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Defoliation frequency effects on winter forage production and nutritive value of different entries of *Agropyron cristatum* (L.) Gaertn

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Abstract

The objective of this study was to evaluate the effect of different defoliation frequencies on winter forage production and nutritive value of improved population of *Agropyron cristatum* (L.) Gaertn. Four entries, a) base population, b) selected plants from mass honeycomb selection (MHS), c) selected plants from pedigree honeycomb selection (PHS) and d) selected plants from pedigree honeycomb selection using the combined criterion $CC = \bar{x}^2 (1 - CV) / CV$ [PHS (CC)] were tested under four defoliation frequencies: 1) frequent, 2) moderate, 3) infrequent and 4) control. Dry matter production under moderate defoliation treatment was 9% and 107% respectively higher than frequent and infrequent the first harvest year, while the second harvest year the corresponding percentages were 26% and 44%. The selected populations of *A. cristatum* consistently exceeded in herbage production the base population under all defoliation treatments during winter. Among the selected entries, [PHS (CC)] had consistently higher DM production compared to MHS and PHS for the two experimental years. The CP content was significantly higher, while NDF, ADF and ADL contents were lower in the increased defoliation frequency compared to the control in both harvest years. There were no significant differences of the nutritive value among the entries ($P > 0.05$). Generally, herbage production of the moderate defoliation frequency was more stable through the years with relatively high nutritive value.

Additional key words: cool-season grasses, cutting frequencies, forage quality, sward management.

Resumen

Efectos de la frecuencia de defoliación en la producción y el valor nutritivo de forraje de invierno de diferentes entradas de *Agropyron cristatum* (L.) Gaertn

El objetivo de este estudio fue evaluar el efecto de diferentes frecuencias de defoliación sobre la producción y el valor nutritivo de poblaciones mejoradas de *Agropyron cristatum* (L.) Gaertn. Se examinaron cuatro entradas: a) población base y plantas seleccionadas mediante b) selección masal en diseño «panal de abejas» (MHS), c) selección pedigree en diseño «panal de abejas» (PHS) y d) selección pedigree en diseño «panal de abejas» usando el criterio combinado $CC = \bar{x}^2 (1 - CV) / CV$ [PHS (CC)] bajo cuatro frecuencias de defoliación: 1) frecuente, 2) moderada, 3) infrecuente y 4) control. La producción de materia seca (MS) en el tratamiento de defoliación moderada fue un 9% y un 107% respectivamente más alta que en frecuente e infrecuente durante el primer año de recolección, mientras que durante el segundo año, los porcentajes correspondientes fueron 26% y 44%. Las poblaciones seleccionadas de *A. cristatum* sistemáticamente excedieron la producción de hierba de la población base en todos los tratamientos de defoliación durante el invierno. Entre las entradas seleccionadas, [PHS (CC)] presentó sistemáticamente una mayor producción de MS comparada con MHS y PHS en los dos años experimentales. El contenido de PB fue significativamente más alto, mientras que los de FND, FAD y LAD fueron más bajos en la frecuencia aumentada de defoliación comparada con el control, en ambos años de recolección. No hubo diferencias significativas en el valor nutritivo entre las entradas (P>0,05). En general, la producción de hierba en la frecuencia de defoliación moderada fue más estable a lo largo de los años, con un valor nutritivo más alto.

Palabras clave adicionales: calidad del forraje, frecuencia de corte, herbáceas de climas templados, manejo de praderas.

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Abbreviations used: ADF (acid detergent fibre), ADL (acid detergent lignin), CC (combined criterion), CP (crude protein), CV (coefficient of variation), DM (dry matter), NDF (neutral detergent fibre), MHS (mass honeycomb selection), PHS (pedigree honeycomb selection), Pn (net photosynthetic).

