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Article

Forage accumulation in *Lotus corniculatus* L. as a function of harvest strategy

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Abstract:

Different harvest strategies can substantially affect yield in forages. A study was carried out to determine the optimum harvest strategy for *Lotus corniculatus*, genotype 255301, during two production periods among four tested strategies: three determined by the percentage of light intercepted by the canopy (90, 95 and 100 % IL), and one season-defined fixed cut (FC).

The treatments (IL and FC) were distributed in a randomized block design with three repetitions. Forage yield in the FC was 27 % lower than the 95 % IL in the first period (19,915 *vs* 28,417 kg DM ha^{-1}), and 29 % lower than the average of all three IL treatments in the second period (19,100 *vs* 26,952 kg DM ha^{-1}). Average seasonal yield in both periods was higher in spring (9,447 kg DM ha^{-1}) than in autumn (3,120 kg DM ha^{-1}). The leaf was the component that contributed most (56 %) to yield, particularly in spring in the 95 % IL treatments. Plant height was greatest in the 90, 95 and 100 % IL treatments (average= 21.5 cm) and lowest in the FC treatments (average= 17 cm). By season, plant height was greatest (average= 24 cm) in spring and lowest in winter (average= 17 cm). In both periods, average leaf:stem ratio was highest in the FC treatment (2.3) followed by the 90, 95 and 100 % IL treatments. *Lotus corniculatus* genotype 255301 yield was optimum when harvested using intercepted light percentages as an indicator; leaf production was highest in the 95 % intercepted light treatments.

Key words: *Lotus corniculatus* L., Forage production, Harvest strategy, Intercepted light.

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Introduction

Lotus corniculatus L., commonly known as bird's-foot trefoil, is the most important forage species of its genus. This includes about 200 species, both annuals and perennials(1), which occupy approximately 90 % of the planet's crop surface(2). Its yield and nutritional quality (between 18.9 to 21.8 % of crude protein, dry basis) are similar or superior to alfalfa (*Medicago sativa* L.) and white clover (*Trifolium repens* L.)(3). It also contains less cellulose and more non-structural carbohydrates than these species(4), additionally, due to its concentration of condensed tannins does not produce bloat in grazing ruminants(5). As with all other forage species, productivity and persistence in *L. corniculatus* are a function of forage accumulation, and both are influenced by harvest strategy and efficiency(6,7).

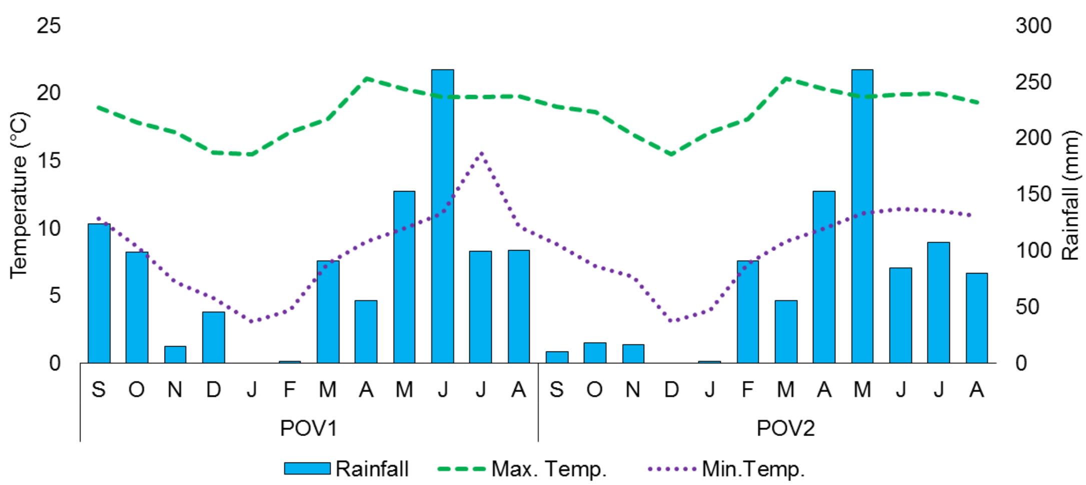
Plant growth and management practices are variables which interact with soil and climate(8). In forages, competition between individuals occurs as growth progresses, particularly during regrowth periods when pasture light quantity and quality are reduced(9). For example, the point when 95 % intercepted light is reached in a pasture is optimum for harvest since it is when optimum productivity is obtained(10). In other words, proper management of intercepted light in a pasture ensures the best forage productivity(11). High correlations have been found between forage accumulation and intercepted light in temperate climate legumes(12). Only limited research has been done on *L. corniculatus* in this regard, therefore, the present study objective was to identify optimum harvest strategy for *Lotus corniculatus* (genotype 255301) in four harvest interval scenarios: three light interception-dependent scenarios and one seasonally-defined fixed cutoff.

