A Study of Nitrogen Use in a Browntop (*Agrostis capillaris* L.) Seed Crop

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ABSTRACT

In cropping soils nitrogen (N) is generally the most limiting nutrient. This study was conducted to determine the effect of N in a browntop (*Agrostis capillaris* L.) seed crop. Browntop cv. Grasslands Sefton, grown on a Temuka silt loam, was given one of four rates of spring nitrogen (0, 60, 120 or 240 kg ha^{-1} N). Increasing N decreased heads m^{-2} but increased seed yield by producing more nodes per head and seeds per node. Nitrogen application increased dry matter production. Herbage N percentage was increased by N but decreased with time. Herbage N at stem elongation had a significant effect on seed yield (R^2 = 49%). Nitrogen fertilizer increased thousand seed weight, germination, and seedling weight. Nitrogen recovery efficiency (NRE) was greatest at 120 kg ha^{-1} N; at 240 kg ha^{-1} N NRE was only 50%, which could have implications for leaching losses.

Additional index words: browntop, *Agrostis capillaris* L., nitrogen, seed yield components, dry matter production, herbage N concentration (%).

INTRODUCTION

Browntop (*Agrostis capillaris* L.) is a common constituent of New Zealand pastures (Brown, 1971; Corkill and Rumball, 1980) and an important turf grass for golf greens, home lawns and parks throughout the world (Rumball and Robinson, 1982; Smith and Cattani, 1993). There has recently been an increase in demand for browntop seed for amenity use in New Zealand and overseas (B.R.Guy, Wrightsons Seeds, *pers. comm.*).

In cropping soils, nitrogen (N) is generally the most limiting nutrient (Rowarth, Archie and Baird, 1993). It is also the most difficult to correct, as it is mobile within the soil and plant. In an attempt to achieve high seed yields, seed growers are using increasing amounts of nitrogenous fertilizer; this is causing concern amongst those socially responsible for land and water use (Griffith, Alderman, and Streeter, 1994). Efficiency of use of N is achieved by matching N availability with crop needs throughout the growing season (Baethgen and Alley, 1989), by applying regular small doses of fertilizer (Wallace, 1994). However, although there has been considerable research on crop N requirements in some grasses, particularly ryegrass (Rowarth and Archie, 1994) there has been limited research on the N requirements for browntop (Rowarth, Clifford, Archie and Guy, 1993).

Common practice in the Netherlands and Oregon is to apply around 100 kg ha^{-1} N to browntop in spring (Corkill and Rumball, 1980; Youngberg, 1980); in New Zealand, 60 kg ha^{-1} has been traditional but rates have increased to 120 kg ha^{-1} in mature stands (Guy, Archie and Rowarth, 1990). Following research on timing of N in browntop Brown and Archie (1986) concluded that N applied to a vegetative crop (early spring) was wasted, but that late spring N would achieve increased seed yield. However the highest seed yields (209 - 437 kg ha^{-1}; hand harvested) in both years of the experiment were low,and were achieved with the latest application of N (28th October 1981; 15th November 1982). In a rate of N trial in browntop Brown and Archie (1986) investigated four rates of N fertilizer (0, 20, 40 or 80 kg ha^{-1}) applied in early spring (15th September). No response was seen in seed yield, probably because the crop was still vegetative and N fertilizer rates were relatively low. Hence there are no conclusive reported data on the effect of N fertilizer on seed yield in browntop; this has been identified as an information gap in management of browntop seed crops (Rowarth *et al.*, 1993).

Our objective was therefore to investigate the relationship between fertilizer N and seed yield, seed quality and N recovery efficiency in browntop.

MATERIALS AND METHODS

Browntop cv. Grasslands Sefton was sown in March 1991 at 2.2 kg ha^{-1} at a 30 cm row spacing into a Temuka silt loam. A field experiment was established in 1993, using four rates of spring N (0, 60, 120, or 240 kg ha^{-1}) applied as calcium ammonium nitrate (N = 27%) in a randomised complete block with four replicates. The N totals were achieved by three applications at monthly intervals (Table 1). Plot size was 20 m^2. Quick test soil analysis results on 30 July 1992 were P 30, K 22, S 6, pH 5.7.

