Article

Effect of the production cycle on the yield potential and nutritional quality of forage corn in the Comarca Lagunera

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Abstract

The objective of this study was to evaluate the effect of the production cycle on the yield potential and nutritional quality of forage corn in the Comarca Lagunera. The experiment was established at the La Laguna Experimental Field of the National Institute of Forestry, Agricultural and Livestock Research, in Matamoros, Coahuila, Mexico. The hybrid corn SB-302 was used in the spring and summer agricultural cycles under a completely randomized block design with four repetitions during 2018, 2020 and 2021. The information was analyzed with the PROC MIXED of SAS using the agricultural cycle as a fixed effect and the year as a random effect. The following were evaluated: yields of green (GFY) and dry forage (DFY), dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), *in vitro* digestibility of NDF at 30 hours of incubation (DNDF-30 h), net energy of lactation (NE_L), starch and lignin, potential milk production per tonne and per hectare, and yields of NDF, DNDF-30 h and NE_L, starch and lignin. The GFY and DFY were higher in spring than in summer by 8.8 and 3.7 t ha^{-1}, respectively. The production cycle did not affect DM, NDF, NE_L, starch and lignin. However, for the spring cycle, the contents of CP, ADF and DNDF-30 h were higher than in the summer by 0.57, 1.98 and 7.87%, respectively. In addition, the potential milk production per tonne and yields of NDF, DNDF-30 h and NE_L were higher in spring than in summer. In general, corn sown in spring had higher forage yields per hectare and with better fiber digestibility than corn sown in summer in the Comarca Lagunera.

Keywords: *Zea mays* L., forage, spring, summer.

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Introduction

Corn is one of the most important crops in Mexico because it is used for human food and animal nutrition. Forage corn is distinguished from grain corn because the former is offered as stover or silage to ruminants. The yield potential and nutritional quality of forage corn is influenced by many agronomic factors, but the production cycles of this crop significantly influence the parameters of production and nutritional quality of the forage (Fassio *et al*., 2018).

The Comarca Lagunera is one of the areas with the highest production of forage corn in Mexico (SIAP, 2021). The environmental conditions of this region allow producing forage corn during the spring and summer. The production of corn during these two production cycles allows the great need for forage required by dairy cattle in this area to be potentially met. Nevertheless, forage production per hectare and the nutritional quality of corn forage are affected by the production cycle. This depends largely on the climatic conditions that occur in each production cycle (Moore *et al*., 2021).

The yield potential and quality of forage corn can be modified by the effect that the environment has on the physiology of the plant. This crop shows a high photosynthetic rate when the temperature (Escalante *et al*., 2008) and light intensity increase (Velasco *et al*., 2010). If there is a shortage of solar radiation in the corn plant from the time the crop has full cover until its reproductive stage, the forage yield per hectare will be limited (Endicott *et al*., 2015). Thus, environmental temperature is a key factor for the growth and development of forage corn (Noriega *et al*., 2011).

All this is because temperature promotes photosynthesis, respiration and cell growth in plants. Generally, the environmental conditions in the Comarca Lagunera during the spring and summer are different. The recommended sowing dates for spring are from March 20 to April 15 and for the summer from June 20 to July 30 (Núñez *et al*., 2011). During the summer production cycle, there are higher temperatures than in the spring production cycle, but with a higher precipitation during the summer.

Consequently, the wettest period of the year is mainly associated with the summer cycle. Additionally, the high night temperature during the summer is an important factor since it accelerates the development of the crop and reduces the yield of corn due to the lower interception of solar radiation (Carter *et al*., 2016; Lizaso *et al*., 2018). Therefore, the objective of this study was to evaluate the effect of the production cycle on the yield potential and nutritional quality of forage corn in the Comarca Lagunera.

Materials and methods

The experiments were established during the spring and summer production cycles of 2018, 2020 and 2021 at the La Laguna Experimental Field of INIFAP in Matamoros, Coahuila, Mexico. The experimental site is located at 25º 53’ 31” north latitude and 103º 24’ 11” west longitude at an altitude of 1 116 m. The soil where the experiments were established has a clay texture, with a bulk density of 1.07 g cm^{-3}, an organic matter content of 1.5% and a pH of 8.4.

