Article

Productive response of bird's foot clover as a function of the percentage of light intercepted

Perpetuo Álvarez Vázquez[1]
Sergio Iban Mendoza Pedroza[2§]
Gabino de Los Santos García[3]
Juan De Dios Guerrero Rodríguez[4]
Adelaido Rafael Rojas García[5]
Juan Antonio Encina Domínguez[1]

[1]Department of Renewable Natural Resources-UAAAN. Calzada Antonio Narro 1923, Buenavista, Saltillo, Coahuila. CP. 25315. (perpe-alvmiz@hotmail.com; jaencinad@gmail.com). [2]Genetic Resources and Productivity-Livestock-Postgraduate College-Montecillo *Campus*. Carretera Méx-Tex km 36.5, Montecillo, Texcoco, Mexico. CP. 56230. [3]Genetic Resources and Productivity-Seed Production-Postgraduate College-*Campus* Montecillo. (garciag@colpos.mx). [4]Strategies for Regional Agricultural Development-Puebla *Campus*-Postgraduate College. Puebla, Mexico. CP. 72760. (grjuan2000mx@yahoo.com). [5]Faculty of Veterinary Medicine and Animal Husbandry no. 2-Autonomous University of Guerrero. Cuajinicuilapa, Guerrero, Mexico. CP. 41940. (rogarcia@uagro.mx).

[§]Corresponding author: sergiomp@colpos.mx.

Abstract

The productivity of a forage species can be described in terms of the behavior of its morphological components and the combination with the entity in the grassland. The objective was to evaluate the productive behavior of bird's foot clover (L. *corniculatus*), under different defoliation strategies. The experiment was carried out at the Postgraduate College, from September 2015 to September 2016, in a randomized block design, with three repetitions, with the hypothesis that when harvesting the species at 95% intercepted light (IL); it has a better productive behavior. A fixed cutoff interval (FC) had lower production in winter (3 441 kg DM ha^{-1}), summer (5 024 kg DM ha^{-1}) and accumulated annual (20 710 kg DM ha^{-1}), compared to the rest of the treatments (26 689 kg DM ha^{-1}, annual average). Also, it showed lower plant height (21 vs 26 cm, average in the IL). However, the FC had a higher leaf: stem ratio, both seasonal and annual average (2.3 *vs* 1.5 average in the IL). The highest seasonal values were recorded in autumn and winter (1.9). In spring and summer, the highest heights were presented with 29 cm vs. winter with 19 cm. The leaf contributed 51% to the annual yield, followed by the stem, weeds and dead material with 32, 10 and 6%, respectively. In conclusion, the best productive performance of bird's foot clover, genotype 260012, was presented in the IL harvest strategies with respect to the FC.

Keywords: botanical and morphological composition, harvest intervals, forage production.

Reception date: February 2020
Acceptance date: April 2020

Introduction

The productivity of a forage species can be described in terms of the behavior of its morphological components and the combination with the entity in the grassland (Sbrissia and Da Silva, 2008). This may be influenced by environmental variables such as temperature (Duru and Ducrocq, 2000), availability of water, nutrients (Martuscello *et al*., 2005), defoliation management (Sousa *et al*., 2010) and light (Van Esbroeck *et al*., 1989). Thus, temporal variations in light intensity have ecological consequences on plants, affecting photosynthesis, morphology, shade tolerance, growth and survival of the species (Kimmins, 1987).

However, the measurement of light under the canopy of a plant population is complicated, since there is an irregular distribution of solar radiation in space and time and a variable distribution of gaps in the canopy (Geiger *et al*., 2003), in addition to the fact that the plant canopy, as a three-dimensional structure, changes over time (Grant, 2009).

In some studies, the growth of forage crops has been evaluated by analyzing the percentage of light interception received by the canopy (Gobbi *et al*., 2009; Crestani, 2015), in addition to other variables that are correlated with forage production and its structure, such as grassland height and leaf area index (Hammer *et al*., 2002).

Therefore, the combination of variables measured in the grassland, can lead us to develop different management strategies in species where the harvest criteria have been based on rest periods and not on the physiology of the plant and its growth dynamics (Paciullo *et al*., 2008). *Lotus corniculatus* L., commonly known as bird's foot clover, is a forage species with high productive potential, comprising a wide variety of cultivars (Naydenova *et al*., 2015).

It is the species, within the Lotus genus, with greater agronomic importance since it can be used for grazing, such as hay, or silage, together with its high nutritional value similar or greater to *Medicago sativa* L. and *Trifolium* ssp. (Escaray *et al*., 2012) also, it does not produce tympanism when used in grazing, due to the presence of condensed tannins (MacAdam *et al*., 2013).

