The Relationship Between Applied Nitrogen, Nitrogen Concentration in Herbage and Seed Yield in Perennial Ryegrass (*Lolium perenne* L.). III. Cv. Palmer at Two Sites in France.

G. Sicard[1] and J.S. Rowarth[2]

ABSTRACT

Research to identify an indicator of seed yield to allow applied nitrogen (N) to be matched to the specific requirements of the perennial ryegrass (*Lolium perenne* L.) crop has concentrated on cv. Grasslands Nui. Further research was conducted using cv. Palmer at two sites in France over two seasons. Nitrogen (0-160 kg ha^{-1} N) was applied to create a range of plant N concentrations in spring. Dry matter yield and herbage N concentration were assessed 14 days after spikelet initiation and at the end of stem elongation, and N content and apparent nitrogen recovery calculated. Seed yield and components were assessed at harvest. At all sites N had a significant effect on seed yield, but at Lavaur in 1996, drought prevented a response at high N inputs. The greatest seed yields ranged from 1329-1715 kg ha^{-1} and were achieved with 40-160 kg ha^{-1} applied N. The concentration of N in herbage 14 days after spikelet initiation accounted for over half the variability in seed yield at three of the sites, whereas N content accounted for over 80 %. The latter relationship indicated that for a seed yield of over 1400 kg ha^{-1}, an N content of over 40 kg ha^{-1} would be required in early spring.

Additional index words: cultivar, herbage nitrogen content, seed yield components, spikelet initiation, seed yield variability.

INTRODUCTION

Nitrogen (N) concentration in herbage 14 days after N application at spikelet initiation has been found to be a predictor of likely relative yield in perennial ryegrass (*Lolium perenne* L.) cv. Grasslands Nui seed crops, where N is the only limiting factor (Rowarth and Archie, 1994, 1995). However, herbage N content in early spring may be a more universally useful indicator than N concentration, as it includes the effect of soil temperature (Rowarth, Boelt, Hampton, Marshall, Rolston, Sicard, Silberstein, Sedcole and Young, 1998). Furthermore, it has been established that for cv. Grasslands Nui, 50 kg ha^{-1} of N applied at spikelet initiation will increase herbage N concentration by 0.45%. Similar results have been reported for cultivars in Oregon (Young, Silberstein, Chastain and Rowarth, 1998). Although cv. Grasslands Nui dominates ryegrass production in New Zealand (Rowarth, Hampton and Hill, 1998), in France it does not establish well, or survive winter conditions. This research was established to test the relationships developed for cv. Grasslands Nui on cv. Palmer, a turf-type cultivar typical (in agronomic terms) of those grown in France.

MATERIALS AND METHODS

Perennial ryegrass cv. Palmer was drilled (Table 1) at two sites in France, Lavaur (43 °N) and St Pouange (48.5 °N), in the autumn of 1995 and 1996. Nitrogen (liquid fertiliser, N=39 % of which 25 % is nitrate-N, 25 % is ammonium-N and 50 % is urea) treatments were applied as indicated (Table 2); at St Pouange an extra treatment with N applied as ammonium nitrate was included. Pesticides were applied prophylactically at both sites in both years. Meteorological data were collected at Lavaur and Troyes (6 km from the St Pouange site). The Lavaur trials were irrigated (15 mm on 14.6.96 and 20 mm on 17.4.97; 40 mm on 24.4.97 and 20 mm on 29.5.97); no irrigation was available at the St Pouange site.

Stage of development was recorded (Table 3) and, 14 days

after spikelet initiation and at the end of stem elongation, the herbage was cut just above the leaf sheath from a known area. Herbage was dried overnight at 65°C, and dry weight recorded, before being sent to New Zealand for analysis (Basson, 1976). Seed was harvested when seed moisture was 15-30 %. After air drying, threshing and cleaning, seed yield and thousand seed weight (TSW) were recorded.

Nitrogen use efficiency (NUE; kg extra seed/kg applied N) and apparent nitrogen recovery (%) were calculated as described in Rowarth *et al.* (1998). Nitrogen content was calculated from dry matter yield and herbage N concentration 14 days after early spring nitrogen application and at the end of stem elongation. Relative seed yield was calculated for each trial in each year relative to the maximum seed yield for that trial in that year.

