Evaluation of the soil nitrogen supply system – opportunities for further improvements to the nitrogen economy of the GB potato crop

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Summary

This interim report covers the second year of the British Potato Council funded project investigating the reliability of soil analysis in determining N fertilizer recommendations for potato crops. In 2002, field experiments on differing soil types and using contrasting varieties tested the accuracy of N recommendations made using the field assessment method with those based on measurement of soil mineral N in the spring.

Collectively, the 2001 and 2002 data show that, at present, the soil analysis method is less reliable than the field assessment method. Until further work has identified the causes of this variation, use of soil nitrogen supply analysis should be avoided. The field assessment method, whilst more reliable than the soil nitrogen supply analysis method, systematically overestimated the amount of N required for the optimal growth and yield of potato crops. It is therefore recommended, that growers using the field assessment method use the smaller value of the range of N recommendations given in the 7th edition of Reference Book 209.   This would result in an average reduction in N use by about 20-30 kg N/ha without detrimental effect on marketable yield.

In order to better understand the failings of the soil mineral nitrogen analysis approach, experiments in 2001 and 2002 tested the effects of timing of soil cultivations on mineralization of N from soil organic matter. These results show that N is mineralized faster when cultivations are done in soils that are warm and moist. Furthermore, the timing of soil sampling relative to the sequence of cultivations and environmental conditions will determine the quantity of N in the soil sample and, in consequence, how much N fertilizer would be recommended. Work will continue in 2003 to better understand the factors controlling N mineralization so that a reliable protocol for the soil mineral nitrogen analysis method may be developed.

A further series of experiments in 2001 and 2002 used contrasting varieties, plant spacings and N application rates to generate crop canopies of differing structure and persistence. The purpose of these experiments was to better understand how these factors interact and how they effect yield formation. To date the experiments have shown that the amount of N associated with the production of units of leaf area is variable and since a consistent amount of N cannot be associated with a leaf area index of a certain size this will limit the usefulness of a “canopy management” approach to guide N application to potato crops. Analysis of these experiments has also shown that branches and tubers compete with each other for N taken up by the

mainstem and that large branch N uptakes are generally associated with slow tuber N uptake and slow tuber bulking. Using data from Potato Marketing Board supported experiments done in 1992-1995, analysis has shown that N uptake by the crop occurs in two phases: an initial rapid phase and slower phase. During the initial phase, the rate of N uptake is proportional to the amount of radiation intercepted by the crop, however, in the second phase radiation may be absorbed without any significant N uptake.   These data also suggest that the change from the rapid to the slow phase occurs at similar time in each season but, at present, it is not clear whether this was due to an environmental signal (i.e. day length) or a physiological one (i.e. flowering). Collectively, these data suggest that canopy persistence and yield potential may be determined relatively early in the season. If further work planned for 2003 confirms this hypothesis, diagnostic methods may be devised that will allow likely canopy persistence to predicted early in the season and allow improvements to current N recommendation systems.

Using measurements of soil mineral nitrogen to make N fertilizer recommendations for potato crops

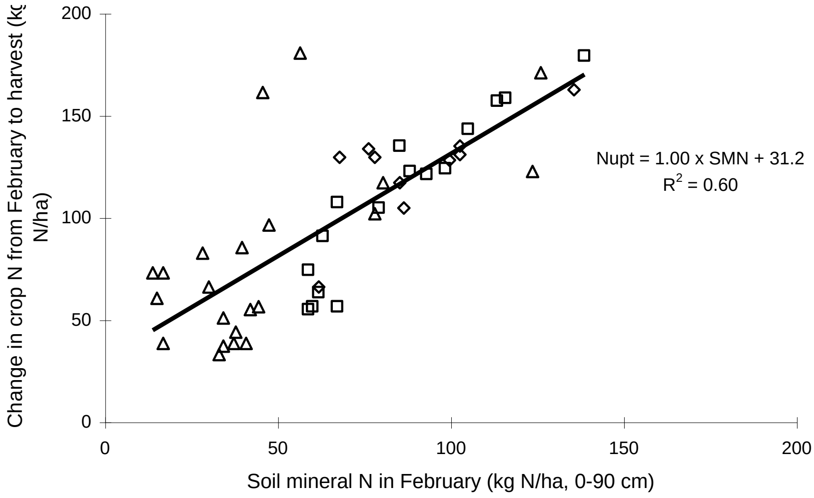
General introduction to the programme

In 2000, the seventh edition of *Fertilizer Recommendations for Agricultural and Horticultural Crops (Reference Book 209)* was published and for potatoes the N recommendations were substantially revised to bring them into line with the results of ongoing research. In the latest edition of *Reference Book 209*, the N index system was replaced with the soil nitrogen supply (SNS) Index. For cereals and other arable crops, there are seven (0-6) SNS indices, although for potatoes these have been amalgamated into three. There are two methods to estimate a field's SNS Index. The first is the "field assessment method" which is essentially the same as the old N Index system and uses information on soil type and previous cropping to estimate the quantity of N supplied by the soil. From this estimate, the amount of fertilizer N needed may be calculated. The second method is the "SNS measurement" approach and this uses direct measurement of the amount of soil mineral N (SMN) and crop N in the spring. The basis for this approach was that earlier work on cereals and oilseed rape had shown there was a reasonably close relationship between the amount of N taken up by the crop in the absence of fertilizer and the SNS within the crop rooting depth. An example of this relationship is shown in Figure 1. Thus, for cereals and oil seed rape, the SNS index was defined as:

SNS index = SMN (kg/ha, 0-90 cm) + Crop N (kg/ha) + N mineralization during season (kg/ha)

Reference Book 209 suggests that on soil with low organic matter content the quantity of N mineralized post sampling is negligible and may be omitted. As a consequence, for cereals and oilseed rape, a point measurement of soil and crop N in spring gives the SNS Index from which the N fertilizer requirement may be calculated. The SMN analysis method was included in the N recommendations for potatoes even though "there has been little specific research or practical experience on the use of this approach in potatoes". In 2001, the British Potato Council funded a programme of work at Cambridge University Farm to test whether the SMN analysis method could be used reliably on the potato crop.

Figure 1. **Relationship between crop N uptake between sampling in February and final harvest and soil mineral Nitrogen in February for winter wheat crops grown in 1993 (◊), 1994 (□) and 1995 (Δ). Adapted from Stokes *et al.* (1998)**



Results from 2001 have been presented in the CUPGRA Annual Report for 2001 (pages 49-74) and in an interim BPC Report (Project Report 2002/10). In this report, the results for individual sites will be discussed separately and then combined with 2001 data in order to make some general inferences about the utility of the SMN analysis system within the potato crop.

Experiments in 2002

In 2002, experiments were done on eight sites that tested various components of the SNS analysis system. Most experiments attempted to relate measurements of SMN made in the spring to estimates of optimum N rate made at final harvest. A cultivation experiment and a Variety*Nitrogen*Planting Density experiment were designed to gain a better understanding of fundamental processes implicit in current N recommendation systems. Field, crop and management details for all experiments are given in Table 1.

Acknowledgements

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Table 1. Details of soil, previous cropping, organic manure usage, seed, planting and final harvest dates for SNS experiments in 2002

	Bransford	Llanwarne	Wrentham	Taunton	Thetford	CUF N*V*D	CUF N*V	CUF Cult
O.S. Grid Reference	SO 808526	SO 496295	TG 450905	ST 164240	TL 967886	TL 427602	TL 427602	TL 425605
pH	7.4	6.3	6.1	6.9	7.8	7.3	7.3	7.2
Sand (%)	19	46	86	32	85	70	70	80
Silt (%)	44	32	8	35	10	19	19	13
Clay (%)	37	22	5	33	5	11	11	7
Organic matter (%)	5.7	10.3	6.2	6.1	1.7	5.4	5.4	4.6
Soil Texture	Clay	Clay loam	Loamy sand	Clay loam	Loamy sand	Sandy loam	Sandy loam	Loamy Sand
mg P/l and Index	15 1	39 3	50 4	74 5	65 4	78 5	78 5	99 5
mg K/l and Index	240 3	46 0	78 1	330 3	152 2	365 3	365 3	559 4
mg Mg/l and Index	342 5	108 3	43 1	244 4	49 1	79 2	79 2	93 2
Previous crop	Spring rape	Grass (7 year)	Set aside	Winter wheat	Winter barley	Winter barley	Winter barley	Fallow
Organic manures within previous year	7.5t/ha poultry manure	12.5 t/ha poultry manure	None	None	25 t/ha poultry manure	None	None	None
Variety 1	Estima	Maris Peer	Maris Peer	L Rosetta	L Rosetta	Estima	Estima	Cara
Grade Count/50 kg	UC 1025	SE2 1286	SE2 1243	SE2 2410	SE2 2410	E2 3290	E2 1355	SE2 2896
Variety 2				R Burbank	R Burbank	Cara	Cara	
Grade Count/50 kg				SE2 2001	SE2 2001	SE2 2896	SE2 1237	
Variety 3							Hermes	
Grade Count/50 kg							E1 1061	
Variety 4							Courlan	
Grade Count/50 kg							E1 1309	
Planting date	19 April	10 April	26 April	18 April	22 April	3 April	5 April	P1 25 April P2 29 May P3 11 July
Defoliation date	29 August	15 & 25 July	5 July	-	9/13 August	-	-	-
Harvest date	17 September	1 August	24 July	16 September	29 August	9 October	3/4 October	20 September