Herbage was sampled fortnightly from an area of 0.18m2 per plot from September to January using mechanical shears. After dissection into green or dead material, herbage was dried overnight at 65°C and weighed. The green material was analyzed monthly by AgResearch Invermay Soil Fertility Service for total N (Kjeldahl; Basson, 1976). Herbage N uptake was measured above ground level. Four replicates each of ten tillers were sampled fortnightly from each N treatment from April to January to monitor apex length, development and height.

Seed was hand harvested (from 0.36 m^2 per plot) on 23rd February 1994. Seed yield components were recorded from 20 heads and fertile tillers weighed. Seed

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Table 1. Time of application and rate of fertilizer N used in the experiment

Application date	Nitrogen kg ha^{-1}			
Sept 8 (vegetative)	0	20	40	80
Oct 9 (vegetative)	0	20	40	80
Nov 11 (reproductive[1])	0	20	40	80
Total N applied	0	60	120	240

NB: [1] Formation of lemma primordia.

was hand threshed and machine dressed with an air-screen cleaner. Seed was then separated with a Buro seed cleaner at 30 mm aperture for one minute into heavy seed (first - seed) and light seed (second - seed). The first-seed (quality seed) was recorded as seed yield. Seed was also analyzed by AgResearch Invermay Soil Fertility Service for total N. Seed germination (ISTA, 1993) was determined on 100 seeds per treatment. Fresh and dry weights of germinated seedlings were measured at the interim stage to test for seed vigour (Schwass and Allo, 1973).

Minitab Version 9.0 was used for statistical analyses [analysis of variance (ANOVA), multiple range tests, and regression analyses]. Genstat Version 5.1 was used for multivariate statistical analyses [principal components analysis (PCA), canonical correlation analysis (CCA), and canonical variate analysis (CVA)] based on the standardized data.

Nitrogen recovery efficiency was defined as the ratio of additional N-uptake (kg ha^{-1} N) in response to N fertilizer application, to the amount of fertilizer N applied (kg ha^{-1} N) and calculated as follows:

NRE = (N uptake for treatment X - N uptake for treatment zero) / treatment X * 100.

RESULTS

Seed yield increased significantly ($P < 0.001$) as N fertilizer application rate increased (Table 2). This relationship was linear: $SY = 44.9 + 0.187\,N$, $R^2 = 49.4\%$. The increase in yield resulted mainly from a significant increase in yield per head (Table 2), which more than compensated for a significant reduction in heads m^{-2} with increasing N (Table 2). Thousand-seed weight (TSW) also increased significantly ($P < 0.01$) with increasing rates of N (Table 2), as did the seed head length, internode length, and dry weight per fertile tiller ($P < 0.01$) (Table 3). However harvest index was only increased at the highest N rate (Table 3).

Examination of apex development in browntop showed that a sharp increase in apex length occurred in early December (Fig. 1), when florets were initiating; apex lengths at 240 kg ha^{-1} N were four times greater than at 0 kg ha^{-1} N by mid December. Apex height above ground was less than 10 mm before August (Fig. 1) and started to rise in October. A sharp increase in apex height occurred in early January (Fig. 1), after floret initiation had finished.

Dry matter (DM) yield increased with time, which corresponded to increasing amounts of N being applied. Herbage N concentration (%) was significantly increased by N at all sampling dates, although N percentage decreased with time (Fig. 2). Maximum N-uptake by browntop was reached earlier at higher N rates (120 and 240 kg ha^{-1} N) than at the lower rate (60 kg ha^{-1} N) or the control treatment (Fig. 3). Stands receiving the low rate of N (60 kg ha^{-1} N) or no N (the control) absorbed only a small amount of N and did not achieve maximum uptake until harvest (Fig. 3).

The relationship between herbage N% at each stage and seed yield was examined using regression analysis (Table 4). Herbage N% was linearly correlated ($P < 0.01$) with seed yield at all samplings, although the highest correlation occurred in December (Fig. 4).

