE) at 24 and 48h was calculated.

Analysis of data

The analysis of the variables of grain production and maize stubble was carried out by means of analysis of variance (Anova), using a completely randomized design with factorial arrangement 3x2: 3 years of evaluation (2014, 2015, 2016) and two sites LL and RR, with three repetitions (plots) in each site. The nutritional quality of maize stubble was analyzed using Anova, using a completely randomized design with factorial arrangement 2x2: 2 sites LL and RR and two years of evaluation (2014, 2015), with three repetitions. When there were differences between treatments (main effects), the Tukey test ($p\leq 0.05$) (Steel and Torrie 1980) was used for the separation of means with the statistical program SAS (SAS Institute, 2006).

Results and discussion

Grain and stubble production

In relation to the total forage production, the statistical analyzes showed differences ($p\leq 0.01$) for the factors of site and year, and also for the interaction ($p\leq 0.05$). The highest total productions were obtained in the LL in 2014 and 2016, with 2 413 and 2 059 kg ha^{-1} (Table 2).

In RR the productions were lower with 318 and 699 kg ha^{-1}, although statistically equal to LL production in 2015 (1 072 kg ha^{-1}). The stubble production in LL was higher in 2014 and 2016 with 2 113 and 1 856 kg ha^{-1}, while in RR 419 and 290 kg ha^{-1} were obtained in the respective years, these data being statistically equal to the production of stubble in LL in 2015 (969 kg ha^{-1}). The stubble in RR in 2015 was 191 kg ha^{-1}, although statistically equal to the other years of the same site. The stubble represented about 90% of the total production on the LL site, while in RR it represented 60%.

The data related to grain production only showed significant differences between years ($p\leq 0.01$), but not between sites or in the interaction. The highest grain production in the two municipalities was obtained in 2014 and 2016 with averages of 289.5 and 197 kg ha^{-1} respectively, while in 2015 the average grain production was 115 kg ha^{-1} (Table 2).

Table 2. Dry matter production (kg ha^{-1}) in rainfed maize in Aguascalientes, Mexico, 2014-2016.

Year	Site	Total production	Stubble production	Grain production
2014	El Llano	2 413 a	2 113 a	299 a
	Rincon de Romos	699 b	419 bc	280 ab
2015	El Llano	1 072 b	969 b	103 c
	Rincon de Romos	318 b	191 c	127 bc
2016	El Llano	2 059 a	1 856 a	201 abc
	Rincon de Romos	483 b	290 bc	193 abc

Different literals in each column indicate significant differences ($p\leq 0.05$).

In general, the production of grain was extremely low and practically what is harvested is only fodder (stubble). On the other hand, it should be noted that the total production was lower in 2015, despite the fact that this year it had a higher rainfall due to having planted until the end of July. Luna and Gaytan (2001), in Sandovales, Aguascalientes, found average productions of seasonal corn grain with the help of piling and fertilization with the improved variety V-209 and a variety of creole, and chemical fertilization with N-P2O5-K2O kg ha^{-1} of 40-40-00, of 2 264 and 1 982 kg ha^{-1} respectively, showing that the pileting was the factor of greater influence even than the chemical fertilization in the final production of corn grain of both cultivars (V -209 and the creole).

On the other hand, Trueba (2012), in the high valleys of the State of Mexico, with better soil and moisture conditions found maize grain productions under seasonal conditions of the order of 2.65 t ha^{-1}, superior to the productions found in El Llano and Rincón de Romos, Aguascalientes, in this experiment.

Nutritious quality

In relation to the PC content of stubble, similar protein levels were found for the different years and sites (5.3 to 6.7%), except for LL in 2015, which was significantly lower ($p\leq 0.05$) with 2.9% (Table 3). The lower protein content in the LL in 2015, as well as higher fiber content, could be due to the fact that in that year there was late rains, in addition to the harvest being done with a chopper machine until the plants are completely dry, what remain standing individually and exposed to rain, so that there may be leaching of soluble nutrients. Meanwhile in RR the method of harvest is manual in green state by making ‘monkeys’, which decreases the exposure of the forage and the leaching of soluble nutrients.

For the FDN parameter, no significant differences were found ($p \geq 0.05$) between sites or years, with values from 55.8% to 65.2%. Regarding FDA, similar values were found from 30.2 to 34.6%, except for the LL in 2015, which presented 38.3%, which was statistically higher ($p \leq 0.05$) (Table 3).

Table 3. Average content of crude protein (PC) and neutral and acid detergent fibers (NDF and FDA), in rainfed maize in Aguascalientes, Mexico, 2014-2015.

