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Nitrogen fertilization and row spacing effects on *Digitaria eriantha*

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Abstract

Crude protein (CP, %), yield of protein dry matter (YPDM, kg ha^{-1}), nitrogen use efficiency (NUE, kg dry matter kg^{-1} N) and nitrogen recovery (NR, %) were evaluated in *Digitaria eriantha* after exposing this species to various field-treatments during 1998–1999 and 1999–2000 in Bahía Blanca (38° 48'S, 62° 13'W), Argentina. Treatments included (1) 3 N fertilization rates (0, 50 or 100 kg ha^{-1}), (2) 2 row spacings (30 or 50 cm), and (3) 2 methods of fertilizer application (either split at the beginning of spring and summer or applied at once in early spring). Plants were cut leaving 5 cm stubble whenever they reached 26–28 cm. Studied parameters were determined on forage harvested in spring, summer or total annual. Crude protein increased ($P < 0.05$) as N fertilization increased in both seasons. Total annual CP averaged 9.7, 12.0 and 14.0%, respectively for the 0, 50 and 100 kg ha^{-1} fertilization rates, respectively. Crude protein was greater ($P < 0.05$) on forage which received split rather than bulk N fertilization, and mean values were 13.2 and 11.7%, respectively. Forage sown at different row spacings had a similar ($P > 0.05$) CP concentration. In general, YPDM responded positively ($P < 0.05$) to N fertilization and to a split application of N fertilizer. Although differences were not always significant, there was an inverse relationship between N fertilization rate and NUE and NR. Nitrogen use efficiency was 34.5 and 24.8 kg dry matter kg^{-1} N ($P < 0.05$), and NR was 98 and 79% ($P < 0.05$) when N fertilization rates were 50 and 100 kg ha^{-1}, respectively. There was a positive ($P < 0.05$) relationship between rainfall and NUE or NR. Nitrogen fertilization in *D. eriantha* should be split with a N fertilization rate close to 50 kg ha^{-1}, and using 30 rather than 50 cm row spacing.

Resumen

Se efectuaron análisis en el forraje cosechado en un experimento realizado en Bahía Blanca (Argentina) durante los ciclos 1998–99 y 1999-00. El ensayo fue en bloques al azar con tres repeticiones. Los tratamientos fueron: 1) dosis de nitrógeno (N): 0, 50 y 100 kg/ha, 2) distancia entre surcos: 30 y 50 cm y 3) sistemas de fertilización: dividida (en mitades al inicio de primavera y de verano) y total (al inicio de primavera). Se efectuaron cortes con frecuencia de 26–28 cm e intensidad de 5 cm de altura. En el forraje cosechado en primavera, verano y total anual se determinaron: 1) proteína bruta (PB, %), 2) rendimiento de materia seca proteica (MSP, kg/ha), 3) eficiencia de utilización de N (EUN, kg MS/kg N) y 4) recuperación de N (RN, %). Todos los parámetros respondieron a la fertilización con N. La PB aumentó con cada dosis de N ($P < 0,05$) en ambas estaciones y en el total anual. El promedio de PB total anual en las tres dosis fue: 9.7, 12.0 y 14.0%, respectivamente. La PB de la aplicación dividida fue mayor que la total y sus promedios fueron: 13.2 y 11.7%, respectivamente ($P < 0,05$) y entre distancias no hubo diferencias ($P > 0.05$). Los rendimientos de MSP respondieron, en general, a la fertilización con N y a su aplicación dividida ($P < 0,05$). La EUN y la RN decrecieron al aumentar la dosis de N aunque no siempre significativamente. Con 50 y 100 kg/ha de N la EUN total fue de 34.5 y 24.8 kg MS/kg N ($P < 0,05$), respectivamente, y la RN total fue de 98.0 y 79.0 %, respectivamente ($P < 0,05$). Hubo una relación positiva ($P < 0,05$) entre la cantidad de lluvia y la EUN o la RN. Se concluyó que es recomendable fertilizar con una dosis de N cercana a los 50 kg/ha con aplicación dividida y sembrar en líneas a 30 cm en lugar de 50 cm.

Key Words: N rate and timing, crude protein, N use efficiency, N recovery, semiarid Argentina, perennial grasses

Research coming from semiarid environments regarding the effects of N fertilization on forage quality of *Digitaria eriantha* is scarce. Nitrogen fertilization with 100, 200 or 400 kg ha^{-1} did increase crude protein (CP) in this species (Grunow and Rabie 1985). Some studies in Argentina also showed that CP increased in *D. eriantha* after application of 100 or 127 kg ha^{-1} N (Veneciano and Terenti 1997, Veneciano et al. 1998). Increases in N or CP percentages as N fertilization rates increase in perennial grasses are common (George et al. 1972, Hanson et al. 1978, Eck et al. 1981, Madakadze et al. 1999).