Table 2. Effect of N fertilizer application on seed yield and yield components

Nitrogen (kg ha^{-1})	Seed yield (g m^{-2})	Heads m^{-2}	Seed yield per head (mg)	Nodes[1] per head	Seeds per node	Seeds per head	TSW[2] (mg)
0	44.9C[3]	5020A	8.9C	9.8C	13.4C	131D	68.3D
60	58.5BC	4150AB	13.8C	10.3B	18.0BC	185C	76.2C
120	63.8B	3280BC	19.4B	10.7A	22.5B	233B	83.5B
240	90.5A	2600C	34.8A	10.8A	5.2A	380A	91.5A
SEM	6.4	205.8	2.6	0.2	3.2	36.0	1.5

[1] *The node of the culm of the seed head according to Langer (1990)*
[2] *Thousand-seed weight*
[3] *Means followed by the same capital letter within a column are not significantly different at $P < 0.01$ according to Duncan's multiple range test. Discrepancies between seed yield as reported in column one and seed yield calculated from yield components are due to sample size.*

Table 3. Effect of rate of N fertilizer application on other agronomic characteristics of seed heads.

Nitrogen kg ha^{-1}	Seed head length (mm)	Internode[1] length (mm)	Dry weight per fertile tiller (mg)	harvest index (%)
0	149 D[2]	15.2 D	252 D	3.8 b
60	175 C	17.1 BC	339 C	3.9 b
120	194 AB	78.2 AB	443 B	3.9 b
240	207 A	19.3 A	481 A	5.1 a
SEM	3.0	0.4	12	0.3

1 *The distance between two adjacent nodes of the culm of the seed head according to Langer (1990).*
2 *Means followed by the same capital letter within a column are not significantly different at $P < 0.01$; means followed by the same lower case letter within a column are not significantly different at $P < 0.05$ according to Duncan's multiple range test.*

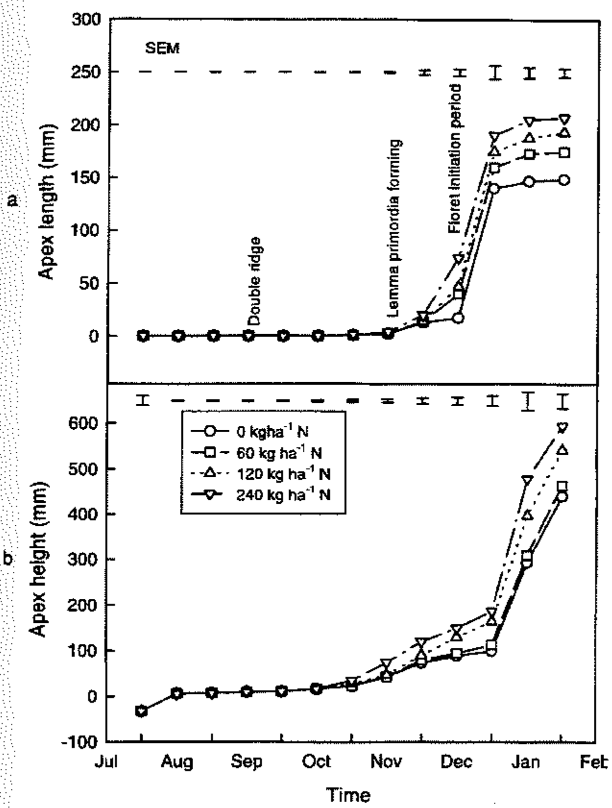

Fig. 1 Effect of N fertilizer application on apex length (a) and height (b) of browntop.

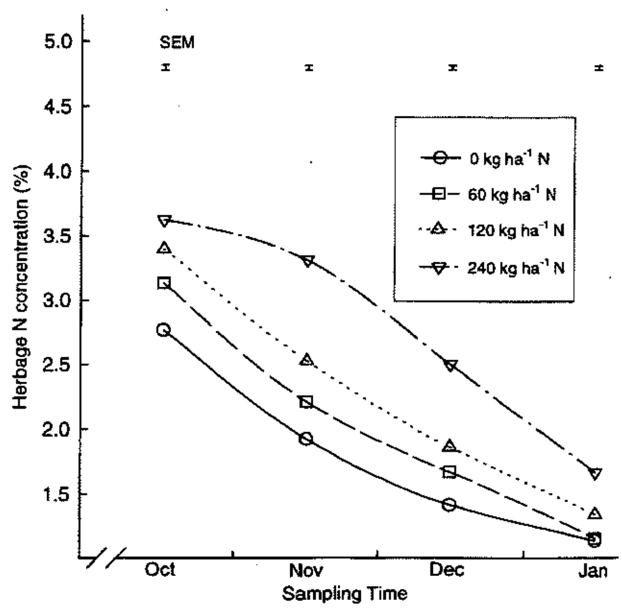

Fig. 2 Effect of N fertilizer application on herbage N concentration (%) of browntop.