Year	Site	PC (%)	FDN (%)	FDA (%)
2014	Rincon de Romos	6.7 a	55.8	30.9 b
	El Llano	6.2 a	56.6	30.2 b
2015	Rincon de Romos	5.3 a	61.4	34.6 ab
	El Llano	2.9 b	65.2	38.3 a

Different literals in each column indicate significant differences ($p \leq 0.05$).

With respect to the *in situ* digestibility of the dry matter (DISMS), the soluble fraction ‘a’ was higher in 2015 than in 2014 (28.34% vs. 18.79%), and better in the LL compared to RR (26.34% *vs* 20.79%) due to the best rain of the second year. Conversely, the slowly digestible fraction ‘b’ presented an inverse compartment, being better in 2014 than in 2015 (74.88% vs 61.11%) and higher in the RR locality compared to LL (69.61% vs 66.38%). In the end, if the digestibility of both fractions (a + b) is added, changes are observed per year (2014: 93.65 vs 2015 89.45, eem= 1.312, P= 0.053), but not by location (LL: 92.71 vs RR: 90.40; eem= 1.312; P= 0.248). The expected digestibility at 48 h (DE-48 h) was slightly higher in the LL locality in 2014 (87.35%) but decreased in 2015 (83.83%), while in RR it was very similar in both years (2014: 82.34% vs 2015: 83.83%) (eem: 2.090, P= 0.179). A change of 5% in digestibility can imply a change of almost 10% of more net energy of lactation, so it is of the greatest importance to increase the nutritional quality of forages for cattle (Table 4).

Table 4. Digestibility *in sit*u (DISMS) in seasonal maize in two locations of Aguascalientes, Mexico, during 2014 and 2105.

Fraction	Year			Location				Interactions: Year x Location			
	2014	2015	Prob.	LL	RR	Prob.	eem	2014-LL	2014-RR	2015-LL	2015-RR
a (%)	18.79^{a}	28.34^{b}	0.0008	26.34^{b}	20.79^{a}	0.0166	1.301	23.09^{a}	14.49^{a}	29.59^{a}	27.09^{a}
b (%)	74.88^{b}	61.11^{a}	0	66.38^{a}	69.61^{b}	0.0351	0.904	73.11^{a}	76.65^{a}	59.64^{a}	62.58^{a}
c (%)	4.46^{a}	5.23^{b}	0.0041	4.74^{a}	4.95^{a}	0.3088	0.138	4.41^{a}	4.51^{a}	5.07^{a}	5.4^{a}
a+b (%)	93.66^{a}	89.45^{a}	0.053	92.71^{a}	90.4^{a}	0.2484	1.312	96.2^{a}	91.13^{a}	89.23^{a}	89.67^{a}
DE-24h	67.99^{a}	71.96^{a}	0.1147	71.1^{a}	68.85^{a}	0.3457	1.589	70.8^{a}	65.18^{a}	71.4^{a}	72.52^{a}
DE-48h	84.84^{a}	84.4^{a}	0.8385	85.59^{a}	83.65^{a}	0.3816	1.4478	87.35^{a}	82.34^{a}	83.83^{a}	84.98^{a}

^{ab}= Rows with different literals are statistically different ($p \leq 0.05$, HSD Tukey). Standard error of the mean (eem) for year and locality they are equal. LL= El Llano, RR= Rincón de Romos. Parameters of the degradability (%) and expected digestibility (DE) curves at 24 and 48 h, using the Orskov and McDonald Model: Y= a + b (1-exp^{-c*t}).

Based on the previous results, statistically adjusted *in situ* digestibility curves of the dry matter were calculated (Figure 2).