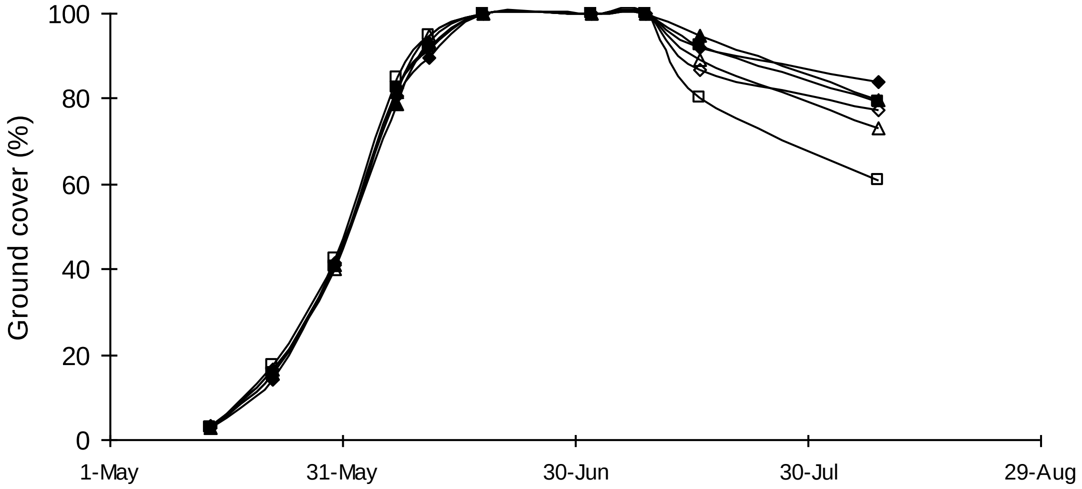
Effect of N application rate on yield of Estima at Bransford, Worcestershire

This experiment was done at Bransford Court on land rented by Cobrey Farms. The experiment tested six rates of N (0-300 kg N/ha in 60 kg N/ha increments) and each N treatment was replicated five times and allocated at random into blocks. Each plot was 4 m long by 4 rows (3.66 m) wide. Estima was planted by hand on 19 April. A single, hand harvest (2.74 m^2) was taken on 17 September.

Emergence and ground covers

The crop reached 50 % by the 5/6 May and all treatments attained *c.* 100 % emergence by 14 May. Nitrogen fertilizer had no significant effect on rate of emergence. Nitrogen fertilizer had no effect on the initial expansion of ground cover and all treatments attained 100 % ground cover (Figure 2). Crop monitoring during the season showed that blackleg affected some plants and this resulted in 'gappy' canopies in many plots. In addition, some plots were found to be lodging from 16 July onwards. The incidence of blackleg and lodging were not associated with N application rate. All treatments had started to senesce by 16 July, the rate of senescence slowing with increasing N applications. The crop was desiccated on 29 August.

Figure 2. Effect of N application rate on ground cover of Estima at Bransford 2002. Key: 0 (□), 60 (∆), 120 (◊), 180 (■), 240 (▲) and 300 (♦) kg N/ha.



Yields and N uptake

When averaged over all treatments, the mean stem population was 125 000/ha (Table 2). The number of stems was significantly affected by N application rate, but the differences were randomly distributed between rates and were most likely a result of blackleg. On average, each stem produced 3.9 tubers >10 mm and the tuber population was 481 000/ha. Nitrogen application rate had no effect on these variates. This is expected since N application rate had no effect on canopy size, and in turn, radiation absorption during the period of tuber initiation. The average tuber fresh weight yield >10 mm was 73 t/ha and when the standard error of yield was taken into account the optimum N application rate was *c.* 60 kg N/ha. Tuber DM concentration was significantly affected by N application rate and tended to decrease as the N application rate increased. On average, the mean tuber size (mu) was 66 mm and reached a maximum of *c.* 67 mm when 60 kg N/ha was applied. Nitrogen application rate had no significant effect on the N concentration in tuber DM which averaged 1.57 % and thus variation in tuber N uptake was mainly due to variation in tuber DM yield.

Soil mineral nitrogen

A measurement of soil mineral nitrogen (SMN) on 22 March, before primary cultivations had taken place, showed that there was *c.* 47 kg N/ha in the top 90 cm of soil (Table 3). A soil sample taken at planting showed that the amount of SMN had increased by *c.* 300 kg N/ha to 345 kg N/ha. Some of this increase was undoubtedly due to the application of 7.5 t/ha of poultry manure in the intervening period. The composted poultry manure was applied on 11 April and incorporated on 13 April. Using the MANNER decision support system (Chambers *et al.* 1999), the default amount of total N in the manure was estimated to be 16 kg N/t FW and the proportion of the total available to the potato crop was 47 %, thus, the poultry manure would have supplied *c.* 56 kg N/ha to the crop. The unexplained increase of *c.* 290 kg N/ha presumably arose from mineralization of organic matter caused by the cultivations used to form the seedbed. The effect of cultivations on soil mineralization will be discussed later in this report. At harvest, SMN in the 0N treatments was 119 kg N/ha, a decrease of 226 kg N/ha, which can be attributed to crop N uptake. The amount of SMN in soils receiving 120 kg N/ha was 230 kg N/ha, suggesting that little of the N fertilizer was used by the crop.

Table 2. Effect of N application rate on yield, grading and N uptake of Estima, Bransford. Harvested 17 September 2002

		N application rate (kg N/ha)						
	Mean	0	60	120	180	240	300	S.E.
Tubers with blackleg (000/ha)	10.9	14.6	8.0	14.6	8.0	6.6	13.8	4.21
Total number of stems (000/ha)	125	127	117	117	126	152	110	8.7
Number of tubers >10 mm (000/ha)	481	477	463	478	487	515	467	27.3
Number of tubers >10 mm per stem	3.9	3.8	4.0	4.2	3.9	3.4	4.3	0.24
Tuber FW yield >10 mm (t/ha)	73.0	62.5	76.1	67.1	71.6	79.9	80.4	4.43
Tuber DM concentration (%)	19.6	20.4	20.3	18.8	19.9	20.2	17.9	0.50
Tuber DW yield >10 mm (t/ha)	14.3	12.8	15.5	12.7	14.3	16.2	14.4	1.04
mu (mm)	66	63	67	65	68	66	69	1.1
sigma (mm)	16.3	15.1	16.0	16.5	17.5	15.6	17.0	0.50
Coefficient of variation (%)	24.5	24.1	23.8	25.3	25.8	23.6	24.6	0.58
Yield in 40-80 mm grade (% of total)	74	80	74	75	70	76	70	2.1
Tuber N concentration (%)	1.57	1.47	1.47	1.43	1.62	1.73	1.71	0.095
Nitrogen uptake by tubers (kg N/ha)	226	187	228	180	232	281	246	21.9

Table 3. Soil mineral nitrogen at Bransford (kg N/ha)

Date	N applied (kg N/ha)	0-30 cm	30-60 cm	60-90 cm	0-90 cm
22 March	0	19	16	12	47
	S.E.M.	1.8	0.9	1.0	3.0
19 April	0	214	101	31	345
	S.E.M.	34.1	20.1	2.7	41.5
17 September	0	71	33	15	119
	120	118	65	47	230
	S.E.	10.7	12.7	8.2	28.2

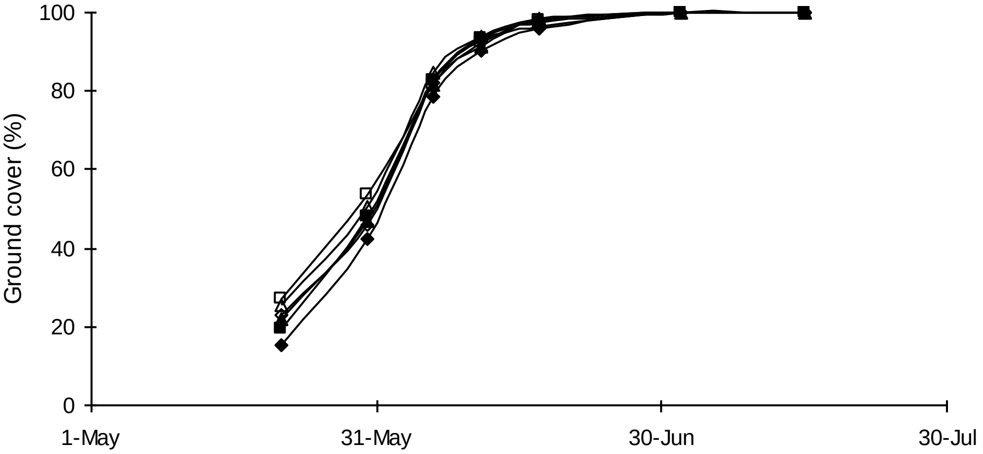
Effect of N applications on yield of Maris Peer at Llanwarne

This experiment was done at Llanwarne on land rented by Cobrey Farms used to produce Maris Peer for the punnet market. The experiment tested six rates of N (0-300 kg N/ha in 60 kg N/ha increments) with each treatment replicated five times and allocated at random to blocks. Each plot was 4 m long and 2 beds (3.66 m) wide, with three rows per bed. Maris Peer was planted by hand on 10 April and a single, hand harvest (2.29 m^2) was taken on 1 August.

Emergence and ground covers

The crop attained 50 % emergence by 12 May and increasing the N application significantly decreased the rate of emergence, however, most plots had reached 100 % emergence by 21 May. Due to the effect of N on emergence, ground covers were reduced by N until the end of May. All treatments achieved 100 % ground cover and these were maintained until the crop was defoliated on 15 July (Figure 3).

Figure 3. **Effect of N application rate on ground cover of Maris Peer at Llanwarne 2002. Key: 0 (□), 60 (∆), 120 (◊), 180 (■), 240 (▲) and 300 (♦) kg N/ha**



Yields and N uptake

Nitrogen had no significant effect on stem population, the number of tubers >10 mm per stem and, therefore, the number of tubers (Table 4). When averaged over all treatments, the average tuber FW yield was 30 t/ha. Nitrogen fertilizer had no significant effect on tuber FW yield and therefore, the optimum N application rate was zero. Tuber DM concentration decreased from

18.3 % when no N was applied to 16.4 % when 300 kg N/ha was applied. The largest tuber dry matter yields (6.2 t/ha) were achieved in the absence of N fertilizer. When averaged over the N treatments, the mean tuber size (mu) was 39 mm and N application rate had no significant effect on this variate.   As a consequence of the relatively large mu, the proportion of the crop in the 25 to 38 mm size grade was only 39 %, with a large proportion of tubers being oversize. The average tuber N concentration was 1.97 % and the average tuber N uptake was 102 kg N/ha. Neither of these two variates was affected by the N treatments.

