Article

Growth analysis in forage sorghum in two planting periods

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Abstract

Growth analysis is a periodic quantification of dry matter yield that allows to determine the optimum cutting moment. The objective was to know the growth, to quantify the accumulation of dry matter in a time interval, in four varieties of forage sorghum: Caña dulce, Silo miel, Esmeralda and Fortuna, similarly, to determine phenology, in two periods of sowing: tip of irrigation (April-October) and rains (June-December) in Montecillo, Texcoco, State of Mexico. Phoenology was determined, height of plant (AP), number of leaves (NDH), number of stems (NDT), number of knots per plant (NDP), yield of dry matter (RMS), leaf area index (IAF), leaf area duration (DAF), crop growth rate (TCC) and net assimilation rate (TAN) was calculated. The experimental design complete randomized blocks with factorial arrangement and four repetitions, significant variables, were compared with the Tukey test ($p \leq 0.05$). Caña dulce presented higher AP (210 cm) in both periods, at 145 days after the average sowing (dds); NDT (33), NDH (8.1), NDN (8.3); TCC (24 g m^{-2} d^{-1} to 75(dds) and 26 g m^{-2} d^{-1} to 84 dds), TAN (19.1 g m^{-2} d^{-1} and 13.8 g m^{-2} d^{-1} from emergency to 20 dds); the above, resulted in higher yields ($p \leq 0.05$) per square meter (15.7 and 15.5 t DM ha^{-1}) at the point of irrigation and the rainy season, respectively. The Silo miel cultivar showed higher IAF with 5 to 125 dds and 4.6 to 120 dds and DAF of 114 days; the above, for irrigation tip and rainfall, respectively. The best cultivar for the region was Caña dulce.

Keywords: *Sorghum bicolor* (L.) Moench, phenology, rainfall, yield.

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Introduction

The sorghum *Sorghum bicolor* (L.) Moench, is a crop increasingly used as fodder, in Mexico in the agricultural cycle 2017 were planted 192 thousand ha of forage sorghum with yields pomedio of 20 t DM ha^{-1} (SIAP, 2019), this is due to its high tolerance to drought, especially in the vegetative stage (Castro *et al*., 2000), it has adapted better than corn, because it produces more dry matter (DM) per unit of water consumed, a sorghum plant consumes 80 to 100 milliliters less than maize in the reproductive stage (Ajeigbe *et al*., 2018).

Sorghum avoids dehydration due to the serous cover in leaves and by osmotic regulation, increases water absorption through its fiber, dense and branched root system, which allows great exploration of the soil and nitrogen absorption (Legarto, 2000) in addition, sorghum slows the transpirational loss of water through the habit of vertical growth of leaves, tolerates high salinity and intensive management of cuts (Rouf *et al*., 2018); the previous, due to its advantages with respect to other fodder crops such as corn, alfalfa, oats, etc; however, in fertile soil with irrigation availability, sorghum does not compete in yield of dry matter with corn or alfalfa, it adapts better to more challenging environments with respect to these crops.

There is little information on forage sorghums in the Central High Plateau of Mexico (Bolaños *et al*., 2013), the studies carried out are mainly on dry matter yield (Borghi *et al*., 2013); however, to better understand the physiological factors that determine yield and differences between varieties, detailed studies of plant growth are required to identify and quantify the distribution of dry matter in phenological stages, duration of the crop cycle and determine the optimum time for cutting for forage production (Egli, 2017; Pérez *et al*., 2017). The phenology refers to the study of biological events involved in the life of plants, such as emergence, tillering, flowering, fruiting, maturation and the interaction of these stages with the climate (Granados and Sarabia, 2013).

The crop cycle changes between varieties, this means that different varieties planted in the same site may present different stages of development, after the same chronological time has elapsed, therefore, management practices must be adapted to the crop phenology (Solorzano, 2007).

Regarding the analysis of growth, it is basic to understand physiological processes that determine the production of dry matter and rationalize management practices (Azam, 2013), as well as fertilization to increase crop efficiency, giving better growth rates, such as the growth rate of the crop (TCC), average rate of net assimilation (TAN), leaf area index (IAF) and leaf area duration (DAF, Hunt, 1990, Escalante and Kohashi, 2015). In this regard, Gaytan *et al*. (2001), mention that varieties with high rates of TCC, TAN and IAF have greater translocation in the formation of reproductive structures, which has an impact on total dry weight, these indices can make it possible to determine differences between varieties of the same species and select the appropriate ones (Bednarz *et al*., 2000).

The objective was to know the phenology, through analysis of growth and quantification of dry matter yield in four varieties of forage sorghum, with two sowing dates: irrigation tip (April-October) and rainy season (June-December) in Montecillo, State of Mexico.

Materials and methods

The experimental plots were located in the experimental area of the Campus Montecillo Postgraduate College, Texcoco, State of Mexico (19° 29’ north latitude, 98º 51’ west longitude, 2 250 m), BS_1 climate, the least dry of the aggregates with rains in summer, average annual temperature 14.6 °C, 559 mm of precipitation (García, 2005). Also, the soil of the place is of alkaline type, pH 9, EC 3.44 dS m^{-1} and OM 1.29% and loamy clay texture. The present study was carried out on two sowing dates; this is due to the fact that there is a wide variability in temperature and distribution of rainfall for one year. The first period (tip of irrigation), was sown on April 12, with a single irrigation (40 mm) that allowed the germination and emergence of the plants, the second period (rain), was planted on June 17, both in the year 2013.

