J. Range Manage.
57:280-290 May 2004

Fertilization with nitrogen and potassium on pastures in temperate areas

MARÍA ROSA MOSQUERA-LOSADA, ANTONIO GONZÁLEZ-RODRIGUEZ, AND ANTONIO RIGUEIRO RODRÍGUEZ

Authors are Researcher, Crop Production Department, Escuela Politécnica Superior, University Santiago de Compostela, 27002-Lugo, Principal Researcher in Milk Production of the Agrarian Research Centre of Mabegondo. 15080. A Coruña, and Professor, Crop Production Department, Escuela Politécnica Superior, University Santiago de Compostela, 27002-Lugo.

Abstract

Fertilizer application enable producers to influence pasture production. The effect of N fertilization on grass production and leguminous plant content of pasture and strategic N application has received much attention. Changing agricultural policies suggest that chemical fertilizer inputs may be diminished and that alternative sources of nutrients are desired. The aim of this study was to evaluate the effect of N and K fertilization on production, botanical composition, and forage mineral composition to gain some insight into what influence changing fertilization practices would have on pasture productivity. Three K and 3 N application rates were applied in a factorial design on a white clover (*Trifolium repens* L.)—perennial ryegrass (*Lolium perenne* L.) sward. Potassium and nitrogen application increased herbage production and had differential influences on botanical composition. Nitrogen decreased clover content in the pasture, whereas K increased the proportion and production of white clover. The effects of K application appeared later in the experiment than those associated with N. We concluded that K is very important for development and maintenance of white clover in pasture, which increases herbage and protein production. Nitrogen was associated with lesser amounts of N, P, K, and Mg in pasture, because of lesser amounts of clover in the sward. Changing fertilization practices will have definite influences on sward composition and pasture productivity. Any interpretation of pasture mineral content should take botanical composition changes into account.

Key Words: clover, nutrient, botanical composition

Resumen

La fertilización es una práctica de manejo que permite a los ganaderos modificar la producción de pasto. Por este motivo, el efecto de la fertilización nitrogenada y su aporte estratégico sobre la producción y el contenido de leguminosas del pasto ha sido estudiado en numerosas ocasiones. La política agraria actual promueve la utilización de fuentes alternativas a los fertilizantes inorgánicos, limitando su aporte. El objetivo de este estudio fue evaluar el efecto de la fertilización nitrogenada y potásica sobre la producción, composición botánica y mineral para determinar la influencia del cambio de las prácticas de fertilización sobre la capacidad productiva del pasto. Los tratamientos consistieron en la aplicación de 3 dosis de potasio y 3 de nitrógeno en un diseño factorial sobre una pradera de raigrás inglés (*Lolium perenne* L.) y trébol blanco (*Trifolium repens* L.). El aporte de potasio y nitrógeno incrementó la producción de hierba y ocasionó diferencias en la composición botánica. La aplicación de nitrógeno redujo el contenido de trébol en el pasto, mientras que la de potasio aumentó la producción y proporción de trébol. Los efectos de la aplicación de potasio aparecían más tarde que los debidos al nitrógeno. Se concluye que el potasio es muy importante para el desarrollo y mantenimiento del trébol blanco en el pasto, el cual incrementa la producción de hierba y proteína. El aporte de nitrógeno provocó una reducción de N, P, K y Mg en el pasto, debido a la menor presencia de trébol. El cambio de las prácticas de fertilización modificará la composición y capacidad productiva del pasto. Las interpretaciones sobre el contenido mineral del pasto deberían tener en cuenta las modificaciones sobre la composición botánica.

Nitrogen fertilization, the main technique controlled by the farmer to influence herbage production, has been studied for many years. The response of grass production (González 1992, González et al. 1996) botanical composition (González 1988) to N fertilization, and strategic N application (Mosquera et al. 1992) was reported for northwestern Spain and for regions with similar climatic conditions. Inorganic nitrogen fertilizers can damage the environment when applied in large amounts (González et al. 1996), suggesting that ecologically benign sources of N should be considered for agricultural systems.

Atmospheric N introduced into the soil by symbiotic *Rhizobia* is positively related to legume content in pasture, resulting in improved pasture production (Frame and Newbould 1984). The percentage of clover is related to protein production, leading to better pasture nutritive value. Clover content in pasture is inversely related to N fertilization (Meister and Lehmann 1985, Chapman et al. 1996), and positively with the K (Rodríguez and Pinto 1987, Simpson et al. 1988). Pasture fertilization influences nutrient availability in soil or modifies relationships with other elements in the soil, increases pasture growth, and as a result causes changes in nutrient bioavailability where soil pH is modified (Chevalier 1981, Frame 1990, Whitehead 1995, Chapman et al. 1996, Clark and Harris. 1996).

Research was funded in part by Agricultural, Food and Fisheries National Ministry and by Agricultural and Fisheries Galician Regional Ministry. 111
Manuscript accepted 19 Jul. 03.

Moreover, fertilization can influence the ecological advantages of some species with respect to others, because of differential responses to mineral nutrient supply. The progressive reduction of fertilizer inputs resulting from European Union agrarian policy will modify botanical composition of pastures and increase forb species that usually have a greater mineral content than found in widely grown grasses such as perennial ryegrass (Babnik et al. 1996). This should be considered when developing mineral supplementation strategies for animal feeding. Understanding the influence of fertilization strategies on the botanical and mineral composition of pasture will help farmers determine the type and quantity of supplement that should be provided to grazing livestock to optimise performance.

The objective of our experiment was to determine the influence of combinations of N and K fertilization on herbage production, sward botanical composition and chemical composition of a grass-clover pasture during a 4-year period.

Materials and Methods

The experiment was conducted in the northwest of Spain (Galicia) from 1989 through 1992, in Mabegondo (A Coruña, 43° 15' N lat.; 8°18' W long. at 100 m above sea level). The pasture was sown in autumn of 1988 with a mixture of 25 kg ha^{-1} of perennial ryegrass (*Lolium perenne* L.) cv. Brigantia and 3 kg ha^{-1} of white clover (*Trifolium repens* var. Huia on a sandy-loam soil, with an average pH of 6.08, low available P (15 ppm) and medium available K (87 ppm) prior to fertilizing. The rate of P_2O_5 application was 90 kg ha^{-1} in the autumn of 1988 and 150 kg ha^{-1} annually in spring each year. Mean temperature and precipitation at the site are presented in Table 1.

Treatments were applied in a split-plot design with 4 replicates (2 by 5 m^2 plots) of each treatment combination. Main plots were N at 0 (N1), 60 (30 + 30) (N2), and 120 (60 + 60) (N3) kg N ha^{-1} applied between 23 February and 7 March, with the second application made after the second cut. Each N treatment had 3 K application rates of 0 (K1), 100 (50 + 50) (K2) and 200 (100 + 100) (K3) kg K_2O ha^{-1} applied at the same time as N.

Cutting times are presented in Table 2. A 4 by 0.9 m^2 area was sampled for fresh and dry mass from each plot, and a subsample (100 g) was dried for 18 hours at 80° C, ground and used for chemical composition analyses. Botanical composition was determined by hand separation of species from 100 g fresh samples.

Table 2. Harvest cutting dates during the 4 studied years.

Cut	1989	1990	1991	1992
First	6/4	3/4	15/4	2/4
Second	5/5	7/5	3/5	4/5
Third	9/6 and 28/7	28/6	26/6	13/8
Fourth	28/12	21/12	22/12	20/12

Micro-kjeldahl digestion was used to determine crude protein (CP) and phosphorus content (Castro et al. 1990). Mineral element contents of herbage were determined by atomic absorption spectroscopy (Perkin-Elmer 460).

Herbage mass, protein, P, Ca K, Mg, Cu, Fe, Zn, and Mn content of pasture and sown grass, sown legumes and other species were analysed in 2 years period: 1989–1990 and 1991–1992 using ANOVA and significant means separated by LSD testing.

Table 1. Mensual mean temperature (T, °C) and rainfall (Pp, mm) per month in 1989, 1990, 1991, and 1992.