Soil mineral nitrogen

An initial soil sampling, taken on 11 March before any cultivations, showed that there was *c.* 50 kg N/ha in the top 90 cm (Table 5). As a result of mineralization of crop residues of the previous grass crop and application of 12.5 t/ha of poultry manure, the amount of SMN had increased to *c.* 400 kg N/ha at planting on 10 April. Because of the short season (which limited N uptake), SMN residues at harvest on 1 August were *c.* 250 kg N/ha when no N had been applied and *c.* 400 kg N/ha when 120 kg N/ha had been applied.

Table 4. Effect of N application rate on yield, grading and N uptake of Maris Peer, Llanwarne Grass. Harvested 1 August 2002

		N application rate (kg N/ha)						
	Mean	0	60	120	180	240	300	S.E.
Total number of stems (000/ha)	196	206	200	186	186	205	191	6.6
Number of tubers >10 mm (000/ha)	816	895	850	834	735	796	783	34.4
Number of tubers >10 mm per stem	4.2	4.4	4.3	4.5	4.0	3.9	4.2	0.17
Tuber FW yield >10 mm (t/ha)	30.1	33.6	30.1	31.8	27.8	29.1	27.9	1.62
Tuber DM concentration (%)	17.3	18.3	17.3	17.4	17.3	17.0	16.4	0.34
Tuber DW yield >10 mm (t/ha)	5.22	6.15	5.22	5.55	4.85	4.96	4.60	0.34
mu (mm)	39	40	39	40	39	39	39	0.4
sigma (mm)	8.3	8.2	8.0	8.2	8.1	8.5	8.6	0.17
Coefficient of variation (%)	21	21	21	21	20	22	22	0.5
Percent of total yield in 25-38 mm grade	39	38	41	38	40	40	39	1.6
Tuber N concentration (%)	1.97	1.82	1.81	2.00	1.99	2.01	2.15	0.111
Nitrogen uptake by tubers (kg N/ha)	102	111	94	110	96	100	99	7.5

Table 5. Soil mineral nitrogen (kg N/ha) at Llanwarne Grass, 2002

Date	N applied (kg N/ha)	0-30 cm	30-60 cm	60-90 cm	0-90 cm
11 March	0	26	14	11	50
	S.E.M.	4.0	0.9	1.5	4.1
10 April	0	257	106	34	397
	S.E.M.	33.5	37.8	12.8	78.4
1 August	0	114	73	66	253
	120	200	110	98	409
	S.E.	33.0	25.2	20.3	73.2

Effect of N applications on yield of Maris Peer at Wrentham

This experiment was done on a loamy sand textured soil at Wrentham, on land used by Wrentham Vegetables for the production of Maris Peer for the punnet market. Due to limitations of space, this experiment tested five rates of N (0-160 kg N/ha in 40 kg increments) with each treatment replicated only three times and allocated at random to blocks. Each plot was 4 m long and two beds (3.66 m) wide with three rows per bed. Maris Peer was planted by hand on 26 April and the crop was harvested by hand on 24 July. The effects of N on skin set were assessed one day after harvest. Twenty five tubers from each plot were selected at random and placed in a scuffing barrel. The barrel was then rotated for 30 seconds at 40 revolutions per minute and the percentage of skin removed from each tuber was estimated by eye.

Yields and N uptake

Nitrogen application rate had no significant effect on number of stems, number of tubers per stem or total number of tubers (Table 6). Tuber FW yield averaged 27.7 t/ha and was not affected by N application therefore, the optimum was 0 kg N/ha. Tuber DM concentration averaged 16.8 % and was unaffected by N fertilizer. Nitrogen application rate had no significant effect on mean tuber size nor the proportion of total yield within 25-38 mm size grade. Applying 160 kg N/ha resulted in a statistically significant increase in tuber N concentration, but overall, the amount of N removed in tubers was unaffected by N application rate. Increasing the N application rate from the optimum (0 kg N/ha) to 120 or 160 kg N/ha doubled the amount of skin removed by the scuffing barrel. This result suggests that increasing the N supply to the crop will delay skin-set, however, since there was only one harvest we cannot reliably quantify this delay.

Soil mineral nitrogen

At the initial soil sampling in mid-March, the soil contained *c.* 40 kg N/ha whilst at planting at the end of April this had increased to *c.* 90 kg N/ha. At harvest in July, the soil contained *c.* 80 kg N/ha irrespective of whether 0 or 80 kg N/ha had been applied to the crop (Table 7).

Table 6. Effect of N application rate on yield, grading and N uptake of Maris Peer, Wrentham. Harvested 24 July 2002

		N application rate (kg N/ha)					
	Mean	0	40	80	120	160	S.E.
Total number of stems (000/ha)	174	164	182	174	186	165	6.8
Number of tubers >15 mm (000/ha)	934	856	1017	948	1010	841	54.0
Number of tubers per stem	5.4	5.2	5.6	5.4	5.5	5.1	0.49
Tuber FW yield >15 mm (t/ha)	27.7	25.4	29.4	27.5	29.7	26.3	1.92
Tuber DM concentration (%)	16.8	16.7	17.3	16.8	16.7	16.3	0.33
Tuber DW yield >15 mm (t/ha)	4.65	4.24	5.11	4.61	4.99	4.28	0.363
mu (mm)	35.3	35.3	35.2	35.1	35.2	35.6	0.36
sigma (mm)	6.0	6.4	6.0	6.1	5.8	5.7	0.25
Coefficient of variation (%)	16.9	18.0	17.1	17.3	16.3	15.9	0.75
Percent of total yield in 25-38 mm grade	63	61	64	64	65	63	2.1
Tuber N concentration (%)	1.06	0.86	0.95	1.08	0.95	1.46	0.105
Tuber nitrogen uptake (kg N/ha)	49	36	48	49	48	62	5.4
Scuffing, (% of tuber surface removed)	46	30	32	49	63	58	5.0

Table 7. Soil mineral nitrogen (kg N/ha) at Wrentham

Date	N applied (kg N/ha)	0-30 cm	30-60 cm	60-90 cm	0-90 cm
14 March	0	19	12	7	38
	S.E.M.	2.3	0.8	0.6	2.4
26 April	0	38	32	18	88
	S.E.M.	0.6	2.3	0.8	3.2
24 July	0	31	28	25	84
	80	30	31	22	83
	S.E.	2.4	2.5	4.4	3.7

Effect of N applications on yield of Lady Rosetta and Russet Burbank at WO & PO Jolly, Thetford

This experiment was done on a loamy sand textured soil near Thetford. The experimental design comprised all combinations of six N application rates (0 to 200 kg N/ha in 40 kg N/ha increments) and two varieties (Lady Rosetta and Russet Burbank). Each treatment combination was replicated four times and allocated at random into blocks. Each plot was 4 m long and 3.66 m (4 rows) wide. The experiment was planted by hand at 25 cm spacing on 22 April and a single harvest was taken (2.74 m^2) on 29 August. The experiment was defoliated earlier than anticipated (9 August) due to blight being found in the experiment.

Emergence and ground covers

The time taken to 50 % emergence was affected by both variety and N application rate (Table 8). On average, Lady Rosetta took *c.* 3 days longer to achieve 50 % emergence than Russet Burbank. Increasing the N application rate from 0 to 200 kg N/ha delayed 50 % emergence by *c.* 4 days. The patterns of ground cover development for Lady Rosetta and Russet Burbank are shown in Figure 4. As N delayed emergence, ground covers early in the season were smaller where large rates of N had been applied. However, irrespective of the N application rate, both varieties eventually achieved 100 % ground cover. The canopies of Lady Rosetta that received 0 or 40 kg N/ha had started to decrease before the crop was defoliated at the beginning of August. There was no evidence of a decline in ground cover in Russet Burbank.

Yields and N uptake

Lady Rosetta produced fewer stems than Russet Burbank and there was evidence that increasing the N application rate was associated with a small but significant decrease in the stem population (Table 8). The number of tubers per stem was larger in Lady Rosetta than in Russet Burbank. Nitrogen application rate had a significant effect on the number of tubers produced per stem in both varieties and this effect was most noticeable in Russet Burbank. More tubers per stem were produced when the crops received 80-120 kg N/ha than when they received either 0 or 200 kg N/ha.

The combined effect of N on number of stems and number of tubers per stem meant that, for both varieties, the largest number of tubers was found in the 80 kg N/ha treatment. Due to the shorter than anticipated season, overall tuber yields were small. For Lady Rosetta, the optimum N rate was *c.* 100 kg N/ha. For Russet Burbank the optimum N application was zero with yield being reduced at the highest rates of N.

Tuber DM concentration was greater in Lady Rosetta than in Russet Burbank and increasing the N application from 0 to 200 kg N/ha reduced tuber DM from 24.1 to 21.4 %. At harvest, the tubers of Lady Rosetta contained, on average 93 kg N/ha compared with only 65 kg N/ha in Russet Burbank. Increasing, the amount of N applied from 0 to 200 kg N/ha increased the average N removal from 58 to 92 kg N/ha.

Soil mineral nitrogen

At planting on 22 April there was an average of 177 kg N/ha in the top 90 cm of soil (Table 9). There was some evidence that the amount of available N was larger in the Russet Burbank plots, however this difference was not statistically different. At harvest on 29 August, there was an average of 76 kg N/ha and this amount was independent of variety or N applications up to 120 kg N/ha.