It is a species adapted to different types of soil and climatic conditions, such as low temperatures, droughts (Vasileva *et al*., 2014), resistance to phosphorus deficiency, high concentrations of aluminum and magnesium (Mitev and Naydenova, 2008). However, this legume has not been extensively studied in Mexico. Therefore, the generation of knowledge about the productivity and morphological changes of this species is relevant to obtain an optimal productive behavior of the species (Álvarez *et al*., 2018a). Therefore, the objective of the present study was to evaluate the productive behavior of bird's foot clover (*Lotus corniculatus* L.) under different defoliation strategies.

Materials and methods

The experiment was carried out at the College of Postgraduates, *Campus* Montecillo, México (19° 29' N, 98° 54' north latitude and 2 250 meters above sea level), from September 2015 to September 2016, as a continuation of a previous work from September 2014 to September 2015

(Álvarez *et al*., 2018b). The climatic region is classified as temperate sub-humid with an average annual rainfall of 645 mm and an average annual temperature of 15 °C (García, 2004).

The weather conditions (temperature and precipitation) during the study were taken from the Autonomous University Chapingo (UACH) meteorological station, located approximately 2 km from the experimental site (Figure 1). The soil texture is characterized as sandy loam, slightly alkaline with a pH of 7.8 (Delgado *et al*., 2014).

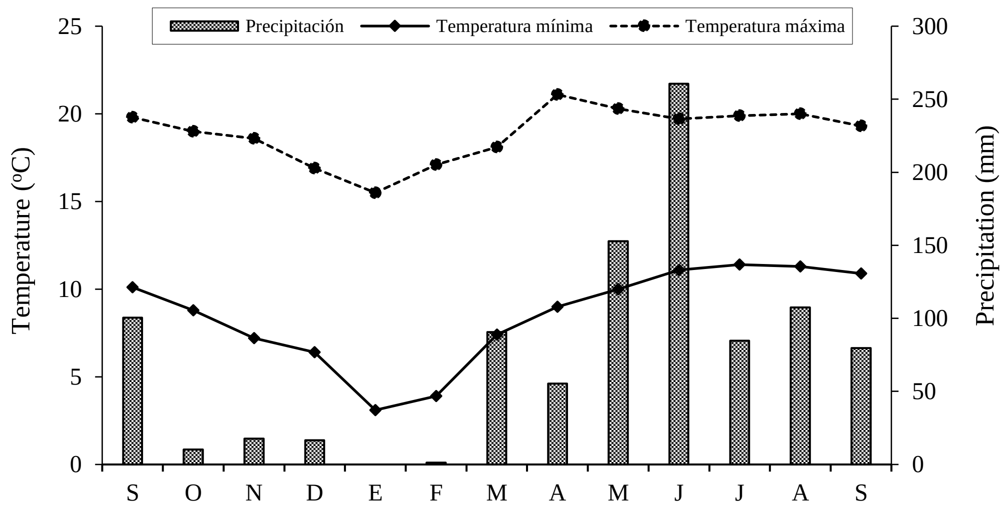

Figure 1. Distribution of precipitation (gray bars) and mean temperatures (solid and dotted line) during the experimental period (September 2015-2016).

A bird's foot clover grassland (*Lotus corniculatus* L.) genotype 260012 with an area of 192 m^2 (16∗12 m), established by transplanting in March 2014 at a plant distance of 33 cm was used. The grassland was divided into three blocks, with four 4 m^2 (2∗2 m) plots, where the treatments were located randomly, generating a total of 12 experimental units. A completely randomized block design with three replications was used. The treatments corresponded to four harvest intervals according to three percentages of intercepted light (IL; 90, 95 and 100%) and a fixed cut (FC) that was defined by season of the year (spring-summer 28, autumn 35 and winter every 42 days between cuts).

The percentage of light intercepted by the plant canopy was monitored weekly around noon, with a canopy analyzer called AccuPAR linear PAR/LAI Ceptometer, model PAR-80 (Decagon Devices), taking six readings below the canopy randomly on each plot (Carnevalli *et al*., 2006), generating cut intervals as shown in Table 1.

The evaluated variables were: forage yield (FY), Botanical and Morphological Composition (BMC), leaf: stem ratio (R:L/S) and plant height (PH), when the plot reached 90, 95, 100% IL, or one of the season-dependent harvest intervals (FC: fixed cut). The FY was determined in two fixed quadrants of 0.25 m^2 (50 x 50 cm) harvesting manually with a sickle, the total biomass present in each post-cut quadrant in each regrowth cycle.

Table 1. Intervals of cuts (days, seasonal average) of clover bird's foot (*L. corniculatus* L.) genotype 260012, as a function of the percentage of intercepted light (IL) and a fixed cut (FC) defined seasonally.