Month	J	F	M	A	My	Jn	Jl	Au	S	O	N	D
T						(°C)						
1989	7.6	8.8	9.9	9.4	16.0	16.8	19.6	19.3	16.8	15.3	11.9	11.5
1990	8.1	11.7	10.9	9.9	15.1	15.6	19.4	19.0	18.2	13.9	9.7	6.7
1991	7.4	7.0	9.8	10.0	13.6	14.9	18.0	19.3	18.2	12.0	10.3	8.9
1992	5.8	5.2	9.6	11.1	15.0	14.5	18.0	17.7	15.0	11.2	12.7	8.8
Pp						(mm)						
1989	31	149	67	133	51	18	11	19	6	95	134	32
1990	96	74	14	100	33	20	13	8	20	200	151	114
1991	157	140	86	64	20	22	67	56	118	84	136	17
1992	75	13	98	49	45	67	3	92	92	99	101	103

Results

Climate

Mean temperature and rainfall for all 4 years are presented in Table 1. There was an unusually prolonged summer drought in 1989, lasting from June through October. March 1990 was unusually dry, and December of the same year unusually cold.

January and February, as well as the autumn of 1991 and 1992, were colder months than usual. April and May of 1991 were drier than usual, and, finally, July, August and September of 1991 had more rain than average. August of 1992 was wetter than normal.

Soil Analysis

Soil analysis, at the end of the experiment, can be seen in Table 3. No N effects were found on different soil parameters. However, increase of fertilization with K significantly raised the level of K and reduced the level of Na in soil.

Nitrogen fertilization effect

Dry matter increased when 30 kg N ha^{-1} applied for first cuttings was positive in the first and fourth year (Fig. 1), but no effect was found in the other years due probably to climatic conditions. No residual effect of this N application was found in the second cutting.

Only in the first year production was positively related to N application. Negative responses to N in 1990 and 1991 and no response at all in 1992 were recorded. Spring N application, did not affect autumn production, despite the differences of clover content of pasture (Table 4). Dry matter production per kg of fertilizer applied can be seen in Table 5. Response to N was different every year for the potassium applications, being somewhat less in the latter years, with the exception of high N application to a medium potassium dose where annual production response to N fertilization was increasing with the years.

Botanical composition: White clover production for each treatment is presented in Fig. 2. There were no significant amounts of clover in the 2 first harvests of 1989 and 1991. Increasing N doses reduced clover production in all spring harvests, with the exception of autumn, when no effect was seen. Differences between treatments as well as clover content were, in all 4 years, greater in the last spring cut, as weather conditions were

Table 3. **Soil analysis at the end of the experiment of plots with different nitrogen doses (N1 = 0, N2 = 30 + 30 and N3 = 60 + 60 kg N /ha) and potassium doses (K1 = 0, K2 = 50 + 50 and K3 = 100 + 100 kg K_2O/ha).**

	Treatment				Treatment			
	N1	N2	N3	Sig.	K1	K2	K3	Sig.
pH	6.00	6.17	6.07	ns	6.19	6.06	6.01	ns
%Al	0.55	0.09	0.20	ns	0.11	0.32	0.35	ns
Ca	5.57	6.17	5.92	ns	6.20	5.75	5.70	ns
K	44.17	48.50	54.33	ns	41.17a	43.00a	62.83b	*
Mg	0.65	0.71	0.71	ns	0.72	0.69	0.66	ns
Na	0.32	0.31	0.31	ns	0.34a	0.30b	0.30b	**
Pasim	12.95	13.13	14.47	ns	13.10	13.22	14.23	ns

***: $P < 0.001$; **: $P < 0.01$; *: $P < 0.05$

advantageous for clover growth. The effect of N Fertilization on clover production was reduced in the 2 last years, in comparison with clover content values in the treatments in the 2 first years.

The proportion of sown species (*Lolium perenne* and *Trifolium repens*) and adventitious ones in the periods 1989–1990 and 1991–1992 are shown in Table 4. The percentage of sown species was gradually reduced from approximately 70%, in the period 1989–90. to approximately 40%, in the period 1991–1992. The proportion of *Lolium* was higher in the treatment fertilised with N in 1989-1990. However, the percentage of that species was significantly higher in non-fertilised treatments in the second 2 year period.

No N effects were found in the proportion of spontaneous species, with the exception of the second sample from the 1991–1992 period, in that cutting, in the treatment N2, the presence of adventitious plants was reduced; due to the better development of *Lolium* in low or medium doses of N treatment. Generally, N fertilization affected the proportion of *Lolium* and *Trifolium* in the pasture, but did not affect the overall percentage of the sown species in pasture.

Protein, Macro-element and Micro-element contents of the pasture

Crude protein in the 2 periods studied is shown in Table 6. Protein percentage was generally higher in pasture from low N doses plots, in the year overall related with a high clover content, but the reverse situation was found in autumn of the 1991–1992 period, when there was also a high clover content in plots fertilised with the higher amounts of N (60 kg N/ha).

The phosphorus, potassium, calcium and magnesium content of pasture in each treatment are shown in Tables 7, 8, 9, and 10, respectively. Higher phosphorus content of pasture was found in plots where there was no fertilization treatment, in the overall period and in the second cutting of 1989–1990, and in the third harvest of 1991–1992, affected probably by clover content.

The application of N had a negative effect on the potassium content of pasture in each period studied, in the second cutting of the 1989–1990 period, and in the third cutting of the 1991–1992 period, although the same tendency was found in nearly all cuttings studied.

The calcium percentage of pasture was lower in pasture fertilised with higher levels of N, but the opposite was found in the autumn 1989–1990 periods. No effect was found in the 1991–1992 period.

The magnesium percentage of pasture is shown in Table 10. Magnesium content was negatively affected by N fertilization in the autumn of 1989–1990 period probably due to a higher content of clover in this cut, but the opposite was found in the third harvest of 1991–1992. In the periods studied overall, there was no effect on potassium content in pasture of fertilization with N and potassium

Zinc, copper, iron, and manganese content of pasture is presented in Tables 11, 12, 13, and 14, respectively. There was no clear answer to N fertilization in Zn pasture content. The results were positive and negative in the second and third harvests of the 1989–1990 period, respectively. No effect was found in the other cuts. No response to N fertilization was found in Cu, Fe, and Mn contents with the exception of a positive response with regard to Mn concentration in the second harvest of the 1991–1992 period.

Protein and potassium outputs

Protein and K pasture content (kg/ha) for all treatments, is presented in Tables 15 and 16, respectively. Nitrogen fertilization had a positive effect on protein production in the first and second cutting, in 1989, in the second harvest in 1990, and in the first cutting in 1991. In some cuttings, normally the last ones, N fertilization had no effect or even negative effect, probably due to a variation of clover content when N is applied to the soil. Nitrogenous fertilization had a

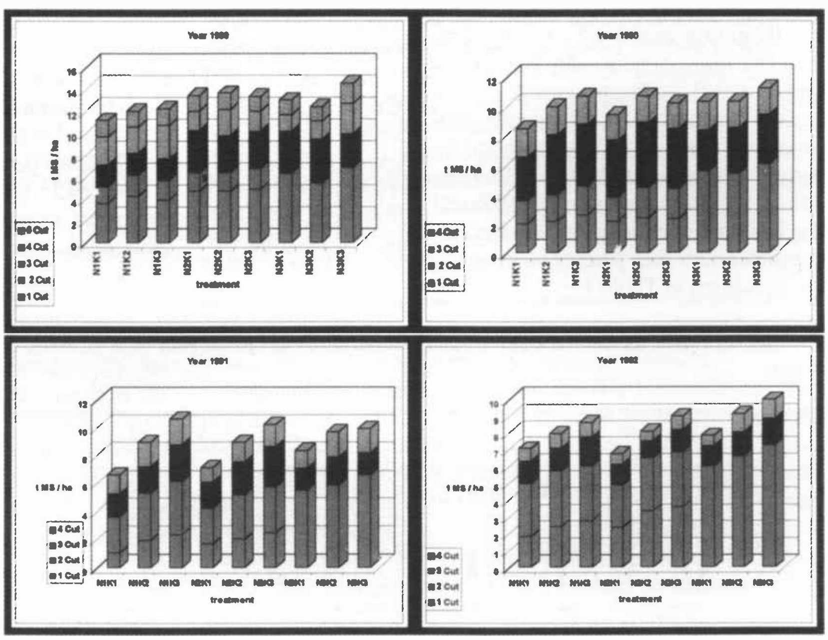

Fig. 1. Pasture production (t/ha) under different treatments at different cutting dates in 1989, 1990, 1991, and 1992 (N1: 0 kg N ha^{-1}; N2: 60 kg N ha^{-1} (30 + 30); N3: 120 kg N ha^{-1} (60 + 60); K1: 0 kg K_2O ha^{-1}; K2: 100 kg K_2O ha^{-1} (50+ 50) and K3: 200 kg K_2O ha^{-1} (100 + 100)).