Table 8. Effect of variety and N application rate on emergence, number of stems and tubers, tuber yield and dry matter concentration at Thetford, 2002

			Nitrogen application rate (kg N/ha)						
		Mean	0	40	80	120	160	200	S.E.
Days from planting to 50 % emergence	Lady Rosetta	34.1	32.6	32.8	33.8	34.4	34.9	36.3	0.41
	Russet Burbank	31.7	30.2	30.7	30.8	32.3	32.6	33.8	
Integrated ground cover (% days)	Lady Rosetta	4918	4739	4984	4954	5023	4851	4928	72.9
	Russet Burbank	5366	5366	5450	5183	5253	5185	5107	
Number of stems (000/ha)	Lady Rosetta	84	88	88	93	78	78	81	5.53
	Russet Burbank	94	107	101	89	99	82	87	
Number of tubers >10 mm per stem	Lady Rosetta	4.6	4.4	4.4	4.6	4.8	4.7	4.6	0.22
	Russet Burbank	4.2	3.7	4.2	5.1	4.4	4.0	3.8	
Number of tubers >10 mm (000/ha)	Lady Rosetta	383	381	390	423	371	366	369	26.2
	Russet Burbank	392	386	427	445	435	329	331	
Tuber FW yield >10 mm (t/ha)	Lady Rosetta	34.4	30.0	29.2	34.9	36.1	35.5	40.4	2.23
	Russet Burbank	29.5	31.7	31.2	33.4	30.5	26.7	23.6	
Tuber dry matter concentration (%)	Lady Rosetta	24.6	25.6	25.7	25.2	24.0	24.2	23.1	0.46
	Russet Burbank	21.7	22.6	22.8	22.3	22.5	20.3	19.7	
Tuber DW yield >10 mm (t/ha)	Lady Rosetta	8.42	7.67	7.47	8.76	8.65	8.59	9.35	0.511
	Russet Burbank	6.44	7.13	7.08	7.44	6.88	5.40	4.69	
Mean tuber size, mu (mm)	Lady Rosetta	54	50	50	52	55	56	58	1.2
	Russet Burbank	46	46	45	47	46	47	45	
Percentage of yield in 40-80 mm grade	Lady Rosetta	92	91	89	92	94	92	93	2.9
	Russet Burbank	76	75	74	78	77	78	73	
Tuber nitrogen uptake (kg N/ha)	Lady Rosetta	93	61	68	90	112	102	127	7.9
	Russet Burbank	65	55	65	71	65	72	58	

Figure 4. **Effect of N application rate on ground cover of Lady Rosetta and Russet Burbank at Thetford. Key: 0 (□), 40 (Δ), 80 (◊), 120 (■), 160 (▲) and 200 (♦) kg N/ha**

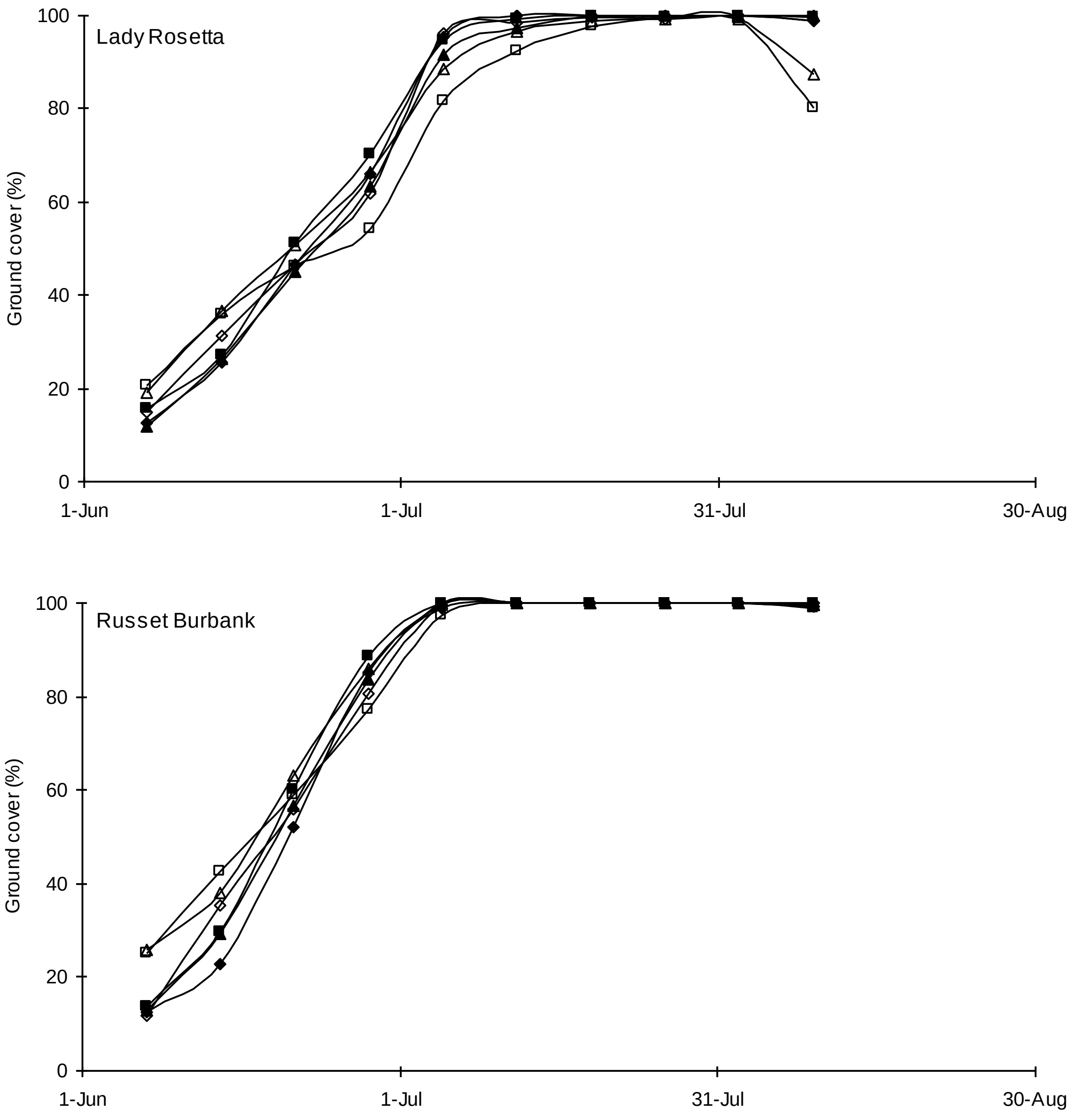


Table 9. **Soil mineral nitrogen at Thetford (kg N/ha)**

Date	Variety	N applied (kg N/ha)	0-30 cm	30-60 cm	60-90 cm	0-90 cm
22 April	Lady Rosetta	0	43	58	42	143
	Russet Burbank	0	60	85	65	210
		S.E.	11.0	21.4	16.6	45.1
29 August	Lady Rosetta	0	31	28	9	68
	Russet Burbank	0	30	29	11	70
	Lady Rosetta	120	37	27	32	95
	Russet Burbank	120	33	27	12	72
		S.E.	3.7	3.8	6.9	10.4

Effect of N applications on yield of Lady Rosetta and Russet Burbank at R J King & Sons, Taunton

This experiment was done on a clay loam textured soil near Taunton, Somerset. The experimental design comprised all combinations of five N application rates (0 to 200 kg N/ha in 50 kg N/ha increments) and two varieties (Lady Rosetta and Russet Burbank). Each treatment combination was replicated four times and allocated at random into blocks. Each plot was 3.52 m long and 3.45 m (4 rows) wide. The experiment was planted by hand at 22 cm spacing on 18 April and a single harvest was taken (2.28 m^2) on 16 September. On 10 April, 100 kg N/ha as urea was applied by accident over the entire experimental area, thus increasing the soil N supply. For the purpose of subsequent analysis, the N applications were treated as a split-dose – a uniform 100 kg N/ha applied pre-planting and a variable amount (0-200 kg N/ha) applied at planting.

