Effect of Nitrogen Supply and Time of Harvest on Seed Yield Components of *Digitaria eriantha* cv. Premier

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ABSTRACT

Nitrogen (N) application markedly increased seed yield of *Digitaria eriantha* cv. Premier in spring but had a small and inconsistent effect in autumn. Seed yield in spring was 2 – 8 times higher than that in autumn. Differences in N response between seasons and years are discussed in terms of initial soil N, rainfall, ambient temperature and occurrence of lodging. N application doubled seed yield in autumn 1990, but it reduced seed yield in autumn 1991. N application higher than 150kg ha^{-1}crop^{-1} reduced seed yield and resulted in lodging. N increased seed yield mainly through increasing inflorescence density and seed weight per inflorescence, both of which were higher in spring than in autumn. Inflorescence density was increased mainly through increased tiller fertility rather than tiller density. The increase in seed weight per ripe inflorescence resulting from N application was associated with larger inflorescences. N application had little effect on seed set per 100 spikelets or on seed quality attributes. Optimal harvest date was two to three weeks after peak anthesis, but varied between 57 and 85 days after the cleaning cut, depending on season and level of N fertilisation. On average, there was a 56% reduction in seed yield a week after maximum seed yield, making identification of optimum harvest date a critical decision.

***Additional index words: Digitaria eriantha*, synchrony, ripening, seed yield, viability, germination rate**

INTRODUCTION

Digitaria eriantha cv. Premier is a subtropical tussock grass adapted to a wide range of soils, and to low rainfall and frost (Strickland, 1987). This cultivar, previously included in the species *D. smutsii*, is now considered to be con–specific with the more widely known strongly stoloniferous, but sterile, pangola grass (previously *D. decumbens*, Kok, 1984). One of its most outstanding attributes is its early spring growth in sub–tropical areas such as the south–east of Queensland (Strickland, 1987).

Premier was released in Australia in 1986, but its commercial use has since been limited by seed availability. At present, there are believed to be fewer than 1000 ha sown to cv. Premier in Australia. It is capable of producing two seed crops per year in the subtropics. However, in common with other warm–season grasses, cv. Premier has prolonged inflorescence emergence and low seed retention (Strickland, 1987). These factors make time of harvest a critical management decision.

Nitrogen (N) fertiliser is an important management tool to increase seed production from herbage seed crops. The positive effects of N on seed production have been studied in several tropical and subtropical grasses (Humphreys and Riveros, 1986). Increased seed yields from cv. Premier could be expected by applying fertiliser N. However, the optimum level and the pathways by which N influences seed production need to be determined.

The aim of this study was to determine:

1. The optimal level of N application and its effect on components of seed yield and
2. The optimal harvest time.

MATERIALS AND METHODS

Site. The experiment was located at Redland Bay, south–east Queensland, on a deep, fertile and well–drained krasnozem soil.

Treatments and experimental design. The experiment was laid out in four blocks (replicates), each of which comprised seven 3 m x 4 m contiguous plots, with each plot consisting of six rows of 16 plants. The seven treatments were: 0, 50, 100, 150, 200, 250 and 300 kg ha^{-1}crop^{-1} (designated control, N_{50}, N_{100}, N_{150}, N_{200}, N_{250} and N_{300}), applied as ammonium nitrate.

Planting and management. Seedlings established in peat pots were transplanted to the field in rows 50 cm apart with 25 cm between plants on 4 December 1989. A basal fertiliser comprising 30, 35 and 29 kg ha^{-1} of N, P and K, respectively, was applied immediately after planting and again a year later (13 January 1991).

The experimental area was irrigated as necessary to avoid water stress and encourage good growth. Plots were hand weeded during the initial stages. Cleaning cuts were on 7 January for both autumn crops and 6 September for both spring crops. All cleaning cuts were made at 7 cm above ground level and the cut material was removed from the plots.

Seed harvests and data collection. The experimental period was January 1990 to December 1991, during which two autumn crops and two spring crops were grown.

In each plot, inflorescences were counted weekly in a randomly located fixed quadrat of 50 cm x 100 cm, up to the stage of destructive sampling. Six quadrats of 50 cm x 100 cm were located within each plot, avoiding the guard rows. These were harvested at weekly intervals (H_1 ... H_6), the timing designed to cover the time of peak seed yield. Only inflorescences and

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upper peduncles were harvested, to avoid any possible carry–over effect which might have resulted from harvesting the whole plant. The six quadrats were harvested in random order, with the first harvest after peak anthesis. Seed harvests for autumn 1990, spring 1990 and autumn 1991 crops were taken at weekly intervals from and including 7 March 1990, 22 November 1990 and 7 March 1991, respectively. Differences in synchrony of treatments in the spring 1991 crop resulted in the harvest sequence being started on 5 or 12 November for the lower N treatments and 29 October for the N_{300} treatment.

Harvested inflorescences were air dried for 2 – 3 days, and classified into ripe, immature, shed and damaged. To facilitate threshing, ripe inflorescences were kept between sheets of damp paper for two days and then dried at 38°C for 48 h, threshed and sieved to remove raceme fragments. Threshed spikelets were dried at 38°C for 48 h and then weighed. A random subsample of about 100 spikelets was drawn from each sample and separated into spikelets with and without a caryopsis. Both fractions were weighed and the relative weights of the two fractions used to calculate pure seed, *i.e.* spikelets with caryopses.