The treatments consisted of a local variety (Caña dulce, company Berentsen) and three varieties used in the state of Jalisco [Silo miel (Genex), Esmeralda (ABT) and Fortuna (INIFAP)], all of fodder use. The extension of the plot where the experiment was developed was 1 000 m^2. Seeding was done manually with continuous deposit of seeds (chorrillo), distance between rows 70 cm and density of 25 kg ha^{-1} of SPV, later twenty-five days after sowing (dds) thinning was performed, until obtaining a density of 17 plants m^{-2}, after 40 dds, was fertilized at a rate of 80 kg N ha^{-1}, in hilling. During the growth cycle of the crop, average maximum, minimum weekly and weekly sum of precipitation was recorded.

The experimental units consisted of five rows of 5 m long, of which, as a useful plot, 3 m were taken from three central furrows. The experimental design was randomized complete blocks and factorial arrangement with four repetitions, where four varieties, five sampling dates and two planting periods were taken into account. Analysis of variance and Tukey test ($p\leq 0.05$) were performed on variables that were significant, with the package for statistical analysis InfoStat (InfoStat, 2008).

Phenology

The phenological stages were recorded in days after sowing (dds), because the measurement was visual (Solorzano, 2007): vegetative (V-1= emergence, V-2= third ligulate leaf, V-3= fifth ligulate leaf, V-4= eighth ligulate leaf, V-5= visible flag leaf) and reproductive (R-6= extended panicle within the flag leaf sheath, R-7= flowering, R-8= grain soft doughy, R-9= grain hard doughy), data were recorded when 50% of the population had the aforementioned characteristics.

Growth variables

They were recorded by periodic and destructive evaluations of one tiller per experimental unit; in measurements plant height (AP), number of leaves (NDH) and number of nodes (NDN), the measurement was made in the main stem, AP was cut at ground level, the stem and was measured with graduated rule, from the basal part until the last leaf or inflorescence. NDH were counted at the time of removing leaves and pods to expose the stem knots (NDN) and perform counting. NDT was performed when cutting the tiller. All measurements were made at 25, 55, 85, 115 and 145 dds; IAF, DAF, TCC and TAN were also calculated.

The yield of dry matter (RMS, t DM ha^{-1}), was obtained by cutting at ground level, then the plant material was placed on work tables and separated into its morphological components and the leaf blades were passed through an integrator of leaf ares LI-COR 3100, then each component was placed in paper bags properly labeled and remained for 72 h in forced air circulation oven, at 70 °C, then removed and weight in analytical balance and transformed t DM ha^{-1}

The calculations were made in cut-off intervals: 0-25, 26-55, 56-85 and 86-115 dds, including IAF, DAF, TAN and CBT; for which, the formulas of Escalante and Kohashi (2015) were used: $IAF=[(AF/NP)*(DP/10\ 000\ cm^2)]$, $DAF=[(IAF_2-IAF_1)/(T_2-T_1)]$, $TCC=[(PS_2-PS_1)/(T_2-T_1)]$ and $TAN=\{[(PS_2-PS_1)/(AF_2-AF_1)]/[(InAF_2-InAF_1)/(T_2-T_1)]\}$; where: AF= leaf area, NP= number of plants, DP= population density, T= time, 1 and 2= start and end of interval, IAF= leaf area index, PS= weight of DM, InAF= natural logarithm of the foliar area.

Results and discussion

Elements of the climate and phenological stages

In conditions of tip of irrigation, the minimum temperature fluctuated from 2.3 to 12.6 °C and the maximum from 23.9 to 31.7 °C, the accumulated precipitation was 630 mm, where 42% (269 mm) occurred in the vegetative phase and 58% (361 mm) in reproductive stage (Figure 1).