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Nitrogen pollution in both surface and subsurface water is a major environmental problem and is partly due to widespread use of N fertilizer in agriculture. Decreasing N fertilization on grasslands would possibly diminish the risk of N leaching and runoff and would decrease the cost of production. Therefore, efforts must be focused at improving nitrogen use efficiency (NUE), that is, producing greater or similar forage dry matter yields with less N fertilizer. However, because nutritive value is an important consideration in perennial grasses, obtaining improved NUE should also aim at maintaining or improving forage N concentration to meet ruminant nutrition requirements (Minson 1982). This is important since greater dry matter yields and NUE may lead to lower N concentrations in forage grasses (Lemaire and Salette 1984).

Digitaria eriantha forms a dependable perennial base for many pasture enterprises in the southeastern Argentina. This species is also a promising alternative forage grass for livestock-forage systems under limited nitrogen fertilizer inputs in Texas (Sanderson et al. 1999). The importance of this species has extended to southern Africa where ecotypes of *Digitaria eriantha*, each associated with a particular rainfall region and/or habitat conditions, have been selected suitable for restoration of denuded areas in arid and semi-arid grasslands (Theunissen 1997). Research by various rangeland ecologists (Janse Van Rensburg and Bosch 1990, Bosch and Theunissen 1992) has revealed that *Digitaria eriantha* is an important pasture grass species in the semiarid grasslands of that part of the African continent. This species occupies a wide variety of soil and vegetation types and habitats over a large geographical area in southern Africa (Theunissen 1997), including grassland, savanna and woodland, and extending into marshes and along riverbanks (Chippindall and Crook 1976). Roberts (1971) and Roberts and Fourie (1975) are of the opinion that this species often occurs on sandy soils, whereas Müller (1984) states that *D. eriantha* also prefers stony soils. This species can be established using stolon scions or seeds. Although *D. eriantha* is associated with well managed vegetation, this species also becomes abundant in moderately severely overgrazed vegetation (Theunissen 1997). This involves the participation of different *D. eriantha* ecotypes. Among several perennial grasses in central Puerto Rico, *D. eriantha* presented the best forage acceptability by grazing animals (Ramos-Santana and McDowell 2000).

This research is a follow-up of another, previous study in *D. eriantha* (Gargano et al. 2003) where yields responded to N fertilization, mainly when it was split rather than applied at once. In that study, no definite yield response was observed when sowing at different row spacings. In vitro dry matter digestibility increased slightly after N application, and was then of doubtful biological significance. It was recommended that a N fertilization rate of 50–100 kg ha^{-1} using split applications, and 30 cm row spacing be used when producing *D. eriantha*. Objectives of this study were to examine the effects of row spacing and N fertilization on crude protein, yield of protein dry matter, nitrogen use efficiency and nitrogen recovery in *D. eriantha*. More information is needed about these parameters to manage this grass species for most efficient production in Argentina.

Materials and Methods

Study Area

This study was conducted within the semiarid region of Argentina, in Bahía Blanca (Elias and Castellvi Sentis 1996; 38° 48'S, 62° 13'W). The most common activity in the region is cattle raising and production of light steers, which occupies 82% of the total surface area in Bahía Blanca (Gargano et al. 1990). The major forage resource for these activities is rangeland vegetation. There is some agriculture, which mostly includes wheat production. Further details on location and edaphic characteristics at the experimental site, soil tillage, sowing and plot size are given in Gargano et al. (2003). Climate data at the study area are given in Table 1. Most relevant methodological aspects from this previous work will be briefly exposed.

Experimental Design and Treatments

The experiment was a split-plot in a randomized complete block design. Studied factors and its corresponding levels were: 1) Nitrogen levels (main plots): 0, 50, or 100 kg ha^{-1}. Fertilizer was urea which was broadcasted after a rainfall or an irrigation equivalent to 3-4 mm; 2) Row spacings (main plots): 30 or 50 cm, and 3) Fertilization methods (subplots): bulk or split fertilization. Bulk fertilization means that N was applied all at once in early spring, while in the split fertilization method, the total annual amount of N fertilizer was applied half in early spring and the other half in early summer.

Each block was composed of 6 main plots (3 N levels x 2 row spacings) and 12 subplots (6 x 2 fertilization methods). Numbers of treatments and replicates differ between spring and summer because of the split N fertilizer application. The level of 25 kg ha^{-1} N was applied in early spring because of fractioning the 50 kg ha^{-1} N level. As a result, the total number of treatments equaled 8 (4 N levels x 2 row spacings). Number of replicates were unequal because each row spacing had 2 replicates of the 0 and 50 kg ha^{-1} N treatments, and only 1 replicate of the 25 and 100 kg ha^{-1} N application. However, treatment number was 12 (3 N levels x 2 row spacings x 2 fertilization methods) during summer and the total annual, when the experimental design was random blocks with split plots and 3 replicates.