Material and methods

Two experiments were carried out under field conditions at the College of Postgraduates (Colegio de Posgraduados), Texcoco, Mexico (19°29'N, 98°54'W; 2,250 m asl): one in autumn-summer 2014-2015 (POV1); and a second in autumn-summer 2015-2016 (POV2). Soil texture at the experimental field is sandy loam and slightly alkaline, with 7.8 pH(13). Regional climate is temperate subhumid with summer rains, average annual precipitation 645 mm and average annual temperature of 15 °C(14).

During the study periods, air temperature (minimum and maximum) and precipitation data were collected at the meteorological station of the Autonomous University of Chapingo (Universidad Autónoma de Chapingo) (Figure 1), located 2 km from the experimental field. During period POV1 accumulated rainfall was 1,043 mm, while during POV2 it was 877 mm. Maximum temperatures occurred in the spring-summer in both periods.

Figure 1: Maximum and minimum mean monthly temperature, and monthly accumulated rainfall



POV1= Autumn 2014-Summer 2015; POV2 = Autumn 2015-Summer 2016. Data from Autonomous University of Chapingo meteorological station.

The experimental field consisted of *Lotus corniculatus* L. genotype 255301 established by transplanting in March 2014 at a planting interval of 33 cm. Plants were from greenhouse material. No fertilizer was applied. In seasons with little or no rainfall the field was irrigated to field capacity every two weeks. At the beginning of the study (5 September 2014), a manual cut was made 7 cm above ground level to standardize forage height. Experimental units were 4 m^2 plots. The treatments consisted of four manual harvest strategies: cutting intervals when intercepted light percentages reached 90, 95 and 100 %; and fixed cut intervals implemented by season (i.e. autumn= 35-d interval, winter = 42-d interval, spring-summer = 28-d interval). Residual forage height was 7 cm in all treatments(3). Intercepted light percentages were monitored prior to cutting, by taking six readings in each plot at 1200 h with a ceptometer (Accupar LP-80, Decagon Devices, USA). The four treatments were randomly assigned to four 4 m^2 plots in a completely randomized block design with three replicates, and four plots per block, creating twelve experimental plots.

Forage yield (kg DM ha^{-1}) was measured using the biomass harvested in two fixed 0.25 m^2 quadrants per replicate, established at the beginning of the experimental period. Harvested material was placed in labeled bags and dehydrated at 60 °C to constant weight in a forced air oven (Felisa, Mod. FE-243A). The botanical and morphological composition (BMC) of the harvested forage was quantified by taking an approximately 10 % subsample and separating it into leaves, stems, dead (senescent) material and weeds. Each fraction's contribution to yield was calculated in kg DM ha^{-1}. Leaf and stem data from the BMC were used to calculate the leaf:stem ratio by dividing the weight of the leaf fraction by the weight of the stem fraction. Estimation of average plant height was done by taking twelve measurements one day before cutting at random within each replicate using a 50 cm long graduated ruler. The values of the cuts from each season were averaged and these averages used to calculate the equivalence in forage yield per centimeter of plant height, dividing yield by plant height by the number of cuts(15).

The effect of the treatments (harvest strategy) on the response variables was analyzed by grouping the data seasonally and by study period. The data were analyzed using a randomized block experimental design with four treatments and three replicates. Comparison of means was done with a Tukey test ($P \leq 0.05$). All statistical analyses were run with the PROC GLM procedure in the SAS statistical package(16).