CI	Autumn	Winter	Spring	Summer	$\bar{x}$
90	53	82	42	42	55
95	54	84	46	56	60
100	63	85	53	56	64
FC	35	42	28	28	33
$\bar{x}$	51	73	42	46	53

Fixed cut (FC)= autumn = 35, winter = 42 and spring-summer = 28 days between cut. CI= cutting interval.

From each sample of the forage harvested, a sub-sample of approximately 10% was taken, separating it into leaf, stem, dead material and weed, to determine the BMC, from which the weight of the leaf and stem was considered to estimate the R:L/S. Subsequently, the material was subjected to a drying process for 72 h, at 60 °C to constant weight in a Felisa-FE243A forced air stove.

To determine the best harvesting strategy, the data was organized by station and analyzed using the PROC GLM procedure of the Statistical Analysis System, version 9.4 (SAS, 2009), for Windows, according to an experimental design of random blocks with four treatments and three repetitions. The means were compared through the Tukey test, adopting 5% significance. In this way, possible differences and interactions between harvesting frequencies (90, 95, 100% IL and FC) and seasons of the year were verified.

Results and discussion

Forage yield

The FY varied significantly between harvest intervals (CI) and season of the year (Table 2). This was affected by the CI ($p< 0.0001$) and the season of the year ($p< 0.0001$). A FC interval caused a lower forage production in the winter seasons (3 441 kg DM ha^{-1}), summer (5 024 kg DM ha^{-1}) and in the accumulated annual (20 710 kg DM ha^{-1}), regarding the harvest intervals depending on the percentage of light intercepted. According to Duru and Ducroq (2000), the plants with a higher frequency of defoliation (Table 1), present lower forage yield, caused by a reduction in the multiplication of cells.

Table 2. Forage yield (kg DM ha^{-1}) of clover bird's foot (*Lotus corniculatus* L.) genotype 260012, depending on the harvest interval (90, 95 and 100% IL and FC) and the season of the year.

CI[1]	Autumn	Winter	Spring	Summer	Annual	MSE
90	6 256 Ab	5 640 Ab	9 215 Aa	7 111 ABab	28 222 A	897
95	5 947 Ab	5 799 Ab	8 669 Aa	7 547 Aab	27 962 A	738
100	5 729 Abc	4 716 ABc	7 510 Aa	5 929 BCb	23 884 AB	420

CI[1]	Autumn	Winter	Spring	Summer	Annual	MSE
FC	4 581 Ab	3 441 Bb	7 664 Aa	5 024 Cb	20 710 B	782
$\bar{x}$	5 628 bc	4 899 c	8 265 a	6 403 b	25 194	497
MSE	687	533	1 037	553	5 442	

Means with the same capital letter in the column and the same lowercase letter in the row do not differ significantly (Tukey; p>0.05). IL= light intercepted; CI= cutting interval; MSE= mean standard error; fixed cut (FC)= autumn= 35, winter = 42 and spring-summer= 28 days between cut; [1]= effect of CI interaction x season of the year ($p\leq$ 0.05).

Thus, at the end of the year the harvesting frequencies 90 and 95% IL were higher than the FC, with values of 28 222, 27 962 and 20 710 kg DM ha^{-1}, respectively, which could have been caused by poor accumulation of stems at the crown level (Da Silva *et al*., 2010; Table 3). In general, seasonally, the FY varied from 3 441 kg DM ha^{-1} in winter in the FC, to 8 265 kg DM ha^{-1} in summer in 95% IL. This last management strategy presented the highest yield in the winter and summer seasons with 5 799 and 7 547 kg DM ha^{-1}, respectively (p> 0.05).

Therefore, the harvest conditions with 95% IL, in the winter, summer and in the annual accumulation, the FY was higher than the FC (p< 0.05). In the autumn and spring seasons there were no differences between the different harvesting strategies (Table 2). However, if there were differences between seasons (p< 0.05), spring was greater (8 265 kg DM ha^{-1}) than that recorded in winter (4 899 kg DM ha^{-1}). The foregoing was probably the result of a greater and lesser production of leaf, stem and plant height, in the different harvest intervals, within each season (Table 3), with which it is highly correlated (Rojas *et al*., 2016).

Table 3. Annual forage yield (kg DM h^{-1}) by botanical and morphological component of bird's foot clover (*Lotus corniculatus* L.) genotype 260012 depending on the harvest interval (90, 95 and 100% IL and FC) and the season of the year.