During the growing cycle, which extends from September of 1 year to April of the following year, forage produced during spring (Sp) was harvested separately from that produced in summer (Su). Total annual forage production was calculated as Sp+Su. At clipping, forage was hand-clipped leaving 5 cm stubble whenever plants reached 26–28 cm height. Number of clippings taken within each season and study cycle was reported by Gargano et al. (2003). Forage was dried at 65° C for 72 hours, weighed and ground through a cyclone mill with a 1-mm screen for chemical analysis. Within the same dry matter subsamples obtained in that work, the following determinations were conducted: (1) Crude protein (CP, %). Nitrogen was determined by the semimicro-Kjeldahl method (Bremner 1996) and

Table 1. Monthly rainfall and monthly average maximum and minimum, and mean monthly air temperatures during both study cycles.

Annual Cycle	Month	Rainfall	Air temperature Maximum	Minimum	Mean
		----(mm)----	----------(°C)----------		
1998–1999	September	56.5	17.1	5.3	11.2
	October	5.3	25.3	9.5	17.4
	November	66.1	26.6	11.9	19.2
	December	35.1	29.3	15.8	22.6
	January	72.6	28.7	15.1	21.9
	February	90.4	28.0	15.4	21.7
	March	122.0	23.0	13.2	18.1
	April	13.8	19.6	7.7	13.7
1999–2000	September	42.0	18.5	6.7	12.6
	October	27.0	22.8	8.9	15.9
	November	55.0	25.3	11.9	18.6
	December	58.0	28.9	14.7	21.8
	January	63.0	32.1	17.6	24.8
	February	176.0	27.6	14.8	21.2
	March	48.0	24.5	12.9	18.7
	April	5.0	22.2	9.2	15.7

was then multiplied by 6.25 to obtain CP; (2) Yield of protein dry matter (YPDM, kg ha^{-1}). It was obtained as dry matter yield times %CP; (3) Nitrogen-use efficiency (NUE, kg DM kg^{-1} N). It was determined following (Novoa and Loomis 1981) as

$$\text{NUE} = \frac{\text{dry matter yield of fertilized plot (kg)-dry matter yield of unfertilized plot (kg)}}{\text{Total N applied (kg)}},$$

and (4) Percent fertilizer N recovery (NR, %). It was calculated following White and Brown (1972) as

$$\text{NR} = \frac{\text{N yield in the fertilized plot (kg)- N yield in the unfertilized plot (kg)} \times 100}{\text{Total N applied (kg)}}$$

Statistical Analysis

Determinations in spring were analyzed using 2-way ANOVA with unbalanced blocks but proportional replicates. A 3-way ANOVA with split blocks was used to analyze summer and total annual values. Multiple comparisons were conducted using the least significant difference test. Nitrogen recovery values were transformed to arcsine $\sqrt{\%}$ for statistical analysis (Snedecor and Cochran 1971). Linear regression analysis was used to study the relationship between N fertilization rate and %CP, NUE and rainfall, and NR and rainfall.

Results and Discussion

Crude Protein

There was no interaction between years and treatments for spring, summer or total annual values. Because of this, values from both study years were averaged for analysis. There was a significant ($P < 0.05$) relationship between N fertilization rate and %CP, and %CP increased ($P < 0.05$) in forage with increased rate of N fertilization (Fig. 1). Increased CP percentages at higher N fertilization rates have been widely reported in perennial grasses (George et al. 1972, Alagarswamy et al. 1988, Cuomo and Anderson 1996, Madakadze et al. 1999). Crude protein was 0.4 to 0.9% greater at 50 than 30 cm row spacing but differences were not statistically significant ($P > 0.05$). Anyhow, crude protein concentrations in *D. eriantha* were high enough as to not reduce dry matter intake (Minson 1982).

During summer, only the main effects of N level and fertilization method were significant ($P < 0.05$). Response to N fertilization rate in summer was similar to that in spring (Fig. 1). Crude protein concentrations were greater ($P < 0.05$) when fertilization with N was split (13.2%) than when it was applied all at once (11.7%) in spring. Hanson et al. (1978) reported that applying N fertilizer after the first cutting in 3 perennial grass species increased second cutting forage N content, indicating forage responded more from a split than from a single application. Gargano et al. (2003) also reported that dry matter yields were greater in *D. eriantha* under a split than bulk application of N fertilizer. Bittman and Kowalenko (1998) concluded that split applications could have practical advantages, even with no yield increases, by evening out the yield and crude-protein concentration over the season.

Changes in CP with increasing N fertilization rate were equivalent to those reported for the in vitro dry matter digestibility of *D. eriantha* by Gargano et al. (2003), although the magnitude of increases was substantially different. Increases in crude protein were of 23.7 and 44.3%, while those of in vitro dry matter digestibility were of 3.7 and 8.1%, when N fertilization rates were 50 and 100 kg ha^{-1}, respectively. Increases in crude protein were greater than values reported in other studies which used N fertilization rates either intermediate or higher than those used in this study (Veneciano and Terenti 1997, Gargano et al. 2001). *D. eriantha* is expanding as a forage crop in the cattle production systems of semiarid Argentina (Frasinelli et al. 1983, Gargano et al. 1997). Use of N fertilization rates higher than 50 kg ha^{-1} does not seem to be economically viable in these systems according to the obtained results.

