Effect of defoliation strategies on the productivity, population and morphology of plantain *(Plantago lanceolata)*

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Abstract
This trial provided information about effects of defoliation frequency, defoliation intensity and winter management (grazing or rest) on the productivity, morphology and plant population of a 3-year-old plantain (*Plantago lanceolata*) stand. Plant population density declined drastically over time independently of grazing management, with the greatest decrease in summer. Winter grazing had a critical effect on the productivity and population remaining 6 months later. Frequent grazing during summer increased plantain contribution. Grazing intensity reduced crown weight and diameter of individual plants. Further studies are required to determine the interactions of defoliation management with pastures of different age including the natural reseeding as a mechanism to maintain plant recruitment.

Keywords: defoliation, grazing, morphology, population

Introduction
Plantain (*Plantago lanceolata*) is recommended as an alternative pasture for less fertile environments, and is also described as a drought-tolerant species (Stewart 1996). Previous studies in Uruguay showed high a potential of plantain in mixtures with *Lotus corniculatus,* when used for fattening lambs during summer (Barrios 2006), achieving liveweight gains of 226 and 158 g/hd/day with 10 and 18 lambs/ha, respectively. These growth rates were higher than those obtained with traditional summer legumes (lotus, red clover), promoting interest for this novel herb. Sheep preference for plantain is lower than for other forage species (Corkran 2009), but if used in mixtures animal productivity is maximised (Golding *et al*. 2008).

However, plantain grazing management has not been widely reported and suggestions of its poor persistence have gained some currency. The objective of this trial was to evaluate the defoliation effect on the productivity, morphology and plant population of a 3-year-old plantain stand.

Materials and Methods
The experimental area was located at INIA Treinta y Tres, Uruguay, South America (Latitude 33º 54´ S, Longitude 54º 38´ W) on a fine, mixed vertic Argiudoll (ARS-USDA classification), with a pH 5.2, organic carbon (%): 2.12, phosphorus using acid citric extractant (µg P/g): 16.2 and potassium (meq/100 g): 0.34 in the first 7.5 cm depth. Pasture was established in May of 2005, sowing 4 kg/ha of plantain Ceres Tonic, being annually fertilised with 150 kg/ha of N-P-K (18-46-0). Additionally, the paddock received a spring fertilisation with 50 kg/ha of N-P-K (46-0-0) and the application of an herbicide (Haloxifop-metil, 200 g/ha) to control annual grasses. General management included grazing during the first 2 years with fattening lambs.

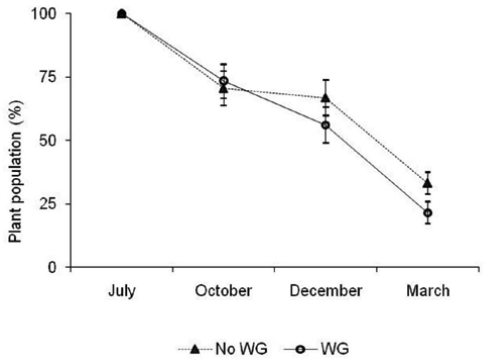
Over a 3-year-old stand, a factorial (3x2) split plot design with three replicates was established from July 2007 to March 2008. The main plot was grazed two times in winter (WG: 24/07/07, 29/08/07) or not grazed during winter (No WG), combined with grazing intensities (I: 2, 7 and 12 cm postgrazing heights) and two grazing frequencies (F: 21 and 42 days grazing intervals) during spring and summer. Plots of 150 m^2 were grazed by sheep in short periods (10-12 hours), at high stocking rates (approximately 450 hd/ha).

Determinations included pregrazing and postgrazing mass (two quadrats 20 x 50 cm/plot were cut, weighed and dried), sward height for grazing control (30 measurements/plot) and botanical composition dissecting all part of plantain plants into leaves and reproductive stems (1 bulk sample/plot). Samples were oven-dried at 60°C for 48 hours. The plant population density was evaluated in two fixed quadrats/plot (50 x 50 cm each), and destructive harvests were made in a quadrat/plot (20 x 50 cm) on 25/07/07, 8/10/07, 18/12/07 and 3/03/08. All samples were washed free of soil. Individual plants were separated, then shoots per plant, leaves per shoot, crown and shoot diameter were evaluated; all plants parts were oven-dried.

The variables were analysed by a repeated measurements model over time using the PROC GLM procedures of the SAS program.

Results and Discussion
Over the experimental period (July-March), rainfall conditions were higher than the 15-year average. From September to December rainfall was 390 mm and from

Figure 1. Change in plantain population density from July to March (expressed as a percentage of initial plant population in July (96 plants/m2=100) under two winter grazing managements.