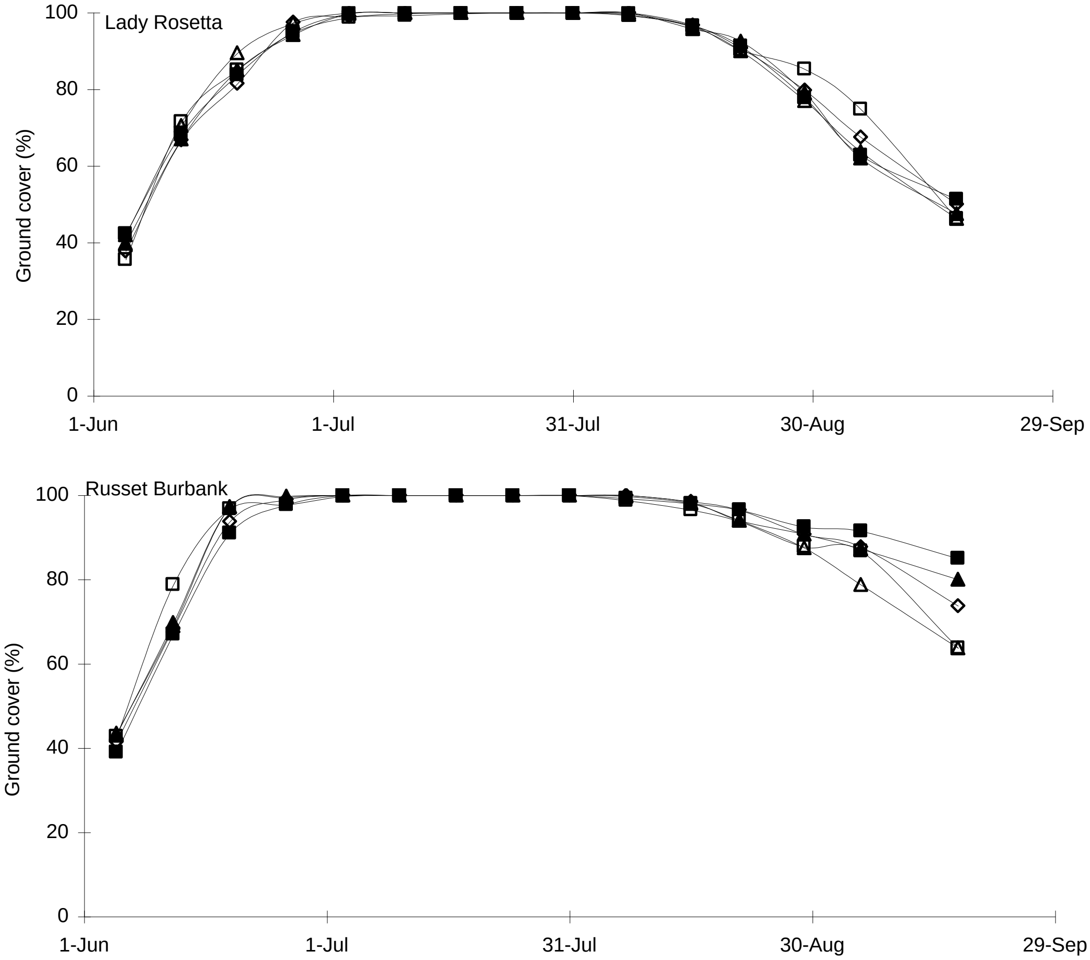
Emergence and ground covers

When averaged over the N treatments, Russet Burbank attained 50 % emergence *c.* 31 DAP compared with *c.* 35 DAP for Lady Rosetta. Nitrogen application rate had no significant effect on emergence and all treatments attained 100 % emergence. The patterns of ground cover development for the crops of Lady Rosetta and Russet Burbank are shown in Figure 5. Generally, there were few differences between treatments during the early phases of canopy expansion and even in the absence of N fertilizer, both varieties achieved 100 % ground cover and maintained complete cover for several weeks. Irrespective of N application rate, the canopies of Lady Rosetta and Russet Burbank started to decline at the beginning of August. However, this decrease in ground cover was more rapid in Lady Rosetta than in Russet Burbank. Integration of the ground cover curves showed that Russet Burbank had a slightly larger canopy than Lady Rosetta but the effects of N fertilizer were small and not statistically significant (Table 10).

Yields and N uptake

Russet Burbank had a larger stem population than Lady Rosetta and for both varieties, the stem population was not affected by N application rate (Table 10). However, since Lady Rosetta produced more tubers per stem than Russet Burbank, both varieties had similar tuber populations at final harvest and for both varieties the tuber population was independent of N application rate.

Figure 5. Effect of N application rate at planting on ground cover of Lady Rosetta and Russet Burbank at Taunton. Key: 0 (□), 50 (△), 100 (◊), 150 (■) and 200 (▲) kg N/ha



The average tuber FW yield for Lady Rosetta was 64 t/ha compared with 71 t/ha for Russet Burbank. Nitrogen at planting had no significant effect on yield and thus the optimum N application rate for both varieties was ≤ 100 kg N/ha (i.e. the amount applied pre-planting). There was some evidence that as the amount of applied at planting increased from 0 to 200 kg N/ha the yields of both Lady Rosetta and Russet Burbank decreased, however, this effect was not statistically significant.

The tubers of Lady Rosetta had a significantly greater DM concentration than those of Russet Burbank and for both varieties increasing the amount of N applied at planting from 0 to 200 kg N/ha decreased the tuber DM concentration from 25.5 to 22.9 %. The concentration of N in the tubers increased as the amount of fertilizer applied increased, however, there were no varietal differences. Tuber N uptake averaged 232 kg N/ha and was not significantly affected by variety or N rate.

Table 10. Effect of variety and N application rate at planting on number of stems and tubers, tuber yield, dry matter concentration, grading characteristics, nitrogen concentration and uptake at Taunton 2002

			Nitrogen applied at planting (kg N/ha)					
		Mean	0	50	100	150	200	S.E.
Integrated ground cover (% days)	Lady Rosetta	9301	9365	9296	9285	9306	9253	138.9
	Russet Burbank	9907	9883	9785	9919	9957	9991	
Number of stems (000/ha)	Lady Rosetta	96	110	101	94	94	90	9.0
	Russet Burbank	114	126	114	114	115	102	
Number of tubers >10 mm per stem	Lady Rosetta	5.1	4.5	5.0	5.1	6.0	5.0	0.39
	Russet Burbank	4.4	4.5	4.2	4.5	4.1	4.6	
Number of tubers >10 mm (000/ha)	Lady Rosetta	482	492	498	483	483	454	29.5
	Russet Burbank	493	548	482	500	476	459	
Tuber FW yield >10 mm (t/ha)	Lady Rosetta	64.0	66.7	70.7	64.1	62.7	56.0	4.96
	Russet Burbank	71.2	80.6	70.2	71.0	66.4	68.1	
Tuber dry matter concentration (%)	Lady Rosetta	25.1	26.3	24.9	25.5	24.8	24.1	0.58
	Russet Burbank	22.9	24.8	22.7	22.8	22.4	21.7	
Tuber DW yield >10 mm (t/ha)	Lady Rosetta	16.1	17.5	17.6	16.4	15.5	13.5	1.29
	Russet Burbank	16.4	20.0	15.9	16.2	14.9	14.8	
Mean tuber size, mu (mm)	Lady Rosetta	64	63	64	63	63	63	1.1
	Russet Burbank	58	59	57	59	59	59	
Percentage of yield in 40-80 mm grade	Lady Rosetta	86	88	87	86	85	86	1.7
	Russet Burbank	90	91	93	90	88	88	
Tuber N concentration (%)	Lady Rosetta	1.49	1.30	1.43	1.39	1.55	1.79	0.074
	Russet Burbank	1.43	1.08	1.44	1.53	1.41	1.71	
Tuber N uptake (kg N/ha)	Lady Rosetta	236	226	248	225	238	242	13.9
	Russet Burbank	228	210	227	246	208	247	

Soil mineral nitrogen

An initial soil sampling, on stubble from the previous crop, showed there was *c.* 65 kg N/ha in the top 90 cm of soil (Table 11). At planting, on 18 April, the amount of soil mineral N had increased to *c.* 700 kg N/ha. This large increase was due, in part, to the 100 kg N/ha applied as urea on 10 April and, possibly, to the effect of cultivations on mineralization of N from the soil organic matter. However, these factors cannot fully explain the large increase in soil mineral N between the first and second samplings. Recent work at the Scottish Crop Research Institute (Wheatley *et al.* 2001) has shown that rates of nitrification (a component of the N mineralization process involving the conversion of ammonium to nitrite) may be increased by the addition of small amounts of simple inorganic and organic compounds to soils. Whilst the studies at SCRI are not directly applicable to this experiment, it is possible that the addition of 100 kg N/ha as urea stimulated the microbes involved in N mineralization to release a large amount of nitrate from the soil organic matter.

Table 11. Soil mineral nitrogen at Taunton (kg N/ha)

Date	Variety	N applied (kg N/ha)	0-30 cm	30-60 cm	60-90 cm	0-90 cm or 0-60 cm
21 March	Stubble	0	17	23	23	64
		S.E.M.	1.1	11.4	10.7	21.7
18 April	Lady Rosetta	100	321	206	142	669
	Russet Burbank	100	392	173	158	722
		S.E.	44.0	54.2	90.6	128.2
16 September	Lady Rosetta	100 + 0	39	33	-	73
	Russet Burbank	100 + 0	34	29	-	63
	Lady Rosetta	100 + 100	41	38	-	79
	Russet Burbank	100 + 100	38	32	-	70
		S.E.	3.2	2.9		5.0

At final harvest on 16 September, it was not possible to take representative soil samples from depths of 60-90 cm. However, the data from 0-60 cm show that the amount of soil mineral nitrogen remaining in the soil at harvest averaged 71 kg N/ha. Applying 100 kg N/ha at planting did not increase the amount of soil mineral N compared with applying no N at planting and both varieties left similar amounts of residual N. The large difference between the amount of SMN measured at planting and SMN measured at harvest (*c.* 630 kg N/ha) cannot be explained by N uptake since this was, on average, 232 kg N/ha. It is probable that a proportion of the N that is unaccounted for was in the 60-90 cm layer that was not sampled at harvest on 16 September. However, even if this layer is ignored from the samples taken at planting the shortfall is still *c.* 260 kg N/ha. It is possible that during the period from planting to emergence a substantial quantity of SMN was re-immobilized by soil micro-organisms.