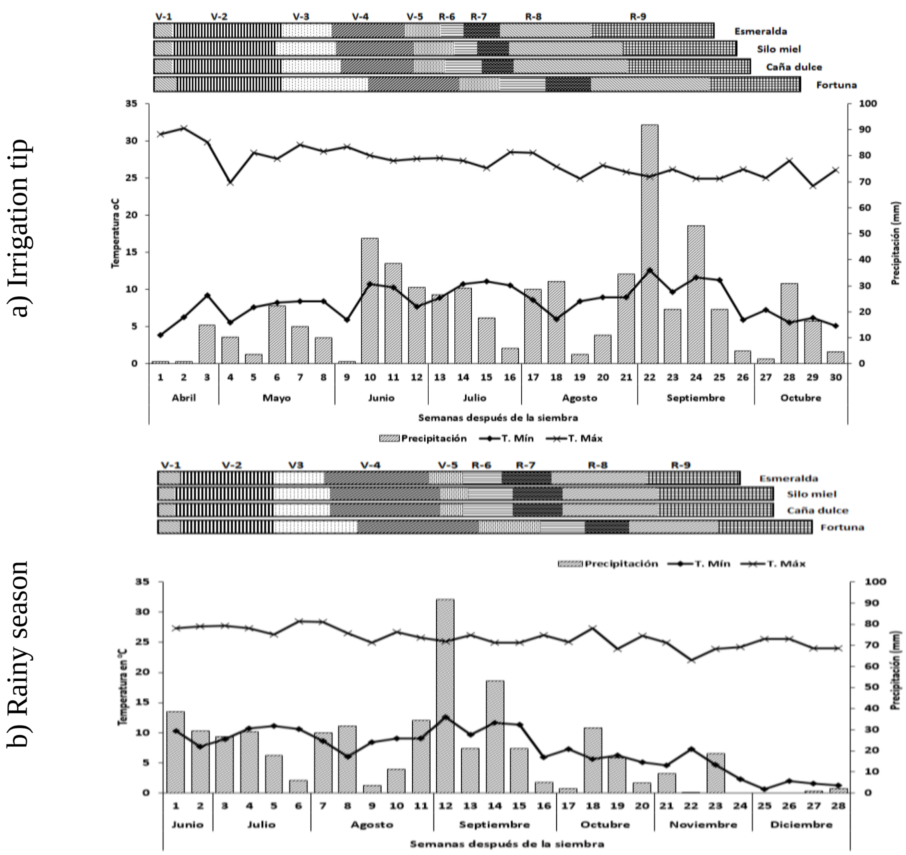

Figure 1. Climatic conditions and phenological stages in four varieties of forage sorghum, in Montecillo, State of Mexico, 2013.

In the rainy season, the minimum temperature fluctuated from 2-12.8 °C and maximum 24-28.5 °C, on the other hand, the cumulative rainfall was 534 mm, where 84% (444 mm) occurred in the vegetative phase and 16% (90 mm) in reproductive stage. In this regard Cordoves and Grizel (2009), report that sorghum requires 450-650 mm of precipitation per crop cycle, therefore, the precipitation was adequate for the development of the crop in both sowing periods; however, in Texcoco, State of Mexico, the average maximum temperature in both periods was 26 °C, with cold mornings (8 °C), which limited the development of sorghum, given that the optimum temperature has a range of 27- 29 °C and C4 plants, require minimum growth temperature of 10 °C.

Despite variations in humidity and temperature, the phenology was similar for both sowing periods, the reproductive stage started at 13 weeks; the early cultivar was Esmeralda, which reached physiological maturity in 25 weeks and the later cultivar (Fortuna) in 28 weeks. The interval between phenological stages of sorghum is determined by genotype and environment, where temperature and precipitation have greater influence, which can advance or lengthen the life cycle of plants (Solorzano, 2007).

Morphological components

They are the result of the environmental, nutritional and genetic expression of the varieties (Solorzano, 2007), where the character of greater economic value is the yield of dry matter. In this sense, the highest yield was slightly higher in the irrigation period (Table 1). The variety that accumulated the largest amount of biomass in less time was sweet cane both in irrigation period (15.7 t DM ha^{-1}) and temporary (Table 2), 15.5 t DM ha^{-1}) at 145 dds in temporary we could cut from 115 dds, because the increase in dry matter is minimal, and we avoid deterioration by lignification.

Differences were observed ($p \leq 0.001$, Table 1 and 2) between varieties, sowing periods, AP, NDT, NDH, NDN and RMS, they increased as the crop cycle progressed at the beginning, the growth was slow, reflecting in small values of AP, NDT, NDN and RMS. Regarding Afzal *et al*. (2012), evaluated yield of fertilized forage sorghum with 75 kg N ha^{-1} and indicate that the plant grew 180 cm, as a response to fertilization increase the number of knots and distance between them, report 43 stems per tiller.

Table 1. Morphological components and yield in fodder sorghum in irrigation period, in Montecillo, State of Mexico, 2013.

Variety	dds	Measurement by plant				RMS
		AP (cm)	NDT	NDH	NDN	(t DM ha^{-1})
Caña dulce	145	220.4 a	46.5 a	7.7 abc	8.3 a	15.7 a
	115	220.4 a	46.5 a	7.7 abc	8.3 a	14.3 b
	85	105.9 cd	9 c	7.7 abc	3 d	7.5 e
	55	51 fgh	5.6 c	6.5 bcde	0.5 e	3.6 l
	25	31.3 ghi	3.8 c	5.7 cde	0 e	1.4 k

Variety	dds	Measurement by plant				RMS
		AP (cm)	NDT	NDH	NDN	(t DM ha^{-1})
Silo miel	145	146.8 b	33.5 a	9 a	6.5 bc	14.2 b
	115	146.8 b	33.5 a	9 a	6.5 bc	11.8 c
	85	97.7 cd	4.8 c	9 a	3 d	5.6 f
	55	59 f	5 c	7 abcd	0.3 e	3.2 ij
	25	26.9 h	3 c	4.8 de	0 e	1 k
Esmeralda	145	122.9 bc	31 ab	8.2 ab	7.4 a	9.5 d
	115	122.9 bc	31 ab	8.2 ab	7.4 a	9 d
	85	85.8 de	5.5 c	8.2 ab	3.3 d	5 fg
	55	52.7 fgh	3.3 c	6.6 bcd	0.3 e	0.9 ij
	25	24.1 l	3 c	4.5 e	0 e	0.01 k
Fortuna	145	95.5 de	15.8 bc	7.8 abc	5.3 c	4.9 fg
	115	95.5 de	15.8 bc	7.8 abc	5.3 c	4.4 g
	85	69.9 ef	3.8 c	7.8 abc	0.6 e	2.9 h
	55	54.3 fg	4 c	7 abcd	0 e	0.05 jk
	25	26.6 i	3 c	5 de	0 e	0.02 k
Average		116	37.9	9	4.1	5.7
Variety		***	***	*	***	***
Variety∗dds∗period		***	NS	*	***	***

Means with different literal between columns are statistically different Tukey ($\alpha \leq 0.05$), AP= plant height, NDT= number of stems per tiller, NDH= number of leaves in main stem, NDN= number of knots in main stem, RMS= dry matter yield (t DM ha-1), Significance *= $p \leq 0.05$, ***= $p \leq 0.001$, NS= not significant.