Yield of Protein Dry Matter

Years and treatments interacted significantly ($P < 0.05$) so that each annual cycle was analyzed separately. Nitrogen level and row spacing interacted significantly ($P < 0.05$) in spring of each study period (Table 2). Except between 25 and 50 kg

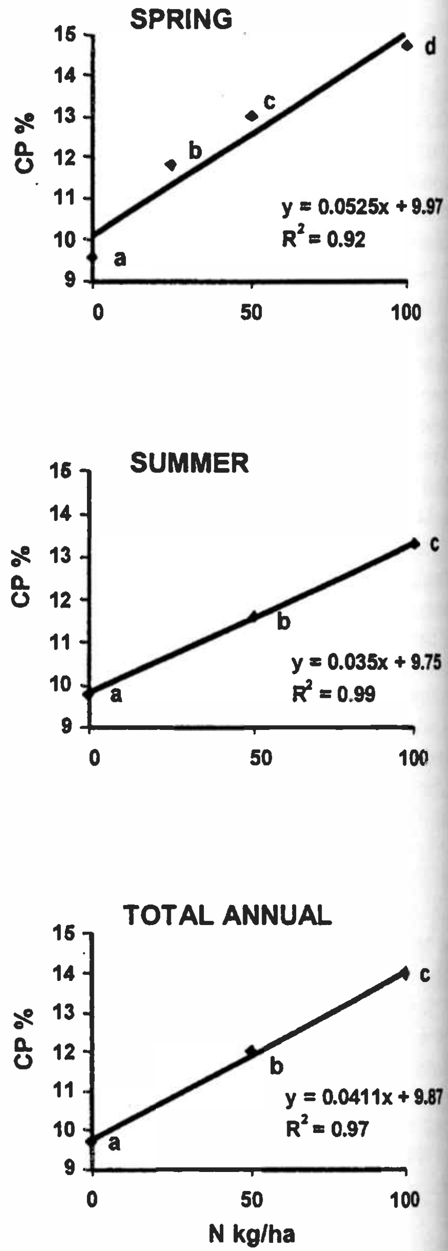

Fig. 1. Spring, summer or total annual percentage crude protein (CP) as a function of N fertilization rate in forage of *D. eriantha*. Within each panel, different letters indicate significant differences at $P < 0.05$. Each symbol is the mean of n = 12.

Table 2. Yields of protein dry matter (kg ha^{-1}) during spring in each of 2 growing cycles. Values are mean ± 1 standard error of n = 3 for N fertilization rates of 25 and 100 kg ha^{-1} and n = 6 for rates of N fertilization of 0 and 50 kg ha^{-1}.

Annual cycle	Row spacing	N fertilization rate (kg ha^{-1}) 0	25	50	100
	(cm)	(kg ha^{-1})			
1998–1999	30	192 ± 2.2 a †	315 ± 7.3 c	339 ± 9.7 c	474 ± 9.1 e
	50	195 ± 2.2 a	258 ± 6.2 b	333 ± 3.9 c	425 ± 7.2 d
1999–2000	30	143 ± 6.7 b	217 ± 7.3 c	252 ± 2.4 d	299 ± 5.6 f
	50	116 ± 2.4 a	198 ± 2.1 c	274 ± 3.0 e	376 ± 7.7 g

†Within each study period, means with a different letter are significantly different ($P < 0.05$).

ha^{-1} N at 30 cm row spacing, yield of protein dry matter increased ($P < 0.05$) as N fertilization rates also increased in 1998-1999. Yields of protein dry matter were similar or greater at 30 than at 50 cm row spacing. The effects of the rate of N fertilization and row spacing were mainly determined through its effects on dry matter yields (Gargano et al. 2003) because CP only responded to N fertilization. In 1999-2000, yield of protein dry matter depended on both dry matter yields (Gargano et al. 2003) and CP levels. As a result, all treatments responded to fertilization. The effect of row spacing did not show a consistent pattern.

During the summer of 1998-1999, only the main effects of N fertilization rate and method of fertilization were significant ($P < 0.05$). At this time, yield of protein dry matter increased ($P < 0.05$) as N fertilization rate also increased (Table 3). Yields of protein dry matter were greater ($P < 0.05$) when fertilization was split (mean = 477 kg ha^{-1}) than when it was applied all at once (322 kg ha^{-1}).

In 1999–2000, N fertilization rate interacted significantly ($P < 0.05$) with row spacing within each fertilization method. Yields of protein dry matter increased ($P < 0.05$) as N fertilization rates also increased. Row spacing did not show a consistent response on yields of protein dry matter. Results confirmed once again the beneficial effects of N fertilization, split application of N fertilizer and sowing at a 30 cm row spacing. Yields of protein dry matter were greater ($P < 0.05$) in spring and summer of 1998–1999 than in both seasons in 1999–2000. This was the result of higher dry matter yields in the first than in the second study year (Gargano et al. 2003).