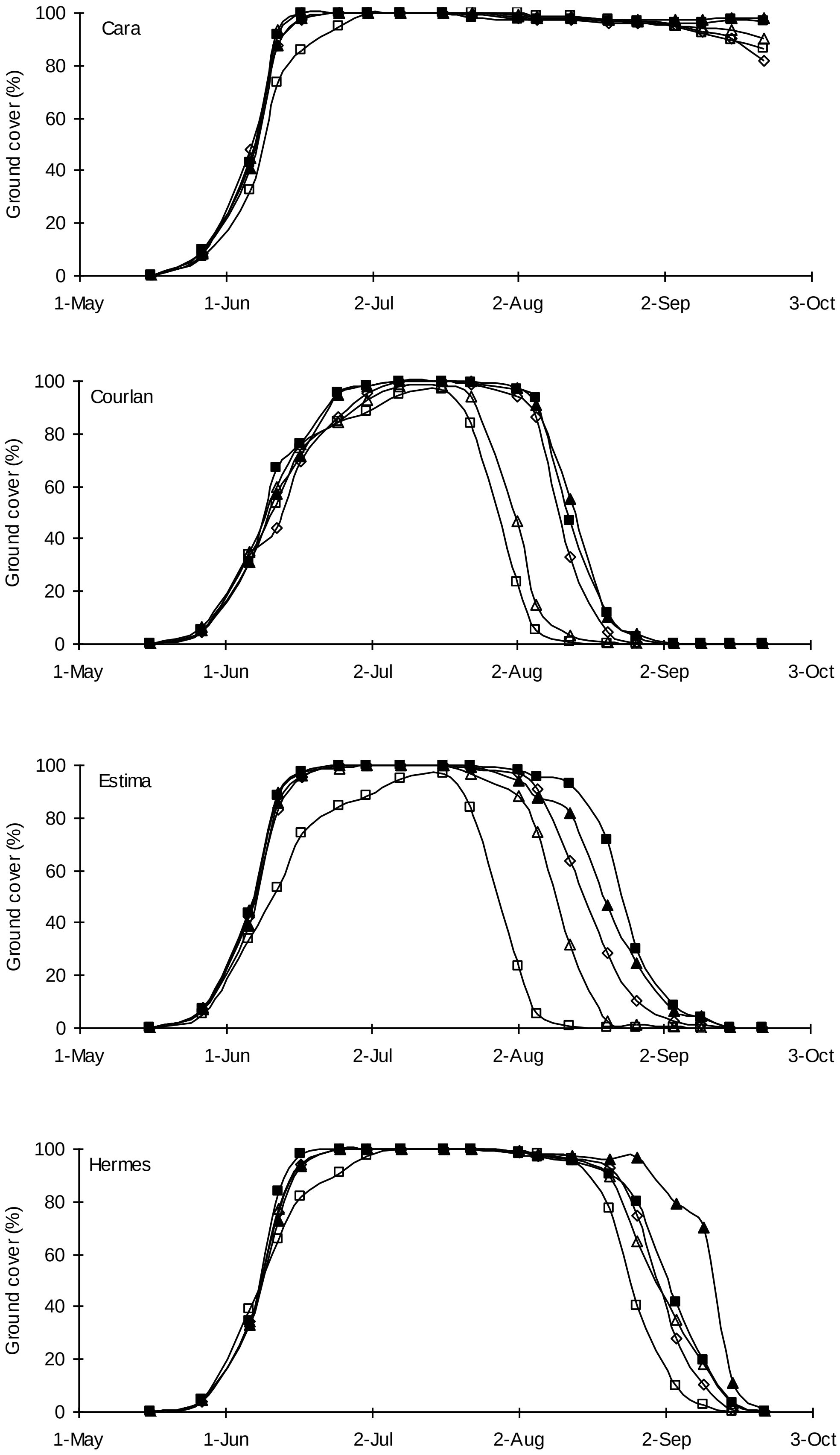
Effects of N fertilizer on growth and yield of contrasting varieties at CUF

Four varieties (Cara, Courlan, Estima and Hermes) were grown in combination with five rates of N (0-320 kg N/ha in 80 kg N/ha increments) in a randomized block design with three replicates. The experiment was planted by hand into preformed ridges (76 cm centres) on 5 April. Fertilizer N was then applied and the ridges raked-up. A single harvest (2.28 m^2) was taken on 3 October.

Emergence and ground covers

For all treatments, the interval between planting and 50 % emergence was *c.* 42 days. Cara achieved 50 % emergence first (41 days) and Hermes last (44 days). Increasing the amount of N applied from 0 to 320 kg N/ha delayed emergence by *c.* 1 day. The effects of N fertilizer on the development of ground cover are shown in Figure 6. For Cara, omitting N fertilizer resulted in a one week delay in attaining 100 % ground cover compared with treatments receiving N fertilizer. At the end of the season, ground covers started to decrease where 0, 80 and 160 kg N/ha had been applied but they retained *c.* 80 % ground cover to the end. Full ground cover persisted where 240 or 320 kg N/ha was applied. In the absence of N, Courlan failed to achieve 100 % ground cover and the crop canopy had started to senesce by mid-July. With applications of fertilizer N, all treatments achieved 100 % ground cover, but even at the largest rate (320 kg N/ha) ground covers started to decrease by early August and the crop canopy had totally senesced by the end of August. The pattern of ground cover development in Estima was broadly similar to that in Courlan. In the absence of N fertilizer, the canopy struggled to achieve 100 % ground cover and then rapidly senesced. Once N had been applied complete ground cover was reached by mid-June and then the delay in onset of senesce was generally related to the amount of fertilizer applied. The pattern of ground cover development in Hermes was generally intermediate to those of Estima and Cara. The effects of N on integrated ground cover are given in Table 12.

Figure 6. Effect of N application rate on ground cover of four varieties at Cambridge University Farm. Key: 0 (□), 80 (Δ), 160 (◊), 240 (■) and 320 (▲) kg N/ha



Yields and N uptake

Nitrogen fertilizer had no effect on the total number of stems, number of tubers per stem and, in consequence, the total number of tubers per hectare (Table 12). However, Cara produced the most stems and had the largest tuber population whereas Hermes produced the fewest stems and had the smallest tuber population despite having the largest number of tubers per stem.

Table 12. Effect of N application rate on integrated ground cover, number of stems and tubers, FW and DW yield and DM concentration for four varieties at Cambridge University Farm

		N application rate (kg N/ha)					
	Mean	0	80	160	240	320	S.E.
Integrated ground cover (% days)							
Cara	10708	10403	10812	10685	10812	10830	207.4
Courlan	5721	4620	5083	6010	6461	6430	
Estima	7010	5953	6533	7123	7938	7505	
Hermes	8539	7724	8471	8430	8683	9388	
Number of stems (000/ha)							
Cara	204	209	211	200	200	201	8.5
Courlan	117	104	114	124	124	118	
Estima	132	128	130	137	134	131	
Hermes	82	79	80	88	88	74	
Number of tubers per stem							
Cara	2.7	2.6	2.9	2.6	2.7	2.5	0.34
Courlan	3.9	3.9	3.8	4.1	4.4	3.2	
Estima	3.8	3.8	3.9	3.6	3.7	3.9	
Hermes	4.7	4.6	4.6	4.3	4.7	5.5	
Total number of tubers (000/ha)							
Cara	538	540	614	524	528	486	34.9
Courlan	446	397	437	500	532	363	
Estima	497	490	500	494	486	515	
Hermes	382	351	370	376	410	404	
Total tuber FW yield (t/ha)							
Cara	78.4	56.6	85.0	82.3	81.6	86.6	5.44
Courlan	52.3	31.5	46.3	63.8	63.9	56.1	
Estima	65.5	39.3	57.9	78.8	73.4	78.1	
Hermes	67.7	46.4	66.5	65.9	76.0	83.9	
Tuber DM concentration (%)							
Cara	21.7	23.7	21.8	21.8	20.8	20.3	0.69
Courlan	22.1	22.8	22.4	21.9	21.3	21.8	
Estima	18.9	19.5	19.1	19.0	18.5	18.4	
Hermes	22.8	23.0	22.3	22.1	23.3	23.4	
Total tuber DW yield (t/ha)							
Cara	16.9	13.4	18.6	17.7	17.0	17.7	1.22
Courlan	11.4	7.2	10.3	14.0	13.5	12.2	
Estima	12.3	7.7	11.0	15.0	13.5	14.3	
Hermes	15.5	10.6	15.0	14.5	17.7	19.6	

The effects of N on tuber FW yield were consistent with the effect on the pattern of ground cover development (Figure 6) and integrated ground cover (Table 12). In the absence of N fertilizer, tuber FW yields >10 mm ranged from 39 t/ha (Courlan) to 57 t/ha (Cara). The optimum N application rate for Cara was *c.* 80 kg N/ha whilst for Estima and Courlan the optimum was *c.* 160 kg N/ha. The response of Hermes to N was somewhat atypical as the optimum was *c.* 200 kg N/ha. It is possible that since Hermes had relatively few stems a large rate of N application was needed in order to promote branching thereby increasing ground cover and radiation absorption. At the optimum application rate, the yields of Cara, Courlan, Estima and Hermes were *c.* 85, 64, 79 and 76 t/ha respectively. In this experiment the effect of N application rate on tuber DM concentration was small and statistically non-significant. On average, Hermes had the greatest tuber DM concentration (23 %) and Estima the lowest (19 %).

The effects of N application on tuber N concentration and uptake were studied in Cara, Estima and Hermes (Table 13). On average, Cara had a lower tuber N concentration than Estima or Hermes and increasing the amount of N applied from 0 to 320 kg N/ha increased tuber N concentration from 1.10 to 1.63 %.

Table 13. Effect of N application rate on tuber N concentration uptake, mean tuber size and proportion of total yield in the ware (40-90 mm) size grade for four varieties at Cambridge University Farm

		N application rate (kg N/ha)					
	Mean	0	80	160	240	320	S.E.
Tuber N concentration (%)							
Cara	1.13	0.95	1.03	1.25	1.16	1.27	0.077
Estima	1.51	1.23	1.43	1.57	1.56	1.76	
Hermes	1.51	1.13	1.43	1.62	1.49	1.86	
Tuber N uptake (kg N/ha)							
Cara	191	128	191	219	195	223	19.8
Estima	190	93	159	237	212	252	
Hermes	240	120	214	236	262	366	
Mean tuber size (mu)							
Cara	66	58	66	66	69	71	1.1
Courlan	60	51	57	62	64	67	
Estima	59	50	56	64	63	63	
Hermes	68	59	68	69	72	75	
Percent of yield in 40-80 mm							
Cara	76	91	78	72	70	68	2.6
Courlan	89	92	95	91	86	80	
Estima	88	87	94	87	88	86	
Hermes	75	94	79	75	68	60	

On average, Hermes had a greater N uptake than either Cara or Estima and increasing the amount of N applied from 0 to 320 kg N/ha increased N uptake from 114 to 280 kg N/ha. At the optimum N application rate for maximum FW yield, the amount of N in the tubers of Cara, Estima and Hermes was 191, 237 and 236 kg N/ha respectively.