In the present work, sweet cane at 145 dds in both sowing periods, presents higher values in AP and similar NDT, in irrigation period. The average number of leaves and knots at 145 dds, in both planting methods was similar; In this regard, Kapanigowda *et al*. (2013), when evaluating 48 lines of sorghum, the number of leaves varied by one per plant.

The varieties of sorghum presented their phase of accelerated growth after 55 dds, which covers from the phenological stage V-3 to R-8. In the stage V-3 the elongation of internodes was given, as reported by Afzal *el al*. (2012), this is reflected at 85 dds with higher AP, NDT, NDH, NDN and RMS (Table 1 and 2). Caña dulce presented the best morphological parameters with respect to the other varieties studied, because it is adapted to edaphoclimatic conditions of the Central High Plateau of Mexico.

Table 2. Morphological components and yield in forage sorghum during the rainy season, in Montecillo, Estado de México, 2013.

Variety	dds	Measurement by plant				RMS
		AP (cm)	NDT	NDH	NDN	(t DM ha^{-1})
Caña dulce	145	200.1 a	20 a	8.5 a	8.4 a	15.5 a
	115	133.8 bc	15 abc	8.4 ab	7.5 ab	15.2 ab
	85	136.4 b	14.5 abc	8 abc	6.2 bcd	7.2 e
	55	92.7 bcdefg	10 abc	7.5 abcd	2.2 e	1.8 hi
	25	20.6 hij	8.3 abc	6.3 bdd	0 f	0.07 j

Variety	dds	Measurement by plant				RMS
		AP (cm)	NDT	NDH	NDN	(t DM ha^{-1})
Silo miel	145	133.8 bc	11.8 abc	8.3 ab	7.2 abc	14.1 b
	115	122.4 bcd	9 abc	7.8 abc	6.3 bcd	12.3 c
	85	108 bcde	6.8 bc	7 abcd	4.8 d	5.8 ij
	55	70.5 defghij	7.8 abc	6.8 abcd	1.3 ef	1.2 ij
	25	20.6 ij	7 bc	5.3 d	0 f	0.04 j
Esmeralda	145	144.9 ab	16.3 ab	8 abc	7.8 ab	8.8 d
	115	99.8 bcdef	7.5 bc	8 abc	7.2 abc	8.3 de
	85	74 defghi	4 bc	7.8 abc	2.8 e	4.6 fg
	55	50 fghij	3.3 c	6 abcd	1.4 ef	0.7 ij
	25	15.9 j	3 c	5.8 cd	0 f	0.02 j
Fortuna	145	142 b	13.3 abc	8.4 ab	7.1 abc	5.2 fg
	115	78.2 cdefgh	3 c	7.2 abcd	5.5 cd	4.3 g
	85	51.8 efghij	3 c	7.1 abcd	0.3 cd	2.6 h
	55	35.6 ghij	3 c	6.3 abcd	0 f	0.4 j
	25	13.9 j	3 c	5.9 cd	0 f	0.02 j
Average		109.1	10.6	9.1	4.8	5.5
Variety		***	***	*	***	***
Variety∗dds∗period		***	NS	**	***	***

Means with different literal between columns are statistically different Tukey ($\alpha \leq 0.05$). AP= plant height; NDT= number of stems per tiller; NDH= number of leaves in main stem; NDN= number of knots in main stem; RMS= dry matter yield (t DM ha^{-1}). Significance $^{*}= p \leq 0.05$; $^{***}= p \leq 0.001$; NS= not significant.

Leaf area index (IAF)

In general, the four varieties showed an increase as the crop cycle progressed, Silo honey presented a higher IAF at 114 dds with 5 on the tip of irrigation and 6.8 in the rainy season (Figure 2).

Subsequently, it decreased when reaching the physiological maturity of the crop, due to leaf senescence and translocation to reproductive organs (Smart, 1994). Similar results were found by Soto and Hernandez (2012), when evaluating *Sorghum bicolor* (L.) Moench cultivate ISIAP Dorado, where the maximum value was 5.6 to 80 dds, under irrigation conditions. The variety Silo miel presented higher IAF in irrigation tip (6 to 120 dds) and rainy period (7, to 120 dds) and Fortuna, presented lower value in tip of irrigation (4.5, to 125 dds) and period of rains (2.9, to 145 dds).

This was mainly due to the fact that Silo honey presented leaves of greater length and width, while Fortuna, presented smaller leaves.