Table 4. Percentages of sown grass, clover, and other species in each treatment and in the periods 1989–1990 and 1991–1992.

			Grass					
Grass	N0	N30	N60	Sig	K0	K50	K100	Sig.
1989-1990	------------------(%)-----------------				------------------(%)-----------------			
Total	43.97a	55.68b	57.20b	*	54.07	51.27	50.66	ns
1 cut	44.25b	63.25a		*	53.75	57.12	50.37	ns
2 cut	53.00b	55.75ab	74.42a	*	57.25	56.17	59.75	ns
3 cut	39.36b	56.72a	53.58a	*	52.19	49.28	48.19	ns
4 cut	48.50ab	44.91b	60.83a	*	56.75	48.33	49.17	ns
1991-1992								
Total	31.25	33.28a	19.79b	*	23.65b	31.59a	32.53a	*
1 cut	38.58	36.50		ns	28.37b	40.57ab	43.69a	*
2 cut	33.17b	45.67a	30.50b	*	31.94b	37.19ab	40.19a	ns
3 cut	23.04a	23.72a	13.17b	*	17.37	20.09	22.17	ns
4 cut	21.96a	18.30a	10.33b	*	11.21b	22.54a	16.50ab	*
			Legume					
	N0	N30	N60	Sig	K0	K50	K100	Sig.
1989-1990	------------------(%)-----------------				------------------(%)-----------------			
Total	26.75a	12.61b	10.63b	*	12.95b	16.93ab	21.54a	*
1cut	18.58a	8.92b		*	7.25	17.62	16.37a	ns
2 cut	13.33a	9.08a	2.67b	*	5.58	8.67	10.83	ns
3 cut	37.01a	15.78b	15.81b	*	17.61	22.94	28.08	ns
4 cut	17.42a	10.33b	3.08c	*	8.08b	6.67b	16.08a	*
1991-1992								
Total	10.07ab	12.36b	18.38a	*	9.69b	14.06b	19.63a	*
1 cut	16.12	14.21		ns	9.25b	19.19b	20.06a	*
2 cut	10.56	11.03	12.58	ns	9.19	11.75	13.22	ns
3 cut	23.00ab	13.00b	21.17a	*	14.33b	19.59b	29.79a	*
4 cut	6.29b	10.27b	18.29a	*	6.37b	10.00b	18.50a	*
			Others					
	N0	N30	N60	Sig	K0	K50	K100	Sig.
1989-1990	------------------(%)-----------------				------------------(%)-----------------			
Total	29.35	31.75	32.23	ns	33.44	31.87	27.82	*
1 cut	37.17a	27.83b		*	39.00a	25.25ab	33.25b	*
2 cut	33.66	35.17	33.17	ns	37.17	35.25	29.58	ns
3 cut	23.58	27.56	30.67	ns	30.25	27.83	23.72	ns
4 cut	34.50	44.83	36.00	ns	35.58	34.75	45.00	ns
1991-1992								
Total	54.89	54.36	61.95	ns	66.67a	54.36b	48.15b	*
1 cut	45.75	49.33		ns	62.31a	43.31b	37.00b	*
2 cut	56.27a	43.39b	56.94a	*	58.83	51.03	46.75	ns
3 cut	54.21	63.18	59.92	ns	68.37a	61.41a	48.29b	*
4 cut	71.79	71.34	71.50	ns	82.54a	67.46b	64.96b	*

Table 5. Response to nitrogen and potash fertilization (kg dry matter per kg of fertilizer applied).

	Potash response			Nitrogen response		
	N = 0	N = 30	N = 60	K = 0	K = 100	K = 200
	From 0 to 100 kg K_2O			From 0 to 30 kg N		
Year						
1989	8.2	2.3	-5.8	22.4	16.5	11.3
1990	15.1	10.9	0.3	19.0	12.0	-7.7
1991	23.3	18.2	13.0	8.8	0.3	-7.0
1992	8.9	13.8	13.3	-5.5	2.7	6.0
	From 0 to 200 kg K_2O			From 0 to 60 kg N		
1989	5.4	0.1	7.9	15.2	3.5	19.4
1990	11.0	3.0	4.5	15.5	3.2	4.7
1991	20.2	15.4	7.7	14.8	6.2	-6.0
1992	7.9	11.3	10.8	6.4	10.1	11.2

positive effect on protein production (for the silage cut) in the second and third harvest in 1989 and in 1990, although this situation was reversed in the same cuttings for the following years. This might be due to the fact that in spite of a higher production in plots with higher doses of N the content of clover was higher in those with lower N doses. No effect was recorded in the autumn. Potassium content in the sward was not affected by N fertilization in most cuts, and no clear effect of N application on potassium content in pasture was found.

Potassium Fertilization effects

Potassium fertilization increased pasture DM production in most harvests, as shown in Fig. 1. This effect was clear after the second experiment year. Differences in accumulated pasture production rose from 5%, by use of no potassium doses, to 30%, using high K rates, respectively. The application of 200 kg K_2O ha^{-1} meant 2 or 3 tonnes of grass dry matter more than no K fertilization. Dry matter (DM) production response per kg of K_2O applied was reduced when N doses increased (Table 4). This response raised from the first to the third year until 23 kg DM kg^{-1} of K_2O applied. On the other hand, pasture production increase was higher when this fertilization rose from 0 to 100 kg K_2O ha^{-1} than when the increment was from 100 to 200 kg K_2O ha^{-1}, because in the first case, the limit effect was more important.

Botanical composition

Clover content in pasture was greater in plots with higher K rates. Higher K fertilization meant 50% more clover than no K application, reaching, in some cases 85%, and the response between treatments increased from 1989 to 1992.

Potassium effects on the proportion of sown and spontaneous species are shown in Table 5. The fertilization with potassium did not affect the percentage of *Lolium perenne* in pasture in the 1989–1990 period. However, the application of this element improved the rye-grass proportion in pasture in 1991–1992. The clover content of pasture was always increased by K fertilization (Fig. .2). No clear effect of fertilization with this nutrient on the percentage of other species in pasture was found in the 1989–1990 period. However, K fertilization reduced such rate in 1991–1992 significantly.

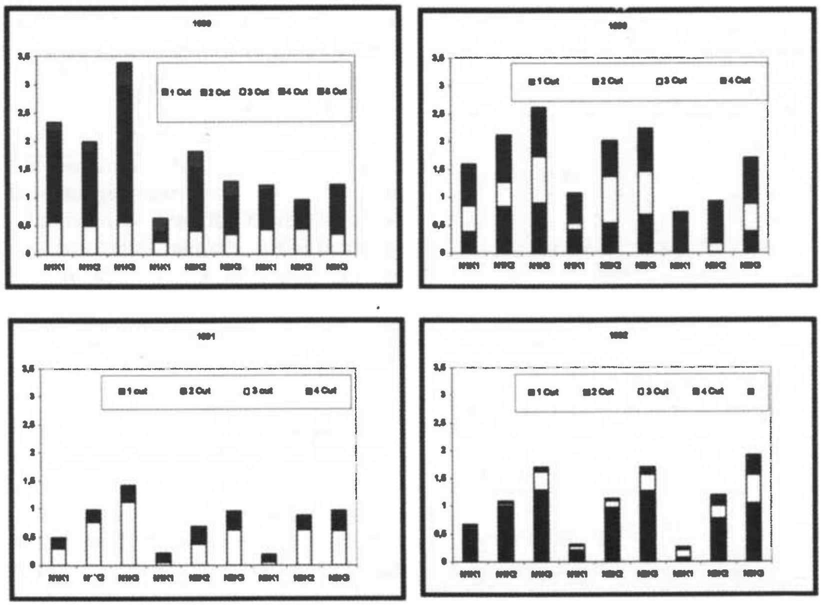

Fig. 2. Clover production (t/ha) under different treatments at different cutting dates in 1989, 1990, 1991, and 1992 N1: 0 kg N ha^{-1}; N2: 60 kg N ha^{-1} (30 + 30); N3: 120 kg N ha^{-1} (60 + 60); K1: 0 kg K_2O ha^{-1}; K2: 100 kg K_2O ha^{-1} (50+ 50) and K3: 200 kg K_2O ha^{-1} (100 + 100)).