Soil mineral nitrogen

Soil samples taken from unfertilized plots shortly after planting on 11 April showed there were *c.* 120 kg N/ha in the top 90 cm of soil (Table 14). Over the following month, there was little change in the total amount of N or its' distribution as shown by a second sampling taken *c.* 10 days before the crop emerged. However, by 6 June, the amount of N at each depth increased so that the total amount of N in unplanted plots was 190 kg N/ha. At the final sampling, the amount of soil mineral N had decreased in all treatments and these effects were largest at 30–60 cm and 60-90 cm in plots planted with Cara.

Table 14. Variation in soil mineral nitrogen (kg N/ha) in Variety and N experiment, CUF

Date	Variety	N applied (kg N/ha)	0-30 cm	30-60 cm	60-90 cm	0-90 cm
11 April	Unplanted	0	60	33	25	117
		S.E.M.	5.4	1.6	5.9	1.3
8 May	Unplanted	0	70	26	18	114
		S.E.M.	3.3	2.5	2.5	1.6
6 June	Unplanted	0	107	51	33	191
		S.E.M.	2.6	8.4	5.2	8.3
17 October	Cara	0	26	12	13	50
	Estima	0	41	25	17	83
	Unplanted	0	30	35	39	104
		S.E.	5.9	7.0	5.4	13.2

Analysis of the relative merits of the Field Assessment method and the Soil Nitrogen Supply Analysis method for determining N requirements using 2001 and 2002 data

The objective of this section is to compare N recommendations made using the Field Assessment method and the SNS Analysis method with optima measured in field experiments in 2001 and 2002. Where possible, the methods outlined in the 7th edition of *Reference Book 209* were used and any modifications are detailed below.

For the purpose of these analyses, Courlan (FL 1953) was assumed to be in Variety Group 1 (very determinate). The length of growing season was calculated from the date of 50 % emergence to the date of defoliation or date of harvest in those crops that were harvested when there was still appreciable ground cover. In some experiments, particularly those at CUF in 2001 and 2002, the date of final harvest was several weeks after the canopies of Courlan and Estima had senesced. To avoid overestimating the length of season in these two varieties, an estimate of the maximum potential duration of ground cover was used as season length (*c.* 100 days for both Estima and Courlan). This estimate was based on experiments at CUF and from crop monitoring in commercial crops. For the SNS analysis method, values of soil mineral N taken at planting (± 7 days) was used to estimate the soil nitrogen supply index of the field. Soil samples were taken from plots prior to N application. For both systems, the estimate of N fertilizer required is presented as the mid range of the values given in RB209. Reference Book 209, advises against using the SNS analysis method on fields that have recently been ploughed out of grass (i.e. in these experiments, Llanwarne). However, an initial analysis showed that including Llanwarne made little difference to the analyses or conclusions. Summaries of the methods of calculation, the N fertilizer requirement estimated by the Field Assessment and by the SNS Analysis methods and the actual fertilizer requirement are given in Table 15 and Table 16.

Table 15. Summary of N recommendation calculated using the Field Assessment method (RB209) and actual N requirement found in experiments

						Calculation of N requirement using field assessment				
Site	Variety	Variety group	Length of season	Soil type as per RB209	Previous crop	SNS index	N required (kg N/ha)	Manures-N (kg N/ha)	Fertilizer-N (kg N/ha)	Actual (kg N/ha)
Season 2001										
GOS Johnsons West	Hermes	2	130	Medium	Carrots	0/1	225	0	225	160
GOS Robins Wood	Hermes	2	130	Medium	Winter wheat	0/1	225	0	225	160
JEPCO Field 15	Desiree	3	75	Fertile silts	Daffodils	0/1	140	0	140	-
JEPCO Field 57	Cara	4	90	Fertile silts	Winter wheat	0/1	85	0	85	0
CUF Cage Field	Cara	4	110	Medium	Winter barley	0/1	110	0	110	100
CUF Cage Field	Courlan	1	100	Medium	Winter barley	0/1	255	0	255	100
CUF Cage Field	Estima	1	100	Medium	Winter barley	0/1	255	0	255	100
CUF Cage Field	Hermes	2	110	Medium	Winter barley	0/1	190	0	190	150
Season 2002										
Wrentham Dodd's Field	Maris Peer	2	40	Light sand	Set aside	0/1	115	0	115	0
Cobrey Llanwarne	Maris Peer	2	60	Medium	Grass	2-4	75	90	0	0
Cobrey Bransford	Estima	1	120	Medium	Spring rape	2-4	210	60	150	60
Jolly Thetford	Lady Rosetta	2	80	Light sand	Winter barley	0/1	165	180	0	100
Jolly Thetford	Russet Burbank	3	80	Light sand	Winter barley	0/1	140	180	0	0
King Taunton	Lady Rosetta	2	120	Medium	Winter wheat	0/1	190	0	190	100
King Taunton	Russet Burbank	3	120	Medium	Winter wheat	0/1	150	0	150	100
CUF Cage Side Field	Cara	4	140	Medium	Winter barley	0/1	120	0	120	80
CUF Cage Side Field	Courlan	1	100	Medium	Winter barley	0/1	255	0	255	160
CUF Cage Side Field	Estima	1	100	Medium	Winter barley	0/1	255	0	255	160
CUF Cage Side Field	Hermes	2	120	Medium	Winter barley	0/1	210	0	210	200
								Mean	155	96

Table 16. Summary of N recommendations using Soil Nitrogen Supply analysis method and those found in experiments

Site	Variety	Soil N at planting (kg N/ha)	SNS Index	Fertilizer N required (kg N/ha)	Actual (kg N/ha)
Season 2001					
GOS Johnsons West	Hermes	87	2-4	170	160
GOS Robins Wood	Hermes	111	2-4	170	160
JEPCO Field 15	Desiree	163	5/6	70	-
JEPCO Field 57	Cara	65	0/1	90	0
CUF Cage Field	Cara	167	5-6	20	100
CUF Cage Field	Courlan	167	5-6	170	100
CUF Cage Field	Estima	167	5-6	170	100
CUF Cage Field	Hermes	167	5-6	100	150
Season 2002					
Wrentham Dodd's Field	Maris Peer	88	2-4	75	0
Cobrey Llanwarne	Maris Peer	397	5-6	50	0
Cobrey Bransford	Estima	345	5-6	170	60
Jolly Thetford	Lady Rosetta	177	5-6	75	100
Jolly Thetford	Russet Burbank	177	5-6	50	0
King Taunton	Lady Rosetta	64	0-1	190	100
King Taunton	Russet Burbank	64	0-1	150	100
CUF Cage Side Field	Cara	117	2-4	70	80
CUF Cage Side Field	Courlan	117	2-4	210	160
CUF Cage Side Field	Estima	117	2-4	210	160
CUF Cage Side Field	Hermes	117	2-4	160	200
			Mean	155	96

To test the reliability of the two methods in predicting N requirements, regression analysis was used to compare the actual N requirement found in the experiments with the predictions made by the Field Assessment method and the SNS analysis method. These analyses showed that the Field Assessment method (Figure 7) explained more of the variation ($R^2 = 0.51$) in actual N requirement than the SNS analysis method (Figure 8) where the R^2 was only 0.38. Thus, using the Field Assessment method will result in more "accurate" estimates of N requirement than using the SNS analysis method, but the accuracy of the individual recommendations is poor.

Figure 7. **Relationship between actual N requirement and that estimated by the Field Analysis method. Dashed line is 1:1, solid line is regression line**

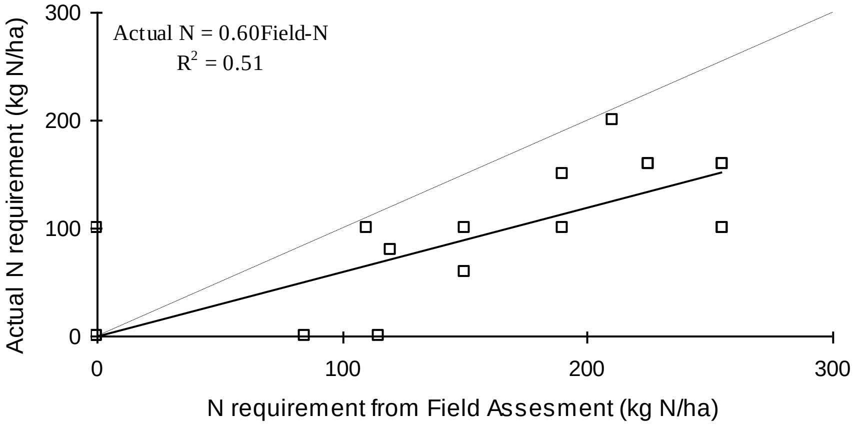


Figure 8. **Relationship between actual N requirement and that estimated by the SNS Analysis method. Dashed line is 1:1, solid line is regression line.**

1500	18.4
2000	30.3

Planted	Accumulate at end Feb (°C days)	Root at end Feb (km/m2)	Root at end Feb (km/m2)
01-Sep	1339	16.4	15.0
15-Sep	1130	12.3	11.3
01-Oct	912	8.0	8.0
15-Oct	745	4.8	5.8
01-Nov	573	1.4	3.9

The 1:1 line marked on both Figures indicates the ideal relationship, where the estimated N requirement corresponds precisely to the actual N requirement. For the Field Assessment method, all points except one lay below the 1:1 line which means this method always recommends too much N. In most cases, this will have little impact on tuber yield since N response curves show negligible yield penalties once the optimum N rate has been exceeded. However, excess N may have a large effect on tuber quality and therefore economic return. For example, in the experiments reported here N applied at rates above the optimum depressed DM concentration (Taunton) and appeared to delay skin set (Wrentham). Excess N may also delay tuber bulking and the achievement of target size specification and this effect is most pronounced in indeterminate varieties such as Russet Burbank and Cara. Excess N may therefore delay defoliation and harvest date. In consequence, there is more opportunity for disease ingress into tubers and there will be increased production costs due to additional blight sprays. Since the Field Assessment method systematically overestimates the fertilizer N

requirement, subtracting a fixed amount from each recommendation could reduce this error. For example, using the smaller values rather than the mid-point of the ranges given in RB209 would reduce the amount of N recommended by *c.* 20-30 kg N/ha. This would move the regression line closer to the 1:1 line but, in most cases, would not result in underestimates of N requirement that lead to significant loss of yield.