When total annual protein dry matter yields were considered, N fertilization rates interacted significantly ($P < 0.05$) with row spacing in 1998-1999 and 1999-2000 within each method of fertilization (Table 4). Results reflected responses found in spring and summer, and N fertilization was thus the major determinant of plant responses. It increased protein dry matter yields in all treatments. Nitrogen fertilization rates of 50 kg ha^{-1} increased yields of protein dry matter by 86% in comparison to untreated controls. Increases of protein dry matter yields with 100 kg ha^{-1} N were of only 29% over values obtained when fertilizing with 50 kg ha^{-1} N. The effects of row spacing on yields of protein dry matter were inconsistent.

Table 3. Yields of protein dry matter (kg ha^{-1}) during summer in each of 2 growing cycles. Values are mean ± 1 standard error of n = 12 in 1998–1999 and n = 3 in 1999–2000.

Annual cycle	Method of fertilization	Row spacing	N fertilization rate (kg ha^{-1}) 0	50	100
		(cm)	(kg ha^{-1})		
1998–1999	average	average	203 ± 5.6 a†	432 ± 4.8 b	556 ± 6.2 c
1999–2000	split	30	164 ± 7.6 a	245 ± 3.7 b	427 ± 8.9 d
		50	162 ± 4.9 a	348 ± 8.1 c	429 ± 3.1 d
	bulk	30	131 ± 5.9 a	232 ± 3.7 c	319 ± 6.0 d
		50	164 ± 2.6 b	262 ± 5.6 c	373 ± 9.2 e

†In 1998–1999, means with a different letter are significantly different (P < 0.05). In 1999–2000, means with a different letter within each fertilization method are significantly different (P < 0.05).

Table 4. Total annual yields of protein dry matter (kg ha^{-1}) in each of 2 growing cycles. Values are mean ± 1 standard error of n = 3 in 1998–1999 and 1999–2000.

Annual cycle	Method of fertilization	Row spacing	N fertilization rate (kg ha^{-1}) 0	50	100
		(cm)	(kg ha^{-1})		
1998–1999	split	30	368 ± 2.6 a †	852 ± 4.0 d	965 ± 9.7 e
		50	395 ± 4.1 b	822 ± 9.0 c	998 ± 9.2 f
	bulk	30	378 ± 6.3 a	678 ± 9.7 c	951 ± 3.8 e
		50	397 ± 9.2 b	684 ± 8.9 c	900 ± 9.0 d
1999-2000	split	30	307 ± 5.5 b	462 ± 4.2 c	662 ± 9.3 e
		50	288 ± 8.1 a	504 ± 8.7 d	678 ± 6.5 f
	bulk	30	274 ± 4.2 a	501 ± 2.2 b	618 ± 5.6 d
		50	281 ± 8.6 a	522 ± 6.2 c	683 ± 9.6 e

†Means with a different letter within each fertilization method are significantly different (P < 0.05).

Nitrogen Use Efficiency

Both study periods needed to be studied separately as a result of the interaction ($P < 0.05$) between study period and treatments for spring, summer and total annual data. Nitrogen fertilization rate and row spacing interacted ($P < 0.05$) in spring 1998–1999; the highest value for nitrogen use efficiency was obtained at a N fertilization rate of 25 kg ha^{-1} and 30 cm row spacing (Table 5). In general, nitrogen use efficiency was reduced ($P < 0.05$) as N fertilization rates increased for both row spacings although differences were not always significant. Several studies on perennial grasses have shown that NUE often decreases with increasing N application (Power 1985, Campell et al. 1993, Greef 1994, Liang and Mackenzie 1994, Asseng et al. 2001). It needs to be recalled, however, that efficiency of nitrogen use after fertilization may be a combination of morphological, anatomical, physiological and crop management factors (Alagarswamy et al. 1988, Gardner et al. 1994, Jiang and Hull 1998, Brégard et al. 2000). Despite being of a small magnitude, there were significant ($P < 0.05$) differences between rates of N fertilization and efficiency of N use during 1999–2000.

Nitrogen fertilization rates and row spacing interacted ($P < 0.05$) in both fertilization methods during the summer of 1998–1999 and 1999–2000 (Table 6). Of

Table 5. Nitrogen use efficiency (kg dry matter kg^{-1} N) during spring in each growing cycle. Values are mean ± 1 standard error of n = 3 for rates of N fertilization of 25 and 100 kg ha^{-1} and n = 6 for the N fertilization rate of 50 kg ha^{-1} in 1998–1999, and n = 6 for the N fertilization rates of 25 and 100 kg ha^{-1} and n = 12 for the 50 kg ha^{-1} N fertilization rate in 1999–2000.