In autumn and spring 1990, three ripe inflorescences were randomly chosen from each replicate at each of the six seed harvests, to determine number and length of racemes, spikelet density and seed set (*i.e.* standing seed set, the percentage of spikelets on an inflorescence which contained a caryopsis). Spikelet density was measured on a raceme from an intermediate level inflorescence node on each selected inflorescence. The total number of spikelets on each of these racemes was determined only in the autumn crop; in the subsequent spring crop, spikelets were counted along the central 5 cm part of each of the three racemes. To calculate standing seed set, the three ripe inflorescences were thoroughly threshed and the percentage of spikelets containing caryopses was determined on a sample of about 100 spikelets by microscopic examination.

The total number of tillers within each harvested quadrat was counted before cutting the plants. Tillers less than 10 cm long were included in a separate category. Tiller fertility was estimated as the percentage of tillers more than 10 cm long with an inflorescence. Tillers less than 10 cm long were excluded from this calculation as they were assumed to have emerged after peak anthesis. Degree of lodging was determined at regular intervals by visual assessment using a scale of 0 (upright) to 10 (flat).

Shed spikelets were retrieved weekly from plastic 15 cm diameter filter funnels located centrally in each plot, with the upper margin 20 cm above ground level. The retrieved spikelets were cleaned and divided into two subsamples, one for analysis of N concentration, and the other for germination tests, which were carried out eight and twelve months after retrieval. Lots of 100 seeds per replicate and treatment were placed on germination pads in petri dishes. Half of each lot was placed on pads previously soaked in a solution of 0.2% potassium nitrate; the other half was placed on pads soaked with tap water. Both groups were incubated in an alternating temperature and light regime (20/35°C for 8/16 h) for 28 days, and the pads were kept moist. Counts of germinated seeds and abnormal seedlings were made at intervals of 2 – 3 days. Germination rate was defined as the slope of the graph relating percentage germination to time. Seeds that failed to germinate after 28 days were dissected and stained in the dark in a solution of 0.1% (w/v) tetrazolium chloride at 35°C over a period of 12 h, to determine viability.

Statistical analyses. For each of the four crops, comparisons were based on the harvests which gave maximum seed yield; these did not necessarily fall on the same date for the various N treatments. Data were analysed statistically as a complete factorial design within each season.

RESULTS

Rainfall and temperature. In spring 1991, temperatures rose earlier than in spring 1990. Consequently, the number of weeks with maximum weekly temperatures above 25°C was higher during spring 1991 (Figure 1). Average temperatures in autumn were higher than in spring, with autumn 1991 slightly warmer than autumn 1990. Total weekly rainfall during autumn (1990 and 1991) was higher than in spring (1990 and 1991). Rainfall was more evenly distributed in autumns than in springs, but in autumn 1990 the number of weeks with a total weekly rainfall above 40 mm was higher than in autumn 1991.

Lodging. Application of N caused crop lodging, which was more severe at the levels of N higher than 150 kg ha^{-1}crop^{-1}. Lodging occurred at about peak anthesis in spring, whereas in autumn it happened earlier. In both seasons, lodging occurred after the period of non–destructive inflorescence recording, so did not lead to damage during recording.

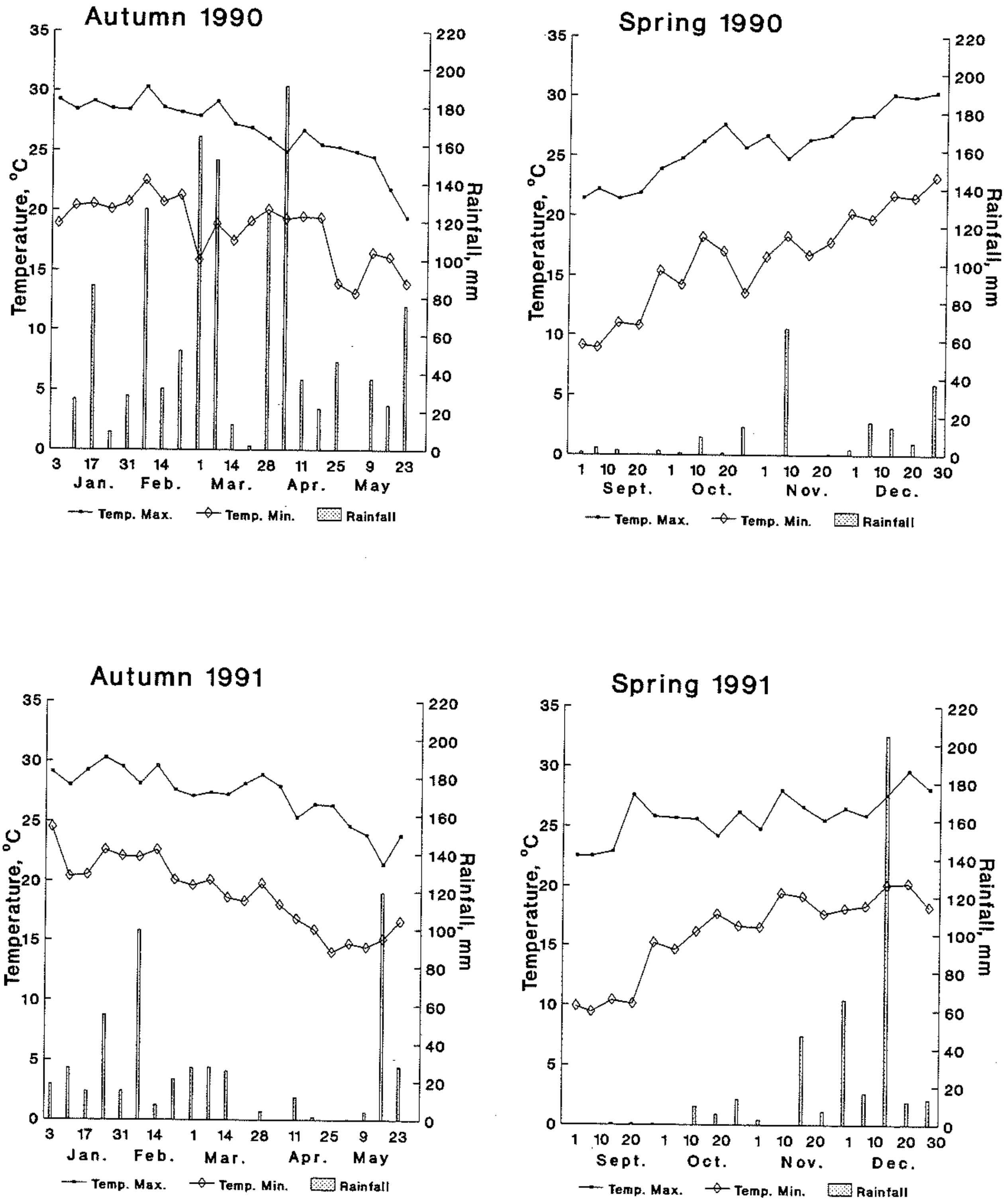
Time of harvesting. At maturity, the colour of the inflorescences and upper peduncles changed from a purplish–green colour to a lighter straw colour. Also, seed was easier to remove from the racemes.