The preparation of the land consisted of a fallow, harrowing and leveling with a scraper. In the three years, the sowing was carried out in wet soil (*tierra venida*) with a John Deere seeder, guaranteeing a density of 90 000 plants per hectare. The agronomic management of the crop in each year and production cycle adhered to the recommendations of Núñez *et al*. (2011). In each production cycle, the SB-302 variety was used. Each experimental plot consisted of four furrows 0.75 m wide and 8 m long. A completely randomized block design with four repetitions was used. The dates of sowing and harvesting in the three years by production cycle can be seen in Table 1.

Table 1. Sowing and harvesting dates in each production cycle during the three years of study.

Item	2018		2020		2021	
	Spring	Summer	Spring	Summer	Spring	Summer
Sowing	02/04/2018	03/07/2018	15/04/2020	15/07/2020	23/04/2021	15/07/2021
Harvest	31/07/2018	10/11/2018	03/08/2020	31/10/2020	18/08/2021	03/11/2021

The fertilization dose that was applied in the spring cycle was 300-80-00 and in the summer cycle 280-80-00 units of nitrogen, phosphorus and potassium per hectare, respectively. This dose was to ensure that the crop did not lack nutrients and thus expressed its maximum production potential. The total phosphorus was applied at the sowing, while the nitrogen was fractionated, applying 40% of the total dose in the sowing and 60% before the first supplemental irrigation.

In each production cycle, four supplemental irrigations were applied at 28, 47, 65 and 85 days after sowing. These irrigations were independent of the pre-sowing irrigation. The applied irrigation sheets that were estimated in each irrigation varied from 15 to 20 cm. With these irrigation sheets, it was guaranteed to give a total irrigation sheet of not less than 70 cm throughout the crop cycle. A multi-gate irrigation system with well water from the same experimental site was used.

During the development of the crop in each production cycle, applications of granulated Clorver® were made plant by plant for the control of fall armyworm (*Spodoptera frugiperda*). In addition, chlorpyrifos (750 ml ha^{-1}) and cypermethrin (400 ml ha^{-1}) were applied to control this same pest. The control of the red spider mite (*Tetranychus urticae*) was carried out with applications of the insecticide Abamectina® (500 ml ha^{-1}). In each production cycle, the days to male and female flowering were monitored in each experimental unit. Male flowering was recorded when the stem propelled the panicle, becoming fully unfolded and the release of pollen began. Female flowering was recorded when the styles appeared through the bracts.

The harvest of the crop in each production cycle was carried out when the crop reached the phenological stage of one third of the milk line of maturity in the grain. The two central furrows were used as a useful plot; removing 1 m from each end to exclude the edge effect. The cut was made leaving approximately 10 cm of the stem from the base of the soil. In total, six meters in length were harvested for each of the treatments (9.12 m^2). Before harvesting, the total number of plants in the useful plot was counted to estimate the density of plants in each production cycle, the height of three plants taken at random in the two central furrows was measured and the harvest date was recorded to have the days after sowing (DAS). The fresh forage of each useful plot was weighed to estimate the GFY per hectare.

Of the total of complete plants cut from each useful plot, seven plants were selected at random; five of them were dissected into leaves, stems, bracts and cobs to estimate the percentage of cob on a dry basis. The other two were chopped to a particle size of 1 cm and mixed to pre-dry in a paper bag in a greenhouse for 10 consecutive days. Similarly, the samples of dissected plants were pre-dried. After this pre-drying, all the samples were dried at 60 °C until a constant weight in a forced air oven to determine the DM content.

The DFY was determined by multiplying the GFY per hectare by the DM content of the samples. The dry plants that were mixed from each useful plot were subsequently ground in a blender and consecutively in a mill using a 1 mm mesh. In these samples, the contents of CP, NDF, ADF, lignin, DNDF-30 h, starch, NE_L and ashes were analyzed. The determination of these nutritional quality values was based on the prediction equations and databases generated by Cumberland Valley Analytical Services (CVAS) and Rock River Laboratory.