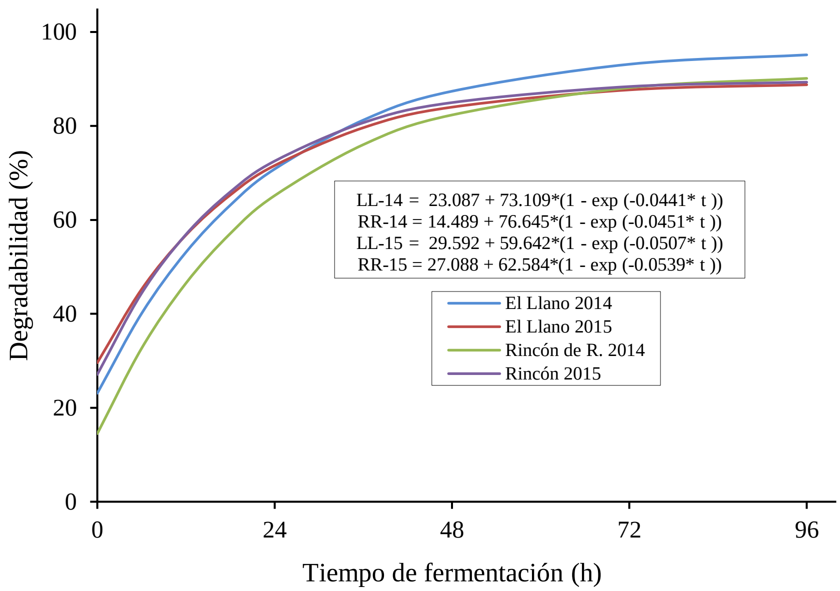

Figure 2. Digestibility *in situ* of the dry matter DISMS (%) of corn stubble in Rincón de Romos (RR) and El Llano (LL), Aguascalientes, during 2014 and 2015. Digestibility curves statistically adjusted to the model of Orskov and Mconald (1979) Y= a + b∗(1-exp(-c∗t)).

The results show that the adjusted curves of DISMS were statistically similar ($p \geq 0.05$) in the two localities (Rincón de Romos and El Llano), and the two years of evaluation (2014 and 2015). However, there were significant differences in fractions a, b and c.

These results are consistent with the performance of forages in general, where DISMS declines as forage maturity advances due to the expected effect of increased forage fiber fractions (FDA and FDN) (Krysl *et al*., 1987). In addition, the *in situ* digestibility of the dry matter is related to the concentrations of FDA and FDN independently of hybrid maize grown under irrigation and fertilization, and those of the harvested maize cultivated under rainfed conditions (Lundvall *et al*., 1994).

Núñez *et al*. (2001), working with intermediate and early maize hybrids under irrigation, found differences in the FDA variable that fluctuated between 28 and 30%, while for the (FDN) values ranged between 49.2 and 63.3% in northern Mexico, Very similar values in both RR and LL, Aguascalientes, between 2014 and 2015, although the latter under rainfed conditions. With respect to the *in situ* digestibility of the dry matter (DISMS), the same varieties of hybrid corn under irrigation conditions showed values that changed between 64.1 and 73.2% achieved by the shorter cycle hybrids which showed greater digestibility, which agrees with Cummings and Dobson Jr. (1973).

The low nutritive quality of the corn stubble determined by the scarce crude protein and high content of the fiber fraction (FDN and FDA) and its effect in decreasing the digestibility, may be associated with differences in the hardness of the leaf structure and the stem, young and mature tissue, and with the turgor characteristics between dead and living tissue (Sosa *et al*., 2000). This supports the argument of corn producers under seasonal conditions that indicate that the stubble keeps its animals as well as dry forages in the dry season (Guevara *et al*., 2014). The low digestibility of forages, including those found in corn stubble, could be associated with physical limitations in the consumption of the animal due to diets high in fiber, or because the animal makes its consumption speed more efficient given the number of snacks and the individual weight of the same (Chacón and Stobbs, 1976).

Conclusions

In situ dry matter digestibility (DISMS) of maize stubble was low in both sites, although numerically higher in RR, perhaps due to the effect of the green maize harvest that is customary in this municipality. The productive alternative carried out in the state of Aguascalientes in almost 122 000 ha, as it is the sowing of corn under rainfed conditions, is neither an activity neither productive nor ecologically sustainable, since it generates an accelerated erosion of the soil and productions both corn grain and very poor stubble.

Programs like the PROCAMPO (PROAGRO) of the official sector do not contribute positively in the economic empowerment of the social sector dedicated to the cultivation of corn under rainfed conditions, especially that located in the arid and semiarid zones of Mexico, on the contrary, they are catalysts of the cycle perverse that increases economic poverty and the destruction of the soil. There is a lack of very deep education of the population of the rural sector that is able to sensitize them and look for more sustainable production alternatives. It is highly recommended the help of the pileteo (irrigations of aid) in those sites that have boards or some work of infrastructure to harvest rainwater, to significantly increase the yields of corn sown under dry conditions in the arid and semi-arid zones of Mexico, including the state of Aguascalientes.

With the still undetermined effect of climate change on the general climatology of the world, but especially that which affects the arid and semi-arid zones, the total replacement of the areas currently used for the production of temporary crops by productive systems is highly recommended. chords to the climatology of these zones like the animal production and the biodiversity as they are it the native grassland, that take advantage of a better way the scarce and poorly distributed pluvial precipitations that affect year after year in this type of zones of high sinisterness and then redirect resources once this is achieved, to boost the social and economic development of these huge areas.

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