Seed yield. Pure seed yield in spring was 2 – 8 times higher than in autumn. The application of N significantly increased pure seed yield in spring, but in autumn there was little effect (Figure 2). In spring 1990, maximum seed yield (about four times that of the control) was obtained with N_{50}. In spring 1991, however, maximum seed yield (about seven times that of the control) was obtained with N_{150}, but was lower than the yield in spring 1990. In both spring crops the application of more than 150 kg ha^{-1} of N was detrimental to seed yield.

In autumn 1990, maximum seed yield (about twice that of the control) was obtained with N_{100} (Figure 2), but in autumn 1991 the application of N reduced seed yield.

In spring 1990, the peak seed yield for all N levels was obtained at the November 30 harvest (85 days after the cleaning cut). However, in spring 1991 maximum seed yield for all N levels was recorded earlier and at different times, from 19 – 30 November (74 days after the cleaning cut, except for the control and N_{250}, both 81 days after the cleaning cut). Similarly, in autumn 1990, maximum seed yield for all N levels was obtained from 7 – 22 March (59 – 74 days after the cleaning cut), and in autumn 1991, from 6 – 31 March (58 – 83 days after the cleaning cut).

Pure seed yield over the six harvests within each season varied markedly within N treatments, reaching a pronounced peak and then falling rapidly (Table 1 – data for optimal N level only). On average, for optimal N treatments, there was a 56% fall in seed yield in the week following peak seed yield. A fortnight after peak seed yield, 71% of the seed crop was lost.



Autumn 1990

Spring 1990

Autumn 1991

Spring 1991

Figure 1. Maximum and minimum weekly mean temperature and total weekly rainfall (vertical bars) during the experimental period.