Introduction

Low-elevation zone (up to 800 m altitude) rangelands in Greece and generally in the Mediterranean region are characterized by relatively mild winters and hot, dry summers often with prolonged drought. In these environments, C_4 perennial and C_3 annual grasses are the dominant components (Papanastasis, 1999) and produce relatively high proportion of forage grazed by livestock during spring (C_3 annual grasses) summer and fall (C_4 perennial grasses). However, winter forage is very limited and based on some perennial C_3 grass species. The gap in forage availability from October until late February may be filled by improved cool-season perennial grasses (Asay, 1991). Their forage quality is generally better than that of dormant warm-season grasses (Kloppenburg *et al.,* 1995). Moreover, introduction of C_3 perennial grasses may reduce the cost of feeding livestock during late autumn and winter. Although soil water- deficits and high temperatures during summer, reduce survival and limit the number of potentially adapted species, there are perennial cool-season grasses that have the ability to survive and recover rapidly once water becomes available in the fall (Kemp and Culvenor, 1990).

Agropyron cristatum (L.) Gaertn, a cross-pollinated species (x = 7), meets the above criterion as it is a drought adapted and cold resistant cool-season perennial grass, with high productivity and nutritive value for forage and pasture (Rogler and Lorenz, 1983). It is a complex of diploid, tetraploid and hexaploid species (Asay, 1992). It is indigenous to the steppe region of European Russia and south western Siberia (Robins *et al.*, 2006). It was introduced in North America in 1906 (Asay, 1992) and it has since become a major component of seeding early season pastures and rangelands in northern Great Plains of USA and in Canada (Ray *et al.*, 1997). It is a native grass of semiarid, sandy soil grasslands of North and Central Greece (Tutin *et al.*, 1980). The first diploid cultivar, 'Fairway' was released by Agriculture Canada in 1932 (Hanson, 1972). This cultivar was introduced and tested at the Experimental Station of the Institute of Forest Research in Chrysopigi, Greece, in 1982.

A population of the above cultivar was subjected to different selection procedures in order to improve its winter dry matter (DM) production. The selected populations were evaluated under sward conditions and exceeded in DM production compared to base population during winter (Abraham and Fasoulas, 2001). Selected populations may respond differently under specific management practices. As it was reported by Simons *et al.* (1972), there was significant interaction between genotype and management practice in *Lolium perenne.* Additionally, the ranking of *L. perenne* varieties was found to change under different management (Gilliland and Mann, 2000). Thus, in order to achieve the optimum output in terms of forage production, nutritive value and sward persistency of the selected populations, the appropriate management practice is needed.

Defoliation frequency is a major management factor that strongly affects the DM production (Nevens and Rehuel, 2003) and nutritive value (Turner *et al.*, 2006a) of forage grasses by changing the morphology and physiology of plants (Ahmed *et al.*, 2001). Generally, increasing the number of cuts had a beneficial effect on nutritive value of many grass species (Pontes *et al.,* 2007). However, their response to defoliation frequency as far as the DM production is concerned, differs. *Dactylis glomerata, Festuca arundinacea, Holcus lanatus* (Pontes *et al.*, 2007) and *Festuca rubra* (Briemle, 1997) displayed significant reductions in DM production in response to an increase in defoliation frequency. On the contrary, *Lolium perenne* and *Poa trivialis* increased their DM production slightly under 6 cuts yr^{-1} compared to 3 cuts yr^{-1} (Pontes *et al.*, 2007). Similarly, frequent defoliation increased the DM production of *A. cristatum*, but only the first harvest year (Malinowski *et al.,* 2003).

The response of cool-season grasses to defoliation has been evaluated in several studies (Belesky and Fedders, 1994; Bryan *et al.*, 2000; Carlassare and Karsten, 2002; Gillen and Berg, 2005). Comparisons among studies can be difficult because of the differences in species, intensity and frequency of defoliation. Furthermore, responses are likely to change across climates, soil types, soil water and soil fertility conditions (Volesky and Anderson, 2007). For these reasons defoliation recommendations in general are difficult. Additionally, the research about the defoliation effect on forage production and nutritive value mainly has been focused on growing season and limited information is available about this effect out of the growing season, *i.e.* during winter.

Therefore, the present study was conducted with the following objectives: 1) to evaluate the effect of different defoliation frequencies on winter DM production and nutritive value of *Agropyron cristatum* (L.) Gaertn, 2) to identify the best selected population with optimal DM production and nutritive value.