Principal components are a series of independent linear combinations of the variables (Jeffers, 1967). The first such linear combination, the first principal component, accounts for the maximum proportion of the total variance; the second component accounts for the maximum proportion of the remaining variance, and so on (Pearce, 1969). We followed Pearce's (1969) use of these for biological interpretation. The first five components were chosen on the basis of a Seree test of the associated latent roots. The remaining roots accounted for little variation individually. Principal components analysis (PCA) showed that the first component had the highest positive weighting on head length, dry weight per fertile tiller, absolute herbage N uptake in December, herbage N% in December and November (Table 5). Nitrogen uptake in November and October, herbage N% in January and DM yield in December were also given high positive weighting by the first component (Table 5).

Canonical correlation is calculated from a linear combination of the first set of variables and a linear combination of the second set of variables (known as the canonical variate), chosen so the correlation is the largest possible (Digby and Kempton, 1989). Canonical correlation analysis (CCA) showed that N uptake in December had the highest correlation with canonical correlation 1 ($r = 0.908$), immediately followed by herbage N% in November ($r = 0.828$) and herbage N% in December ($r = 0.818$) (Table 6). Among the response

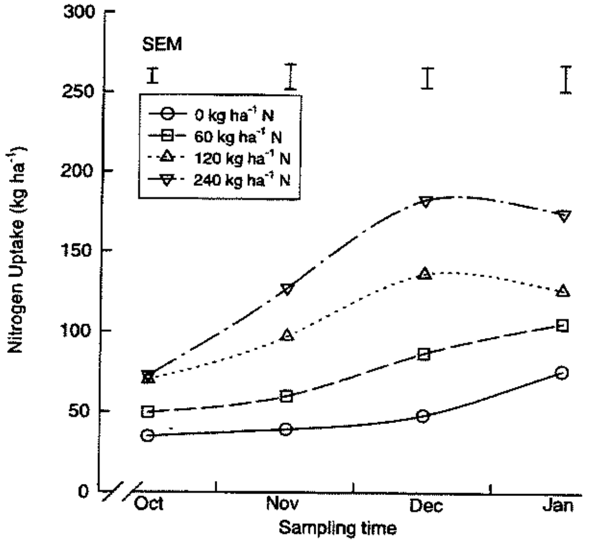

Fig. 3 Effect of N fertilizer application on nitrogen uptake by browntop.

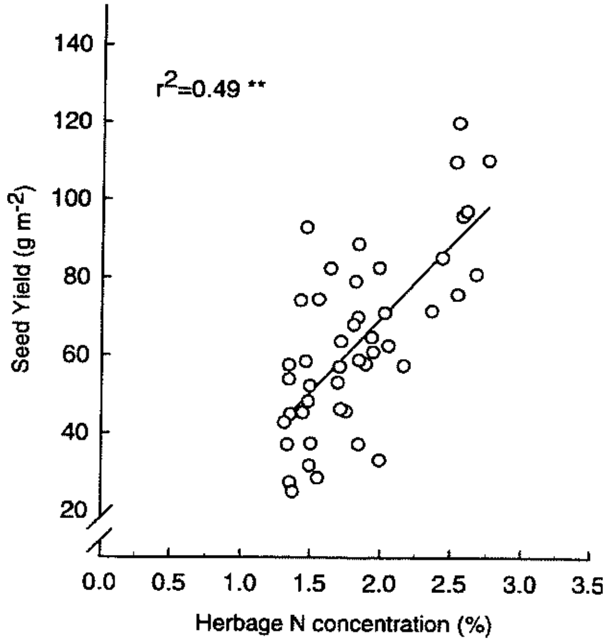

Fig. 4 Relationship between seed yield (February; g m^{-2}) and herbage N concentration (%) (December) of browntop.