Analysis of variance and regression analysis were performed using Minitab. The Cate-Nelson separation technique, which involves partitioning data into diagonally opposite quadrats, was used to establish critical thresholds for response; the more complete the separation, the better the indication of a threshold (Cate and Nelson, 1965).

RESULTS AND DISCUSSION

In the first year of the trial, Lavaur received more rain than average in February and April, but experienced very dry conditions in June (39 mm cf long term average of 61 mm). After a cool February, temperatures were slightly warmer than usual until the end of June. In the second year of the trial, February to April was dry, May was wetter than average and June was very wet.

At St Pouange, in 1996, rainfall was below average in March, April, June and July; March and April were cooler than average, and June and July were warmer than average. In the second year, lack of rainfall for 50 days in March and April had a detrimental effect on growth and N uptake.

Table 1. Establishment data and harvested area.

Site and year	Sowing date	Row spacing (cm)	Sowing rate (kg ha⁻¹)	Previous crop	Plot size (m)	Harvested area (m²)
Lavaur 1996	04.10.95	18.0	6.8	wheat	2.3 x 10	14.0
Lavaur 1997	11.10.96	18.0	8.4	maize silage	2.5 x 10	14.0
St Pouange 1996	13. 9.95	13.0	7.5	wheat	2.0 x 8	10.4
St Pouange 1997	03. 9.96	17.5	7.0	peas	2.5 x 10	13.0

Table 2. Nitrogen treatments at (a) Lavaur and (b) St Pouange.

(a)	End of winter[1]	Spring[2]	Total	(b)	End of winter[1]	Spring[2]	Total
1	0	0	0	1	0	0	0
2	40	0	40	2	40	0	40
3	40	40	80	3	40	40	80
4	60	60	120	4	60	60	120
5	80	80	160	5	80	80	160
				6	60	60	120[3]

[1] 6.3.1996 and 4.3.1997   [1] 11.3.1996 and 29.3.1997   [3] as ammonium nitrate (33.5% N)
[2] 4.4.1996 and 16.4.1997   [2] 1.4.1996 and 10.4.97

Table 3. Date of development stages.

Site and year	Beginning of head emergence	Beginning of anthesis	Harvest
Lavaur 1996	10.5.96	25.5.96	4-11.7.96
Lavaur 1997	3.5.97	21.5.97	8-10.7.97
St Pouange 1996	6.5.96	3.6.96	15-17.7.96
St Pouange 1997	13.5.97	2.6.97	21.7.97

Generally warmer conditions at Lavaur in both years meant that sowing was later (to reduce winter growth) and anthesis and harvesting occurred earlier than at St Pouange (Table 3).

Nitrogen significantly (P<0.05) increased seed yields and head numbers at both sites in both years (Tables 4 and 5). Regressions fitted to the individual response lines for applied N and seed yield gave R^2 of 0.79 - 0.85, except for Lavaur in 1996, where the increase in seed yield per unit of N was less than one (Table 6). Combining the data for the responsive sites revealed a correlation between applied N and relative seed yield (i.e., seed yield relative to the maximum seed yield for the individual trial) of 0.93 (Fig 1). These data indicate that for a relative seed yield of 90 % of maximum, 80 kg ha⁻¹ N should be applied. In contrast, the trials with cv. Grasslands Nui (Rowarth *et al.*, 1998) indicated that 80 kg ha⁻¹ N would give 75 % of relative seed yield. It is possible that cv. Palmer is inherently lower N-demanding, as reflected in lower seed yields than for cv. Grasslands Nui under irrigation, or it may be that the growing conditions restricted yield and, hence N requirements.

Applied N significantly (P<0.05) increased florets per head in 1997 only (Tables 4 and 5); thousand seed weight was not significantly affected in either year (data not presented). At Lavaur in 1996, seed yields were relatively low (maximum 1329 kg ha⁻¹) despite head numbers being greater than 2000 m². Poor floret site utilisation (FSU) indicated that moisture stress was likely to have reduced yields; this was supported by low thousand seed weight (1.58-1.62 g). Maximum seed yield was obtained with only 40 kg ha⁻¹ N.

Nitrogen use efficiency was greatest for the smallest fertiliser addition in all trials (Tables 4 and 5), and diminished with increasing applied N, confirming the principle of diminishing returns (e.g., Rowarth and Cornforth, 1998). Except in the Lavaur 1996 trial, all fertiliser N treatments gave at least three kg extra seed per kg applied N, suggesting that it was economic to apply high rates of N.