December to February 410 mm (46% and 34% higher than 15 year-averages respectively).

After-grazing sward heights achieved on average for the whole period were 3.1 ± 1.3, 7.6 ± 2.2 and 11.8 ± 1.6 for treatments of 2, 7 and 12 cm height respectively.

Herbage production

Winter management and frequency of defoliation showed the main significant effects on total dry matter production (spring and summer), plantain total dry matter, and the contribution of leaves and reproductive stems during summer (Table 1). An increase in total DM production of 45% and 75% was observed during spring and summer respectively, as a consequence of a winter rest (Table 2). The plantain contribution was increased in summer 2.4 times if not grazed in the previous winter.

Total dry matter was significantly increased under short frequency intervals (21 days) in spring (167%) and summer (173%) (Table 2), also summer contributionof plantain increased 162% under frequent grazing. Defoliation intensity only significantly affected total summer production (p=0.0262), with production being reduced under intensive grazing (2 cm height, Table 2).

However, Lavebreux *et al.* (2004) reported that frequent and severe defoliation (5 cm every 3 weeks) reduced productivity 25%, so they promoted long grazing intervals rather than continuous grazing in the conditions of Pennsylvania, USA.

The proportion of plantain leaves increased significantly in spring (971 and 161 kg DM/ha for No WG and WG) and summer (2820 and 1414 kg DM/ha for No WG and WG), if plantain was not grazed in the previous winter (Table 1). The quantity of plantain reproductive stems adversely affected pasture production and quality as occurs in other herbs like chicory (Li 1997). Reproductive stems increased during summer as a consequence of frequent (1584 and 924 kg DM/ha of stems for 21 and 42 days intervals respectively) and less intensive defoliation (899 kg DM/ha for 2 cm height vs. 1461 kg/ha in average for 7-12 cm height) in non WG paddocks. Reproductive stems biomass during summer between WG and No WG paddocks were 551 and 1997 kg DM/ha, respectively.

Table 1. Probabilities of the effects of winter management (WM), frequency (F), and intensity (I), on spring and summer herbage production of a 3-year-old plantain stand.

Parameters	Total DM	Total Plantain	Leaves Plantain	Stems Plantain	Other species
	Spring				
WM	0.0003		0.0008		
F	<0.0001				0.0213
FxWM					
I					0.0255
IxWM					
IxF					0.0127
IxFxWM					
	Summer				
WM	<0.0001	<0.0001	0.0001	<0.0001	
F	<0.0001	0.0025	0.0017	0.0165	0.0002
FxWM					
I	0.0262				
IxWM					
IxF					
IxFxWM					

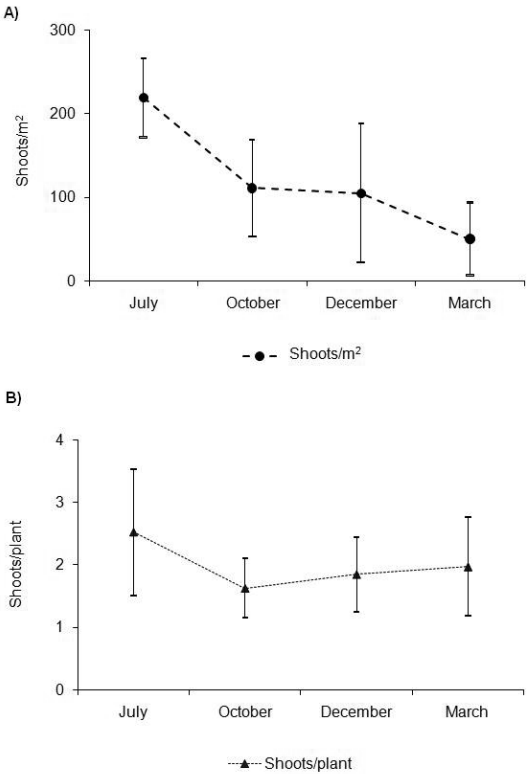
From the soil seed bank present in the paddock, other components in the pasture were *Lotus corniculatus* (Lotus), and annual grasses (*Lolium multiflorum*, *Vulpia australis* and *Gaudinia fragilis*). Annual grasses affected plantain performance, requiring application of herbicide to reduce competition. In contrast with other reports these results showed a better plantain contribution at the end of the third year (64%). In New Zealand, Stewart (1996) reported a contribution between 5-15% increasing to 30% when other components declined after 3 years.

Mixed pastures including herbs like plantain or chicory tend to be more productive improving dry matter distribution in comparison with typical perennial ryegrass-based pastures used in New Zealand (Moorhead & Piggot 2009), and increasing lamb growth rates in late summer and autumn (Golding *et al*. 2008).