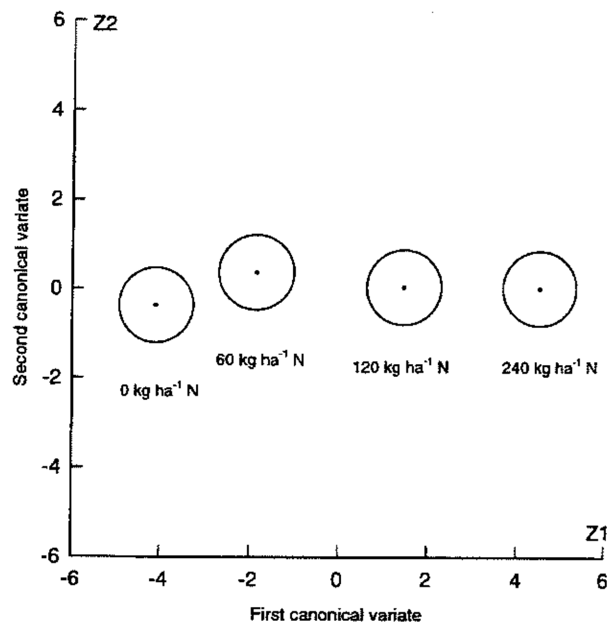

Fig. 5 Canonical variate plot of the main treatment means (4) of nitrogen effect using the first two canonical variates.

variables, the highest correlation was between head length and canonical correlation 1 (r = 0.970), followed by dry weight per fertile tiller (r = 0.899) and internode length (r = 0.718) (Table 6). In canonical correlation 2, the dominant predictor was N% in December and the response was seed yield m^{-2} (Table 6). Examination of the original correlation matrix for the predictor variables showed that there were high correlations among December N%, January N%, October N%, November N%, December N uptake and December DM yield (Table 7). Plotting canonical variates of the four N treatment (Fig. 5) showed that they were clearly separated without any overlap.

Nitrogen recovery efficiency (NRE) averaged for the whole season was highest at 120 kg ha^{-1} N and lowest at 240 kg ha^{-1} N (Table 8). Maximum NRE was apparent in October for the 60 and 120 kg ha^{-1} N treatment, (Table 8) when grass growth was rapid. Although NRE declined with increasing fertilizer, the quantity of seed increased, and economic returns were still apparent at the highest rate (Table 9).

Seed quality components (seed N content (%), germination (%), seed weight, and seedling weight) were also significantly increased by N fertilizer (Table 10).

DISCUSSION

In this experiment, the highest seed yield (hand-harvested) was 900 kg ha^{-1}. Allowing for a 22% loss for machine harvesting (Brown and Archie, 1986) this is equivalent to a machine-harvested yield of 700 kg ha^{-1}. This yield was three times that previously reported (Brown and Archie, 1986), probably reflecting the difference in the timing and amount of N fertilizer applied; whereas Brown and Archie (1986) applied 80 kg ha^{-1} in September, in this experiment, N fertilizer was applied throughout the season. This split application method is important, as early N (September) increased dry matter production and presumably photosynthetic area; the increased vegetative growth built up a foundation for reproductive growth later in the season. This, in turn, increased N uptake efficiency for later N applications (October and November). Consequently, more photoassimilate was available for

Table 4. Regression analysis of herbage N concentration (N%) and seed yield of browntop (SY)

Regression equation	SE (b)	R2	P-level
SY= -46.3 + 34.3 OctN%	6.7	0.36	0.01
SY= -4.9 + 28.4 NovN%	5.9	0.36	0.01
SY= -6.4 + 38.1 DecN%	6.3	0.49	0.01
SY= -8.2 + 42.1 JanN%	6.3	0.48	0.01

Table 5. Correlation coefficients between five principal components and measured variables