Dry matter yield at this site (Table 7) increased significantly (P<0.05) with increasing nitrogen, and was inversely related to FSU, suggesting competition had occurred between tillers and developing

Table 4. Effect of applied nitrogen on seed yield and its components, and nitrogen use efficiency at Lavaur (a) 1996 and (b) 1997.

(a) Nitrogen strategy	Total N (kg ha^{-1})	Seed yield (kg ha^{-1})	NUE[1] (kg seed kg N^{-1})	Heads (m^2)	Florets/head	Seeds/head	FSU[2] (%)
00-00	00	854	-	1407	157	38	23.8
40-00	40	1329	11.9	2249	161	37	23.2
40-40	80	1050	2.5	2347	208	28	13.3
60-60	120	1072	1.8	2672	191	25	13.1
80-80	160	1062	1.3	2746	177	25	13.8
LSD P<0.05		118.0	na[3]	362.4	ns	na	na

(b) Nitrogen strategy	Total N (kg ha^{-1})	Seed yield (kg ha^{-1})	NUE[1] (kg seed kg N^{-1})	Heads (m^2)	Florets/head	Seeds/head	FSU[2] (%)
00-00	00	717	-	1257	127	34	27.1
40-00	40	1056	8.5	1780	135	34	23.1
40-40	80	1333	7.7	1807	147	39	26.4
60-60	120	1454	6.1	1976	152	44	29.3
80-80	160	1446	4.6	2166	154	40	26.3
LSD P<0.05		70.9	na[3]	247.9	13.3	na	na

[1] Nitrogen use efficiency
[2] Floret site utilisation
[3] Not available as calculated from means

Table 5. Effect of applied nitrogen on seed yield and its components, and nitrogen use efficiency at St Pouange (a) 1996 and (b) 1997.

(a) Nitrogen strategy	Total N (kg ha^{-1})	Seed yield (kg ha^{-1})	NUE[1] (kg seed kg N^{-1})	Heads (m^2)	Florets/head	Seeds/head	FSU[2] (%)
00-00	00	1201	-	2648	149	22	18
40-00	40	1519	8.0	3667	147	25	17
40-40	80	1532	4.1	3926	171	23	14
60-60	120	1594	3.3	3930	184	24	13
80-80	160	1715	3.2	3764	175	25	15
60-60[3]	120	1617	3.5	3706	147	22	17
LSD P<0.05		127.6	na[4]	337	ns	na	na

(b) Nitrogen strategy	Total N (kg ha^{-1})	Seed yield (kg ha^{-1})	NUE[1] (kg seed kg N^{-1})	Heads (m^2)	Florets/head	Seeds/head	FSU[2] (%)
00-00	00	705	-	1367	74	30	41
40-00	40	1002	7.4	2091	74	26	36
40-40	80	1033	4.1	2135	88	27	30
60-60	120	1153	3.7	2477	84	28	37
80-80	160	1223	3.2	2300	104	29	31
60-60[3]	120	1145	3.7	2389	99	24	25
LSD P<0.05		126.3	na[4]	205.4	12.7	na	na

[1] Nitrogen use efficiency
[2] Floret site utilisation
[3] Fertiliser applied as ammonium nitrate
[4] Not available as calculated from means

seeds, as has been reported for Italian ryegrass (Griffith, 1992). In 1997 seed yield responded to increasing N up to 120 kg ha^{-1} (Fig. 1). Head numbers and florets per head were reduced in comparison with the previous year, but FSU was increased.

Form of fertiliser (examined at the St Pouange site) had no effect on yield, NUE or components of yield; seed yield increased with N up to 160 kg ha^{-1} in both years; seed yield, head numbers, and florets per head were greater in 1996 than