The calibration of the equipment considered the following procedure: selection of the sample at random, taking of the spectra of the sample, selection of the spectra that represent the samples, laboratory analysis of the selected sample using the reference methodology, comparison of the results of the reference methodology with their respective spectra, internal validation with the samples and carrying out of the analysis by the reference methodology and validation of the calibration equation with the reference results of the internal validation samples. Once the calibration equation with the reference results of the internal validation was satisfactory, it was used for the analysis of all samples.

The yields of NDF, DNDF-30 h, lignin, starch and NE_L were estimated considering the content of these nutrients in the forage and the yield of DM per hectare of each useful plot in each production cycle during the three years of study. Milk production per tonne and per hectare was estimated using the nutritional quality of each hybrid with the Milk2006 program developed by the University of Wisconsin, Madison, USA (Shaver, 2007).

Statistical analysis

Information on DM yield, nutritional quality, and nutritional quality yield was analyzed by means of a two-factor Anova using the Mixed procedure of SAS version 9.3 (SAS, 2011). The statistical model included the effect of the year (2018 *vs* 2020 *vs* 2021), the production cycle (spring vs summer) and the interaction of the year × production cycle. The block was used as a random effect. Because it was found that most of the variables were affected by the year, as a significant effect in the interaction year × the production cycle and a highly significant effect by the year were observed, it was decided to perform a second analysis using the year as a random effect.

In the second analysis, the information on DM yield, nutritional quality, and nutritional quality yield was analyzed by means of a single-factor Anova using the Mixed procedure of SAS. The statistical model included the effect of the production cycle (spring *vs* summer) as a fixed effect and the year was used as a random effect. The Tukey-Kramer test was used to compare treatment means. A statistical difference was declared in all variables at a value of $p \leq 0.05$ and a trend when $0.05 < p \leq 0.1$.

Results and discussion

Climatic conditions

The climatic conditions of the production cycles during the three years of study are shown in Table 2. Minimum and average temperatures in the spring cycle were higher up to 50 days after sowing (DAS) compared to those in the summer cycle. During the growth cycle, maximum temperatures were higher in the spring cycle, with a bigger difference between cycles during and after flowering. Total rainfall was higher during the summer.

Table 2. Climatic conditions of temperature and precipitation in the spring (S) and summer (U) cycles during the three years of study in the La Laguna Experimental Field of INIFAP.

Item	2018		2020		2021		Cycle average		Year average		
	S	U	S	U	S	U	S	U	2018	2020	2021
Maximum T. (°C)	34.93	32.42	34.59	28.76	33.73	32.35	34.42	31.18	33.68	31.68	33.04
Mean T. (°C)	27.52	26.16	27.25	22.72	26.38	25.62	27.05	24.83	26.84	24.99	26
Minimum T. (°C)	19.58	20.23	19.92	16.67	19.33	18.89	19.61	18.6	19.91	18.3	19.11
Precipitation (mm)	18.2	222	5.26	18.56	49.4	65	24.29	101.85	120.1	11.91	57.2

Regarding the climatic conditions by year, we can see in Table 2 that both temperatures (maximum, minimum and average) and rainfall were very varied in each year (2018, 2020 and 2021). This clearly demonstrates why the factor year of production statistically affected the variables evaluated when there was or not interaction with the production cycle. For this reason, it was decided to use the year as a random effect in the statistical analysis.

Analysis of variance showing the effect of the year, production cycle and their interaction

The results of the analysis of variance (Table 3, 4 and 5) show the effects of year, season and the interaction year × production cycle on the variables of yield, nutritional quality, milk and nutritional quality yield in forage corn. There was interaction year × production cycle for most of the variables evaluated, except for cob percentage, bract percentage and DFY (Table 3), NDF and lignin contents in forage (Table 4) and the yields of NDF, DNDFY-30 h, NE_L, starch and lignin (Table 5).

In most of the latter variables that were not affected by the interaction year × production cycle, it was observed that they were statistically affected by the year of production, except for the lignin content, which was not affected by any factor (Table 4). Yang (2010) advises using mixed model analysis where a random effect is used when using a completely randomized block design if one is seeking to focus on making inference about the average yield of an individual treatment beyond an actual experiment.

Table 3. Analysis of variance showing the effect of the year, the production season and their interaction on the variables of yield of forage corn sown in spring and summer in three years in the Comarca Lagunera.