Variables	Principal Components				
	C1	C2	C3	C4	C5
Oct N%	0.718	-0.072	0.336	0.163	-0.114
Nov N%	0.855	0.028	0.363	-0.040	0.029
Dec N%	0.871	-0.189	0.173	-0.006	-0.106
Jan N%	0.741	-0.176	0.188	-0.428	-0.008
Oct DMY	0.576	0.387	-0.648	0.072	-0.044
Nov DMY	0.666	0.597	-0.144	-0.003	0.170
Dec DMY	0.739	0.377	0.132	-0.092	-0.034
Jan DMY	0.599	0.221	0.349	0.181	-0.083
Feb DMY	0.636	0.088	0.281	0.174	-0.486
Oct N uptake	0.742	0.300	-0.526	0.124	-0.084
Nov N uptake	0.780	0.468	0.017	-0.034	0.183
Dec N uptake	0.904	0.137	0.174	-0.092	-0.084
Jan N uptake	0.431	-0.221	-0.604	-0.010	-0.380
No. heads m^{-2}	-0.635	0.352	0.156	0.182	-0.602
DW fertile $tiller^{-1}$	0.904	-0.165	-0.047	0.097	0.126
Seed yield $head^{-1}$	0.704	-0.597	-0.063	-0.175	0.043
No. seeds $node^{-1}$	0.690	-0.640	-0.065	-0.080	0.056
Internode length	0.725	-0.158	0.009	0.598	0.236
Head length	0.934	0.043	-0.033	0.187	0.132
No. nodes $head^{-1}$	0.575	0.342	-0.055	-0.611	-0.142
Harvest index %	0.426	-0.629	-0.217	0.047	-0.313

Table 6. Canonical correlation analysis of browntop experimental data

Canonical variables	1	2	3	4
Canonical correlation	0.917	0.785	0.730	0.424
Correlations between canonical variates and original variables:				
Predictors:				
Oct N%	0.739***	0.210	-0.134	0.085
Nov N%	0.828***	0.207	0.097	-0.98
Dec N%	0.818***	0.469**	0.031	0.041
Jan N%	0.691***	0.315	0.613***	0.083
Oct N uptake	0.809***	-0.186	-0.112	-0.081
Nov N uptake	0.809***	-0.303	0.051	-0.345
Dec N uptake	0.908***	0.182	0.120	-0.229
Dec DMY	0.804***	-0.156	0.090	-0.244
Responses:				
Internode length	0.718***	0.208	-0.403	-0.077
Head length	0.970****	0.028	-0.092	-0.049
DW fertile $tiller^{-1}$	0.899***	0.169	-0.002	0.308
Seed yield $head^{-1}$	0.574	0.570**	0.172	0.226
No. heads m^{-2}	-0.559	-0.081	-0.389	-0.304
No. seeds $node^{-1}$	0.553	0.605**	0.086	0.245
Seed yield m^{-2}	0.588	0.714***	-0.152	0.143

*NB: Probability levels: ****, $P < 0.0001$; ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$. Significant level of the correlation varied with degree of freedom (df); at df=46, if $r >= 0.278$, the confidence level $P < 0.05$; if $r >= 0.355$, $P < 0.01$; if $r >= 0.437$, $P < 0.001$ according to Snedecor and Cochran (1980).*

Table 7. Correlation submatrix for predictor variables used in the canonical correlation analysis

Dec N%	1.000					
Jan N%	0.782	1.000				
Oct N%	0.532	0.374	1.000			
Nov N%	0.612	0.655	0.655	1.000		
Dec N uptake	0.803	0.723	0.593	0.750	1.000	
Dec DM yield	0.481	0.491	0.538	0.689	0.897	1.000
	Dec N%	Jan N%	Oct N%	Nov N%	Dec N uptake	Dec DM yield

N.B. Significance level of the correlation varied with degrees of freedom (df); at df=46, if r>=0.278, the confidence level p<0.05; if r>0.355, p<0.01; if r>=0.437, P<0.001 according to Snedecor and Cochran (1980).