Table 6. Regression relationships between seed yield (kg ha⁻¹) and nitrogen applied (kg ha⁻¹).			
Site and year	**Regression equation**	R^2	**P**
Lavaur 1996	Seed yield = 1042 + 0.40 N	0.00	0.81
Lavaur 1997	Seed yield = 830 + 4.64 N	0.82	0.02
St Pouange 1996	Seed yield = 1292 + 2.76 N	0.79	0.03
St Pouange 1997	Seed yield = 786 + 2.97 N	0.85	0.02
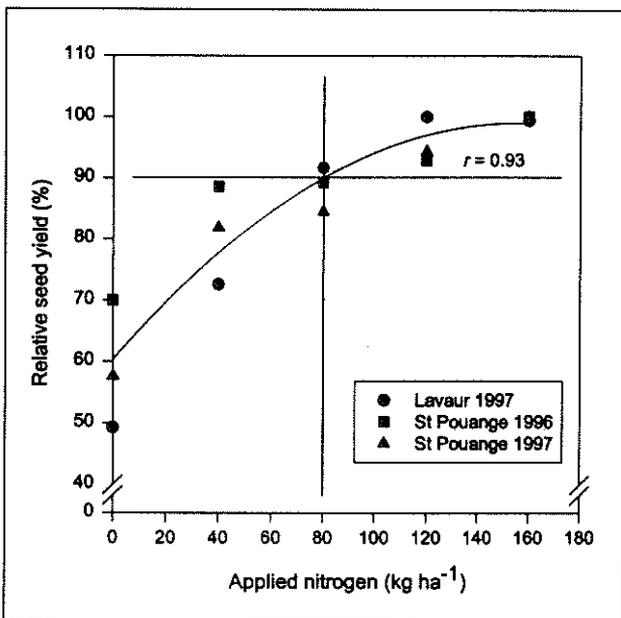
Fig. 1. Effect of applied nitrogen (kg ha⁻¹) on perennial ryegrass seed yield relative to the maximum yield for each trial. Cate Nelson separation technique (Cate and Nelson, 1965) is used to show a critical threshold.

in 1997, but FSU was considerably reduced (Table 5). Form of fertiliser did have a significant effect on herbage N concentration at both sampling times; ammonium nitrate increased herbage N by 0.4 % in comparison with liquid fertiliser (Table 8). Research results reported previously (Rowarth et al., 1998) were based on urea. This may explain some of the differences in apparent responsiveness to N, but the physiological effect within the plant has yet to be elucidated.

Increasing applied N significantly (P<0.05) increased herbage N concentration (%), dry matter yield and N content, both at 14 days after spikelet initiation and at anthesis, at both sites in both years (Tables 7 and 8). All factors were, however, low in comparison with results for cv. Grasslands Nui (Rowarth and Archie, 1994; 1995; Rowarth et al., 1998), which may be a cultivar difference, or reflect the cool growing conditions experienced in France. In contrast, apparent nitrogen recovery (ANR %) was very high, indicating that a considerable amount of the applied N had been taken up within 2-3 months (ANR of >100% indicate that organic N mineralisation was stimulated by adding fertiliser N (Jenkinson, Fox and Rayner, 1985)). At St Pouange in 1996, dry matter yield increased 10-fold between the two cutting times. This very fast growth (>200 g ha⁻¹ day⁻¹) would have created a large N demand (N uptake is primarily influenced by leaf expansion (Grindlay, 1997)), resulting in high ANR (Table 8).

Regressions fitted to the individual response lines for the

effect of applied N on herbage N % 14 days after spikelet initiation gave R^2 of 0.70-0.95 (average = 0.86) and at the end of stem elongation gave R^2 of 0.55-0.91 (average = 0.77) (Table 9). Only at one trial (St Pouange, 1996) did the relationship improve with delay in sampling, possibly reflecting the colder than average March and April and lack of growth. This suggestion is supported by analysis of the response in dry matter to applied N; at 14 days after spikelet initiation R^2 = 0 for St Pouange in 1996, but increased to 0.63 by the end of stem elongation (Table 10). Regression relationships (Table 9) indicate that 50 kg ha⁻¹ N applied at spikelet initiation changed the herbage N concentration by 0.6 % at Lavaur and 0.3% at St Pouange. This compares with an average change of 0.45 % for cv. Grasslands Nui, independent of site (Rowarth et al., 1998). By the end of stem elongation, 50 kg ha⁻¹ N changed the herbage N concentration by 0.3 % at Lavaur and 0.2% at St Pouange in 1997 (in 1997, there was little apparent response, reflecting the dry spring), confirming the suggestion that plants becomes less responsive to applied N with reproductive maturity (Scholefield, 1997).