Source of variation	df	Fem f (DAS)	Male f (DAS)	DAS (days)	Height (m)	GFY (t ha^{-1})	DM (%)	DFY (t ha^{-1})	Leaves (% DM)	Stems (%)	Bract (%)	Cob (% DM)
Year (Y)	2	<0.0001	<0.0001	<0.0001	0.5	0.03	0.03	0.0007	0.23	<0.0001	0.41	0.0002
Season (S)	1	<0.0001	<0.0001	<0.0001	0.03	0.02	0.63	0.01	0.97	0.003	0.01	0.004
Y × S	2	<0.0001	0.06	<0.0001	0.0004	0.01	0.004	0.91	0.05	0.002	0.17	0.27

Fem f= female flowering; Male f= male flowering; DAS= days after sowing; GFY= green forage yield; DFY= dry forage yield; df= degrees of freedom.

Table 4. Analysis of variance showing the effect of the year, the production season and their interaction on the variables of nutritional quality of forage corn sown in spring and summer in three years in the Comarca Lagunera.

Source of variation	df	CP (%DM)	ADF (%DM)	NDF (%DM)	DNDF-30 h (%NDF)	NE_L (Mcal kg^{-1} DM)	Starch (%DM)	Lignin (%DM)
Year (Y)	2	<0.0001	0.009	0.003	<0.0001	0.005	0.001	0.17
Season (S)	1	0.02	0.02	0.70	<0.0001	0.37	0.11	0.95
Y × S	2	0.01	0.01	0.48	<0.0001	0.02	0.08	0.99

CP= crude protein; ADF= acid detergent fiber; NDF= neutral detergent fiber; DNDF-30 h= *in vitro* digestibility of NDF at 30 h of incubation; NE_L= net energy of lactation; df= degrees of freedom.

Table 5. Analysis of variance showing the effect of the year, the production season and their interaction on the variables of milk per tonne and per hectare and the variables of nutrient yield of forage corn sown in spring and summer in three years in the Comarca Lagunera.

Source of variation	df	Milk (kg t^{-1})	Milk (kg ha^{-1})	NDFY (kg ha^{-1})	DNDFY-30 h (kg ha^{-1})	YNE_L (Mcal ha^{-1})	YStarch (kg ha^{-1})	YLignin (kg ha^{-1})
Year (Y)	2	0.0009	0.006	0.001	0.003	0.0005	<0.0001	0.0004
Season (S)	1	0.002	0.04	0.02	0.03	0.01	0.11	0.14
Y × S	2	0.0002	0.007	0.80	0.69	0.74	0.43	0.81

NDFY= neutral detergent fiber yield; DNDFY-30 h= digestible NDF yield; YNE_L= yield of net energy of lactation; Y= yield; df= degrees of freedom.

Agronomic variables and forage yield

Table 6 shows the effect of the production cycle on some agronomic variables in forage corn in the Comarca Lagunera. The male and female flowering of forage corn in this region was five and eight days shorter, respectively, in summer than in spring ($p< 0.0001$). Similarly, the days to which the harvest was made were nine days less in summer compared to spring ($p< 0.0001$). The plant height tended to be 32 cm higher in summer than in spring ($p= 0.07$).

Table 6. Effect of the production cycle on some agronomic variables in forage corn in the Comarca Lagunera.

Item	Spring	Summer	SE	*p*-value
Male flowering (days)	69 a	64 b	2	<0.0001
Female flowering (days)	76 a	68 b	3	<0.0001
Days after sowing	112 a	103 b	2	<0.0001
Height (m)	2.42	2.74	0.12	0.07
Leaves (%DM)	17.47	17.43	1.02	0.97
Stems (%DM)	26.91 b	31.25 a	3.74	0.02
Bract (%DM)	8.26 b	10.73 a	0.69	0.02
Cob (% of DM)	47.36 a	40.59 b	4.33	0.004

a, b= averages within each row with different letters differ at the indicated probability level; SE= standard error of the mean.