Material and methods

The study was conducted near the city of Serres in Northern Greece (lat. 41°09N, log. 23°40E), at an elevation of about 500 m.a.s.l. Soils are derived from conglomerates of the tertiary period and are characterized by a shallow depth and a pH of about 6.0 and organic matter content of 3.22%. Climate is sub-humid Mediterranean (Le Houerou, 1981) with mean annual precipitation 571 mm (22 year average) and a mean annual air temperature 13°C, with a range of minimum and maximum mean from –0.5°C (January) to 23.1°C (July), (National Meteorological Service). The temperature and precipitation data for the experimental periods are presented in Figure 1.

A population (base population) of *A. cristatum,* cultivar 'Fairway' was evaluated for DM production during winter and 10 superior plants were selected using three different procedures: (1) the 10 best plants using mass honeycomb selection (moving-ring selection) (MHS) (Fasoulas and Fasoula, 1995), (2) the 10 best plants using pedigree honeycomb selection (the best two plants from the best five families) (PHS), and (3) the 10 best plants by pedigree honeycomb selection using the combined criterion $CC = \bar{x}^2 (1 - CV) / CV$ that selects jointly for high family mean ($\bar{x}$) and reduced family coefficient of variation (CV) (Fasoulas and Fasoula, 1995). From each of the best five families on the basis of CC, the two highest-yielding plants were finally selected. The selection procedure in details was presented in Abraham and Fasoulas (2001). After open-pollination, the half-sib progenies of the three selected populations and the base population were tested under different defoliation frequencies during winter for two consecutive years (1996-1997 and 1997-1998). The four tested entries were as follow: a) base population, b) selected plants from MHS, c) selected plants from PHS and d) selected plants from [PHS (CC)]. The treatments included four defoliation frequencies (Table 1) as follows: 1) frequent (every 4-weeks), 2) moderate (every 6-weeks), 3) infrequent (every 10-weeks) and 4) control (the plants were cut at the end of the experimental period).

The plots were established in September 1994 and the experimental treatments were initiated in October 1996. The first year of the establishment and each year during the experiment all plots were cut to ground level (about 7 cm) in May and September. Each plot occupied an area of 1.8 m^2 and contained five rows of six plants with 30 cm between plants and between rows (a total of 17 plants m^{-2}). It has to be noticed that the experimental density is difficult to compare with the commonly used by the farmers as they do not seed in rows. Also, the farmers' density refers in weight of seed per surface unit and not to number of plants. Anyway, we consider that the experimental density is lower than the farmers'. The plots were separated by a bare trail of 30 cm and there was an extra row around the plots in order to maintain the same competition among all the plants in the plots. The experiment was carried out under rainfed conditions while no fertilization was applied.

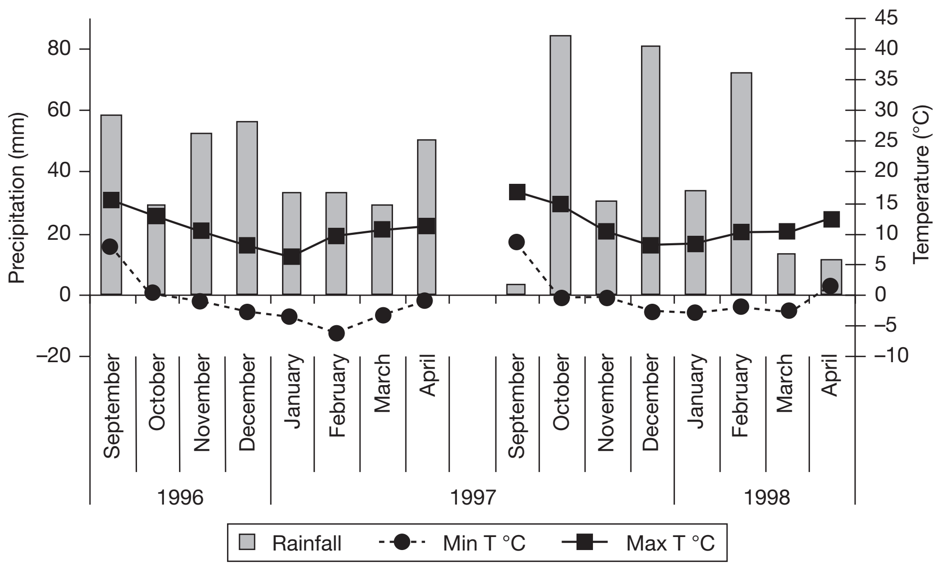

Figure 1. Monthly minimum and maximum temperature (°C) and precipitation (mm) at the experimental period.