Magnesium was negatively related to crude protein or K of pasture overall period ($r^2 = 0.58$) and in the last cutting of spring ($r^2 = 0.80$). The K and protein contents of pasture were positively related to Fe in the overall period ($r^2 = 0.64$), and in the spring ($r^2 = 0.62$), and to copper ($r^2 = 0.88$) in the first cutting of spring.

The relationships between the macro-elements of pasture are shown in Figure 4. A negative and significant relationship was found between Mg and protein in the overall period ($r^2 = 0.55$), and in the last cut of spring ($r^2 = 0.62$), and between K and Mg ($r^2 = 0.74$) in the spring. A positive relationship between Ca and Mg content was found in the overall period ($r^2 = 0.71$).

The relationships between macro-elements and micro-elements are shown in Figure 5. The Cu content of pasture was related to all the macro-elements. These relationships were positive with P ($r^2 = 0.80$), protein ($r^2 = 0.69$), and Ca ($r^2 = 0.77$) in the first cutting, and Mg ($r^2 = 0.78$) in the spring. However, the relationships between Cu and Mg and Cu

Macro-element and micro-element contents

Potassium fertilization did not affect P (Table 8), Ca (Table 9) Mg (Table 10), Zn (Table 11) and Cu (Table 12) contents of pasture in any harvest. The application of K increased protein content of pasture in the first cutting, and Mn content in the second cutting, in 1991-1992 period, but reduced Fe content in the second cutting of the same period. The K content of pasture was increased by fertilizer K application in most harvests.

Protein and potassium output

Plots in which higher K_2O rates were applied produced significantly more protein in the first cutting of the last 3 years. The content of K in pasture was significantly affected in first cuttings, by K_2O fertilization, and K production was increased in the first cuttings of the last 3 years (Table 5).

Relationships between element content of pasture

The significant relationships between P, Mg, Fe, and Cu contents with K and protein proportion of pasture are shown in Figure 3. There were positive relationships between protein, P and K levels in pasture for the overall period ($r^2 = 0.76$), spring overall ($r^2 = 0.88$), and the first ($r^2 = 0.99$) and last ($r^2 = 0.66$) cuts of spring.

Table 6. Crude protein content (%) of pasture in each potsh or nitrogen treatment in the 2 period studied (1989–1990 and 1991–1992).

	Nitrogen				Potash			
	N0	N30	N60	Sig	K0	K50	K100	Sig
1989–1990	--------------------(%)-------------				--------------------(%)-------------			
Total	14.14a	14.02a	12.90b	***	13.92	13.50	13.81	ns
1 cut	16.41	16.35	ns	15.98	16.56	16.61	ns	
2 cut	14.23	13.07	13.59	ns	14.77	12.76	13.38	ns
3 cut	11.22	11.10	10.09	ns	10.69	10.76	10.91	ns
4 cut	15.44	15.45	14.65	ns	14.86	14.98	15.40	ns
1991–1992								
Total	12.45a	11.98ab	11.06b	*	11.40	12.12	11.92	ns
1 cut	14.91	13.68	ns	12.34	13.04	12.88	ns	
2 cut	9.72	9.22	8.64	ns	8.67	10.06	8.86	ns
3 cut	11.01	10.61	11.44	ns	11.03	11.30	10.79	ns
4 cut	14.29b	14.83b	15.69a	*	14.29b	14.52b	16.01a	*

***P < 0.001; *:P < 0.05; ns: not significant.

Table 7. Phosphorus content (%) of pasture in each potash or nitrogen treatment in the 2 period studied (1989–1990 and 1991–1992).

	Nitrogen				Potash			
	N0	N30	N60	Sig.	K0	K50	K100	Sig.
1989–1990	--------------------(%)-------------				--------------------(%)-------------			
Total	0.35a	0.35a	0.33b	**	0.35	0.34	0.34	ns
1 cut	0.39	0.38		ns	0.39	0.39	0.38	ns
2 cut	0.36a	0.36a	0.33b	***	0.36	0.34	0.34	ns
3 cut	0.32	0.32	0.31	ns	0.32	0.32	0.31	ns
4 cut	0.35	0.36	0.34	ns	0.36	0.34	0.34	ns
1991-1992								
Total	0.35a	0.33ab	0.31b	*	0.34	0.34	0.32	ns
1 cut	0.40a	0.38a	0.30b	*	0.36	0.36	0.34	ns
2 cut	0.27	0.26	0.25	ns	0.26	0.28	0.25	ns
3 cut	0.39a	0.35b	0.37ab	*	0.39	0.37	0.36	ns
4 cut	0.34	0.34	0.36	ns	0.35	0.35	0.34	ns

***P < 0.001; **P < 0.01; *P < 0.05; ns: not significant.

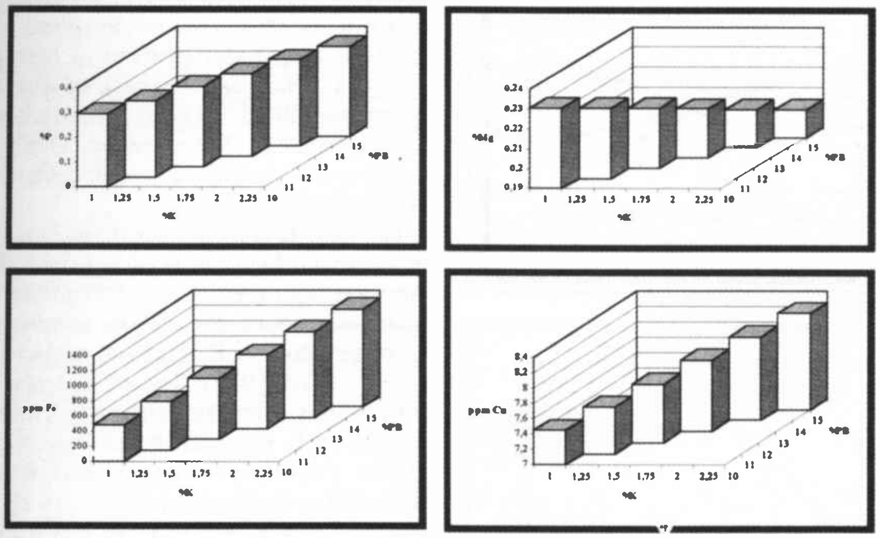

Fig. 3. Relationships between P, Mg, Fe, and Cu concentrations with K and protein proportion of pasture.

and Ca were negative when the content of Mg and Ca were above 0.21 and 0.85 ppm, respectively. Zinc was positively related to Mg in the second cutting ($r^2 = 0.74$) and negatively to Ca in the first cutting ($r^2 = 0.81$). Manganese was negatively related with Ca in autumn ($r^2 = 0.53$).

Discussion

Pasture production increased with application of N with the exception of the second year, when N application was associated with decreased *Trifolium* content. Cold temperatures retard the growth of *Trifolium repens* at the beginning of the growing season, which causes a low N status in soil, unless N fertilizer is applied (Davies 1989). In 1990, the mean temperatures for the 3 first months of the year were 1.44, 2.13, and 3.6 C higher than in 1989, 1991, and 1992, respectively. This favoured fast development of *Trifolium*, leading to more N in soils where N fertilizer was withheld in 1990 than in 1991 and 1992. Berthelsen et al. (1994) found similar changes in soil N associated with *Trifolium repens* in the sward. The appearance of *Trifolium* in the sward was delayed in the establishment year. In 1990, 30 kg N ha^{-1} were introduced by *Trifolium* in 0N plots (Fig. 1) and no response when 30 kg N ha^{-1} fertilizer was applied.

Applying 30 kg N ha^{-1} fertilizer increased annual pasture production in the first year, followed by a decline in the second and third years, and no response in the fourth year. The control (0N) favoured an increase of clover content in the sward resulting in no differences or declines in annual pasture production relative to N application.

Fertilization with K increased pasture production and *Trifolium* content of the first harvest in the last 3 years of the experiment and agrees with observations reported by Simpson et al. (1988). The lack of response to K in the first harvest in 1989 can be explained by insufficient time for different species in the sward to adapt to K fertilization. Production increased at the second harvest where K was applied at the 0N treatment and agrees with earlier findings reported by Mosquera et al. (1992). Nitrogen fertilization of silage cut, increased pasture production, as did K fertilization for the first and second cuttings, in all 4 years of study.

Nitrogen increased pasture DM production by the third cutting of the first

Table 8. Potassium content (%) of pasture in each potash or nitrogen treatment in the 2 period studied (1989–1990 and 1991–1992).