The cob percentage observed during the spring was higher than that observed during the summer (p= 0.004). However, bract percentages were higher in the summer (p= 0.02). Santiago *et al*. (2018) also observed in forage corn that male and female flowerings is eight days shorter in the summer than in the spring and that grain production was 2.7 t ha^{-1} lower in forage corn sown in summer. They attributed the difference in grain production to flowering time, since corn sown in spring develops better photosynthetic capacity due to a longer vegetative state than corn sown in summer.

GF and DF yields (Figure 1) were also affected by the production cycle. GF and DF yields were 8.8 and 3.7 t ha^{-1} higher, respectively, in corn when sown in spring than in corn sown in summer (p< 0.05). The yield and productivity of forage corn (Santiago *et al*., 2018) or grain (Franco *et al*., 2016) is lower in the summer. This effect has been directly associated with the difference in temperature and precipitation between the two production cycles (Brachtvogel *et al*., 2009; Santiago *et al*., 2018). The high temperature and low rainfall cause stress in corn and cause the physiological development of the crop to accelerate, resulting in an inhibition of plant development and reduction of leaf area (Santiago *et al*., 2018).

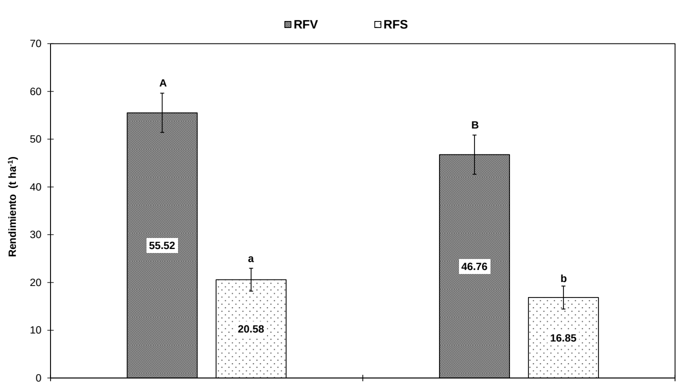

Figure 1. Yields of green (GFY) and dry forage (DFY) in forage corn in response to the production cycle in the Comarca Lagunera. Means with different letters within each category are statistically different (Tukey-Kramer: GFY (p≤ 0.04; SE= 4.1 t ha^{-1}) and DFY (p≤ 0.008; SE= 2.4 t ha^{-1}).

In the present study, the lower yield of DM in the summer cycle was related to a reduction in its growth cycle, resulting from a higher temperature during the pre-flowering period and possibly to a shorter photoperiod in the Comarca Lagunera, already established at 12 h (Delgadillo *et al*., 2012). During the spring cycle, the photoperiod is longer in this region (14 h; Delgadillo *et al*., 2012) and the lower minimum and average temperatures up to 50 DAS caused a longer growth cycle, greater development of cob and greater accumulation of total dry matter.

It is well known that a longer photoperiod (Hunter *et al*., 1977; Struik, 1983) and cooler temperatures (Hunter *et al*., 1977) lead to a higher final production of dry matter in the corn plant. This occurs mainly because the photoperiod influences the final height of the plant through an increase in the number of internodes, length of the internodes and a greater increase in the area of the leaf (Struik, 1983).

Nutritional quality in forage corn

The nutritional quality parameters of forage corn sown in spring and summer are shown in Table 7. There was no difference in the percentage of DM of corn forage at harvest between one production cycle and another (p= 0.7). This indicates that changes in forage yield and nutritional quality were not affected by differences in harvest stages between treatments. No statistical differences were observed in the contents of NDF (p= 0.69), NE_L (p= 0.45), starch (p= 0.14) and lignin (p= 0.95). These results were different from those observed by Santiago *et al*. (2018), who found 17% more NDF in the forage of corn sown in summer respect to spring corn.

Table 7. Average effect of three years (2018, 2020 and 2021) of the production cycle on the nutritional quality of forage corn in the Comarca Lagunera.