Annual cycle	Row spacing	Nitrogen fertilization rate (kg ha^{-1}) 25	50	100
	(cm)	(kg dry matter kg^{-1} N)		
1998–1999	30	28.7 ± 3.0 c †	11.8 ± 1.2 b	12.0 ± 1.2 ab
	50	16.7 ± 1.6 b	12.8 ± 0.5 ab	8.0 ± 1.0 a
1999–2000	average	18.2 ± 1.2 c	12.9 ± 1.3 b	8.2 ± 1.0 a

†Within each study cycle, means with a different letter are significantly different (P < 0.05).

primary importance during 1998–1999 is the nitrogen use efficiency under 30 cm row spacing and 50 kg ha^{-1} N fertilization rate in the split application method of N fertilizer. Nitrogen use efficiency was greater ($P < 0.05$) when the N fertilizer was applied split (mean = 30.8 kg dry matter kg^{-1} N) than all at once (17.8 kg dry matter kg^{-1} N) in 1998–1999. This was mainly due to the differences in dry matter yields between both fertilization methods (Gargano et al. 2003). In 1998–1999 and 1999-2000, nitrogen use efficiency was not always higher at the lowest N fertilization rate, and there was not a clear tendency when comparing both row spacings.

Nitrogen fertilization rate and row spacing again interacted ($P < 0.05$) when considering total annual nitrogen use efficiency (Table 7). The greatest (60 kg DM kg^{-1} N) nitrogen use efficiency was found under 30 cm row spacing and 50 kg ha^{-1} N fertilization rate in the split application method of N fertilizer. Nitrogen use efficiency was similar or greater ($P < 0.05$) at 50 than at 100 kg ha^{-1} N fertilization. There was no consistent tendency in nitrogen use efficiency when both row spacings were compared. Greater dry matter yields in 1998–1999 than in 1999–2000 (Gargano et al. 2003) determined that average total annual nitrogen use efficiency was greater ($P < 0.05$) for the first (34.2 kg dry matter kg^{-1} N) than for the second (25.0 kg dry matter kg^{-1} N) study period. Average total annual nitrogen use efficiency was greater when fertilizing with 50 (34.5 kg dry matter kg^{-1} N) than with 100 kg ha^{-1} N (24.8 kg dry matter kg^{-1} N). Nitrogen use efficiency was satisfactory when fertilizing with 50 kg ha^{-1} N in comparison to values obtained for this variable in other studies on *D. eriantha* (Veneciano and Terenti 1997, Gargano et al. 2001).

Nitrogen Recovery

Years had to be analyzed separately because of year-treatment interactions ($P < 0.05$) for the spring, summer and total annual data. Nitrogen fertilization date and row spacing interacted significantly ($P < 0.05$) in spring 1998–1999 (Table 8). The greater the N fertilization rate, the lower the nitrogen recovery although differences were not always significant. White and Brown (1972) also showed that doubling the N fertilization rate decreased the percentage of N recovered in *Stipa viridula* Trin. Similar results were reported by Spratt and Gasser (1970) and Simonis (1988). Bittman and Kowalenko (1998), however, reported a greater % of N recovery of applied as N fertilization rates

Table 6. Nitrogen use efficiency (kg dry matter kg^{-1} N) during summer in each growing cycle. Values are mean ± 1 standard error of n = 3 in 1998–1999 and 1999–2000.

Annual cycle	Method of fertilization	Row spacing	Nitrogen fertilization rate (kg ha^{-1}) 50	100
		(cm)	(kg dry matter kg^{-1} N)	
1998–1999	split	30	45.3 ± 2.0 c†	25.0 ± 1.0 a
		50	30.0 ± 1.2 b	22.7 ± 1.1 a
	bulk	30	23.0 ± 2.0 c	20.0 ± 1.1 bc
		50	17.0 ± 2.5 b	11.3 ± 1.0 a
1999–2000	split	30	10.3 ± 4.0 a	17.3 ± 1.0 b
		50	26.3 ± 1.4 c	16.3 ± 0.7 b
	bulk	30	17.0 ± 2.4 b	12.0 ± 0.9 a
		50	13.7 ± 1.0 ab	13.3 ± 1.1 ab

†Within each fertilization method, means with a different letter are significantly different ($P < 0.05$).

Table 7. Total annual nitrogen use efficiency (kg dry matter kg^{-1} N) in each growing cycle. Values are mean ± 1 standard error of n = 3 in 1998–1999 and 1999–2000.

Annual cycle	Method of fertilization	Row spacing	Nitrogen fertilization rate (kg ha^{-1}) 50	100
		(cm)	(kg dry matter kg^{-1} N)	
1998–1999	split	30	60.0 ± 3.5 c †	29.7 ± 1.0 a
		50	38.3 ± 2.0 b	30.3 ± 1.1 a
	bulk	30	36.7 ± 2.1 c	32.0 ± 0.9 b
		50	40.6 ± 3.0 b	27.8 ± 1.7 a
1999–2000	split	30	17.0 ± 3.2 a	19.0 ± 1.0 a
		50	37.3 ± 1.2 c	26.3 ± 0.9 b
	bulk	30	29.3 ± 2.4 b	16.3 ± 1.0 a
		50	28.4 ± 1.2 b	21.8 ± 1.1 b

†Within each fertilization method, means with a different letter are significantly different ($P < 0.05$).