Results and discussion

Forage yield

Average seasonal yield was highest in spring (9,447 kg DM ha^{-1}), although this did not differ with that of summer in POV1. This variable was lowest in autumn (3,120 kg), which did not differ from winter in the same period (Table 1). Yield behavior was directly related to optimal temperatures (22 °C) for growth in *L. corniculatus*(3). Temperatures were favorable in spring (Figure 1), which benefited growth and production. This agrees with yield behavior reported in a study of five populations of *L. corniculatus* using grazing intervals of 20 and 40 d(17). Seasonal changes in forage species growth performance can therefore be attributed to seasonal environmental conditions(18). For instance, in *L. corniculatus* seasonal distributions in forage production have been reported of 32 % in spring, 30 % in summer, 23 % in winter and 15 % in autumn; 62 % of production occurred in spring-summer(19). Slightly lower average yields (7,700 kg DM ha^{-1}) have been reported for *L. corniculatus* at a 45-d cutting interval in Texcoco, which were influenced by climate, management and genotype growth habit(3).

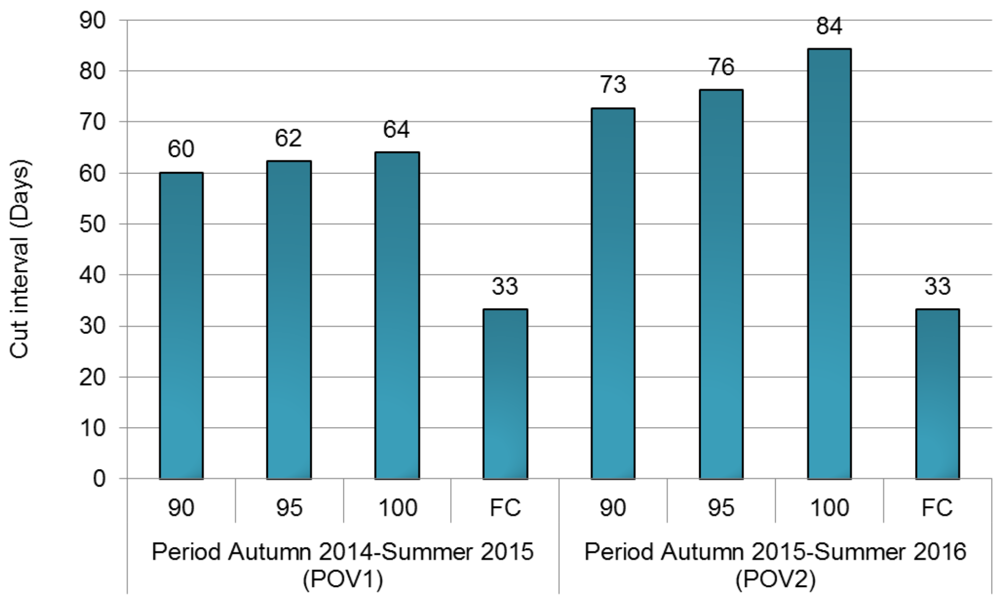
Table 1: Forage yield (kg DM h^{-1}) of *L. corniculatus*, genotype 255301, as a function of intercepted light (IL) and seasonally-defined fixed cut

IL (%)	Autumn	Winter	Spring	Summer	Accumulated	SEM
POV1						
90	4527 Ab	2736 Bb	10326 Aa	9746 Aa	27336 AB	1271
95	4956 Ab	4422 Ab	10346 Aa	9942 Aa	28417 A	481
100	4235 Ab	2716 Bb	11002 Aa	9178 Aa	27132 AB	802
FC	3300 Ab	2431 Bb	8147 Aa	6851 Ba	20730 B	529
Average	4255 b	3076 b	9956 a	8929 a	25904	564
SEM	683	522	1432	637	2461	
POV2						
90	4749 Ac	3247 Ad	9953 Aa	8565 Ab	26515 A	355
95	4676 Ab	3835 Ab	9087 ABa	9515 Aa	27113 A	505
100	5501 Ac	3749 Ad	9732 Aa	8246 Ab	27227 A	477
FC	4603 Ab	1826 Bc	6982 Ba	5689 Bb	19100 B	402
Average	4882 c	3164 d	8938 a	8004 b	24989	306
SEM	628	329	940	668	2397	

FC = Fixed cut (autumn = 35-day interval, winter = 42-day interval, spring-summer = 28-day interval). POV1= Autumn 2014-Winter 2015; POV2= Autumn 2015-summer 2016. SEM = standard error of the mean. Significant difference ($P \leq 0.05$) is indicated by different uppercase letters between columns and different lowercase letters between rows.