Table 1. Definition of defoliation treatments during the experimental period

Year	Defoliation treatment	Cutting schedule	Number of cuttings
1st	F (Frequent)	30/11/1996, 30/12/1996, 30/01/1997, 29/02/1997, 15/03/1997	5
	M (Moderate)	30/11/1996, 15/01/1997, 29/02/1997	3
	I (Infrequent)	30/12/1996, 15/03/1997	2
	C (Control)	15/03/1997	1
2nd	F (Frequent)	30/11/1997, 30/12/1997, 30/01/1998, 29/02/1998, 15/03/1998	5
	M (Moderate)	30/11/1997, 15/01/1998, 29/02/1998	3
	I (Infrequent)	30/12/1997, 15/03/1998	2
	C (Control)	15/03/1998	1

At each defoliation event (Table 1), the plots were cut to a height of approximately 7 cm and DM production was determined following drying at 60°C for 48 h. The dried samples were ground through a 1 mm screen and analysed for nitrogen (N) using a Kjeldahl procedure (AOAC, 1990). Crude protein (CP) was then calculated by multiplying the N content by 6.25. Plant fibre analysis was performed according to the method of Van Soest *et al.* (1991). Samples were extracted individually in Berzelius beakers on a reflux rack and filtered through coarse porosity Gooch crucibles for neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL). Acid detergent lignin (ADL) was based on the treatment of the sample with ADF followed by incubation with 70% sulphuric acid (Van Soest *et al.*, 1991).

The experiment consisted of two factors (entries and treatments) in a completely randomized-block design. A total of 64 experimental plots were used (4 entries × 4 treatments × 4 replications). The data of each year was analysed separately using the general linear models Anova procedure in SPSS 14 for Windows. Variation was partitioned into treatments and entries as main effects and corresponding interactions. Additionally, the data for sampling dates were analysed for each defoliation treatment separately, as repeated measurements in time (Quinn and Keough, 2002). The LSD test (Steel and Torrie, 1980) at the 0.05 probability level was used to detect the differences among means.

Results

Herbage dry matter production

Significant differences (Table 2) were detected among the defoliation treatments and the entries for DM production in the first and the second year of the experiment. Additionally, significant interaction between treatments and entries was observed for DM

Table 2. Statistical significance of F ratios from the analysis of variance for dry matter (DM) production, CP (crude protein), NDF (neutral detergent fibre), ADF (acid detergent fibre) and ADL (acid detergent lignin) content of *Agropyron cristatum*

Source of variation	df	DM		CP		NDF		ADF		ADL	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F	Mean square	F
1st year											
Treatments (T)	3	25,012.1	418.1*	13,826	31.9*	70,714	85.8*	4,318	5.8*	30	1.2
Entries (E)	3	6,455.5	107.9*	22	0.05	876	1.06	109	0.1	4	1.2
T * E	9	457.5	7.7*	46	0.10	172	0.21	57	0.07	5	1.2
Error	48	59.8		432		823		746		25	
2nd year											
Treatments (T)	3	4,962.8	41.6*	9,168	16.7*	74,229	136.3*	3,468	9.4*	94	9.9*
Entries (E)	3	4,516.7	37.8*	30	0.05	16	0.03	130	0.4	1	0.08
T * E	9	413.7	3.5*	87	0.16	54	0.09	41	0.1	3	0.3
Error	48	119.4		549		544		369		9.5	

* Significant (F Test at $P \leq 0.05$).