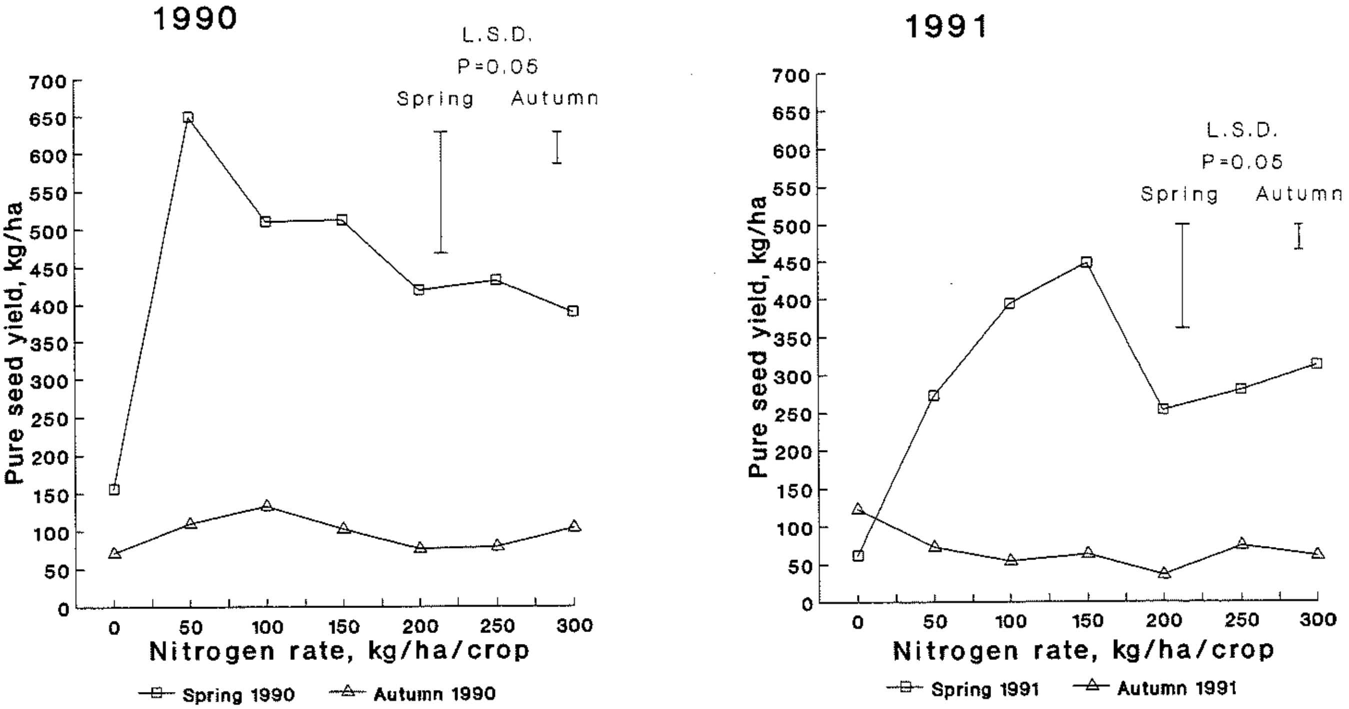


Figure 2. Pure seed yield as influenced by N rates in spring and autumn (1990 and 1991). Pure seed yields are maximum values obtained from the six harvests in each cropping sequence.

Table 1. Pure seed yield (kg ha^{-1}) at optimal N application over six successive weekly harvests.

Season	N (kg ha^{-1})	Harvest 1	2	3	4	5	6	LSD (P<0.05)
Autumn 1990	100	52	84	133	18	13	6	41
Spring 1990	50	430	650	381	186	99	73	160
Autumn 1991	0	94	123	61	48	24	13	34
Spring 1991	150	7	236	448	244	170	88	143

Table 2. Effect of N on seed set and seed weight per inflorescence (N values for autumn crops do not include the 30 kg $ha^{-1}crop^{-1}$ basal N fertiliser applied).

Level of applied N (kg $ha^{-1}crop^{-1}$)	Spring 1990		Autumn 1990		Spring 1991		Autumn 1991	
	Seed set (%)	Seed wt (mg)	Seed set (%)	Seed wt (mg)	Seed set (%)	Seed wt (mg)	Seed set (%)	Seed wt (mg)
0	43.6	95	35.3	60	47.0	86	28.2	47
50	58.0	134	28.8	50	49.6	140	15.6	31
100	48.9	102	24.5	56	46.4	143	13.2	30
150	40.7	120	15.8	44	46.2	176	15.6	26
200	46.6	110	20.5	36	43.4	140	20.2	27
250	46.2	105	15.0	38	35.3	146	20.9	61
300	43.2	92	23.5	44	41.5	145	21.7	26
LSD P<0.05	12.9	NS	8.8	19	13.3	50	7.8	23

Seed set. Seed set in spring was higher than in autumn. In spring 1990, but not in spring 1991, seed set increased in response to the application of N_{50}, while the higher levels had a detrimental effect (Table 2). Nitrogen application in autumn tended to reduce seed set.

Inflorescence emergence, density and size. Application of N resulted in earlier inflorescence emergence in spring, but there was little effect in autumn (Figure 3). This effect was similar at all levels of N applied. However, N effects on number of days to peak inflorescence emergence were inconsistent. Number of days to peak inflorescence emergence between the N–treated plots ranged from 77 – 100 and from 67 – 103 in spring 1990 and 1991, respectively.