Apart from the Lavaur 1996 trial, seed yield was positively related to dry matter yield (Table 11). Greatest seed yields came from the sites with greatest dry matter yield (St Pouange 1996). Although 'bulk at harvest' can cause harvesting difficulties when climatic conditions are not conducive to drying, low dry matter will result in low seed yields. Hence nitrogen fertiliser is important to increase leaf area and head numbers. What happens to the potential yield after it has been set depends upon the ability of the plants to provision the seed and tillers; the seed yield component data (Tables 4 and 5) confirm that ryegrass has the ability to compensate and will abort seeds if inputs (e.g. assimilate or water) do not match demand.

Herbage N concentration was positively related to seed yield, except at the Lavaur 1996 site (Table 12). Regressions fitted to the individual response lines indicated that herbage N % 14 days after spikelet initiation accounted for over half the variability in seed yield (average, excluding Lavaur 1996, R^2 = 0.67); at the end of stem elongation the average, excluding Lavaur 1996, was R^2 = 0.45 (Table 12). Pooling the data for the three responsive sites indicated a correlation of r = 0.84 between herbage N % and relative seed yield (Fig. 2) and that for a relative seed yield of 85 %, herbage N % should be above 2 % (Cate and Nelson, 1965). This is a lower recommendation than that for cv. Grasslands Nui (Rowarth and Archie, 1994; 1995; Rowarth et al., 1998), even taking the effect of different form of fertiliser into account; the cultivars need to be compared under similar growing conditions to identify whether the effect is genetic or environmental, although it is recognised that their different climatic requirements could make a comparison difficult to achieve.

N content was positively and significantly related to seed yield (except for Lavaur 1996) at both testing times (Table 13); average R^2 for 14 days after spikelet initiation was 0.85 and for stem

Table 7. Effect of applied nitrogen on herbage nitrogen (%), dry matter yield (kg ha^{-1}), nitrogen content (kg ha^{-1}) and apparent nitrogen recovery (%) at Lavaur (a) 1996 and (b) 1997

(a) Total N (kg ha^{-1})	Herbage N[1] (%)	DMY[1] (kg ha^{-1})	N content[1] (kg ha^{-1})	ANR[1,2] (%)	Herbage N[2] (%)	DMY[3] (kg ha^{-1})	N content[3] (kg ha^{-1})	ANR[3] (%)
00	1.40	1640	23.0	-	0.93	5110	47.5 -	
40	1.63	3790	61.8	97.1	0.82	6830	56.0	21.2
80	2.11	3880	81.9	73.6	1.04	9160	95.3	59.7
120	2.80	4240	118.7	79.8	1.84	9640	177.4	108.2
160	2.97	4850	144.1	75.7	2.07	9910	205.1	98.5
LSD P<0.05 0.10		720	14.9	na	0.24	1110	22.37	na

(b) Total N (kg ha^{-1})	Herbage N[1] (%)	DMY[1] (kg ha^{-1})	N content[1] (kg ha^{-1})	ANR[1,2] (%)	Herbage N[2] (%)	DMY[3] (kg ha^{-1})	N content[3] (kg ha^{-1})	ANR[3] (%)
00	1.21	1410	17.1	-	1.18	2410	28.5	-
40	1.33	2710	36.1	47.6	1.08	4460	48.6	50.2
80	2.30	2670	61.2	55.1	1.44	5580	80.2	64.6
120	2.81	2910	81.3	53.5	1.65	6660	109.9	67.9
160	3.09	3230	99.1	51.3	1.94	6790	131.8	64.6
LSD P<0.05 0.31		190	7.01	na[4]	0.21	470	14.68	na

[1] Analysed 14 days after spikelet initiation
[2] Apparent nitrogen recovery
[3] Analysed at end of stem elongation
[4] Not available as calculated from means

Table 8. Effect of applied nitrogen on herbage nitrogen (%), dry matter yield (kg ha^{-1}), nitrogen content (kg ha^{-1}) and apparent nitrogen recovery (%) at St Pouange (a) 1996 and (b) 1997