Table 3. Dry matter production (g plot^{-1}) of *A. cristatum* entries in sward conditions, under different defoliation frequencies the first year of the experiment. Means ± SD

	Frequent	Moderate	Infrequent	Control	Mean
Base population	97 ± 7.2	116 ± 6.3	56 ± 8.1	65 ± 5.2	84 ± 25.5
Mass honeycomb (MHS)	130 ± 9.2	136 ± 3.6	60 ± 7.5	73 ± 9.1	100 ± 35.2
Pedigree honeycomb (PHS)	149 ± 9.3	155 ± 7.7	80 ± 7.5	79 ± 9.7	115 ± 38.4
Pedigree honeycomb combined criterion [PHS (CC)]	164 ± 9.2	182 ± 6.0	88 ± 9.9	85 ± 3.3	130 ± 45.8
Mean	135 ± 27	147 ± 26	71 ± 15	76 ± 10	
SE	4				
LSD	7				

production (Table 2) in both experimental years, indicating different performing of the tested entries of *A. cristatum* under different defoliation frequencies.

Mean DM production (the mean across the entries) under moderate defoliation treatment (Table 3) was significantly higher than frequent, infrequent and the control the first and the second harvest year. DM production of infrequent defoliation treatment (Table 3) was not significantly different from the control the first harvest year. However, both frequent and infrequent defoliation treatment had significantly lower DM production than the control (Table 4) the second harvest year. In particular, DM production under moderate defoliation treatment was 9% and 107% respectively higher than frequent and infrequent the first harvest year, while the second harvest year the corresponding percentages were 26% and 44%.

Regarding the tested entries, the selected ones had significantly higher DM production (Table 3 and 4) compared to the base population in both harvest years. DM production of MHS, PHS and [PHS (CC)] was 19%, 37% and 55% respectively higher than the base population during the first harvest year, while the second harvest year the corresponding percentages were 22%, 23% and 44%. Among the selected entries, [PHS (CC)] had consistently higher DM production (Table 3 and 4) compared to PHS and MHS under all the defoliation treatments over the two experimental years. The only exception was the frequent and infrequent one the second harvest year, where [PHS (CC)] did not significantly differ from MHS and PHS respectively. Moreover, PHS had significantly higher DM production than MHS under all the defoliation frequencies during the first harvest year, while the second had significantly lower or did not differ from the MHS. As far as the effect of defoliation frequency on the tested entries was concerned, DM production was higher in the moderate frequency for all the tested entries. Exception was MHS and PHS the first harvest year where there were no significant differences between the moderate and the frequent. Similarly, PHS and Base population the second harvest year did not significantly differ under moderate defoliation frequency and the control.

The first sampling date, DM production (average over entries) was approximately 60 g plot^{-1} under frequent and moderate treatment and 50 g plot^{-1} under infrequent in the first harvest year. The respective DM production in the second harvest year was approximately 30 g plot^{-1} under frequent, 60 g plot^{-1} under moderate and 40 g plot^{-1} under infrequent. These results indicated the reduced regrowth of plants under the frequent treatment the second harvest year. The second

Table 4. Dry matter production (g plot^{-1}) of *A. cristatum* entries in sward conditions, under different defoliation frequencies the second year of the experiment. Means ± SD

	Frequent	Moderate	Infrequent	Control	Mean
Base population	82 ± 5.0	107 ± 11.5	80 ± 12.8	104 ± 2.9	93 ± 15.3
Mass honeycomb (MHS)	115 ± 7.0	134 ± 9.9	90 ± 4.3	113 ± 12.5	113 ± 18.2
Pedigree honeycomb (PHS)	110 ± 8.1	125 ± 9.2	102 ± 14.8	120 ± 13.5	114 ± 14.0
Pedigree honeycomb combined criterion [PHS (CC)]	119 ± 1.9	172 ± 17.3	103 ± 9.6	144 ± 17.4	134 ± 29.4
Mean	106 ± 15.8	134 ± 26.8	93 ± 14.0	120 ± 19.1	
SE	6				
LSD	9				