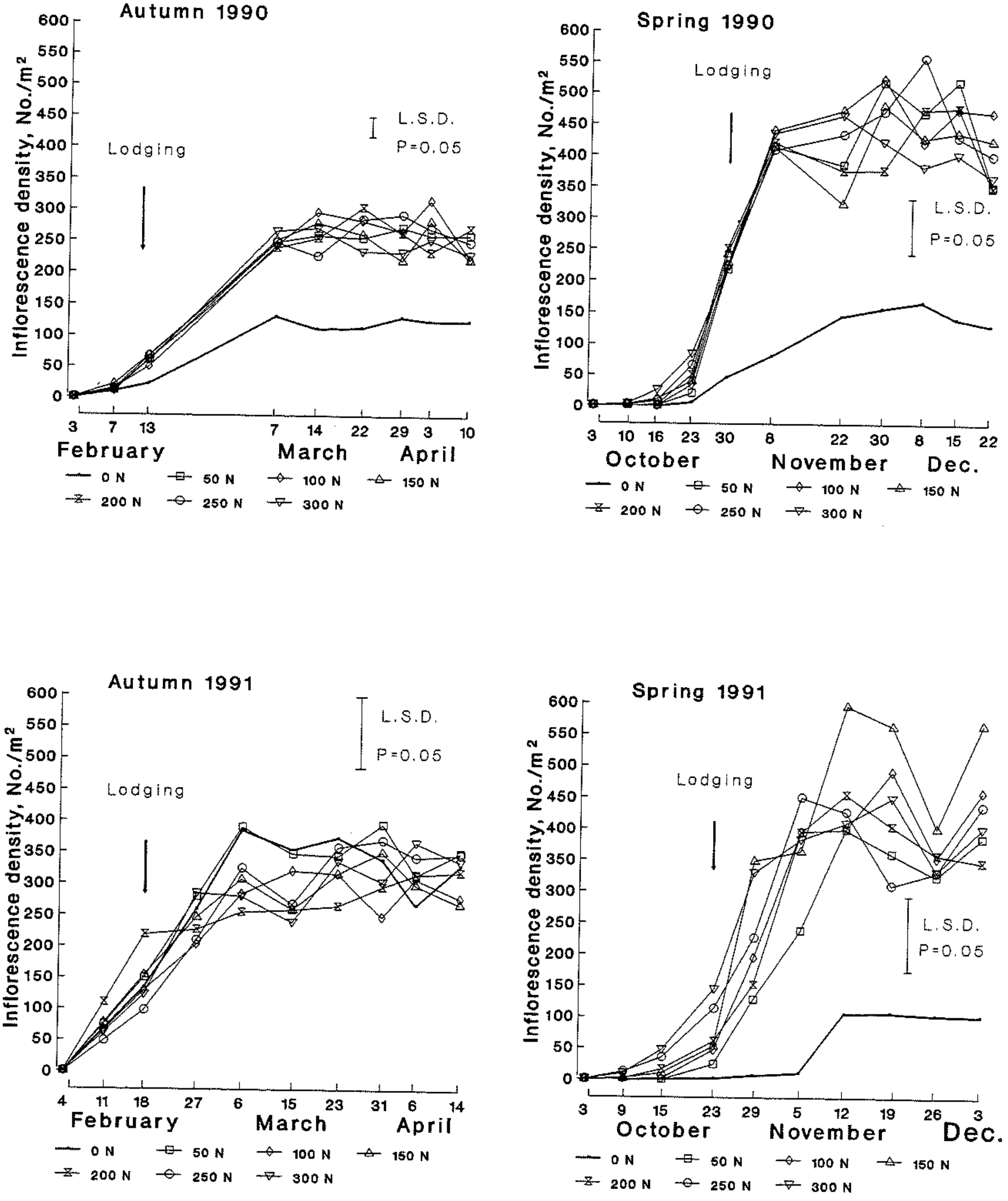


Figure 3. Inflorescence density as influenced by N rates and season.

In 1990, the N_{50} treatment tripled inflorescence density (number of inflorescences per unit ground area) in spring and doubled it in autumn (Figure 4). In spring 1991, maximum inflorescence density was about six times higher than the control and was obtained with the N_{150} treatment. However, in autumn 1991, there was no significant effect of N on inflorescence density at harvest. In both years, inflorescence density in spring was much higher than in autumn.

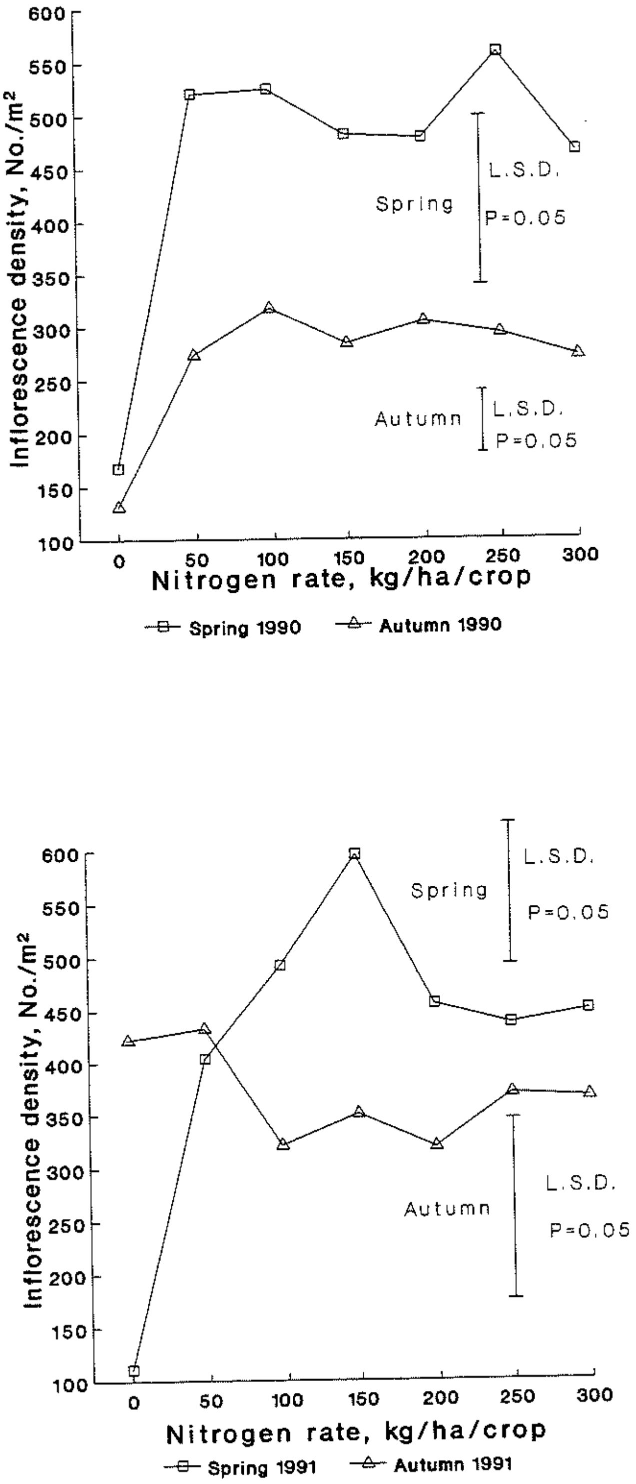


Figure 4. Infloresence density as influenced by N rate during spring and autumn (1990 and 1991).

At peak seed yield, seed weight per ripe inflorescence was increased in spring by N application, although the effect was significant only in spring 1991. In autumn, on the other hand, N application tended to have a negative effect on seed weight per inflorescence (Table 2).