CI[1]	Botanical and morphological component				MSE
	Leaf	Stem	MD	Weed	
90	15 087 Aa	10 548 Ab	711 BCc	1 908 Ac	1 523
95	13 291 Aa	9 408 ABb	2 376 Ac	2 933 Ac	841
100	11 600 Aa	7 905 Bb	2 180 ABc	2 223 Ac	1 028
FC	11 654 Aa	4 923 Cb	687 Cb	3 494 Ac	749
$\bar{x}$	12 908 a	8 196 b	1 489 c	2 639 d	439
MSE	1 378	958	565	1 228	

Means with the same capital letter in the column and the same lowercase letter in the row do not differ significantly (Tukey; p>0.05). IL= light intercepted; CI= cutting interval; MSE= mean standard error; fixed cut (FC)= autumn= 35, winter = 42 and spring-summer= 28 days between cut; [1]= effect of CI interaction x season of the year ($p\leq$ 0.05).

Botanical and morphological composition

The morphological components of the species and botanical composition of the prairie were influenced by the CI (p< 0.0001), component (p< 0.0001), and the interaction of CI x component (p< 0.0001). The frequency of harvest of the FC, resulted in less production of stems and dead material, compared to the rest of the treatments ($p< 0.05$; Table 3). This was probably the result of a shorter regrowth period in the FC of 33 days annual average, with respect to the cut-off intervals depending on the percentage of light intercepted at 55, 60 and 64 days, annual average for 90, 95 and 100% IL, respectively (Table 1).

However, the leaf and the weed did not differ between treatments ($p> 0.05$); however, the averages show us that the leaf is the component that made the greatest contribution to the annual yield with 12 908 kg DM ha^{-1} (Table 3). The leaf contributed 51% of the annual yield (25 194 kg DM ha^{-1}, Table 2), followed by the stem, weeds and dead material with 32, 10 and 6%, respectively. This was reflected in a higher and lower total forage yield, depending on the amount of leaf produced, between seasons and treatments, given the high correlation between these variables (Álvarez *et al*., 2018a).

However, the stem is also an important morphological component that allows a spatial arrangement of the plants and accumulation of assimilates that translocate to the leaves (Fagundes *et al*., 2006). According to Barbosa *et al*. (2011), the accumulation of stems increases in spring and declines as there is a greater deficit of water and low temperatures; during autumn and winter (Figure 2), altering the leaf:stem ratio (Table 4).

Table 4. Relationship leaf stem (R: H/T) of clover bird's foot (*Lotus corniculatus* L.) genotype 260012 depending on the harvest interval (90, 95 and 100% IL and FC) and the season of the year.

CI[1]	Autumn	Winter	Spring	Summer	$\bar{x}$	MSE
90	1.9 Ba	1.5 Bb	1.1 Bc	1.4 Bbc	1.5 B	0.11
95	1.7 Ba	1.7 Ba	1.4 ABab	1 Cb	1.5 B	0.25
100	1.4 Bb	2.2 Aa	1.1 Bb	1.2 BCb	1.5 B	0.14
FC	2.6 Aa	2.4 Aa	1.7 Ab	2.5 Aa	2.3 A	0.17
$\bar{x}$	1.9 a	2 a	1.4 b	1.5 b	1.7	0.08
MSE	0.26	0.16	0.14	0.09	0.09	

Means with the same capital letter in the column and the same lowercase letter in the row do not differ significantly (Tukey; $p>0.05$). IL= light intercepted; CI= cutting interval; MSE= mean standard error; fixed cut (FC)= autumn= 35, winter = 42 and spring-summer= 28 days between cut; [1]= effect of CI interaction x season of the year ($p\leq 0.05$).

Seasonally, the leaf was affected by the CI ($p< 0.0001$), season of the year ($p< 0.0001$) and the interaction CI x station ($p= 0.0381$). It was the highest component in all seasons, followed by stem, weed, and dead material. Its greatest presence was in spring with 5 551 kg DM ha^{-1} (CI average; Figure 2).

This may be related to a greater availability of climatic factors that favor its growth such as water, temperature and light (Barbosa *et al*., 2011). According to Marcelino *et al*. (2006), under suitable environmental conditions, the plants increase the appearance and elongation rates of the leaf, therefore, they make the accumulation of biomass basically depend on the production of leaves.

For its part, the stem was influenced by the CI ($p< 0.0001$), season of the year ($p< 0.0001$) and the Station x CI interaction ($p= 0.0185$). Similar to the leaf, this was higher in spring with 3 204 kg DM ha^{-1} (average of the cut intervals), favored by optimal environmental conditions (Barbosa *et al*., 2011). In the case of the leaf, only in autumn and spring, the treatment with 90% IL, marked differences with the rest of the harvest intervals ($p< 0.05$) and, on the other hand, the stem was greater in 90 and 95% IL to FC ($p< 0.05$), in all seasons of the year (Figure 2).