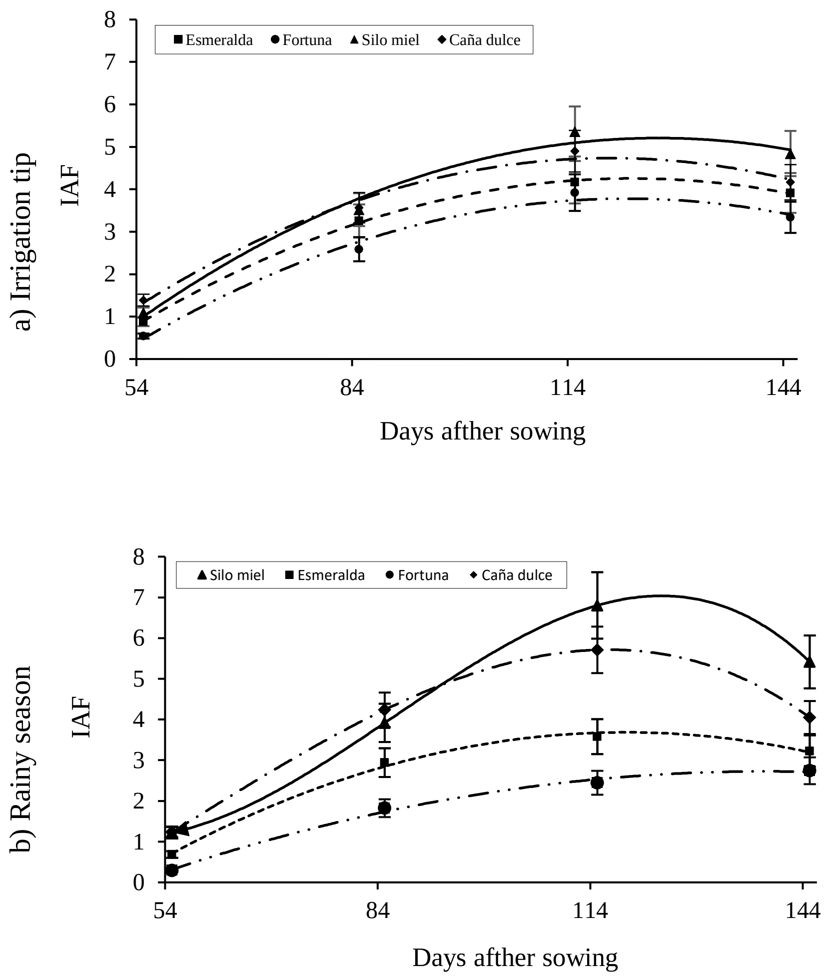

Figure 2. Leaf area index (IAF), in four varieties of sorghum under irrigated and seasonal conditions, in Montecillo, State of Mexico, 2013.

Duration of leaf area

The maximum DAF was presented in the Silo miel cultivar with 114 dds at irrigation point and in the rainy season; this is due to the fact that in this last period it had the highest IAF and the canopy obtained the highest radiation intercepted (Figure 3) (Rodríguez and Leihner, 2005), while Fortuna had a lower DAF at 110 days at irrigation point at 80 days under conditions of rains.

The IAF is as important as the DAF, as it is more effective over time, implies greater efficiency in the use of solar radiation; which manifests itself in greater growth and accumulation of dry matter during the crop cycle (Hernández and Soto, 2013).

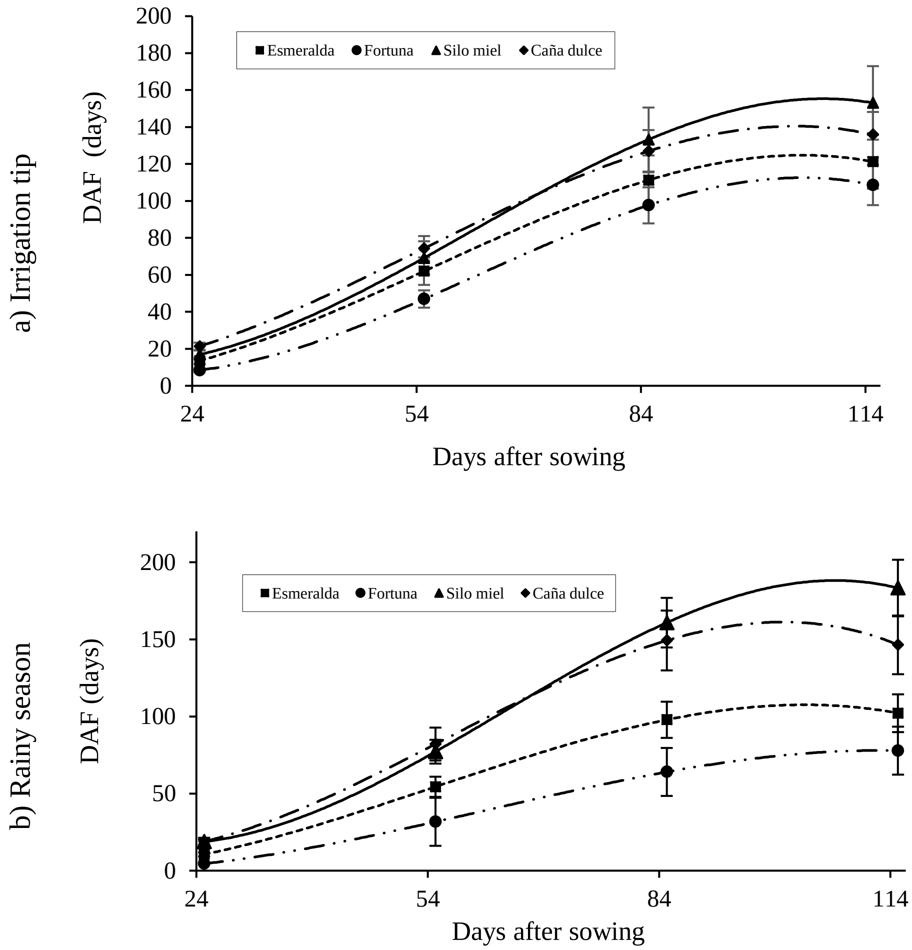

Figure 3. Duration of leaf area (DAF), in four varieties of sorghum under irrigated and seasonal conditions, in Montecillo, State of Mexico, 2013.

Growth rate of the crop (TCC)

In general, for the four varieties an increase in emergence was observed at 25 dds (6.2 g m^{-2} d^{-1}, Figure 4).