Table 8. Effect of nitrogen fertilizer application on nitrogen recovery efficiency (NRE %) with time

Nitrogen (kg ha^{-1})	60	120	240
Oct	75	88	47
Nov	52	72	56
Dec	64	73	56
Jan	49	42	41
Mean	60	69	50

Table 9. Effect of increasing nitrogen fertilizer application (kg ha^{-1} N) on profit[1] in browntop seed production

Nitrogen (kg ha^{-1})	0	60	120	240
Cost of N ($ ha^{-1})	0	78	156	312
Seed yield (kg ha^{-1})	449	585	638	905
Value of seed ($ ha^{-1})	2694	3510	3828	5430
Net profit ($ ha^{-1})	2694	3432	3672	5118

[1] *Assuming that the price of browntop seed is NZ $6 kg^{-1}, and nitrogen can be applied for NZ $1.3 kg^{-1}.*

Table 10. Effect of N fertilizer on seed nitrogen content and seed quality parameters.

Nitrogen (kg ha^{-1})	Seed-N content (%)	Germination (%)	TSW (mg)	Seedling Fresh Weight[1] (mg)	Dry Weight[1] (mg)
0	2.7D[2]	92a	68.3D	488D	56D
60	2.8C	94ab	76.2C	559C	66C
120	3.2B	95ab	84.5B	624B	74B
240	3.4A	96b	91.5A	723A	84A
SEM	0.1	1.6	1.5	17	2.0

[1] *Recorded at the interim count (14 days).*

[2] *Means followed by the same capital letter within a column are not significantly different at P < 0.01: means followed by the same lower case letter within a column are not significantly different at P < 0.05 according to Duncan's multiple range test.*

apical growth (spikelet and floret initiation) and seed filling. In Brown and Archie's trial, although the early N might have increased vegetative growth, N was also required for reproductive growth. This is supported by results from the present research, as differences in N application became apparent at floret initiation. Limited nutrient supply during floret initiation may limit the growth of florets, many of which are potential seeds (Ryle, 1963).

Seed yield of browntop responded linearly up to the highest rate of applied N (240 kg ha^{-1}). This rate was twice as much as has been suggested as optimum for ryegrass seed crops (120 kg ha^{-1}; Hampton, 1987). At this optimum rate (120 kg ha^{-1} N), a ryegrass seed crop can produce 7.45 t of dry matter with herbage N% of 1.28% in mid November (between head emergence and anthesis) (Rowarth, *unpubl.*). In comparison, results from the present trial show that at the same rate of N (120 kg ha^{-1}) and a similar biological stage (between head emergence and anthesis), about 9.0 t of dry matter at 1.6% herbage N (Fig. 2) was produced. At the top rate of N applied (240 kg ha^{-1}), about 10.5 t of dry matter at 2.0% herbage N was produced. This suggests that browntop had a higher N uptake efficiency than ryegrass, but as data from only one season are available, further investigation is required.

The positive response in seed yield to applied N occurred mainly through an increase in the number of seeds per head and in TSW, which compensated for a decrease in the number of heads m^{-2}. This supports the suggestion (Brown, 1980) that high grass seed yields do not necessarily come from high density crops but from those containing the largest heads which bear the heaviest seeds. Similar observations have also been reported for ryegrass (Hebblethwaite and Hampton, 1982) and timothy (Evans, 1954; Langer, 1959).

Apex height might be a factor to be considered when managing sheep-grazing on browntop fields (Scott, 1973). However the browntop apex was out of reach of sheep before August, and grazing therefore resulted in negligible damage to apex growth and development. In Canterbury, farmers could allow sheep to graze their browntop fields until early winter without fearing any apex damage.

The decline in herbage N% with time is consistent with the pattern in cereals (Scharrer and Mengel, 1960; Batey, 1977) and can be attributed to a dilution effect (Mengel and Kirkby, 1982). Despite the decline with time, there was a strong relationship between herbage N% and seed yield (R = +0.705). This supports work by Rowarth et al. (1993), Schoberlein and Wahl (1993), and Rowarth and Archie (1994; 1995). The correlation of herbage N concentration with seed yield was higher (R = +0.705) than with dry matter yield at harvest (R = +0.618). Rowarth *et al.* (1993) also found that seed yield was more sensitive than dry matter yield to change in herbage N%. It is possible that herbage N% may be used as a diagnostic indicator of plant N status to predict seed yield (Rowarth *et al.*, 1993; Rowarth and Archie, 1994; 1995).