	Nitrogen				Potash			
	N0	N30	N60	Sig	K0	K50	K100	Sig
1989–1990	--------------------(%)-------------				--------------------(%)-------------			
Total	2.00a	1.94a	1.68b	*	1.69a	1.93a	1.69b	*
1 cut	2.52	2.48		ns	1.88c	2.64b	2.98a	*
2 cut	2.47a	2.28ab	2.17b	*	2.15b	2.30ab	2.44a	*
3 cut	1.60	1.64	1.48	ns	1.37a	1.62ab	1.74b	**
4 cut	1.68	1.54	1.36	ns	1.50	1.52	1.47	ns
1991-1992								
Total	1.76	1.82	1.70	ns	1.63b	1.69ab	1.95b	*
1 cut	1.85a	1.73a	1.30b	*	1.28b	1.56b	1.94a	*
2 cut	1.61	2.22	1.98	ns	1.99	1.81	2.01	ns
3 cut	1.28a	1.30a	1.06b	ns	1.23ab	1.12b	1.30a	*
4 cut	2.33	2.13	2.44	ns	2.07b	2.30ab	2.53a	*

***$P < 0.001$; *$P < 0.05$; ns: not significant.

Table 9. Calcium content (%) of pasture in each potash or nitrogen treatment in the 2 period studied (1989–1990 and 1991–1992).

	Nitrogen				Potash			
	N0	N30	N60	Sig	K0	K50	K100	Sig
1989–1990	--------------------(%)-------------				--------------------(%)-------------			
Total	0.87a	0.83ab	0.78b	*	0.85	0.82	0.83	ns
1 cut	0.98a	0.85b		*	0.89	0.91	0.94	ns
2 cut	0.68	0.72	0.63	ns	0.73	0.65	0.65	ns
3 cut	0.86a	0.76ab	0.75b	*	0.80	0.75	0.83	ns
4 cut	0.77b	0.82b	0.97a	*	0.92	0.87	0.86	ns
1991-1992								
Total	1.16	1.26	1.27	ns	1.23	1.24	1.23	ns
1 cut	0.75	0.72	0.81	ns	0.81	0.75	0.73	ns
2 cut	1.08	1.18	1.22	ns	1.10	1.17	1.20	ns
3 cut	1.69	2.08	1.97	ns	1.91	1.99	1.83	ns
4 cut	1.37	1.46	1.52	ns	1.45	1.43	1.48	ns

*$P < 0.05$; ns: not significant.

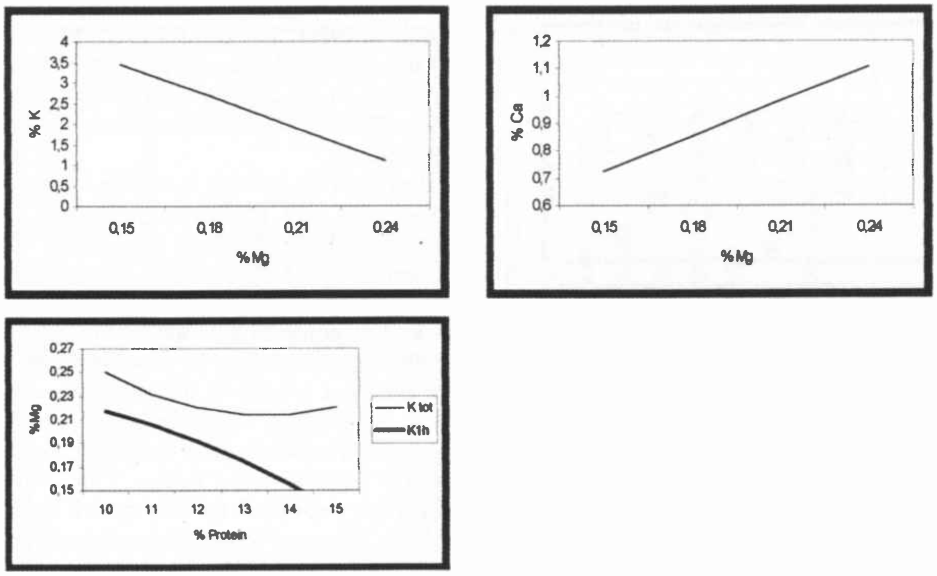

Fig. 4. Relationships between the maco-elements of pasture.

year, but decreased DM production in the second and third years, with no response observed for the last year. *Trifolium* content decreased with N and increased with K and corresponds to observations reported by Chapman et al. (1996), and Clark and Harris (1996). High temperatures and rainfall stimulated clover development, which led to N accumulation in the soil. On the other hand, K fertilization increased resistance to water stress, as found by Robin et al. (1989). This caused an interaction between K and N fertilization.

Nitrogen fertilization significantly increased annual total and spring production in 1989. However, K fertilization increased DM yield in all years, with the exception of 1989. Comparing N1K3 and N3K3 treatments showed that N could substitute for K leading to similar amounts of herbage DM production This indicates that *Trifolium* is very dependent on K fertilization, even in soils with moderate amounts of K. Farmers question the value of *Trifolium* as a source of N, because the presence and amount of clover in a sward is unpredictable as is the amount of N fixed by the legume in the sward. However, it is very important to note what happens to K in the soil. Annual fertilization with K is very important when high rates of N are applied, as high pasture yield can deplete K from the soil with time, as suggested by Simpson et al. (1988).

Protein production increased as N fertilization increased, but only when N application increased pasture production, which compensated for the lower proportion of protein in the grass dominated swards (second cuttings of the first and second years). The situation changed as *Trifolium* increased as a fraction of the sward. *Trifolium* increased protein in herbage because of the inherently greater protein in legume (Norton 1982) and because of overall increased productivity (Meister and Lehmann 1985). These factors contribute to the overall increased protein content of swards fertilized with K.

The high K content of herbage growing in soils with high levels of K is normally due to a high proportion of *Trifolium* in such swards (Chevalier 1981). *Trifolium* is more sensitive to K fertilization than are grasses (Cox 1973). The persistence of leguminous plants in pasture is closely related to K fertilization (Floate et al. 1981). Pasture production efficiency attributed to fertilizer inputs was 16 kg of DM per kg of K and 15 kg of DM per kg of N (Simpson et al. 1988). In the present experiment, the values were 9.68 and 8.72 kg DM per kg nutrient, respectively. This could be explained because K content in the soil, was deficient and N was low in the experiment reported by Simpson et al. (1988).

Protein, P, K, and Cu levels in pasture

Table 10. Magnesium content (%) of pasture in each potash or nitrogen treatment in the 2 period studied (1989–1990 and 1991–1992).

		Nitrogen		.		Potash		.
	N0	N30	N60	Sig	K0	K50	K100	Sig
1989–1990		--------------------(%)-------------				--------------------(%)-------------		
Total	0.2	0.2	0.2	ns	0.2	0.2	0.2	ns
1 cut	0.2	0.2		ns	0.21	0.2	0.2	ns
2 cut	0.17	0.18	0.17	ns	0.18	0.17	0.17	ns
3 cut	0.19	0.18	0.18	ns	0.18	0.18	0.18	ns
4 cut	0.27a	0.28a	0.25b	***	0.27	0.26	0.27	ns
1991–1992								
Total	0.22	0.22	0.24	ns	0.23	0.23	0.22	ns
1 cut	0.18ab	0.17b	0.20a	*	0.19	0.18	0.17	ns
2 cut	0.21	0.22	0.22	ns	0.22	0.22	0.21	ns
3 cut	0.25b	0.27ab	0.28a	*	0.25	0.27	0.27	ns
4 cut	0.26	0.28	0.29	ns	0.27	0.27	0.28	ns

Table 11. Zinc content (ppm) of pasture in each potash or nitrogen treatment in the 2 period studied (1989–1990 and 1991–1992).

		Nitrogen		.		Potash		.
	N0	N30	N60	Sig	K0	K50	K100	Sig
1989–1990		--------------------(ppm)-------------				--------------------(ppm)-------------		
Total	26.51	26.84	26.16	ns	26.49	26.43	26.68	ns
1 cut	30.36	29.58		ns	29.72	29.76	30.41	ns
2 cut	22.60b	22.12b	26.93a	*	23.51	24.64	23.50	ns
3 cut	24.52ab	25.97a	23.08b	*	24.70	24.09	24.78	ns
4 cut	28.58	30.35	29.68	ns	29.58	29.51	29.58	ns
1991-1992								
Total	26.38	26.64	28.17	ns	27.14	27.98	26.17	ns
1 cut	22.49	22.40		ns	23.19	24.01	23.05	ns
2 cut	25.17	24.51	26.34	ns	24.88	26.21	24.93	ns
3 cut	26.14	25.71	26.23	ns	26.05	26.54	25.56	ns
4 cut	34.29	37.04	39.11	ns	38.20	38.39	33.85	ns

*P < 0.05; ns: not significant.