Total N (kg ha^{-1})	Herbage N[1] (%)	DMY[1] (kg ha^{-1})	N content[1] (kg ha^{-1})	ANR[1,2] (%)	Herbage N[2] (%)	DMY[3] (kg ha^{-1})	N content[3] (kg ha^{-1})	ANR[4] (%)
00	2.05	960	19.7	-	0.83	7700	63.9	-
40	2.44	1420	34.7	37.4	0.86	11300	97.2	83.2
80	2.87	1250	35.9	20.3	1.23	13300	163.6	124.6
120	2.56	1250	32.0	10.3	1.31	12500	163.8	83.2
160	3.42	1310	44.8	15.7	1.46	13500	197.1	83.2
120[5]	2.97	1070	31.8	10.1	1.69	10600	179.1	96.0
LSD P<0.05 0.47		1210	6.0	na[6]	0.30	1200	40.05	na

Total N (kg ha^{-1})	Herbage N[1] (%)	DMY[1] (kg ha^{-1})	N content[1] (kg ha^{-1})	ANR[1,2] (%)	Herbage N[2] (%)	DMY[3] (kg ha^{-1})	N content[3] (kg ha^{-1})	ANR[4] (%)
00	1.51	1520	23	-	0.63	4220	26.6	-
40	1.49	2300	34.3	28.5	0.58	7050	40.9	35.8
80	1.96	2330	45.7	28.4	0.64	7980	51.1	30.6
120	1.96	2590	50.8	23.2	0.80	9110	72.9	38.6
160	2.27	2940	66.7	27.4	0.76	8030	61.0	21.5
120[5]	2.40	2760	66.2	36.3	0.93	9210	85.7	49.2
LSD P<0.05 0.27		480	10.62	na[6]	0.07	990	10.2	na

[1] Sampled 14 days after spikelet initiation
[2] Apparent nitrogen recovery 14 days after spikelet initiation
[3] Sampled at end of stem elongation
[4] ANR at end of stem elongation
[5] Fertiliser-N applied as ammonium nitrate

[6] Not available as calculated from means

Table 9. Regression relationships between nitrogen applied (kg ha⁻¹) and herbage N (%) (a) 14 days after spikelet initiation and (b) at the end of stem elongation.

(a) Site and year	Regression equation	R^2	P
Lavaur 1996	Herbage N % = 1.32 + 0.011 N	0.95	0.003
Lavaur 1997	Herbage N % = 1.10 + 0.013 N	0.93	0.005
St Pouange 1996	Herbage N % = 2.10 + 0.007 N	0.70	0.050
St Pouange 1997	Herbage N % = 1.44 + 0.005 N	0.85	0.016
(b) Site and year	Regression equation	R^2	P
Lavaur 1996	Herbage N % = 0.68 + 0.008 N	0.77	0.030
Lavaur 1997	Herbage N % = 1.04 + 0.005 N	0.86	0.016
St Pouange 1996	Herbage N % = 0.80 + 0.004 N	0.91	0.008
St Pouange 1997	Herbage N % = 0.59 + 0.001 N	0.55	0.094

Table 10. Regression relationships between nitrogen applied (kg ha⁻¹) and dry matter (a) 14 days after spikelet initiation (kg ha⁻¹) and (b) at the end of stem elongation

(a) Site and year	Regression equation	R^2	P
Lavaur 1996	Dry matter = 2306 + 17.2 N	0.73	0.04
Lavaur 1997	Dry matter = 1818 + 9.60 N	0.69	0.05
St Pouange 1996	Dry matter = 1132 + 1.33 N	0.00	0.40
St Pouange 1997	Dry matter = 1710 + 7.82 N	0.86	0.02
(b) Site and year	Regression equation	R^2	P
Lavaur 1996	Dry matter = 5648 + 31.0 N	0.85	0.02
Lavaur 1997	Dry matter = 2988 + 27.4 N	0.89	0.01
St Pouange 1996	Dry matter = 9100 + 32.0 N	0.63	0.07
St Pouange 1997	Dry matter = 5342 + 24.2 N	0.57	0.09

Table 11. Regression relationships between seed yield (kg ha⁻¹) and dry matter yield (kg ha⁻¹) (a) 14 days after spikelet initiation and (b) at the end of stem elongation.