Multivariate statistical methods have confirmed the points discussed above. Results from PCA indicated that head length, dry weight per fertile tiller, absolute herbage N uptake in December, herbage N% in December and November, N uptake in November and October, herbage N% in January and DM yield in December were important variables for understanding browntop seed production processes. These are variables for future study (Jeffers, 1967). Results from CVA indicated that N fertilizer was a factor which had a significant effect on multivariant variables, as CVA was able to separate the nitrogen treatment effect (Chatfield and Collins, 1980; Manly, 1986).

Canonical correlation analysis (CCA) can be regarded as the most generalised form of correlation analysis, measuring the relationships between the observed values of two sets of variables (Digby and Kempton, 1989). Results from CCA showed that the most dominant physiological variables were nitrogen uptake in December and N% in November. The most dominant agronomic variables in response to N fertilizer were head length and dry weight per fertile tiller. Furthermore, although herbage N% in December was the best predictor of browntop seed yield, herbage N% in October and November were closely correlated with herbage N% in December and each other, indicating the possibility of manipulating N status, i.e. it might be possible to influence seed yield by adjusting herbage N% early in the season to ensure optimum herbage N% in December. It is apparent that results from multivariate statistical methods are biologically meaningful and support the biologist's standpoint about the physiological importance of N (Rowarth *et al.*, 1993; Rowarth and Archie, 1994; 1995).

Several approaches have been suggested to improve nitrogen recovery efficiency (Bock, 1984; Kanneganti and Klausner, 1994; Baethgen and Alley, 1989; Wallace, 1994). For example, improvement can be achieved by matching N availability with crop needs throughout the growing season (Baethgen and Alley, 1989) or applying small amounts at each time (Wallace, 1994). However, in this research, attempts to match N requirement of browntop by applying N throughout the season did not result in 100% efficiency of uptake. At high rates (240 kg ha^{-1} N), half of the applied fertilizer could have been available for a subsequent crop or for leaching after rainfall or inappropriate irrigation. At low rates (60 kg ha^{-1} N), NRE was also low (60%). NRE varies with soil properties, application methods, amounts and time of N applications, and other management practices (Bock, 1984). In this experiment, the only variable factor was the amount of N applied; the latter had a major effect on NRE. Since NRE has important implications for the environmental impact of N fertilizers (Bock, 1984; Kanneganti and Klausner, 1994), results from the present trial suggested that the rate of 120 kg ha^{-1} N may cause minimum environmental contamination compared with low rates (60 kg ha^{-1} N) and high rates (240 kg ha^{-1} N).

Nitrogen application increased TSW. These findings are in accordance with earlier reports on perennial ryegrass (Evans, 1959; Ene and Bean, 1975), cocksfoot and timothy (Evans, 1959). In Canada, MacVicar and Gibson (1951) reported that rates in excess of 90 kg ha^{-1} N appreciably increased seed weight and the highest rate of 720 kg ha^{-1} N produced the highest seed weight. This also supports the theory that the variability in seed size may depend on the intensity of competition for N between florets and seed heads (Donald, 1954).

Increasing N had a positive (but agronomically insignificant) effect on germination of the subsequent seed, and a positive highly significant effect on fresh and dry seedling weight. This supports the finding by Ene and Bean (1975) with perennial ryegrass, indicating that increasing maternal N resulted in an increase in seed vigour. This relationship is probably governed by the mobilization of reserve proteins (albumins and globulins) (Ashcroft and Murray, 1979) and a marked increase in respiratory activity of the cotyledons or endosperm in the early stages of germination (Lovato, 1981). Lovato (1981) indicated that seed vigour may be modified by nutrition of the 'mother plant'.

CONCLUSIONS

High yield and quality of browntop seed can be achieved by using high rates of nitrogen fertilizer. There is potential to use herbage N% as a diagnostic indicator of plant N status, predicting seed yield. However, further research is required to refine the yield prediction model. Nitrogen recovery efficiency was greatest at 120 kg ha^{-1} N. Although it appeared to be economic to apply 240 kg ha^{-1} of nitrogen, at this high rate of N, nitrogen recovery efficiency was only 50% which could have implications for leaching losses and environmental contamination. This work needs to be expanded to include root recovery and lysimeter studies, not only with browntop, but also with other grass seed crops.

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