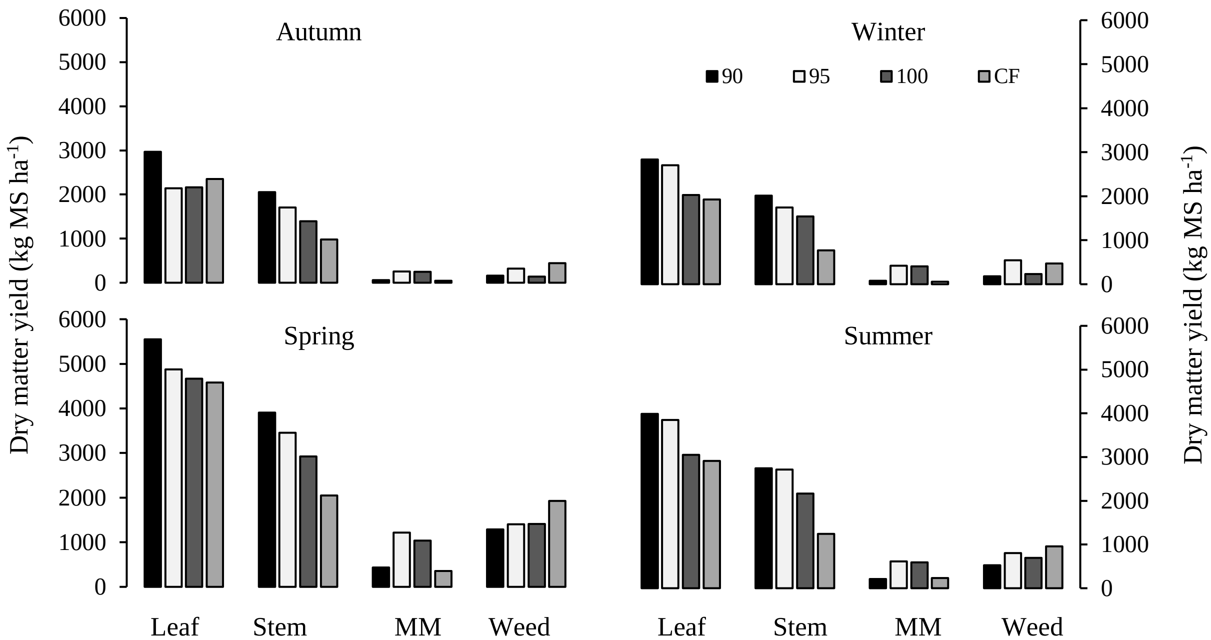

Figure 2. Botanical and morphological composition of bird's foot clover (*Lotus coniculatus* L.) genotype 260012 at various harvest intervals; 90, 95 and 100% IL and a fixed cut (FC) defined by season (autumn: 35, winter: 42 and spring-summer: 28 days between cuts).

Low stem production in FC can be explained by a process of intra-specific competition for growth factors such as light, which gives rise to the process known as 'size/density compensation of stem population' (Matthews *et al*., 1995; cited by Barbosa *et al*., 2011). However, the rate of appearance of leaves determines the production of stems, since this reduces and starts the death of stems when 9% of interception of incident light on the grassland is exceeded and the quality and quantity of light is limiting, therefore, the size of the stems is increased to compensate for the number of these (Mazzanti *et al*., 1994).

Furthermore, when 100% of the light intercepting the plant canopy is intercepted in the grassland, the composition in the light spectrum changes inside the canopy, reducing infrared light (Gautier *et al*., 1999) and this alteration reduces tillering and stem biomass (Barbosa *et al*., 2011). As the number of leaves increases, the plant invests resources in stem elongation in an attempt to place leaf mass on top of the grassland canopy (Da Silva and Hernández, 2010).

Therefore, the quantity and quality of light is progressively reduced at the level of the basal area, causing the presence of dead material as a consequence of leaf senescence, as a way of keeping the number of live leaves per stem relatively stable (Sbrissia and Da Silva, 2008), which was evident in the treatment of 95 and 100% IL in all stations, with the presence of dead material (Figure 2).

However, weeds and dead material were only affected by the season of the year ($p< 0.0001$), registering their highest presence in spring with an average of 1 356 and 859 kg DM ha^{-1}, respectively, which can be reflection of environmental conditions rather than the harvest interval (Rojas *et al*., 2016).

Leaf: stem ratio (R:L/S)

The R:L/S was affected by the season of the year ($p< 0.0001$) and the cutoff interval ($p< 0.0001$) and by the CI x Station interaction ($p< 0.0002$). Both the seasons and the annual average show that the FC presented the highest R:L/S values and the lowest in the harvest intervals depending on the percentage of light intercepted (90, 95 and 100%).