The TCC reached a maximum in the interval 56-85 dds (15.4 g m^{-2} d^{-1}) irrigation tip; in the rainy season, in the emergency interval at 25 dds, he had CBT of 4.3 g m^{-2} d^{-1} and maximum in the range of 56-85 dds (16.95 g m^{-2} d^{-1}), later he decreased in both planting periods, due to the decrease in plant growth, leaf senescence and reduction of photosynthesis (Gutierrez *et al*., 2005). The Caña dulce cultivar showed higher TCC, with 24 g m^{-2} d^{-1} in the interval 56-85 dds in irrigation tip and 26 g m^{-2} d^{-1} in the rainy season. Fortuna had lower TCC with 7.5 g m^{-2} d^{-1} (irrigation tip) and 8 g m^{-2} d^{-1} (rainfall) in the range 26-55 dds. Carrillo and Ruiz (2004), obtained similar results when evaluating six varieties of forage sorghum under irrigation conditions, the cultivar Dine a Mite reached higher TCC with 27.9 g m^{-2} d^{-1} and lower the cultivar Grazer with 24.42g m^{-2} d^{-1} to 58 dds.

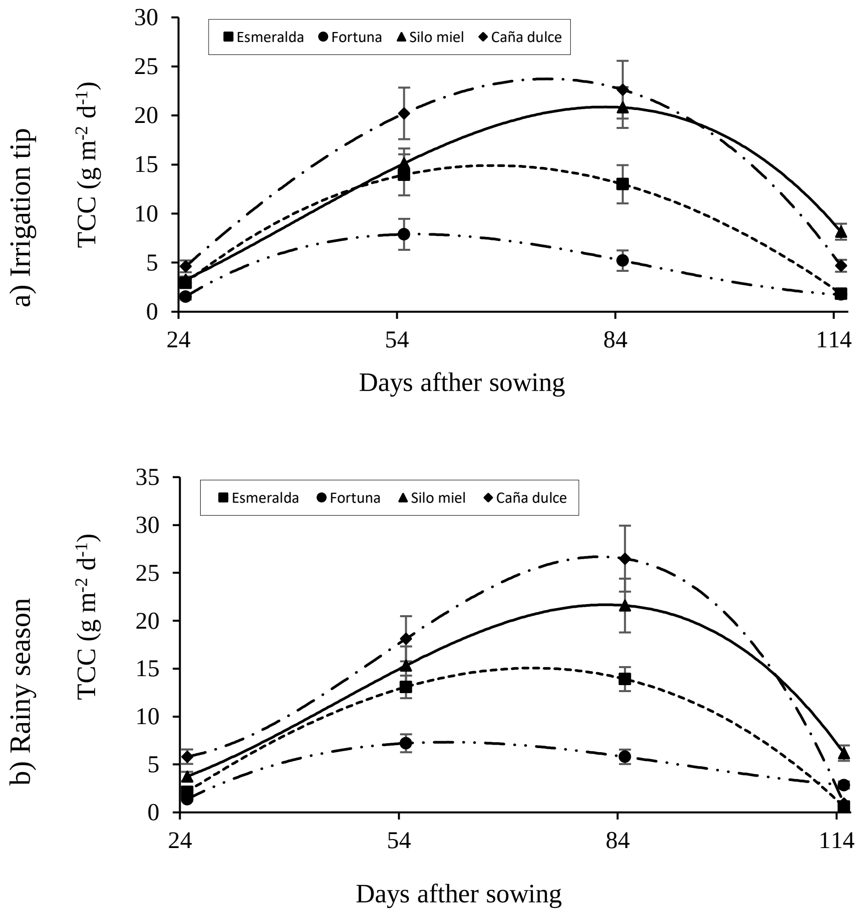

Figure 4. Growth rate of the crop (TCC), in four varieties of sorghum under irrigated and seasonal conditions, in Montecillo, State of Mexico, 2013.

Net assimilation rate (TAN)

The TAN in four varieties of sorghum, under two conditions of production, it was observed that the highest values occurred at the beginning of the emergency in the range of 0 to 54 dds and decreased as the crop development cycle progressed, until reaching physiological maturity, when lower values were presented, this was due to competition for light, nutrients, increase of the vegetal canopy, greater shade and senescence of lower leaves (Naresh and Singh, 2001; Figure 5).

In the irrigated tip condition, the Caña dulce cultivar presented the highest TAN of the emergency period at 25 dds (19.1 g m^{-2} d^{-1}), 26-55 dds (7.3 g m^{-2} d^{-1}) and 56-85 dds (5.4 g m^{-2} d^{-1}). In the rainy season something similar occurred, the sweet cane cultivar presented the highest values of the emergency period at 25 dds (19 g m^{-2} d^{-1}), 26-55 dds (7 g m^{-2} d^{-1}) and 56-85 dds (5.4 g m^{-2} d^{-1}).