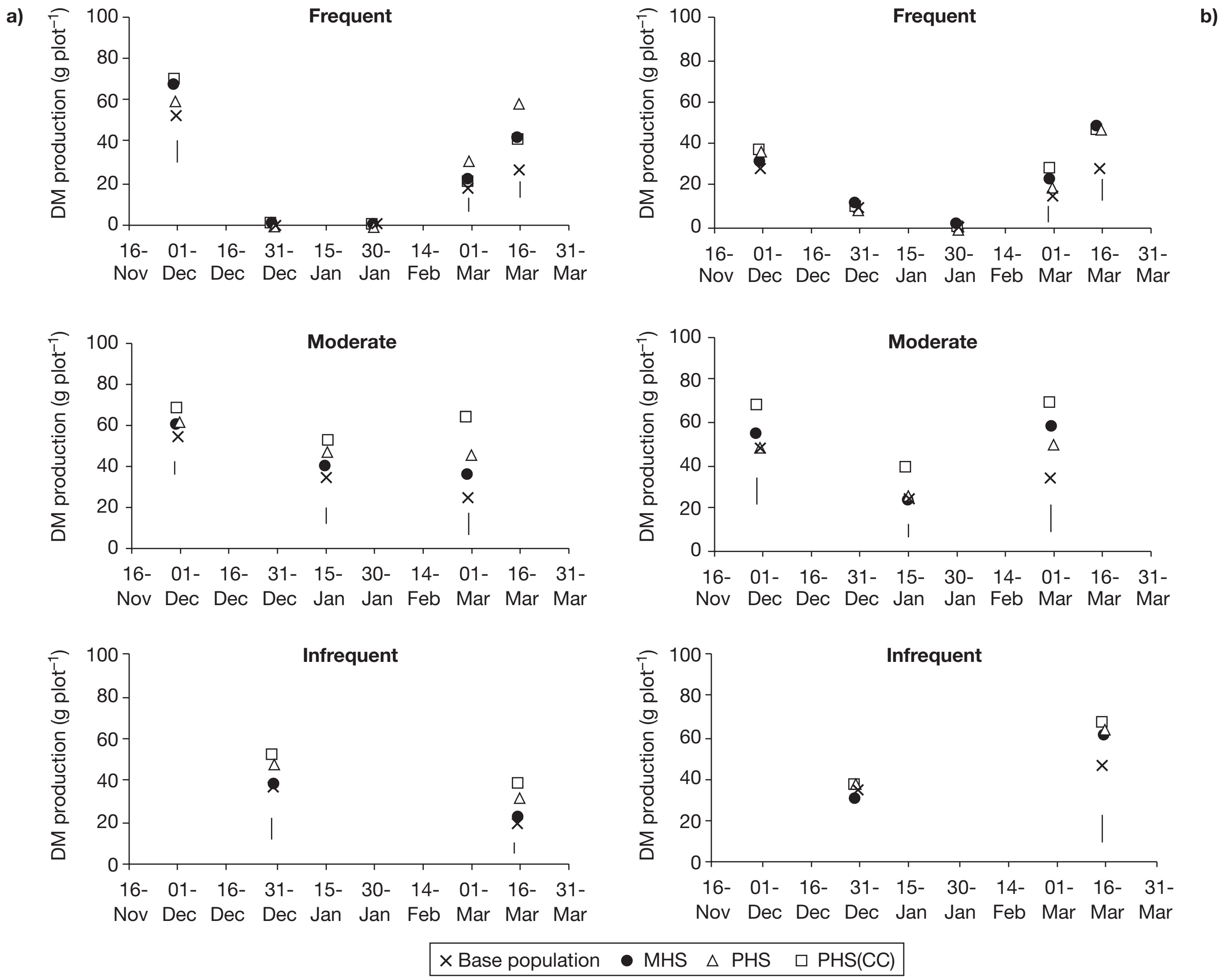

Figure 2. Dry matter production (g plot^{-1}) of entries at sampling dates (a) the 1st year and (b) the 2nd year of the experiment. Vertical bars at the bottom of the figure indicate LSD values ($P \leq 0.05$) for entries comparison at a given date of treatments.

sampling date (Fig. 2), DM production declined rapidly and had the lowest value at December to January for frequent and moderate treatment for both harvest years. In particular, under frequent treatment there was no DM production during December and January.