This may be related to a higher harvest frequency, since the FC had an IC of 33 days (annual average) and the average of the plots managed with 90, 95 and 100% IL was 60 days (Table 1), which that caused an increase in leaf production with respect to the stem (Barbosa *et al*., 2011) and did not allow the species to be harvested at its optimum moment, but in the phase of accelerated growth, where the highest percentage of young leaves is found and little number of stems (Álvarez *et al*., 2018b).

According to Lemaire and Chapman (1996), a greater growth of the leaf is a plastic response of the plant to a high defoliation frequency, considered as a strategy of the plant as an escape to defoliation. Seasonally, the highest average values were recorded during autumn and winter with 1.9 and 2, respectively (Table 4), which may be related to a greater amount of light transmitted at the level of the basal part of the plant, in the seasons where it has lower heights (Table 5).

Table 5. Plant height (cm) of bird's foot clover (*Lotus corniculatus* L.), genotype 260012 depending on the harvest interval (90, 95 and 100% IL and FC) and the season of the year.

CI[1]	Autumn	Winter	Spring	Summer	$\bar{x}$	MSE
90	23 Ab	23 Ab	29 Ba	26 Bab	25 B	1.5
95	24 Ab	19 Bc	32 Aa	32 Aa	27 AB	1.3
100	24 Ab	20 Bc	34 Aa	33 Aa	28 A	1.1
FC*	21 Ab	15 Cc	23 Cab	25 Ba	21 C	0.9
$\bar{x}$	23 b	19 c	29 a	29 a	25	0.7
MSE	1.2	0.9	0.8	1.7	0.5	

Means with the same capital letter in the column and the same lowercase letter in the row do not differ significantly (Tukey; $p>0.05$). IL= light intercepted; CI= cutting interval; MSE= mean standard error; fixed cut (FC)= autumn= 35, winter = 42 and spring-summer: 28 days between cut; [1]= effect of CI interaction x season of the year ($p\leq 0.05$).

This behavior reflects a greater weight of the leaf with respect to the stem, more distant in autumn and winter compared to spring and summer. This may be the result of seasonal fluctuations in the amount of light received by plants, causing alterations in the amount of leaf produced (Matthew *et al*., 1999).

These results are similar to those reported by Álvarez *et al*. (2018a) in the genotype 202700, who found mean values of 2.1 for autumn and winter compared to spring and summer with 1.7, due to a higher density of stems, but of less weight. Giacomini *et al*. (2009), mention that there is a translocation of assimilates from the leaves to the stems higher in spring and summer, which causes a higher weight of stems, but less number of these.

Plant height (PH)

The PH was affected by the season of the year ($p< 0.0001$), the harvest interval ($p< 0.0001$) and the Station x CI interaction ($p= 0.0002$). According to the annual and seasonal average, with the exception of autumn where there were no statistical differences ($p> 0.05$), the frequency of harvest of the FC showed lower plant height with an annual average of 21 cm, compared to the rest of the treatments with 26.6 average cm (Table 5). Seasonal behavior showed that the averages in spring and summer were higher in plant heights with 29 cm, compared to winter with 19 cm ($p< 0.05$).

These results were consistent with the productive behavior of the species in forage yield (Table 2). This could be promoted by a shorter harvest interval of 33 d in the FC compared to 60 d of the grasslands managed with the percentage of light intercepted strategy (90, 95 and 100%) since, at a higher height it corresponded to a higher yield of seasonal forage and between treatments, due to the high correlation that exists between these two productive variables (Halk *et al*., 2012; Álvarez *et al*., 2018b).

Furthermore, the highest values, found in spring and summer, may be the result of more favorable conditions for higher stem growth (Rojas *et al*., 2016). However, some works in the species *Lotus corniculatus* L., relate the height of the plant and forage yield with the growth habit of the genotype, since these can range from erect to prostrate (Schefer *et al*., 2011).

Conclusions

The best productive performance of bird's foot clover (*Lotus corniculatus* L.), genotype 260012, was presented in the harvest strategies under the percentage of intercepted light, compared to the plots harvested under the fixed cut interval defined by season. The leaf was the morphological component that most contributed to yield in all seasons and harvest intervals. These results are part of some studies of the species in Mexico, therefore, it is recommended to continue characterizing the species in the different ecological niches.

Cited literature

Álvarez, V. P.; García, De los S. G.; Guerrero, R. J. D.; Mendoza, P. S. I.; Ortega, C. M. E. y Hernández, G. A. 2018a. Comportamiento productivo de *Lotus corniculatus* L. dependiente de la estrategia de cosecha. Rev. Agrociencia. 52(8):1081-1093.

Álvarez, V. P.; Hernández, G. A.; García, De los S. G.; Guerrero, R. J. D.; Mendoza, P. S. I.; Ortega, C. M. E.; Rojas, G. A. R. y Wilson, G. C. Y. 2018b. Potencial forrajero de *Lotus corniculatus* L. con diferentes estrategias de manejo. Agroproductividad. 11(5):24-28.