Item	Spring	Summer	SE	*p*-value
DM (% of forage)	37.39	36.33	2.69	0.7
CP (%DM)	8.24 a	7.67 b	0.8	0.04
ADF (%DM)	30.04 a	28.06 b	1.05	0.05
NDF (%DM)	45.19	44.8	1.48	0.69
DNDF-30 h (%NDF)	57.39 a	49.52b	4.31	0.01
NE_L (Mcal kg^{-1} DM)	1.32	1.3	0.02	0.45
Starch (%DM)	30.12	27.91	2.18	0.14
Lignin (%DM)	5.03	4.99	0.56	0.95

DM= dry matter; CP= crude protein; ADF= acid detergent fiber; NDF= neutral detergent fiber; DNDF-30 h= *in vitro* digestibility of NDF at 30 h of incubation; NE_L= net energy of lactation; [a,b]= averages within each row with different letters differ at the indicated probability level; SE= standard error of the mean.

The same authors also reported that grain production, grain weight per cob, number of rows per cob, and number of grains per row were statistically higher in spring corn than in summer corn, so the starch content may also have been higher in the spring than in the summer. In the present study, the higher percentage of cob in spring corn did not influence the starch content in both production cycles.

The concentrations of CP, ADF and DNDF-30 h were influenced by the production cycle ($p < 0.05$). The contents of CP, ADF and DNDF-30 h were 0.57, 1.98 and 7.87%, respectively, higher in the forage of corn sown in spring compared to that sown in summer. Among these nutrients, the most important is the digestibility of fiber, since forages with low digestible fiber in dairy cows have been shown to reduce voluntary feed consumption and milk production (Oba and Allen, 1999). The higher DNDF-30 h in the forage of corn sown in spring was associated with the lower proportion of stems and the higher proportion of cob (Table 6) compared to summer corn. Masoero *et al*. (2006) found that the highest DNDF-30 h in the corn plant is found in the leaves (49.81%), followed by the cob (39.45%) and finally by the stems (34.99%).

Potential milk production and nutritional quality yield

The potential milk production and nutritional quality yield in forage corn sown in spring and summer are shown in Table 8. Milk production per hectare in forage corn tended to be higher in the spring than in the summer ($p = 0.09$). However, the potential milk production per tonne was higher in spring corn compared to summer corn ($p = 0.03$). Similarly, the yields of NDF, DNDF-30 h and NE_L were higher by 1 772 kg ha^{-1}, 855 kg ha^{-1} and 4 766 Mcal ha^{-1}, respectively, in spring corn than in summer corn.

Table 8. Average effect of three years (2018, 2020 and 2021) of the production cycle on potential milk production and nutritional quality yield in forage corn in the Comarca Lagunera.

Item	Spring	Summer	SE	*p*-value
Milk per tonne (kg t^{-1})	1 491.66 a	1 392.86 b	49.36	0.03
Milk per hectare (kg ha^{-1})	30 385	26 379	2 694	0.09
NDF yield (kg ha^{-1})	9 329.63 a	7 557.65 b	1 125.64	0.01
DNDF-30 h yield (kg ha^{-1})	4 255.87 a	3 400.92 b	560.05	0.02
Yield of NE_L (Mcal ha^{-1})	26 854 a	22 088 b	3 218	0.009
Starch yield (kg ha^{-1})	5 772.82	5 081.9	943.64	0.1
Lignin yield (kg ha^{-1})	1 037.81	865.81	202.8	0.12

NDF= neutral detergent fiber; NE_L= net energy of lactation. [a, b]= averages within each row with different letters differ at the indicated probability level. SE= standard error of the mean.

Both the potential milk production per tonne and the higher nutritional quality yield observed in corn sown in spring compared to summer corn are due to the higher DFY and better nutritional quality of the forage of corn sown in spring. Starch and lignin yields were similar between spring and summer corn.

Conclusions

The production cycle significantly affects the production of forage corn in the Comarca Lagunera. Corn sown in spring has higher forage yield than summer corn. This effect is associated with a longer growth cycle and a greater development of the cob, which may be associated with lower minimum and average temperatures during the pre-flowering stage compared to the conditions of the summer cycle. Nutritional quality was less influenced by the production cycle. The most outstanding values were the greater digestibility of the fiber and the higher potential milk production per tonne in corn sown in spring compared to corn sown in summer.

The higher digestibility of the fiber was due to the lower proportion of stems and higher proportion of cob during the spring. The higher potential milk production per tonne in spring is the result of higher forage yield and better digestibility of this forage during this production cycle.

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