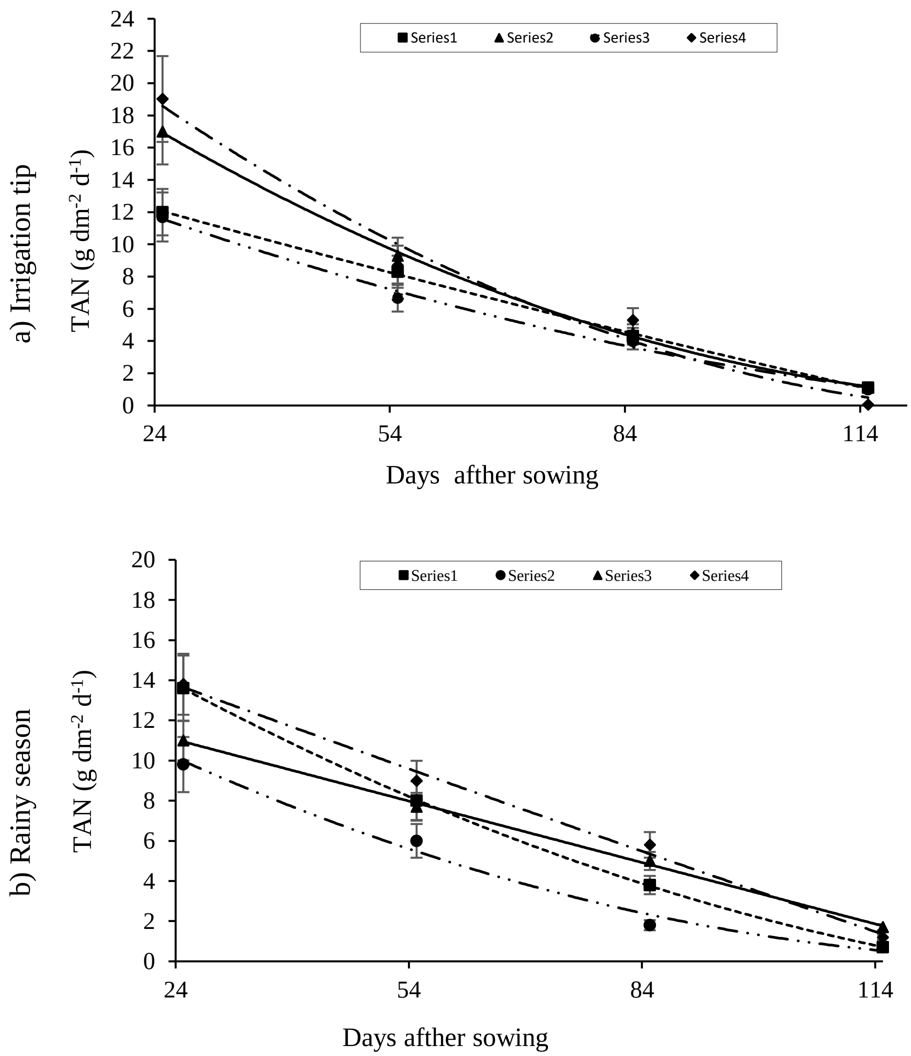

Figure 5. Net assimilation rate (TAN), in four varieties of sorghum under irrigated and seasonal conditions, in Montecillo, State of Mexico, 2013.

The cultivar Fortuna had lower TAN, in all the intervals and both sowing periods (irrigation tip and rainy season), similar values reported Saberi and Siti (2013), levels of (6 g m^{-2} d^{-1}) at 50 dds. While Carrillo and Ruiz (2004), reported TAN to 58 dds in six varieties evaluated, with values ranging from (5.17 g m^{-2} d^{-1}) in the cultivar Beefbuilder-T to (8.12 g m^{-2} d^{-1}) in the Grazer cultivar under irrigation conditions.

It is a crop tillering capacity, *Sorghum bicolor* distributes annual total forage production in more than one cut, so planting at the tip of irrigation has the advantage of harvesting forage, before the physiological maturity of the grain and taking advantage of the suitable temperatures for growth from August to October, to produce a second cut; the above, does not occur in traditional highland crops such as corn. *Sorghum bicolor* is a good option to obtain fresh forage in two harvests, when using sowings at the tip of irrigation.

Conclusions

The cultivar Esmeralda presented the shortest growing cycle; however, the cultivar that showed the highest dry matter yield, plant height, number of stems per tiller, number of leaves, number of knots was Caña dulce, 145 days after sowing. The best rates of crop growth rate and net assimilation rate were observed in sweet cane; however, Silo miel presented higher leaf area index and leaf area duration, therefore, the best cultivar for Montecillos conditions was Caña dulce. When sowing forage sorghum with 'irrigation tip', two to three harvests per year can be harvested and a better distribution of dry matter can be obtained in the Central High Plateau of Mexico.

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Cited literature

Afzal, M.; Ahmad, A. and Ahmad, A. U. H. 2012. Effect of nitrogen on growth and yield of sorghum forage (*Sorghum bicolor* (L.) Moench CV). Under three cuttings system. Agronomical research in Moldovia. 45(4):57-64.

Ajeigbe, H. A.; Akinseye, F. M.; Ayuba, K. and Jonah, J. 2018. Productivity and water use efficiency of sorghum [(*Sorghum bicolor* (L.) Moench.], grown under different nitrogen applications in Sudan savanna zone, Nigeria. Intl. J. Agron. https://doi.org/10.1155/2018/7676058.

Azam, A. S. 2013. Plant and crop science. *In*: Gregory P. J. and S. Nortcliff (Eds.). Soil conditions and plant growth. wiley blackwell. Oxforf, UK. 22-46 pp. https://marwanbaloch.files.wordpress.com/2015/01/soil-conditions-and-plant-growth.pdf.

Bednarz, C. W.; Bridges, D. C. and Brown, S. M. 2000. Analysis of cotton yield stability across population densities. Agron. J. 92:128-135.

Bolaños, A. E.; Claude. E. J. y Guillaume, A. 2012. Rendimiento y calidad de híbridos de sorgo con y sin nervadura café*. Rev. Mex. Cienc. Agríc. 3(2):37-43.