Raceme number per inflorescence was significantly increased by the application of N, from 10.3 to 12.2 and from 10.3 to 12.7 in autumn and spring 1990, respectively. Similarly, raceme length was significantly increased from 11.2 to 12.4 cm and from 10.7 to 13.3 cm in autumn and spring 1990, respectively. For both raceme length and raceme number, the response was to the first 50 kg of N applied; higher rates did not result in a significant response. However, these increases in inflorescence size were partially offset by a reduction in spikelet density from 9.4 to 8.0 spikelets cm^{-1}.

Tiller density and fertility. In spring, but not in autumn, there was a significant trend for surviving tiller density to be reduced by N (Figure 5). Tiller density in spring was slightly higher than in autumn. N application in autumn 1990 tended to increase number of tillers emerged post–anthesis (< 10 cm high at seed harvest).

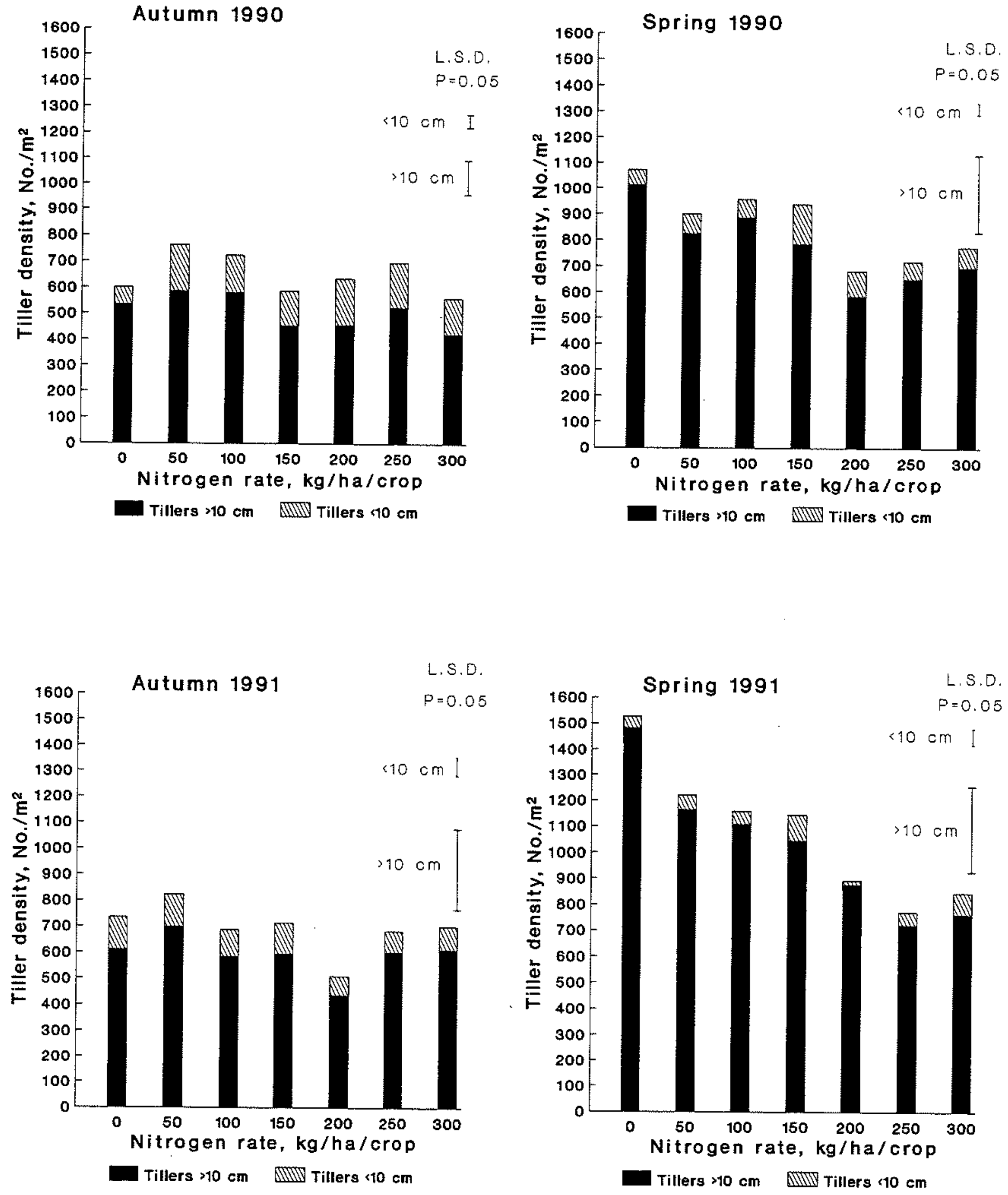


Figure 5. Tiller density at peak seed yield.

Tiller fertility was increased by the application of N ($P<0.05$, all crops) (Figure 6). There was a curvilinear increase in tiller fertility as N rate was increased from 0 to 200 kg ha^{-1}crop^{-1}, after which fertility tended to remain constant. This curvilinear response was consistent over all four crops.