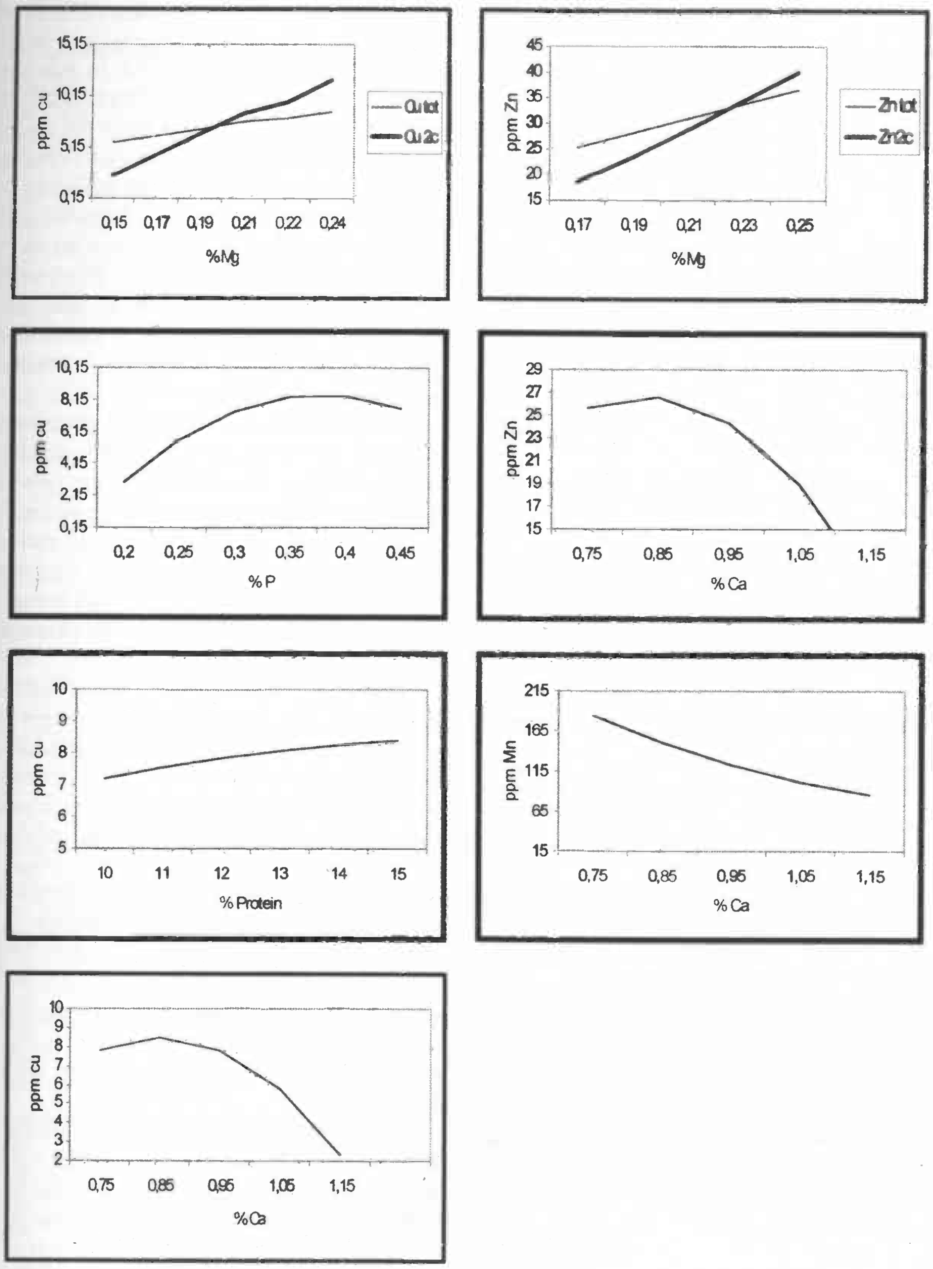

Fig. 5. Relationships between macro-elements and micro-elements of pasture.

herbage were lower in the last spring harvest because of development stage. Calcium, Mn, Fe, and Mg content increased, as described by Reid and Horvath (1980), Metson and Saunders (1978), Hopkins et al. (1994), and Mosquera et al. (1999).

Normal levels of protein and P in the area were found and K content was higher than those found in amphibole-derived soils, as in our research the schist-derived soil had higher K content (Mosquera et al. 1999). Nitrogenous fertilization had a negative effect on protein, P and K content of soil, mainly due to the higher clover proportion in unfertilized plots, in relation to other species (Mosquera and González 1997).

Whitehead (1995) found that N application reduced K concentration where unfertilised plots had less than 2% K. In the present experiment, N fertilization decreased K content of pasture herbage, but this varied with soil K (see Hopkins et al. 1994). The N rates applied in the present experiment were significantly lower than the levels used in the experiments of Hopkins et al. (1994) and Whitehead (1995). However, in the present experiments, clover content was higher in the lower N treatments, which increased the K content of pasture, associated with greater *Trifolium* content in the sward (Chevalier 1981).

Calcium, in 1989–1990, was in a range (0.70–0.95%) considered normal for pastures in temperate regions (Grace 1983a). In 1991–1992, Ca concentration in available herbage increased because the forb content of the sward was higher. In 1991–1992, differences in the percentage of *Trifolium* in swards receiving different amounts of N were less than in 1989–1990, and percentages of other species rose from 31% in 1989–1990 to 71% in 1991–1992. The other species usually had higher levels of Ca than the sown species.

Hopkins et al. (1994) and Babnik et al. (1996) found that N fertilization reduced the Ca content of pasture, as we found in the first year. This could be explained by the higher legume content in non-fertilised plots that had higher Ca contents than did *Lolium* (Whitehead 1995). Magnesium content was generally below a critical value of 0.2%, which may cause osteomalacia in lactating cattle. The critical value was reached and exceeded in 1991–1992, as forbs increased as a proportion of pasture.

The response of Mg in herbage to N is not clear. Hopkins et al. (1994) found that N fertilization reduced Mg content, whereas Simpson et al. (1988) observed an increase. In the present experiment, differences were detected between treatments when Mg concentration and clover content was higher (last cutting of the year).

The critical values of different macroelements in feed suggested as meeting the needs of livestock were always reached (NRC 2001, ARC 1991, Grace 1983a, 1983b, 1983c). In this experiment mean values were crude protein (7.3–11.2%), phosphorus (0.3–0.4%), potassium (0.8%), calcium (0.5%) and zinc (20-50 ppm). Copper and Mg content were below the critical values for milking cows: 12 ppm and 0.2 %, respectively (Loué 1988, Hopkins et al. 1994).

Copper content was in the 6 to 12 ppm range, which was adequate for plant nutrition (Kabata and Pendías 1984), and was not significantly different between treatments in spite of differences in botanical composition of the swards (Babnik et al. 1996). Whitehead (1995) noted the mixed effects of N fertilization on Cu content of pasture, when N source influenced soil pH affecting bioavailability of mineral nutrients from soil.

Iron concentrations in soil were between 300 and 2200 ppm, which meet plant needs (50–250 ppm) for growth (Kabata and Pendías 1984). Generally, N fertilization did not affect Fe content of pasture. Whitehead (1995) indicated that the effect of N fertilization on Fe content in pasture depended on pH effects of N fertilizer.

A critical value of 20 ppm for Zn in available herbage was always exceeded in the present experiment. The effect of N fertilization on Zn content of pasture was not clear. Loué (1988) and Hopkins et al. (1994) attributed the negative effect of N fertilization on Zn content to dilution. However, Whitehead (1995) mentioned that no effect was detected if less than 300 kg N ha^{-1} was applied.

Protein, P, K, and Cu were positively related as Monterroso (1995) found, mainly because these elements are present in high concentrations when pasture is freshly sown, and become less as the sward matures. However, Ca and Mg content was usually higher in mature leaves and flowers than in young plants as described by Willman et al. (1994).