Table 8. Nitrogen recovery (%) during spring in each growing cycle. Values are mean ± 1 standard error of n = 3 for rates of N fertilization of 25 and 100 kg ha^{-1} and n = 6 for the N fertilization rate of 50 kg ha^{-1} in 1998–1999, and n = 6 for the N fertilization rates of 25 and 100 kg ha^{-1} and n = 12 for the 50 kg ha^{-1} N fertilization rate in 1999–2000.

Annual cycle	Row spacing	Nitrogen fertilization rate (kg ha^{-1}) 25	50	100
	(cm)	(%)		
1998–1999	30	78.7 ± 1.0 c†	47.2 ± 2.6 b	43.3 ± 1.6 b
	50	49.7 ± 4.1 b	44.3 ± 1.8 b	34.3 ± 1.2 a
1999–2000	average	52.5 ± 5.6 c	42.8 ± 1.9 b	32.7 ± 1.0 a

†Within each study cycle, means with a different letter are significantly different ($P < 0.05$).

Table 9. Nitrogen recovery (%) during summer in each growing cycle. Values are mean ± 1 standard error of n = 6 in 1998–1999 and n = 12 in 1999–2000.

Annual cycle	Method of fertilization	Row spacing	Nitrogen fertilization rate (kg ha^{-1}) 50	100
		(cm)	(%)	
1998–1999	split	average	102.2 ± 1.0 b†	74.0 ± 1.6 a
	bulk		44.3 ± 4.6 a	41.7 ± 1.1 a
			average	
1999–2000	split	average	42.5 ± 2.2 a	
	bulk		31.8 ± 1.9 b	

†Within each study cycle, means with a different letter are significantly different ($P < 0.05$).

increased. Nitrogen recovery was similar or greater ($P < 0.05$) at 30 than at 50 cm row spacing. These results were mainly determined by dry matter yields in the different treatments (Gargano et al. 2003). In 1999–2000, nitrogen recovery decreased ($P < 0.05$) as N fertilization rate increased. The greatest nitrogen recovery was obtained when fertilizing with 25 kg ha^{-1} N in 1998–1999 and 1999–2000.

Only main effects of the 3 studied variation sources were significant ($P < 0.05$) in the summer of 1998–1999. Greatest nitrogen recovery occurred when application of 50 kg ha^{-1} N was split (Table 9). Average values for split or bulk N fertilization were 88.1 or 43.0%, respectively. Hanson et al. (1978) also found that nitrogen recovery by *Bromus inermis* L. was highest with split applications (up to 50% recovery), but was highest for single annual applications in *Phalaris arundinacea* L. and *Alopecurus arundinaceus* L. Average nitrogen recovery was 70 or 61.5% for row spacings of 30 or 50 cm, respectively. During the summer of 1999–2000, only the main effects method of fertilization and row spacing were significant ($P < 0.05$). On average, nitrogen recovery was greater ($P < 0.05$) for split than bulk N fertilization. Also, nitrogen recovery was greater ($P < 0.05$) for 50 (41.7%) than 30 (32.8%) cm row spacing. The lower nitrogen recovery in the summer of 1999–2000 than in that of the previous study period was due to climatic adversities (Gargano et al. 2003). Soil nitrogen was very likely lost via ammonia volatilization (Keller and Mengell 1986, Fox et al. 1996) which intensifies if urea is used as a N fertilizer (Harrison and Webb 2001). Differences in N recovery values among years in herbage of *S. viridula* Trin. were related to growing conditions, especially availability of soil water (White and Brown 1972).

Nitrogen fertilization rate and row spacing interacted significantly ($P < 0.05$) in 1998–1999 and 1999–2000 when considering total annual nitrogen recovery (Table 10). Except when N fertilization was split at 30 cm row spacing in 1999–2000, nitrogen recovery was greatest at a 50 kg ha^{-1} N fertilization rate. Nitrogen fertilization methods did not differ in nitrogen recovery because effects found in summer were masked when considering total annual results. Total annual nitrogen recovery was greater at 30 than 50 cm row spacing in 1998–1999, and viceversa in 1999–2000.

D. eriantha responded to N fertilization during its whole growing cycle. Nitrogen recovery was greatest at 50 kg ha^{-1} N fertilization, and it was even greater than that obtained at the same experimental site after fertilizing *D. eriantha* winter-deferred forage with 60 kg ha^{-1} N in midsummer (Gargano et al. 2001). Additionally, when N fertilization rate of 50 kg ha^{-1} was split, nitrogen recovery was similar or greater than highest values obtained for this parameter in studies where split application of 100 to 127 kg ha^{-1} N was made in the semiarid region (Veneciano and Terenti 1997, Veneciano et al. 1998). This demonstrates that N fertilization rates used in these studies as well as the 100 kg ha^{-1} N used in this study were excessive.