Barbosa, R. A.; Nacimiento, Jr. D.; Vilela, H. H.; Da-Silva, C. S.; Batista-Euclides, P. V.; Sbrissia, F. A. and Da-Lana, S. B. 2011. Morphogenic and structural characteristics of guinea grass pastures submitted to three frequencies and two defoliation severities. Rev. Bras. Zootec. 40(5):947-954.

Carnevalli, R. A.; Da Silva, S. C.; Oliveira, A. A.; Uebele, M. C.; Bueno, F. O.; Hodgson, J.; Silva, G. V. and Moraes, J. P. 2006. Herbage production and grazing losses in *Panicum maximum* cv. Momba¸ca pastures under four grazing managements. Tropical Grasslands. 40(1):165-176.

Crestani, S. 2015. Respostas morfogênicas e dinâmica da popula¸cão de perfilhos e touceiras em Brachiaria brizantha cv Piatã submetida a regimes de sombra em área de integra¸cão lavoura-pecuária-floresta. PhD Thesis, University of São Paulo, São Paulo, Brazil. 102 p.

Da Silva, S. C. y Hernández, G. A. 2010. Manejo del pastoreo en praderas tropicales. *In*: Velazco, Z. M. E. Los forrajes y su impacto en el trópico. 1ª. (Ed.). Chiapas, México. Universidad Autónoma de Chiapas. 63-95 pp.

Delgado, R.; Escalante, J.; Díaz, R.; Trinidad, S. A.; Morales, E. y Sosa, E. 2014. Defoliación en maíz y su efecto sobre el rendimiento de frijol-maíz en asociación. Rev. Mex. Cienc. Agríc. 5(6):1015-1027.

Duru, M. and Ducrocq, H. 2000. Growth and senescence of the successive grass leaves on a tiller. Ontogenic development and effect of temperature. Annals Bot. 85(5):635-643.

Escaray, F. J.; Menendez, A. B.; Garriz, A.; Pieckenstain, F. L.; Estrella, M. J.; Castagno, L. N.; Carrasco, P.; Sanjuan, J. and Ruiz, O. A. 2012. Ecological and agronomic importance of the plant genus Lotus. Its application in grassland sustainability and the amelioration of constrained and contaminated soils. Plant Sci. 182(1):121-133.

Fagundes, J. L.; Da Fonseca, D. M.; Mistura, C.; De Morais, R. V.; Teixeira, V. C. M.; Gomide, J. A.; Do Nascimento Jr., D.; Casagrande, D. R. e Da Costa, L. T. 2006. Características morfogênicas e estruturais do capim-braquiária em pastagem adubada com nitrogênio avaliadas nas quatro estações do ano. Rev. Bras. Zootec. 35(1):21-29.

García, E. 2004. Modificaciones al sistema de clasificación climática de Köppen. 4ª. (Ed.). Universidad Nacional Autónoma de México (UNAM). México, DF. 217 p.

Gautier, H.; Varlet-Grancher, C. and Hazard, L. 1999. Tillering responses to the light environment and to defoliation in populations of perennial ryegrass (*Lolium perene* L.) selected for contrasting leaf length. Annals Bot. 83(4):423-429.

Geiger, R.; Aron, R. H. and Todhunter, P. 2003. The climate near the ground. 6ª (Ed.). Maryland, USA: Rowman y Littlefield Publishers, Inc. 221 p.

Giacomini, A. A.; Da Silva, S. C.; De L. Sarmento, D. O.; Zeferino, C. V.; Souza Jr., S. J.; Da Trindade, J. K.; Del A. Guarda V. and D. Nacimiento Jr. 2009. Growth of marandu palisadegrass subjected to strategies of intermittent stocking. Scientia Agricola (Piracicaba, Brazil). 66(6):733-741.

Gobbi, K. F.; Garcia, R.; Garcez, N. A. F.; Pereira, O. G.; Ventrella, M. C. and Rocha, G. C. 2009. Morphological and structural characteristics and productivity of Brachiaria grass and forage peanut submitted to shading. Rev. Bras. Zootec. 38(9):1645-1654.

Grant, F. W. 2009. *Lotus corniculatus*. SciTopics. Canada. http://www.scitopics.com/ Lotus_corniculatus.html.

Hakl, J.; Hrevusˇova´ Z.; Hejcman, M. and Fuksa, P. 2012. The use of a rising plate meter to evaluate lucerne (*Medicago sativa* L.) height as an important agronomic trait enabling yield estimation. Grass Forage Sci. 67(4):589-596.

Hammer, G. L.; Kropff, M. J.; Sinclair, T. R. and Porter, J. R. 2002. Future contributions of crop modelling from heuristics and supporting decision making to understanding genetic regulation and aiding crop improvement. Eur. J. Agron. 18(1-2):15-31.