Accumulated forage production differed between treatments ($P \leq 0.05$) (Table 1). In POV1, yield was lowest in the FC treatment, with 27 % less production than in the 95 % IL treatment (28,417 *vs* 20,730 kg DM ha^{-1}). In POV2 the FC treatment had a cumulative yield 29 % less than the average of the three IL treatments (26,952 *vs* 19,100 kg DM ha^{-1}). This may be related to the shorter harvest interval (< 33 d) in the FC treatments versus the longer average harvest interval (70 d) in the IL treatments (Figure 2). This coincides with a study in which *L. corniculatus* (cultivar 202700) grown in Texcoco exhibited a lesser adaptation to a season-defined fixed cut than cuts based on IL percentages; the fixed cut yielded 29 % less forage than the IL treatments[20]. In some forage species, frequent cuts decrease yield and foliar area, leading to greater presence of undesirable species[21], and consequent greater competition with the desired species and depletion of their carbohydrate reserves[22].

Figure 2: Average cut intervals for *L. corniculatus*, genotype 255301



90 = 90 % IL; 95 = 95 % IL; 100 = 100 % IL; CF = season-defined fixed cut (autumn = 35-d interval, winter = 42-d interval, spring-summer = 28-d interval).

Botanical and morphological composition

The morphological component contributing most to yield was the leaf (average= 14,273 kg DM ha^{-1}; 56 %), followed by the stem (30.5 %), dead material (8.5 %) and weeds (4.5 %). Of the IL treatments, the 95 % IL produced the highest average leaf yield (16,526 kg DM ha^{-1}), which was higher ($P \leq 0.05$) than the other IL treatments during POV2. The FC treatments in both study periods produced the lowest average yields of leaves (12,276 kg DM ha^{-1}) and stems (4,710 kg DM ha^{-1}). Dead material and weed percentages did not differ between treatments (P ≥ 0.05) in either period (Table 2).

Table 2: Accumulated seasonal forage yield (kg DM h^{-1}) by botanical and morphological component in *L. corniculatus*, genotype 255301, as a function of intercepted light (IL) and season-defined fixed cut

IL (%)	Leaf	Stem	Dead Material	Weeds	SEM
POV1					
90	13829 Aa	8426 Ab	3337 Ac	459 Ad	961
95	15979 Aa	9450 Ab	2051 Ac	937 Ac	836
100	14540 Aa	7964 ABb	4622 Ac	1291 Ac	754
FC	12715 Aa	5364 Bb	2616 Ab	1329 Ab	1692
Average	14266 a	7801 b	3156 c	1004 d	753
SME	1332	1048	971	662	
POV2					
90	14315 ABa	7996 Bb	1608 Ac	970 Ac	1022
95	17074 Aa	9412 ABb	969 Ac	719 Ac	877
100	13893 ABa	10403 Ab	2326 Ac	605 Ad	533
FC	11838 Ba	4056 Cb	1718 Ac	2053 Abc	748
Average	14280 a	7967 b	1655 c	1087 c	565
SEM	1102	757	570	750	

FC = fixed cut (autumn = 35-day interval, winter = 42-day interval, spring-summer = 28-day interval). POV1= Autumn 2014-Summer 2015; POV2= Autumn 2015-Summer 2016. SEM = standard error of the mean.