Bolaños, A. E. D. y Emile, J. C. 2013. Efecto de la distancia entre surcos y densidad de siembra en el rendimiento y calidad del forraje de sorgo. Rev. Mex. Cienc. Pec. 4(2):161-176.

Borghi, E.; Crusciol, C. A. C.; Nascentec, A. S.; Sousa, V. V.; Martins, P. O.; Mateus, G. P. and Costa, C. 2013. Sorghum grain yield, forage biomass production and revenue as affected by intercropping time. Eur. J. Agron. 51:130-139.

Carrillo, J. C. y Ruiz, J. 2004. Producción de forraje en sorgo y mijo: variables de crecimiento. Agron. Mesoam. 15(1):69-76.

Castro, J.; Ortíz, J.; Mendoza, M. C. y Zavala, F. 2000. Producción de biomasa en líneas de sorgo como respuesta al estrés hídrico. Rev. Fitotec. Méx. 23:321-334.

Cordovés, B. G. y Grizel, M. D. 2009. Sorgo dulce: sus potencialidades productivas. ICIDCA. Sobre los derivados de la caña de azúcar. 48:15-21.

Di, R. J. A.; Casanoves, F.; Balzarini, M. G.; González, M.G.; Tablada, M. y Robledo, C. W. 2008. InfoStat. Universidad Nacional de Córdoba, Argentina. 336 p.

Egli, D. B. 2017. Seed biology and yield of grain crops. 2nd Edition. CABI. Wallingfor, UK. 232 p.

Escalante, E. J. A. y Kohashi, S. J. 2015. El rendimiento y crecimiento del frijol. Manual para la toma de datos. Colegio de Postgraduados. Montecillo, Texcoco, Estado de México. 84 p.

García, E. 2005. Modificaciones al sistema de clasificación climática de Köppen. Cuarta Edición. Universidad nacional Autónoma de México (UNAM). DF. 217 p.

Gaytán, M. A.; Palomo, G. A. y Godoy, A. S. 2001. Eficiencia en la producción y distribución de biomasa en variedades precoces de algodón. Rev. Fitotec. Mex. 24:197-202.

Granados, R. B. y Sarabia, R. A. A. 2013. Cambio climático y efectos en la fenología del maíz en el DDR-Toluca. Rev. Mex. Cienc. Agríc. 4(3):435-446.

Gutiérrez, R. M.; Paul, R. M.; Escalante, E. J. A. y Larqué, S. A. 2005. Algunas consideraciones en la relación entre fotosíntesis y el rendimiento de grano en trigo. Ciencia Ergo Sum. 12(2):149-154.

Hernández, C. N. y Soto, C. F. 2013. Determinación de índices de eficiencia en los cultivos de maíz y sorgo establecidos en diferentes fechas de siembra y su influencia en el rendimiento. Cultivos Tropicales. 34:24-29.

Hunt, R. 1990. Basic Growth Analysis. Plant Growth Analysis. Unwing Hyman. London. 112 p.

Kapanigowda, M. H.; Perumal, R.; Aiken, M. R.; Herald, T. J.; Bean, S. R. and Little, C. R. 2013. Analyses of sorghum [*Sorghum bicolor* (L.) Moench] lines and hybrids in response to early season planting and cool conditions. Can. J. Plant Sci. 93:773-784.

Legarto, J. 2000. L'utilisation en ensilage plante entière des sorghos grains et sucriers: intérêts et limites pour les régions sèches. Fourrages. 163:323-338.

Naresh, K. S. and Singh, C. P. 2001. Growth analysis of maize during long and short duration crop seasons: Influence of nitrogen source and dose. Indian J. Agric. Res. 35:13-18.

Pérez, H. A.; Quero, C. A. R.; Escalante, E. J. A. S.; Rodríguez, G. M. T.; Garduño, V. S. y Miranda, J. L. 2018. Fenología, biomasa y análisis de crecimiento en variedades de sorgo forrajero en valles altos. Agron. Costarric. 42(2):107-117.

Rodríguez, W. y Leihner, D. 2005. Análisis de crecimiento vegetal. Fisiología de los cultivos tropicales. Ed. UCR. Costa Rica. 39 p.

Rouf, A. D.; Eajaz, A. D.; Ajit, K. and Urmila, G. P. 2018. Sweet sorghum-a promising alternative feedstock for biofuel production. Renewable and Sustainable Energy Reviews. 82(3):4070-4090.

Saberi, A. R and Siti, A. H. 2013. Growth analysis of forage Sorghum (*Sorghum bicolor* L.) varieties under varying salinity and irrigation frequency. Inter. J. Biotechnol. 2(7):130-140.

SIAP. 2018. Servicio de Información Agroalimentaria y Pesquera, México. Avance de siembras y cosechas, resumen por cultivo (Sorgo). Ciudad de México, México. http://infosiap.siap.gob.mx:8080/ agrícola_siap_gobmx/ resumendelegacion.do.

Smart, C. 1994. Gene expression during leaf senescence. New Phytologist. 126:419-448.

Solórzano, E. V. 2007. Guías fenológicas para cultivos básicos. Ed. Trillas. México, DF. 152 p.

Soto, C. F. y Hernández, C. N. 2012. Influencia de tres fechas de siembra en el crecimiento y rendimiento de especies de cereales cultivadas en condiciones tropicales. Parte II. Cultivo del sorgo (*Sorghum bicolor* L. Moench var. Isiap Dorado). Cultivos Tropicales. 33:50-54.