Kimmins, J. P. 1987. Forest ecology. A foundation for sustainable management. 2ª (Ed.). New Jersey, USA. Prentice Hall. 596 p.

Lemaire, G. and Chapman, D. 1996. Tissue flows in grazed plant communities. *In*: Hodgson, J. and Illius, A. W. (Eds.). The ecology and management of grazing systems. Wallingford. Cab International. 3-36 pp.

MacAdam, J. W.; Bruner, J.; Islam, A. and Shewmaker, 2013. The benefits of tannin-containing forages. Plants, Soils and Climate, Utah State University AG/Forages. 3-4 pp.

Marcelino, K. R. A.; Do Nascimento Jr., D.; Da Silva, S. C.; Euclides, V. P. B. e Da Fonseca, D. M. 2006. Características morfogênicas e estruturais e produção de forragem do capim-marandu submetido a intensidades e frequências de desfolhação. Rev. Bras. Zootec. 35(6):2243-2252.

Martuscello, J. A.; Da Fonseca, D. M.; Do Nascimento Jr., D.; Santos, P. M.; Ribeiro Jr., J. I.; Daniel de Da Cunha, N. F. V. e De Melo-Moreira, L. 2005. Características morfogênicas e estruturais do capim-xaraés submetido à adubação nitrogenada e desfolha. Rev. Bras. Zootec. 34(5):1475-1482.

Matthew, C.; Lemaire, G.; Sackville-Hamilton, N. R. and Hernández, G. A. 1995. A modified self-thinning equation to describe to size/ density relationships for defoliated swards. Annals Bot. 76(6):579-587.

Matthew, P. N. P.; Harrington, K. C. and Hampton, J. G. 1999. Management of grazing systems. *In*: White, J. Hodgson, J. (Eds.) *In*: New Zealand pasture and crop science. Auckland. Oxford University Press. 153-174 p.

Mazzanti, A.; Lemaire, G. and Gastal, F. 1994. The effect of nitrogen fertilization on the herbage production of tall fescue swards grazed continuously with sheep. 1 -herbage growth dynamics. Grass Forage Sci. 49(2):111-120.

Mitev, D. and Naydenova, G. 2008. Sustainable development of mixed grassland of red fescue and Kenthucky bluegrass on the slopes of the Central Balkan Mountains. Ecology-sustainable development. Vratsa. 96-100 pp.

Naydenova, G.; Vasileva, V. and Mitev, D. 2015. Productivity of Bulgarian pasture ecotypes perennial legumes. J. Mountain Agric. Balkans. 18(6):972-982.

Paciullo, D. S. C.; Campos, N. R.; Gomide, C. A. M.; Castro, C. R. T.; Tavela, R. C. e Rossiello, R. O. P. 2008. Crescimento de capim-braquiária influenciado pelo grau de sombreamento e pela esta¸cão do ano. Pesquisa Agropecuária Brasileira. 43(7):917-923.

Rojas, G. A. R.; Hernández, G. A.; Santiago, J. C.; Maldonado P. M. A.; Mendoza P. S. I.; Álvarez V. P. and Joaquin, T. B. M. 2016. Comportamiento productivo de cinco variedades de alfalfa. Rev. Mex. Cienc. Agríc. 7(8):1855-1866.

SAS. 2009. SAS/STAT® 9.2. Use's Guide Release.Cary, NC: SAS InstituteIcn. USA.

Sbrissia, A. F. e Da Silva, S. C. 2008. Compensação tamanho:densidade populacional de perfilhos em pastos de capim-marandu. Rev. Bras. Zootec. 37(1):35-47.

Scheffer, B. M. S.; Brustolin, R. and Dall, M. A. 2011. Performance of Lotus corniculatus L. genotypes submitted to cutting interval: subsidies to a breeding program. Rev. Bras. Zootec. 40(8):1645-1650.

Sousa, B. M. de L.; Do Nascimento Jr. D.; Da Silva, S. C.; Monteiro, H. C. D. F.; Rodrigues, C. S.; Da Fonseca, D. M.; Da Silveira, M. C. T. and Sbrissia, A. F. 2010. Morphogenetic and structural characteristics of Andropogon grass submitted to different cutting heights. Rev. Bras. Zootec. 39(10):2141-2147.

Van Esbroeck, G. A.; King, J. R. and Baron, V. S. 1989. Effects of temperature and photoperiod on the extension growth of six temperate grasses. *In*: International Grassland Congress, Nice. Proceedings Nice, França. 459-460 pp.

Vasileva, V. 2014. Productivity of dry aboveground and root mass in mixtures. J. Mountain Agric. Balkans 17(4):956-969.