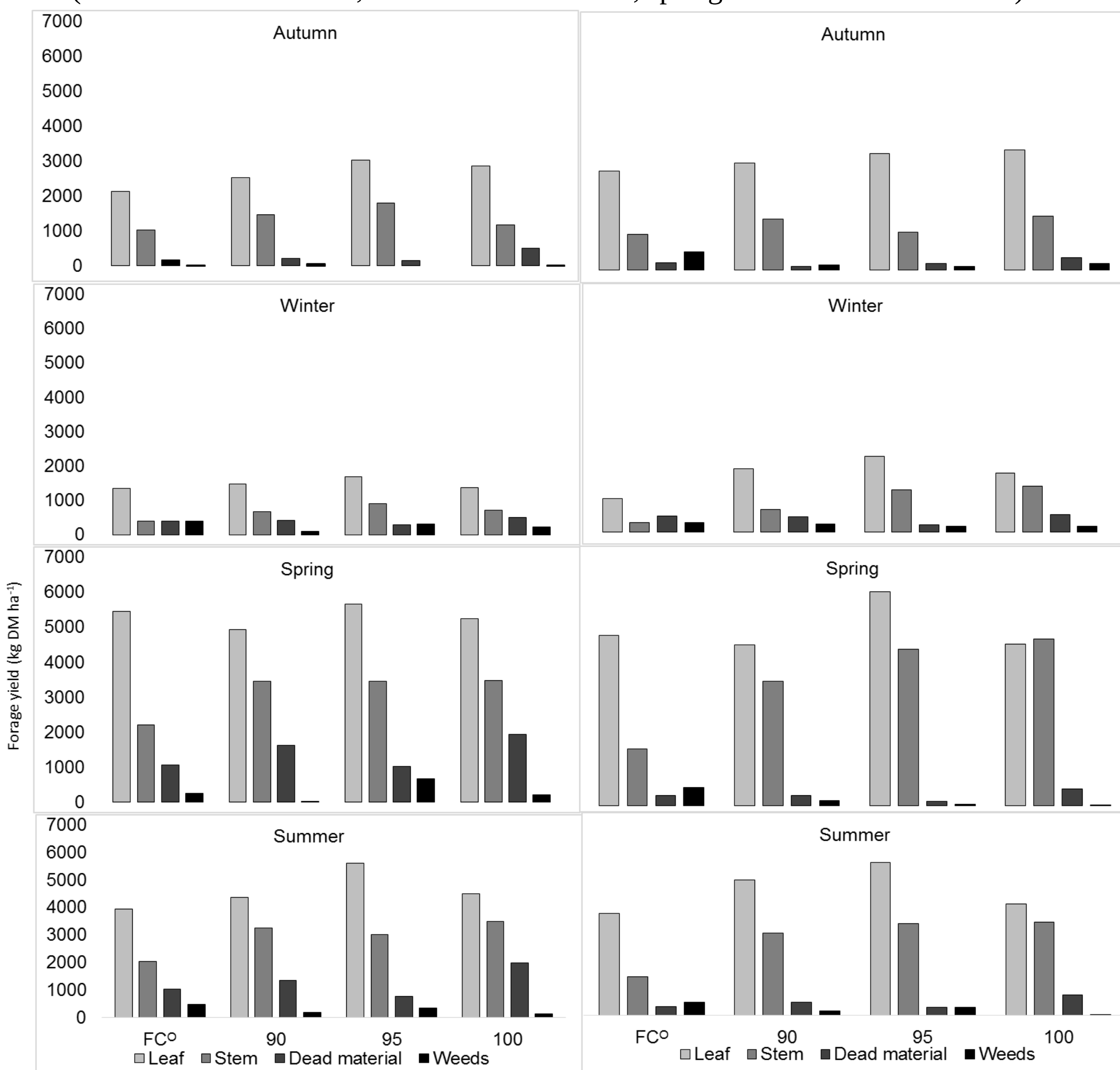
Significant difference ($P \leq 0.05$) is indicated by different uppercase letters between columns and different lowercase letters between rows.

The higher leaf and stem production observed in the 95% IL treatment may be related to greater crop growth age[23]. In addition, the higher leaf production in the 95% IL versus the FC treatment may have resulted from a compensation for greater stem biomass caused by a longer growth period, which implies more time producing photosynthates[24].