(a) Site and year	Regression equation	R^2	P
Lavaur 1996	Seed yield = 788 + 0.080 DM	0.08	0.330
Lavaur 1997	Seed yield = 124 + 0.417 DM	0.79	0.028
St Pouange 1996	Seed yield = 406 + 0.890 DM	0.52	0.110
St Pouange 1997	Seed yield = 141 + 0.378 DM	0.98	0.001
(b) Site and year	Regression equation	R^2	P
Lavaur 1996	Seed yield = 940 + 0.016 DM	0.00	0.750
Lavaur 1997	Seed yield = 307 + 0.173 DM	0.98	0.001
St Pouange 1996	Seed yield = 633 + 0.075 DM	0.85	0.017
St Pouange 1997	Seed yield = 300 + 0.099 DM	0.81	0.023

Table 12. Regressions relationships between seed yield (kg ha⁻¹) and herbage N (%) (a) 14 days after spikelet initiation and (b) at the end of stem elongation.

(a) Site and year	Regression equation	R^2	P
Lavaur 1996	Seed yield = 1048 + 12.0 N%	0.00	0.940
Lavaur 1997	Seed yield = 467 + 342.0 N %	0.81	0.025
St Pouange 1996	Seed yield = 654 + 321.8 N%	0.67	0.060
St Pouange 1997	Seed yield = 135 + 483.0 N%	0.54	0.097
(b) Site and year	Regression equation	R^2	P
Lavaur 1996	Seed yield = 1119 - 34.0 N%	0.00	0.85
Lavaur 1997	Seed yield = 148 + 722 N%	0.53	0.10
St Pouange 1996	Seed yield = 877 + 558 N%	0.57	0.09
St Pouange 1997	Seed yield = 61 + 1410 N%	0.25	0.22

Table 13. Regressions relationships between seed yield (kg ha⁻¹) and herbage N content (kg ha⁻¹) (a) 14 days after spikelet initiation and (b) at the end of stem elongation.

| (a) Site and year	Regression equation	R^2	P
Lavaur 1996	Seed yield = 1006 + 0.78 Ncontent	0.00	0.720
Lavaur 1997	Seed yield = 672 + 8.97 Ncontent	0.85	0.016
St Pouange 1996	Seed yield = 847 + 19.9 Ncontent	0.86	0.015
St Pouange 1997	Seed yield = 530 + 11.2 Ncontent	0.83	0.021
(b) Site and year	Regression equation	R^2	P
Lavaur 1996	Seed yield = 1079 - 0.05 Ncontent	0.00	0.980
Lavaur 1997	Seed yield = 651 + 6.89 Ncontent	0.82	0.022
St Pouange 1996	Seed yield = 1084 + 3.12 Ncontent	0.74	0.039
St Pouange 1997	Seed yield = 523 + 9.94 Ncontent	0.76	0.034
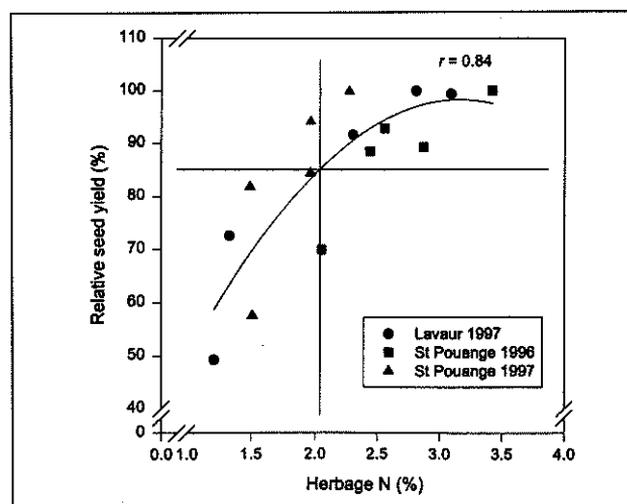
Fig. 2.   Relationship between herbage N concentration (%) fourteen days after spikelet initiation and perennial ryegrass seed yield relative to the maximum yield for each trial. Cate Nelson separation technique (Cate and Nelson, 1965) is used to show a critical threshold.
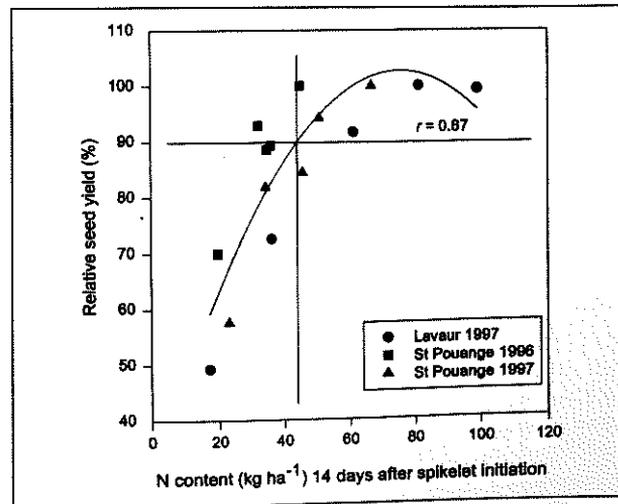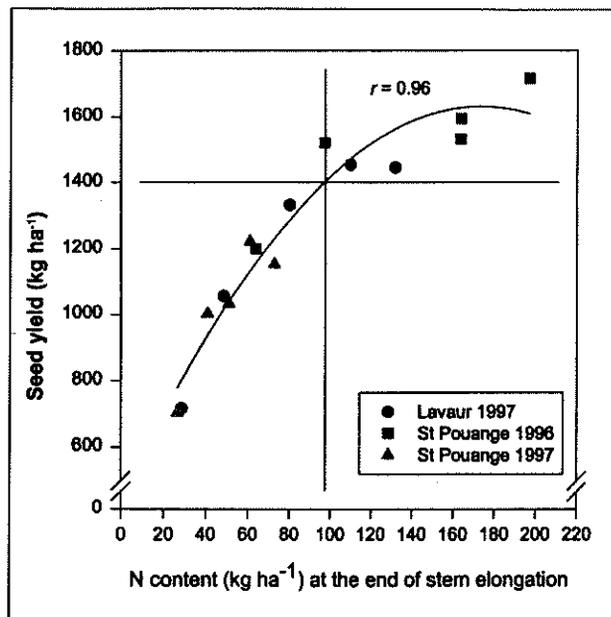
Fig. 3.   Relationship between herbage N content (kg ha⁻¹) fourteen days after spikelet initiation and perennial ryegrass seed yield relative to the maximum yield for each trial. Cate Nelson separation technique (Cate and Nelson, 1965) is used to show a critical threshold.