Plant population

Initially the plant population density was 96±23 plants/m^2, becoming significantly reduced during the experiment ($p<0.01$). In October and December, there were no changes from the WG treatment in plant population (Fig. 1). The reduction in plant population from July to December was 38.5%. In March, there were significant differences ($p<0.05$) as a consequence

Figure 2 Evolution of A) sward density (shoots/m2) and B) plant size (shoots/plant) in a 3-year-old plantain pasture. Data are means for all treatments.



of previous winter grazing, with 32.2% fewer plants in plots grazed in winter. Final population declined 68 and 78% for No WG and WG treatments, respectively.

There were no significant effects ($p>0.05$) on the plant population density over the experimental period as a consequence of spring-summer defoliation treatments (I and F) or their interactions (IxF, IxWG, FxWG, IxFxWG). In another experiment, the pattern of stand reduction was similar with values reaching 64 plants/m^2 at the end of the second year (Ayala, unpublished). With sowing densities of 5 kg/ha and a 1000-seed weight of 2.07 g, the range of potential plants at establishment should be 190-200 plants/m^2 in pure stands.

Labreveux *et al*. (2004) in Pennsylvania, USA, identified a decline in plantain population over 3 years under cow-calf grazing, from 300, to 120 and 48 plants/m^2, under different defoliation strategies; in both the Pennsylvania study and the current work, plant survival was not effectively improved by grazing strategies. Other factors such as genotype, fertilisation, winter temperature or summer heat stress affect plant survival. The cultivar Ceres Tonic is an erect plant type with large leaves, less adapted to heavy grazing in comparison with Grasslands Lancelot, another densely-tillered cultivar released in New Zealand (Rumball *et al*. 1997).

Plant morphology

Shoots/plant and shoots/m^2 were not affected by treatments in any of the sampling dates, however the general pattern showed a significant decline for shoots/m^2 over time ($p<0.01$) (Fig. 2A). A high degree of variation was observed in shoots/plant over the different sampling dates, mainly associated with different ages of plants in the 3-year-old sward (Fig. 2B). Shoot diameter was reduced over time ($p<0.05$) (0.80 cm in July and 0.69 cm in March). Shoot diameter was affected by grazing intensity in December ($p<0.05$), with means of plants defoliated at 2 cm height less than the average of all the other treatments (0.69 cm vs. 0.82 cm). Crown dry weight was affected by grazing intensity in October ($p<0.01$), being 49, 66 and 39 g/m^2 for 2, 7 and 12 cm residual height respectively.

Winter grazing had a critical effect on plantain productivity and population, and the effects were evident 6 months later. This has been reported previously particularly for those cultivars with winter activity like Ceres Tonic (Lavebreux *et al*. 2004). Plant population declined drastically over time independently of the grazing management, with the greatest decrease

Table 2. Spring and summer herbage production of a 3-year-old plantain pasture under different management strategies (LSD, least significant difference $p<0.05$).

Parameters		Spring		Summer	
		Total dry matter (kg/ha)	Plantain dry matter (kg/ha)	Total dry matter (kg/ha)	Plantain dry matter (kg/ha)
Winter management	WG	4404	1375	4299	1965
	No WG	6378	1797	7509	4817
	LSD(0.05)	*923*	--	*1928*	*1836*
Frequency	21 days	6745	1846	7488	4199
	42 days	4038	1326	4320	2583
	LSD(0.05)	*688*	--	*820*	*754*
Intensity	2 cm	4791	1792	5114	2859
	7 cm	5496	1451	6129	3488
	12 cm	5887	1515	6468	3825
	LSD(0.05)	--	--	*1004*	--

in summer. In general, grazing intensity reduced the individual plant parameters that are identified with plant vigour such as crown diameter and stem weight.

Characteristics of the root and crown system of plantain suggest limited conditions for carbohydrate storage in comparison with other crown-forming species, probably restricting regrowth and persistence under intensive grazing or other limiting conditions (plant competition, fertility, water availability, temperature among others). Reproductive stems and old plantain leaves are less palatable than fresh material (Ivins (1952) cited by Stewart (1996). These findings were confirmed in this trial where sheep tended to avoid the oldest plantain leaves. This behaviour could affect leaf turnover and consequently herbage production under less frequent defoliation managements.

Pasture age and the rainfall regime probably contributed to the plant stand reduction, topics that should be attended to in future research. Based on Kuiper & Bos (1992) it is possible to consider plantain as a short-lived forage plant with a half life of 2 to 3 years. Additionally, it is feasible to consider plantain's natural reseeding as a mechanism to maintain stand density, supported by observations under grazing where plantain was able to complete its reproductive cycle and develop new seedlings in the following grazing season.

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