The leaf component also contributed most to forage yield in different seasons (Figure 3). Average yield in both periods was highest in the spring (5,141 kg DM ha^{-1}) and lowest in the winter (1,580 kg DM ha^{-1}), with the 95% IL treatment having the highest yield (5,852 kg DM ha^{-1}) and the FC the lowest (1,163 kg DM ha^{-1}). Stem yield was also highest in the spring (3,347 kg DM ha^{-1}) and lowest in the winter (772 kg DM ha^{-1}). These variations in component yields are probably responses to changes in environmental conditions between different seasons (Figure 1). For example, changes in stem production are known to be a function of seasonal variations in pasture light quantity and quality, precipitation and temperature[18].

Dead material (873 kg DM ha^{-1}) and weed (268 kg DM ha-^{1}) production was highest in summer, although these yields did not differ ($P \geq 0.05$) from the corresponding spring yields during POV1. These yields were lowest in autumn (237 and 133 kg DM ha^{-1}, respectively). This may result from self-shading of the basal area by the plant since growth is greater in seasons with favorable development conditions[25].

Figure 3: Botanical and morphological composition of *L. corniculatus*, genotype 255301, as a function of intercepted light (90, 95 and 100 %) and season-defined fixed cut (FC) (autumn = 35-d interval, winter = 42-d interval, spring-summer = 28-d interval)



Plant height

Plant height differed between treatments and seasons ($P \leq 0.05$). Height was greatest in the 90, 95 and 100 % IL treatments, which averaged 21.5 cm. This is slightly taller ($P \geq 0.05$) than in the 90 % IL treatment in POV2 and noticeably taller than the 17 cm average for the FC treatments in both periods (Table 3). These results are related to pasture age because in the IL treatments the plants had 70 d for regrowth compared to the FC treatments with an average of 33 d in both periods (Figure 2). In the FC treatments, plants were younger and cut more frequently, resulting in lower forage yield(17). Greater height is reported to correspond to higher forage yield(15), and for *L. corniculatus* yield and height have also been linked to erect and prostrate growth habits(3).

Table 3: Plant height (cm) in *L. corniculatus*, genotype 255301, as a function of intercepted light (%) and season-defined fixed cut

IL (%)	Autumn	Winter	Spring	Summer	Average	SEM
POV1						
90	21 ABa	18 Ab	23 Aa	24 Aa	22 A	0.9
95	23 Aa	17 Aa	23 Aba	24 Aa	22 A	2.4
100	18 Bc	20 Abc	24 Aa	23 Aab	21 A	1.6
FC	24 Aa	12 Bc	21 Bab	18 Bb	19 B	1.5
Average	21 a	17 b	23 a	22 a	21	1.5
SEM	1.6	1.1	0.6	0.7	0.8	
POV2						
90	19 Ab	13 Bc	24 Ba	24 ABa	20 B	1.0
95	17 ABc	22 Ab	30 Aa	24 Ab	23 A	1.1
100	19 Ac	26 Ab	31 Aa	22 ABbc	25 A	1.2
FC	15 Bb	8 Cc	16 Cb	22 Ba	15 C	0.8
Average	18 c	17 c	25 a	23 b	21	0.4
SME	1.2	1.3	0.9	0.9	0.5	

FC = fixed cut (autumn = 35-d interval, winter = 42-d interval, spring-summer = 28-d interval). POV1= Autumn 2014-Winter 2015; POV2= Autumn 2015-summer 2016. SEM = standard error of the mean. Significant difference ($P \leq 0.05$) is indicated by different uppercase letters between columns and different lowercase letters between rows.

In both study periods the highest average height (24 cm) was recorded in spring, although this did not differ ($P \geq 0.05$) from average height in the summer and autumn in POV1. Average height was lowest in winter (17 cm), which, in POV2, did not differ ($P \geq 0.05$) from autumn. Plant height was greatest during the seasons with optimal humidity and temperature conditions for growth and yield in *L. corniculatus* (Figure 1). These results coincide with those in a study of twelve *L. corniculatus* genotypes in the State of Mexico, Mexico(3). Adequate photoperiod, temperature and humidity can allow forage plants to accelerate growth and exhibit changes in height between seasons(26). This directly affects forage yield(12), which, in *L. corniculatus* genotype 255301, is associated with its prostrate growth habit(3). Pasture height is therefore predictive of forage production(8). Based on this assumption and using the present results, calculations were done of the equivalence (per centimeter of plant height) of the highest yields by season and treatment. In the spring each centimeter of height corresponded to a yield of 167 kg DM ha^{-1}, as an average of both study periods. In POV1, height in the 95 % IL treatment corresponded to a 144 kg DM ha^{-1} yield, while in POV2 the height in the 90, 95 and 100 % IL treatments corresponded to an average yield of 192 kg DM ha^{-1}.