Fig. 4. Relationship between herbage N content (kg ha⁻¹) at the end of stem elongation and perennial ryegrass seed yield. Cate Nelson separation technique (Cate and Nelson, 1965) is used to show critical thresholds.

elongation was 0.77. The data showed (Fig. 3) a good correlation between N content and relative seed yield, independent of year or site ($r = 0.87$). By the end of stem elongation, N content can be used to predict actual seed yield independent of year and site; $r = 0.96$ (Fig. 4). A good relationship between seed yield and N content at the end of stem elongation across sites and years has been reported previously (Sicard, 1995). However, the later in the season, the less easy it is to change the outcome in terms of yield (Rowarth, unpublished data). The relationship between relative seed yield and N % and N content 14 days after spikelet initiation currently being explored is exciting in that the outcome (in terms of yield) has the potential to be manipulated according to subsequent availability of resources (e.g., water).

A standing N content of approximately 45 and 100 kg ha⁻¹ 14 days after spikelet initiation and at the end of stem elongation, respectively, was required to achieve a seed yield of 90 % relative seed yield (1400 kg ha⁻¹ for these experiments) (Cate and Nelson, 1965). The data presented by Rowarth et al. (1998) suggest that for cv. Grasslands Nui, a 1400 kg ha⁻¹ seed yield could be achieved from a standing N content of 50 kg ha⁻¹ 14 days after spikelet initiation. As discussed earlier, this difference may be genetic, or climatic; it is also relatively small.

CONCLUSIONS

Herbage N concentration 14 days after spikelet initiation can be used to estimate relative seed yield in cv. Palmer. Nitrogen concentration required for 80 % relative seed yield was lower than that required for cv. Grasslands Nui, which may reflect cultivar, form of fertiliser, or the fact that seed yields in this research were not as high as reported for cv. Grasslands Nui (Rowarth et al., 1998). Improved predictions were obtained by considering N content 14 days after spikelet initiation. The similarity in required N content to achieve 1400 kg ha⁻¹ seed yield reported for cv. Palmer and for cv. Grasslands Nui is extremely promising in the development of a response model for nitrogen and ryegrass around the globe.

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