Herbage nutritive value

There were significant differences among defoliation treatments for CP, NDF, ADF in both years of the experiment and for ADL only the second year of experiment, while there were no significant differences among the entries (Table 2). The interaction between treatments and entries was not significant (Table 2) for all the measured components of chemical composition in both experimental years.

There were no significant differences among the main effects of the entries as well as the treatments × entries interaction concerning the chemical composition (Table 2). For this reason, the effects of defoliation frequency on CP, NDF, ADF and ADL content were analyzed across the average of all populations. All the defoliation treatments increased significantly the CP content in comparison to control (Table 5) during the first year, while the infrequent defoliation and the control had significantly lower CP content compared to frequent and moderate ones the second year. Furthermore, increased defoliation frequency reduced the NDF, ADF and ADL contents in both harvest years.

Table 5. Chemical composition (g kg^{-1} DM) of the population under different defoliation frequencies. Means ± SD

Defoliation frequency	CP		NDF		ADF		ADL	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
F[1] (every 4 weeks)	240 ± 22.2	215 ± 19.0	433 ± 28.5	473 ± 28.4	229 ± 18.2	242 ± 15.1	25 ± 4.0	31 ± 2.9
M[2] (every 6 weeks)	240 ± 18.8	195 ± 18.6	528 ± 25.4	574 ± 19.0	249 ± 21.9	254 ± 16.7	25 ± 4.6	33 ± 3.1
I[3] (every 10 weeks)	230 ± 15.9	170 ± 26.2	571 ± 33.8	612 ± 18.2	264 ± 28.4	271 ± 19.3	26 ± 5.4	35 ± 3.2
Control	180 ± 21.4	165 ± 20.6	577 ± 17.8	616 ± 16.7	263 ± 28.7	273 ± 18.8	28 ± 4.4	36 ± 1.8
SE	5	6	7	6	7	5	1	1
LSD	13	15	19	15	17.5	12.4	2.2	2.0

[1] Frequent. [2] Moderate. [3] Infrequent.

Discussion

The defoliation frequency affected the forage production, the nutritive value and the sward persistence of *A. cristatum's* entries during winter. The moderate defoliation frequency (every 6-weeks) from October to March increased the DM production of *A. cristutum* the first harvest year and it ensured sward persistence due to increased DM production the second year. On the other hand the frequent defoliation (every 4-weeks) increased the DM production the first harvest year but it was detrimental to the productivity the second harvest year. These results are in agreement with several grazing and clipping studies (Malinowski *et al.*, 2003; Turner *et al.*, 2006b; Pontes *et al.*, 2007), which reported *A. cristatum* and other perennial cool-season grasses stand deterioration over time due to frequent defoliation. The infrequent defoliation (every 10-weeks) reduced the DM production for both harvest years.

Defoliation directly affects the aboveground biomass of plants by reducing leaf area, by changing photosynthetic or respiratory rates, growth rates and carbon allocation patterns (Ferraro and Oesterheld, 2002). These effects could be negative or positive. The positive effects referred to the increase of photosynthetic area, growth rate and final vegetative biomass (McNaughton *et al.*, 1983) and it is known as compensatory regrowth because the defoliated plants partially or fully compensate for the removal of biomass. In case of *A. cristatum* Peng *et al.* (2007) referred that net photosynthetic (Pn) rate of species increased significantly from non-grazed and reached a peak under moderate-grazed plots and thereafter it declined with increasing grazing intensity. Although the results of Peng *et al.* (2007) referred to grazing and not to clipping study, are indicative about the response of *A. cristatum* to defoliation. Thus, the increased DM production under frequent and moderate defoliation compared to infrequent and control could be attributed to the compensatory regrowth of *A. cristatum*.