Potassium fertilization did not affect the protein, P, Ca, Mg, Cu, or Zn content of pasture, in spite of differences in botanical composition caused by the different treatments. Simpson et al. (1988) indicated that protein content of clover was reduced with higher K, describing also the absence of a response, regarding the protein content, of pasture with K fertilization. The effect of K on botanical composition was clear in 1991-1992, when a possible deficiency of K may have appeared in non-fertilised soil. In this interval, *Lolium* content of pasture was increased by K fertilization.

Potassium fertilization did not affect the Mg content of pasture, but overall there was a negative relationship between Mg content and K. Fertilization with K usually reduced the Mg content of grass (Dampney 1992), but increased this element in clover (Simpson et al. 1988). Therefore, the negative effect of K fertilizer on Mg of some species can be compensated by the increase of *Trifolium* in the sward. On the other hand, lower Mg content occurred in 1989–1990 relative to 1991–1992, when proportion of forbs in the sward increased.

In Galicia, it is normal to apply 100 kg K_2O ha^{-1} and 30 or 40 kg N ha^{-1} after each grazing. From our work, K_2O applications should be increased unless managing the sward under cutting conditions. Increased K should lead to higher pasture and protein production and better forage quality through increased *Trifolium* and *Lolium* production and persistence.

Table 12. Copper content (ppm) of pasture in each potash or nitrogen treatment in the 2 period studied (1989–1990 and 1991–1992).

	Nitrogen				Potash			
	N0	N30	N60	Sig	K0	K50	K100	Sig.
1989–1990	--------------------(ppm)-------------				--------------------(ppm)-------------			
Total	7.55	7.73	7.53	ns	7.69	7.61	7.54	ns
1 cut	8.70	8.94		ns	8.60	8.98	8.62	ns
2 cut	6.71a	6.85a	8.23b	ns	7.61	7.14	7.05	ns
3 cut	6.60	6.81	6.38	ns	6.63	6.44	6.72	ns
4 cut	8.31	8.75	8.17	ns	7.94	8.81	8.38	ns
1991–1992								
Total	7.69	7.59	8.03	ns	7.88	7.99	7.47	ns
1 cut	8.40	7.65		ns	8.07	7.56	7.62	ns
2 cut	5.70	6.01	6.77	ns	6.27	6.13	6.10	ns
3 cut	7.07	7.01	7.9	ns	6.98	8.12	6.98	ns
4 cut	10.24	10.26	11.39	ns	10.87	11.25	9.78	ns

ns:not significant.

Table 13. Iron content (ppm) of pasture in each potash or nitrogen treatment in the 2 period studied (1989–1990 and 1991–1992).

	Nitrogen				Potash			
	N0	N30	N60	Sig	K0	K50	K100	Sig.
1989–1990	--------------------(ppm)-------------				--------------------(ppm)-------------			
Total	1321.6	336.7	310.4	ns	1325	380.4	357.6	ns
1 cut	390.6	407.4		ns	419.65	433.46	343.99	ns
2 cut	314.24	369.62	347.11	ns	318.52	353.94	358.51	ns
3 cut	292	224	205	ns	2935	208	206	ns
4 cut	994	353	373	ns	434	638	562	ns
1991–1992								
Total	974	722	748	ns	895	778	763	ns
1 cut	1285	725	639	ns	1234a	690b	684b	***
2 cut	319	255	322	ns	280	311	305	ns
3 cut	338	227	290	ns	279	293	325	ns
4 cut	2087a	1403b	1257c	***	1397	1630	1598	ns

***$P < 0.001$; ns:not significant

Table 14. Manganese content (ppm) of pasture in each potash or nitrogen treatment in the two period studied (1989–1990 and 1991–1992).

	Nitrogen				Potash			
	N0	N30	N60	Sig	K0	K50	K100	Sig.
1989–1990	--------------------(ppm)-------------				--------------------(ppm)-------------			
Total	63.53	61.76	60.28	ns	58.45	63.77	63.78	ns
1 cut	55.63	54.21		ns	49.32	55.66	59.79	ns
2 cut	81.99	73.10	70.29	ns	69.89	78.19	77.29	ns
3 cut	52.45	61.47	53.43	ns	54.88	57.27	55.21	ns
4 cut	67.86	53.98	53.36	ns	54.80	58.26	59.99	ns
1991-1992								
Total	103.81	96.92	94.91	ns	98.14	101.15	96.10	ns
1 cut	114.81	103.93	94.17	ns	106.35	109.31	95.01	ns
2 cut	91.01b	91.64b	103.13a	*	89.14b	102.36a	94.27ab	*
3 cut	92.51	77.37	71.02	ns	80.26	79.56	81.27	ns
4 cut	117.74	114.13	107.92	ns	115.82	108.45	115.52	ns

*$P < 0.05$; ns: not significant.

Table 15. Protein production (kg/ha) of sward in each cut, year and treatment.

	N = 0	N= 30	N = 60	Sig	K = 0	K = 50	K = 100	Sig.
Year 1989	--------------------(kg/ha)-------------				--------------------(kg/ha)-------------			
1 cut	630	820		***	690	760	710	ns
2 cut	220b	230b	890a	***	440	420	480	ns
3 cut	200b	380a	350a	***	300	300	320	ns
4 cut	360a	240ab	190b	***	250	230	310	ns
5 cut	250		250		270		ns	
240			250		280		ns	
Year 1990								
1 cut	360	360		ns	320b	370ab	400a	***
2 cut	240b	250b	690a	***	360	380	450	ns
3 cut	370ab	440a	310b	**	320	420	390	ns
4 cut	290	280	280	ns	290	280	280	ns
Year 1991								
1 cut	230	310		*	240b	330a	370a	*
2 cut	290a	230ab	160b	**	160b	270a	260a	*
3 cut	250	250	180	ns	180b	250a	250a	*
4 cut	230	210	210	ns	170b	230a	260a	**
Year 1991								
1 cut	320	390		ns	330b	430ab	500a	*
2 cut	390a	320a	190b	***	280	310	310	ns
3 cut	120	100	170	ns	130	130	150	ns
4 cut	100	87	150	ns	70	110	150	ns

***P < 0.001; **P < 0.01; *P < 0.05; ns:not significant.

Table 16. Potash production (kg/ha) of sward in each cut, year and treatment.

	N = 0	N= 30	N = 60	Sig	K = 0	K = 100	K = 200	Sig.
Year 1989	--------------------(kg/ha)-------------				--------------------(kg/ha)-------------			
1 cut	11.0	13.8		**	10.9	13.5	12.5	ns
2 cut	43.7a	43.8a	14.7b	***	69.1	73.0	93.0	ns
3 cut	43.5b	74.9a	74.6a	***	53.9	65.2	74.0	ns
4 cut	31.2a	17.0b	17.8b	***	19.0	22.6	24.4	ns
5 cut	28.6	26.4	27.6	ns	27.0	27.1	28.4	ns
Year 1990								
1 cut	50.9	46.7		ns	23.9b	48.8ab	73.9a	***
2 cut	43.4b	40.3b	106.4a	***	54.6	63.9	72.7	ns
3 cut	46.5b	64.3a	39.1b	***	39.7b	56.9a	54.7a	*
4 cut	21.3a	19.5b	19.3b	***	20.4	19.9	19.9	ns
Year 1991								
1 cut	31.9	37.1		ns	22.2b	37.5ab	56.6a	***
2 cut	44.6	43.1	34.3	ns	27.0b	43.9a	52.6a	***
3 cut	29.6	27.5	24.4	ns	23.1b	26.6ab	32.1a	*
4 cut	28.2	22.3	24.1	ns	18.4b	25.4ab	30.9a	*
Year 1991								
1 cut	41.2	51.5		ns	38.6b	53.8ab	77.9a	***
2 cut	75.6ab	97.0a	45.6b	**	70.5	66.0	81.7	ns
3 cut	14.4	9.3	17.3	ns	12.2	11.8	17.0	ns
4 cut	20.8b	16.3b	32.1a	*	15.3	25.1	28.8	ns

***P < 0.001; **P<0.01; *P < 0.05; ns:not significant

Conclusions

A modest rate of N application is recommended the first year after pasture establishment because legume presence is minimal. In subsequent years fertilization needs appear to depend on legume development affected by growth conditions such as temperatures in early spring and autumn. Nitrogen fertilization increased DM production, at low legume content of swards, and reduced the macro-element concentrations in pasture by dilution. When legume (*Trifolium repens*) content was high, total DM of the sward was high, especially at lower N than at higher N applications. Potassium fertilization increased legume content and DM yield with higher crude protein and K in herbage. Legume-rich pastures developed where low N fertilizer was applied. Mineral content of pastures should take into account the botanical differences among swards arising from fertilization practices.