Table 10. Total annual nitrogen recovery (%) in each growing cycle. Values are mean ± 1 standard error of n = 3 in 1998–1999 and 1999–2000.

Annual cycle	Method of fertilization	Row spacing	Nitrogen fertilization rate (kg ha^{-1}) 50	100
		(cm)	(%)	
1998–1999	split	30	155.0 ± 2.1 c †	95.7 ± 3.2 a
		50	118.0 ± 4.0 b	97.3 ± 2.9 a
	bulk	30	115.0 ± 3.1 c	105.0 ± 1.9 b
		50	104.3 ± 2.8 b	78.7 ± 1.0 a
1999–2000	split	30	53.6 ± 3.2 a	56.7 ± 2.0 a
		50	87.7 ± 3.3 c	68.0 ± 1.9 b
	bulk	30	72.3 ± 2.7 b	55.0 ± 2.0 a
		50	81.7 ± 1.9 c	73.7 ± 1.8 b

†Within each fertilization method, means with a different letter are significantly different ($P < 0.05$).

Table 11. Correlation coefficients (r) and predictive equations with significance levels (p) for Nitrogen Use Efficiency (NUE, kg DM kg N^{-1}) as a function of rainfall (R, mm) (NUE = a+bR) during both annual cycles. Values of NUE during spring were related to rainfall from 1 September to 17 December in 1998, and from 1 September to 22 December in 1999. During summer, NUE values were related to rainfall from 17 December 1998 to 15 April 1999, and from 22 December 1999 to 3 April 2000. Finally, values of total annual NUE were related to rainfall from 1 September to 15 April in 1999, and from 1 September to 3 April in 2000. Within each annual cycle, values used in the regression analysis correspond to both row spacings and methods of nitrogen fertilization.

Annual cycle	Fertilization rate	a	b	R	P=
	--(kg ha^{-1})---				
1998–1999	50	-3.12	0.105	0.76	0.006
	100	-0.25	0.067	0.89	0.000
1999–2000	50	0.86	0.057	0.63	0.041
	100	2.50	0.0395	0.79	0.007

Relationship between NUE or NR and rainfall

Nitrogen use efficiency or NR increased as rainfall also increased (Tables 11 and 12). These findings are similar to those of Asseng et al. (2001), who found that as annual rainfall decreased, nitrogen use efficiency also decreased both on sandy

Table 12. Correlation coefficients (r) and predictive equations with significance levels (p) for Nitrogen Recovery (NR, %) as a function of rainfall (R, mm) (NR = a+bR) during both annual cycles. Values of NR during spring were related to rainfall from 1 September to 17 December in 1998, and from 1 September to 22 December in 1999. During summer, NR values were related to rainfall from 17 December 1998 to 15 April 1999, and from 22 December 1999 to 3 April 2000. Finally, values of total annual NR were related to rainfall from 1 September to 15 April in 1999, and from 1 September to 3 April in 2000. Within each annual cycle, values used in the regression analysis correspond to both row spacings and methods of nitrogen fertilization.

Annual cycle	Fertilization rate	a	b	R	P=
	--(kg ha^{-1})---				
1998–1999	50	0.80	0.267	0.82	0.007
	100	6.30	0.192	0.89	0.002
1999–2000	50	16.60	0.120	0.70	0.073
	100	13.00	0.107	0.86	0.018

and clay soils. Water supply is the most important factor in achieving high NUE, with the highest NUE in wheat having been reported under irrigation (Fisher et al. 1993). Whitfield and Smith (1992) reported a higher NUE under irrigation than under rainfed conditions. Garabet et al (1998) also found that NUE is increased by higher rainfall and irrigation.

Conclusions

All studied parameters in *D. eriantha* responded significantly to N fertilization, which corroborates results found in a previous work (Gargano et al. 2003). In this study, however, it was made clearer the convenience of applying a N fertilization rate close to 50 kg ha^{-1} N. Even though values of some parameters significantly increased when fertilizing with 100 rather than 50 kg ha^{-1} N, they were in general of a small magnitude and then of doubtful biological and/or economical significance. Additionally, NUE and NR were greater when fertilizing with 50 than with 100 kg ha^{-1} N. Because of this, and given that cultivation of *D. eriantha* is fostered in semiarid regions for cattle raising, which is per se a cattle production system of low productive efficiency, it would not be recommended to fertilize with more than 50 kg ha^{-1} N.

Split N fertilization and row spacing of 30 cm are recommended over bulk N fertilization or 50 cm row spacing. However, row spacing did not have a major relevance on the results. It is likely that a 50 cm row spacing could improve plant responses under conditions of water stress greater than those registered during the second study period.

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