Leaf:stem ratio

Average leaf:stem ratio values in both periods were highest in the fixed cut treatment ($P \leq 0.05$), followed by the 90, 95 and 100 % IL treatments (Table 4). In POV1, this ratio in the FC treatment was 36 % higher than the average of the 90, 95 and 100 % IL treatments (2.8 *vs* 1.8), while in POV2 the ratio in the FC was 44 % higher than in the 100% IL treatment (3.2 *vs* 1.4). The larger leaf:stem ratio in the FC treatments was caused by more frequent harvests (average= 33-d interval)(Figure 2). *Lotus corniculatus* is in the accelerated growth phase at this interval, which is not optimal for harvest, since it exhibits the highest percentage of young leaves and fewer stems(27). In addition, post-cut incident light quality and quantity in a pasture are altered by cutting interval, leading to variations in leaf and stem production and consequent changes in the leaf:stem ratio(10).

Table 4: Leaf:stem ratio in *L. corniculatus*, genotype 255301, as a function of intercepted light (%) and season-defined fixed cut

IL (%)	Autumn	Winter	Spring	Summer	Average	SEM
POV1						
90	2.5 Aa	2.0 Bab	1.7 Bb	1.5 Ab	1.9 B	0.2
95	1.9 Aa	2.3 Ba	1.5 Ba	1.4 Aa	1.8 B	0.3
100	2.1 Aa	2.2 Ba	1.8 Ba	1.8 Aa	1.8 B	0.2
FC	2.5 Ab	4.0 Aa	2.6 Ab	2.1 Ab	2.8 A	0.4
Average	2.3 ab	2.6 a	1.9 b	1.7 b	2.1	0.2
SEM	0.2	0.3	0.2	0.4	0.2	
POV2						
90	2.1 Ab	2.9 Ba	1.7 Bb	1.7 Bb	2.1 B	0.1
95	3.0 Aa	1.8 Cb	1.0 Cc	1.7 Bb	1.9 B	0.1
100	2.3 Aa	1.3 Cb	1.0 Cb	1.2 Cb	1.4 C	0.2
FC	2.9 Aa	3.7 Aa	3.4 Aa	2.7 Aa	3.2 A	0.3
Average	2.6 a	2.4 a	1.8 b	1.8 b	2.2	0.1
SEM	0.3	0.2	0.2	0.1	0.1	

FC= fixed cut (autumn = 35-d interval, winter = 42-d interval, spring-summer= 28-d interval).
POV1= Autumn 2014-Winter 2015; POV2= Autumn 2015-summer 2016. SEM= standard error of the mean.
Significant difference ($P\leq$ 005) is indicated by different uppercase letters between columns and different lowercase letters between rows.

The leaf:stem ratio was higher in winter ($P\leq 0.05$): 2.6 in winter POV1; 2.5 average in autumn and winter POV2. In some forage species leaf:stem ratio values are lower in seasons when plant growth is lower (e.g. autumn and winter) due to higher stem density coupled with lower weight[27]. The lower ratio values ($P\leq 0.05$) observed here during the spring and summer in both periods resulted from higher individual stem weight[26], which is a possible response to greater translocation of assimilates from the leaves to the stems during these seasons[7].

Conclusions and implications

The harvest strategies dependent on the percentage of intercepted light exhibited similar forage yields and plant heights, both markedly superior to the seasonally-defined fixed cut strategy. However, the latter had a higher leaf:stem ratio. The leaf was the morphological component that the made largest contribution to forage yield in all treatments, but particularly in the 95 % intercepted light harvest strategy.

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