Literature Cited

ARC, 1991. AFRC. Technical Committee on Responses to Nutrients, Report 6. A reappraisal of the calcium and phosphorus requirements of sheep and cattle. Nutr. Abstr. Rev.. Ser. B: Livestock Feeds and Feed. 61(9):573–612.

Babnik, D., V. Znidarsic-Pongrac, J. Verbic, and J. Verbic. 1996. The effect of fertilization on the concentration of mineral elements in grasses, forbs and legumes from the permanent karst grassland. Grassl. Science in Europe. 1:373–376.

Berthelsen, H.B., J. Ford, J. Evans, and J.R. Caradus. 1994. Effect of mineral N on spring growth and N fixation of white clover lines. Proc. Ann. Conf. Agron. Soc. of New Zealand. 24:37–41.

Castro, P., A. González, and D. Prada. 1990. Simultaneous determination of nitrogen and phosphorus in sward samples (In Spanish), p. 200–207. *In:* Pastos (ed.) Actas de la XXX Reunión Científica de la Sociedad Española para el Estudio de los Pastos. San Sebastian, Spain.

Chapman, D. F., A. J. Parsons, and S. Schwimming. 1996. Management of clover in grazed pastures: expectations, limitations and opportunities, p. 21–22. *In* D. R. Woodfield (ed.)White clover: New Zealand's competitive edge. Proc. of a joint symposium between Agron. Society of New Zealand and New Zealand Grassl. Assoc.. Lincoln Univ., Lincoln, New Zealand.

Chevalier, H. 1981. Mixed sward Fertilization (In French). Au service de L´agriculture 20: 1–28.

Clark, D.A. and S.L. Harris. 1996. White clover or nitrogen fertilizer for dairying?, p. 107–114. *In* D. R. Woodfield (ed.) New Zealand and New Zealand Grassl. Assoc.. Lincoln Univ., New Zealand.

Cox, W.J. 1973. Potassium for pastures. J. Agr. Western Australia 14:3–13.

Dampney, P.M.R. 1992. The effect of timing and rate of potash application on the yield and herbage composition of grass for silage. Grass Forage Sci. 47:280–289.

Davies, A. 1989. The structure of the grass/clover swards and its implications in sward management, p. 1065–1066. *In:* European Grassland Federation (ed.) 16 Int. Grassl. Congr. Nice, France

Floate, M.I.S., A. Rangley, and F. R. Bolton. 1981. An investigation of problems of sward improvement on deep peat with especial reference to potassium responses and interactions with lime and phosphorus. Grass Forage Sci. 36:81–90.

Frame, J. 1990. The effects of nitrogen and potassium fertilizer on the productivity of perennial ryegrass/white clover swards, p. 596. *In:* International Scientific Centre of Fertilizers - CIEC (ed.) Proc. 10 World Fertilizer Congr. of Int. Scientific Centre of Fertilizers (CIEC), Nicosia, Cyprus.

Frame, J. and P. Newbould. 1984. Herbage production from grass/white clover swards, p. 15–35. *In:* D.J. Thomson (ed.) 16 Occasional Symposium Brit. Grassl. Society. Mainhead, UK.

González, A. 1988. Clover evolution, nitrogen fixation and seasonal distribution of a mixed sward response to Fertilization and grazing, p. 272–276. *In:* European Grassland Federation (ed.) Proc. 12 General Meeting EGF. Dublin, Ireland

González, A. 1992. Las praderas de gramínea y trébol y la fertilziación nitrogenada en Galicia, p. 383–393. *In:* Consellería de Agr. (ed.) 100 Años de Investigación Agraria. Xunta de Galicia. Santiago de Compostela, Spain.

González, A., J. Piñeiro, and M. Cropper. 1996. Extending the grazing season. In: Parente, G., J. Frame and S. Orsi (ed.) General Meeting on 'Grassland and land use systems', Grassland Science in Europe, Vol. 1. EGF. Grado, Italy.

Grace, N.D. 1983a. Calcium, p.100–105. *In:* N.D.Grace (ed.) The mineral requiements of grazing ruminants, 9. N. Z. Soc. of Anim. Prod. Hamilton, New Zealand.

Grace, N.D. 1983b. Magnesium, p. 92–99. *In:* N.D. Grace (ed.) The mineral requirements of grazing ruminants,13. N. Z. Soc. of Anim. Prod. Hamilton, New Zealand.

Grace, N.D. 1983c. Phosphorus, p.106–112. *In:* N.D. Grace (ed.) The mineral requirements of grazing ruminants, 15. N. Z. Soc. of Anim. Prod. Hamilton, New Zealand.

Hopkins, A., A.H. Adamson, and P.J. Bowling. 1994. Response of permanent and reseeded grassland to fertilizer nitrogen. 2. Effects on concentrations of Ca, Mg, K, Na, S, P, Mn, Zn, Cu, Co and Mo in herbage at a range of sites. Grass Forage Sci., 49,9–20.

Kabata, A. and H. Pendías. 1984. Trace elements in soil and plants. CRC Press Inc. Boca Ratón, Fla.

Loué, A. 1988. Los microelementos en agricultura. Ediciones Mundi-Prensa. Madrid, Spain.

Meister, E. and J. Lehmann. 1985. Mutual influence of temperate legumes and grasses grown in associations at different nitrogen levels, p. 585–587. *In:* Science Council of Japan and Japanese Society of Grassland Science (ed.) Proc. of the 15 Int. Grassl. Congr. Kyoto, Japan.

Metson, A.J. and W.M.H. Saunders. 1978. Seasonal variations in chemical composition of pasture. I. Calcium, magnesium, potassium, sodium and phosphorus. New Zealand J. Agric. Research, 21:341–353.

Monterroso, M.C. 1995. Characterization of edaphogeochemical processes in a dump of lignite in a environmental restoration process (In Spanish). PhD Tarsis. Universidade de Santiago de Compostela, Santiago de Compostela, Spain.

Mosquera, M.R. and A. González, 1997. Nitrogen and potassium use to increase the production and persistence de white clover (In Spanish). Pastos 27(2): 207–218.

Mosquera, M.R., A. González and A. Rigueiro. 1999. Ecología y manejo de praderas. Ministerio de Agric. Santiago de Compostela-Madrid, Spain.

Mosquera, M.R., A. González, and T. Brea.1992. Effect of the dose and application time of the first nitrogen in a mixed sward (In Spanish), p. 185–193. *In:* Sociedad Española para el Estudio de los Pastos (ed.) XXXII Reunión Científica de la Sociedad Española para el Estudio de los Pastos. Pamplona, Spain.

Norton, B.W. 1982. Differences between species in forage quality, p. 91–109. *In:* J.B. Hacker (ed.) Proc. of an Int. Symposium held at St. Lucia, 1981. Nutritional Limits to Animal Production from Pastures?. Queensland, Australia

NRC. 2001. Nutrients requirements of dairy cattle. Seventh Revised edition Update, 1989:National Research Council, 408 pp. Washington D.C., United States.

Reid, R.L. and D.J. Horvath. 1980. Soil chemistry and mineral problems in farm livestock. A review. Animal Feed Sci. Tech. 15:95–167.

Robin, C., L. Shamsun-Noor, and A. Guckert. 1989. Effect of potassium on the tolerance to PEG-induced water stress of two white clover varieties (Trifolium repens L.) Plant and Soil 120:153–158.

Rodríguez, M. and M. Pinto. 1987. Fertilization nitro-fosfo-potásica on naturals grasslands in Basque Country (in Spanish). Pastos, 17(1-2):203–218.

Simpson, D., D. Wilman, and R. Adams. 1988. Response of white clover and grass to applications of potassium and nitrogen a potassium deficient hill soil. J. Agr. Sci. 10:159–167.

Whitehead, D.C. 1995. Grassland Nitrogen. CAB Int., 397 pp. Wallingford, Oxon United Kingdom.

Willman, D., G.H. Acuña, and P. Joy Michaud. 1994. Concentrations of N, P, K, Ca, Mg and Na in perennial ryegrass and white clover leaves of different ages. Grass Forage Sci.. 49:422–428.