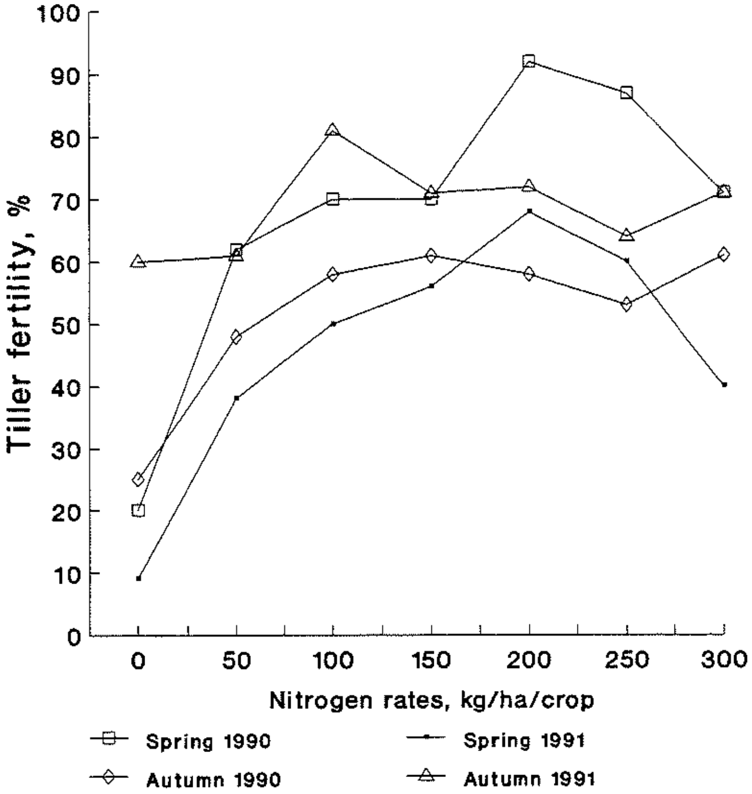


Figure 6. Tiller fertility at different N rates, during spring and autumn (1990 and 1991).

Seed quality. There was no effect of the potassium nitrate treatment on germination percentage and results from the two treatments are therefore combined.

Rate of seed germination, seedling abnormality and total germination were not significantly influenced either by N application or by duration of storage at room temperature. The frequency of abnormal seedlings, which usually had poor root growth, was significantly decreased by extending storage from 8 to 12 months. Seed N concentration was consistently increased by N, whereas 1000–seed weight was not affected (Table 3, data for germination rate not presented).

Table 3. Quality of shed seed, 8 and 12 months after seed was retrieved in spring 1991.

Parameter	Time after retrieval (months)	N level (kg ha^{-1}crop^{-1}) 0	100	200	300	LSD ($P<0.05$)
Viability (%)	8	93.5	92.3	87.3	87.5	5.6
	12	90.8	90.0	88.0	89.9	
Abnormal seedlings (%)	8	8.5	6.5	6.5	6.5	3.1
	12	3.8	3.0	2.8	3.8	
N concentration (%)	8	2.1	2.2	2.5	2.8	0.2
1000-seed weight (%)	8	0.58	0.59	0.56	0.56	NS

DISCUSSION

Tiller density and fertility. Nitrogen fertiliser had a pronounced effect on seed yield in this study, mainly through increasing inflorescence density, as has been reported in other tropical and subtropical grasses (Humphreys and Riveros, 1986). This increase was due to an increase in tiller fertility, since N reduced tiller density at seed harvest.

The negative effect of N on tiller density of *D. eriantha* was compensated for by an increase in tiller fertility. Reduced tiller density was in part caused by lodging, which resulted in death of some tillers. Application of N increased both tiller density and fertility of *Paspalum plicatulum* (Cameron and Humphreys, 1976) and inconsistently in *Setaria sphacelata* (Bahnisch and Humphreys, 1977; Hacker 1994). However, Chadhokar and Humphreys (1970) considered tiller fertility of *P. plicatulum* to be independent of N nutrition.

Inflorescence emergence, size and density. The application of N resulted in earlier inflorescence emergence in spring, probably due to earlier floral initiation, as has been found in *P. plicatulum* (Chadhokar and Humphreys, 1973). However, the less consistent effect of N upon time of emergence and on seed maturation suggests that these later phases of development are less sensitive to N application, which parallels reports in *P. plicatulum* (Chadhokar and Humphreys, 1973).

The application of N had a consistent effect on inflorescence size, increasing the number and length of racemes, but causing a compensatory reduction in spikelet density. This is probably associated with the same number of spikelet initials being present on a more elongated axis. N increases size of inflorescences or inflorescence components of a number of tropical and subtropical grasses (*e.g.* Haggar, 1966; Boonman, 1972a; Chadhokar and Humphreys, 1973; Cameron and Humphreys, 1976; Febles *et al.*, 1982; Hacker 1994). However, compensatory pathways may differ from the one observed in *D. eriantha*.

Maximum inflorescence density was obtained with N application of 250 and 150 kg ha^{-1}crop^{-1} in spring 1990 and 1991 respectively. Higher levels of N reduced inflorescence density. In contrast, inflorescence density of *P. plicatulum* was positively associated with increasing levels, up to 400 kg ha^{-1}, of N supply (Cameron and Humphreys, 1976). In *A. gayanus*, inflorescence density increased up to an application of N_{100}, with no further increase at N_{200} (Haggar, 1966). The negative effect of very high levels of N on inflorescence density found in this experiment was probably due to the large biomass produced during the vegetative phase that caused excessive shading to young tillers, resulting in reduced survival and fertility. This, in turn, led to a decrease in inflorescence production. This is supported by the depression in tiller fertility caused by shading in *Panicum maximum* var. *trichoglume* (Wong and Wilson, 1980). Lodging could also have had an effect, although this would only have been in later stages of the growth cycle, as it mostly did not occur until about anthesis.

Time of harvesting. The optimum seed harvest time was 2 – 3 weeks after peak anthesis. This was about 70 – 80 days after the cleaning cut in spring (*cf* 56 – 81 days in autumn). A delay in the time of harvest resulted in an increasing percentage of seed loss, with 56% of seed lost a week after peak seed yield and 80% a fortnight after peak seed yield, averaged over the four harvest sequences. This pronounced and well–defined peak in seed yield makes accurate selection of harvest date a critical management decision.