According to the results of the present study moderate defoliation frequency exceeded in DM production compared to frequent for both harvest years. Conversely, Malinowski *et al.* (2003) reported that frequent and intensive defoliation resulted in a greater cumulative herbage yield compared with a moderate one during the growing season. Generally, the magnitude of compensatory response has been associated with several factors like nutrient level (Hicks and Reader, 1995), flexible carbon allocation (Briske *et al.*, 1996) and recovery conditions (Oesterheld and McNaughton, 1988). In the present study the plants grew during winter with relatively low temperatures and the interval of 4-weeks (frequent defoliation) probably was not enough for their completely recovery and regrowth.

However, the frequent defoliation reduced DM production the second harvest year. This could be attributed to the effect of defoliation during the first harvest year on root growth. Indeed, it has been reported that multiple grass defoliations reduced grass root weight, root area, root length, and weight of total non-structural carbohydrates in roots more than single defoliations did (Engle *et al.*, 1998). Moreover, when defoliation combined with other stresses (low temperatures in this case), enlarged the priority for leaf regrowth at the expense of roots (Fulkerson and Donaghy, 2001; Cullen *et al.*, 2006). It seems that all these factors contributed to a reduced root DM at the end of the first harvest year. However, any factor that retards root growth has a carry-over effect on the rest of plants' growth due to restriction in uptake of water and nutrients (Clement *et al.*, 1978) and generally an impact upon plant survival (Rawnsley *et al.*, 2002). As a result, there was reduced DM production under frequent treatment the second harvest year.

As far as the nutritive value is concerned, defoliation frequency affected the CP, NDF, ADF and ADL concentrations. A frequent and moderate defoliation by reducing the standing herbage mass at cutting date (Lemaire and Gastal, 1997) significantly increased the CP concentration of herbage for both harvest years. On the other hand, the frequent defoliation treatment reduced the NDF, ADF and ADL concentration in comparison to moderate, to infrequent treatment and to undefoliated plants in both harvest years. Similar results were reported by Turner *et al.* (2006a) and Pontes *et al.* (2007) for several cool-season grasses and by Van Man and Wiktorsson (2003) for warm season grasses.

The frequent defoliation improved the herbage nutritive value due to increased CP and to reduced NDF, ADF and ADL concentration. Nevertheless, CP concentration in the two years of study was high in frequent (mean 228 g kg^{-1} DM), moderate (mean 218 g kg^{-1} DM) and infrequent (mean 200 g kg^{-1} DM) defoliation treatments. Generally the CP concentration of *Agropyron* species is high during the early stages of development (Mayland *et al.*, 1992). This CP concentration was higher than mean CP concentration of forage grasses (115 g kg^{-1} DM) (Minson, 1990) and sufficient for small ruminant's demands (maintenance and lactation) (NRC, 1981; 1985). Additionally, the NDF concentration in all cases was less than 75% of DM, the critical point in grass-only diets which could affect feed intake for mature beef cows (Buxton, 1996).

The tested entries ranked to the same order in all defoliation treatments and this order was identified to that of previous experimental work (Abraham and Fasoulas, 2001). The selected populations had higher DM production than base population under all defoliation treatments. Among the selected populations, [PHS (CC)] exceeded in DM production compared to MHS and PHS, followed by PHS. Both [PHS (CC)] and PHS are pedigree selection methods between and within families in absence of competition (Fasoulas and Fasoula, 1995). The difference between them is that in [PHS (CC)] for families evaluation was used the high mean and the reduced CV, as a measure of their stability. The consistently high DM production of [PHS (CC)] under all the defoliation treatments confirms that joint selection in the absence of competition for high family mean yield and high stress tolerance measured by a low family CV, leads to efficient selection for high and stable yield.

As final conclusions, the improved population of *A. cristatum* consistently exceeded in herbage production compared to base population under various defoliation frequency regimes during winter. The recommended defoliation frequency for maximizing productivity and persistence of *A. cristatum*'s winter pastures is three times from October to March (6-week interval). The more frequent defoliation at this time of the year would result in high herbage production the first harvest year and higher nutritional value (lower NDF and ADF and higher CP concentration) but it would threaten pasture persistence. The herbage production of moderate defoliation was more stable through the years for all the tested entries and the nutritive value was also high enough to cover the small ruminant's requirements for maintenance and lactation.

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