Seed yield. The positive effect that N application had on seed yield of *D. eriantha* was mostly associated with an increase in inflorescence density. This is in agreement with reports for other tropical forages (Boonman, 1972a, 1972b; Pedreira *et al.*, 1976; Febles *et al.*, 1982; Humphreys and Riveros, 1986; Hacker 1994). The lack of seed yield response in this experiment to higher levels of N could be related to the high soil fertility of the experimental site.

Levels of N exceeding 150 kg ha^{-1}crop^{-1} tended to reduce seed yield. There are likely to be two main causes for this detrimental effect. First, the high level of N applied and the optimal conditions for plant growth resulted in an early increase in herbage biomass, which had an adverse effect on inflorescence density, as discussed above. Secondly, the large aerial biomass, produced during stem elongation by high levels of N, associated with heavy rainfall and strong winds, led to a high degree of lodging. Since this occurred at or before anthesis, lodging may have caused an unfavourable environment for pollination and seed development, and thus resulted in less seed per inflorescence but this needs to be determined. Similar observations have been made in temperate grasses (Hebblethwaite *et al.*, 1978).

Seed yields and responses to N were markedly higher in spring than in autumn. Climatic conditions, especially heavy rainfall, associated with reduced radiation levels and temperature in autumn, could be the main reason for the difference between seasons. However, the cleaning cut which preceded the autumn crop was necessarily immediately after the spring crop was harvested, whereas there was a prolonged adjustment period between when the autumn crop was harvested and the spring clearing cut. This suggests that some physiological factors might be involved. The clearing cut in spring would have left apices of all or almost all tillers unscathed, as they would have been below the cutting height of 7 cm. In contrast, the cleaning cut after the spring harvest would have left some apices undamaged below cutting height, but most tillers would have subsequently developed from basal buds. The competitive relationships between these cohorts of tillers could have contributed to the lower tiller and inflorescence density at harvest in autumn than in spring.

Seed quality. Application of high levels of N tended to reduce percentage seed set in three out of four seasons (Table 2). This negative effect of N supply upon seed set could have been a consequence of crop lodging.

Boonman (1972a) found a reduction in seed set of *Setaria sphacelata* associated with N application, probably related to a prolonged flowering. He suggested that seed set is the seed yield component most affected by the application of N. In contrast, caryopsis count and germination of *Cenchrus ciliaris* "seed" was not affected by the application of N (Cameron and Mullaly, 1969). The higher seed set in this experiment in spring compared with autumn could be associated with the higher rainfall in autumn, combined with the frequent strong winds. Continuous rain during flowering reduces cross–pollination and thus seed set (Dennis, 1984). Strong winds, combined with heavy rains, caused earlier lodging in autumn than in spring, in which lodging occurred about the time of anthesis.

Although seed from fertilised plots had a higher N percentage, its 1000–seed weight and germination rate were similar to seed from the unfertilised plots, as in some (*e.g.* Cameron and Mullaly, 1969; Chadhokar, 1971; Boonman, 1972a), but not all (*e.g.* Diulgheroff *et al.*, 1991) tropical and subtropical grasses. Dannhauser (1985) similarly noted that fertiliser treatment of seed crops did not affect germination of harvested seed of *D. eriantha*. Competition for assimilates between and within a greater number of large inflorescences from the fertilised plots could be associated with this lack of effect of N on the 1000–seed weight. In addition, N application resulted in lodging, which may have caused restriction in seed development, as has been suggested in *Lolium perenne* (Hebblethwaite *et al.*, 1978).

In contrast to this experiment, percentage germination of *P. plicatulum* (Chadhokar, 1971) and *Brachiaria decumbens* (Carmo *et al.*, 1988) seed was increased by the application of N. Cameron and Humphreys (1976), on the other hand, reported a reduction in germination of *P. plicatulum* seed. The variable germination percentage, ranging from 21 – 81% in the above reports, suggests that other factors, such as dormancy, uneven seed maturity, and/or non–viable seed, could be associated with these N responses. The high germination percentage observed in this experiment in the absence of applied N allowed no opportunity for expression of any negative response to N.

Seedling abnormality during germination was significantly reduced after 12 months seed storage, as compared with eight months storage. This was probably because when the seeds were germinated after eight months storage some of them had just broken dormancy. However, four months later, most seedlings developed a normal root. Similar observations have been made in *P. maximum* (J.M. Hopkinson, personal communication).

Practical implications. In comparable environmental conditions and soil fertility to those at the experimental site, maximum pure seed yields of *D. eriantha* in spring can be obtained by applying no more than 180 kg $ha^{-1}crop^{-1}$ (including the 30 kg $ha^{-1}crop^{-1}$ basal N applied in this experiment), with lower rates in the first year. In autumn, however, N levels of about 50 kg $ha^{-1}crop^{-1}$ or less would be adequate to achieve maximum seed yield. Where soil is less fertile, and in less wind–prone districts, higher N levels could be required.

The optimum time for seed harvest in spring was about 2 – 3 weeks after peak anthesis. Frequent winds, as at Redland Bay, make the decision of harvest date critical, since a high proportion of seed produced could be lost in a matter of one or two days. Perhaps the most valuable tool to estimate the optimal time for harvest is frequent observation of the development of the crop – every one or two days – from shortly after initial emergence of inflorescences.

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