As recognized by Neeteson (1990) the deficiency of the SNS analysis method is that soil samples taken at planting cannot estimate mineralization of N from soil organic matter and crop residues post-sampling. In RB209, the advice for estimating the amount of N mineralized is, at best, vague. It states in RB209 (Appendix 2), “in soils of low to average organic matter content the amount of mineralizable nitrogen will be small and not practically significant”. Furthermore, it states, “a soil with a topsoil organic matter content of 10 % may release 60-90 kg N/ha more potentially available N than an equivalent soil with 3 % organic matter content”. Reference Book 209 does not explicitly define what constitutes “low” or “average” organic matter contents nor how much potentially plant available N may be released from a soil with 3 % organic matter. Earlier studies (BPC Report 2002/10) have shown that large amounts of N (>100 kg N/ha) may be mineralized from soils with moderate organic matter contents (*c.* 7 %). Clearly, the advice given in RB209 is of little relevance to potato growers. More detailed examination of these data using regression analysis, showed that the precision of the SNS analysis method was not significantly improved if factors such as soil organic matter content, use of organic manures, variety or length of growing season were included in the regression of actual N requirement on the N requirement predicted by soil analysis. Thus, it would seem that even if growers knew their field’s organic matter contents, this information cannot be combined in useful ways with measurements of SMN to achieve more precise N recommendations.

At present, the most reliable N recommendations are achieved by using the Field Assessment method. However, the analysis to date shows that this method tends to overestimate the N requirement by *c.* 60 kg N/ha. Reducing the N recommendations given in RB209 by 25-30 kg N/ha will help maximize biological and economic performance of potato crops. Owing to its unreliability and the additional cost, when compared with the Field Assessment method, the SNS analysis method cannot be recommended at present.

Effect of timing of soil cultivations on soil mineral nitrogen and nitrogen uptake by Cara

An experiment in 2001 showed that the sequence of cultivations used to establish potato crops could result in an apparent doubling of N mineralization rates when compared with soils left uncultivated. There was also evidence that the timing of these cultivations could also affect the rate of mineralization. It was suggested that soil temperature and moisture content at the time of cultivation could affect the subsequent rate of mineralization and, in turn, affect how data from soil analysis should be interpreted when making N recommendations. This experiment was repeated in 2002 so that more information could be collected on the effect of timing of cultivation on soil mineral N and crop N uptake.

The experiment was carried out on Farm Field at CUF. Each block of the experiment comprised the following treatments: an uncultivated control that was kept free of vegetation with herbicides and three dates of cultivations. For each date of cultivation there were factorial combinations of planted and unplanted and applications of 0 or 100 kg N/ha. The treatments were allocated at random to blocks and were replicated four times. The variety Cara was planted, by hand, at 25 cm spacing in ridges 76 cm apart and N fertilizer, as ammonium nitrate, was applied at planting. Details of the timing of cultivations are shown in Table 17. The planted area of each plot was 4 m long by 4 rows (3.05 m) wide. At harvest on 20 September, an area of 2.28 m^2 was dug, by hand, from the centre of each plot to measure yield and N uptake by haulm and tubers. The crops were unirrigated but received crop protection chemicals according to best practice. Soil samples (0-90 cm) were taken, in key treatments, at regular intervals from March until harvest in September. Increases in SMN are discussed in terms of net mineralization, which is gross mineralization minus losses of SMN via re-immobilization, gaseous loss and leaching.

Table 17. Timing of cultivations used to establish crops, Farm Field, Cambridge University Farm

	Early Cultivation	Mid Cultivation	Late Cultivation
Ploughing	26 March	3 May	11 June
Power harrow and ridge	12 April	20 May	4 July
Planting	25 April	29 May	11 July
Harvest	20 September	20 September	20 September

Yields and N uptake

All treatments achieved 100 % emergence and maintained 100 % ground cover until harvest. When averaged over all treatments, the total number of stems was 131 000/ha (Table 18). The stem population was not significantly affected by either planting date or N application rate. Haulm FW and DW yield, at final harvest, were larger when 100 kg N/ha was applied but were not significantly affected by planting date. Late planting significantly reduced the number of tubers per stem and in consequence, the tuber population. There was no effect of N on these variables. Despite an absence of irrigation, the early plantings gave an average tuber FW yield of *c.* 52 t/ha. However, late plantings produced only *c.* 5 t/ha. Nitrogen application rate had no significant effect on tuber FW yields >10 mm. Tuber DM concentrations were largest from early plantings and smallest in the latest plantings. Applying 100 kg N/ha tended to reduce tuber DM concentration but the effect decreased with delay in planting and, overall, the effects were non significant. Tuber DM harvest index averaged 41 % and was reduced by late planting and by applying 100 kg N/ha. Total N uptake averaged 250 kg N/ha and was not affected by any treatment. The N harvest index averaged 29 %, and, like the DM harvest index, was reduced by late plantings and by N application. However, the difference in values between DM and N harvest indices show that material translocated from haulm to tubers has a large and variable C:N ratio when compared with the haulm. As a consequence of this, tuber yields are likely to be relatively independent of crop N content.

Effect of cultivation treatments on soil mineral N

Irrespective of cultivations the amount of soil mineral N remained relatively constant from the first sampling on 6 March until the fourth sampling on 30 April and averaged *c.* 120 kg N/ha (Table 19 and Figure 9). This suggests that there was little net N mineralization taking place during this period. After the end of April, the quantity of soil mineral N in the stubble treatments started to increase and continued to increase until the beginning of August. A broadly similar pattern was found for the early cultivation (ploughed on 26 March), although the increase in soil mineral N continued until the end of September. For the mid cultivations (ploughed on 3 May) the increase in soil mineral N also occurred after the end of April, but the rate of increase in soil mineral N was more rapid than for the control or early cultivations.

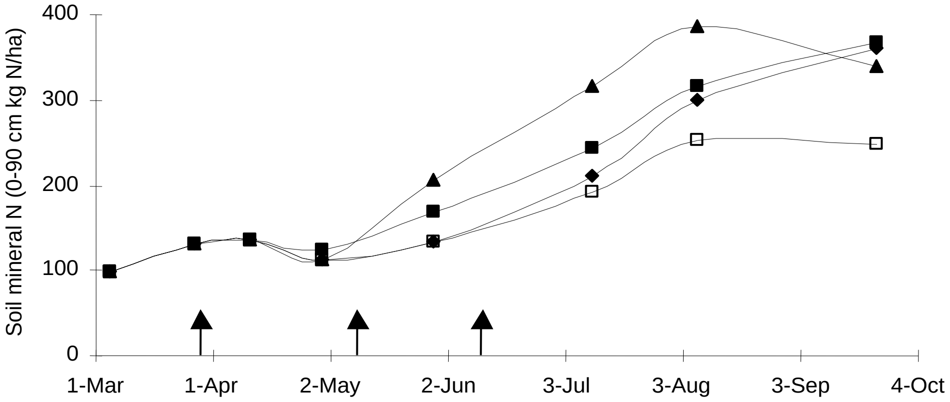
Table 18. Effect of planting date and N application rate on yield of Cara, Farm Field. Harvested 20 September

		Planted 30 April		Planted 29 May		Planted 11 July		
	Mean	0 kg N/ha	100 kg N/ha	0 kg N/ha	100 kg N/ha	0 kg N/ha	100 kg N/ha	S.E.
Haulm yield (t FW/ha)	44.7	27.9	52.0	47.0	62.6	38.5	40.3	7.15
Haulm yield (t DW/ha)	5.36	3.33	6.22	5.65	7.50	4.62	4.85	0.858
Number of stem (000/ha)	131	121	123	115	125	156	147	14.7
Number of tubers >10 mm (000/ha)	387	439	429	438	484	294	242	32.1
Number of tubers >10 mm per stem	3.2	3.7	3.8	4.0	4.0	1.9	1.7	0.35
Tuber yield >10 mm (t FW/ha)	26.0	54.9	48.4	23.5	19.1	5.4	4.7	2.31
Tuber DM concentration (%)	17.6	20.4	19.0	19.0	18.3	14.4	14.7	0.69
Tuber yield >10 mm (t DW/ha)	4.95	11.10	9.15	4.50	3.50	0.77	0.67	0.435
Mu (mm)	47	63	61	49	45	32	32	0.8
Sigma (mm)	10.5	12.9	13.8	11.7	10.9	7.0	6.5	0.66
Yield in 40-80 mm grades (%)	57	87	85	78	67	14	12	2.9
Total yield (t DW/ha)	10.33	14.47	15.40	10.15	11.02	5.40	5.52	0.893
Dry matter harvest index (%)	41	77	60	47	32	15	14	4.5
Total nitrogen uptake (kg N/ha)	249	241	300	216	294	204	240	39.4
Nitrogen harvest index (%)	29	66	43	31	20	7	7	4.4

Table 19. Effect of time of cultivations on soil mineral N (kg N/ha) in plots receiving no fertilizer. CUF Farm Field 2002

Date	Treatment	Planted	0-30 cm	30-60 cm	60-90 cm	0-90 cm
6 March	Stubble	Unplanted	50	26	23	99
	S.E.M.		6.5	4.7	3.0	12.4
27 March	Stubble	Unplanted	61	39	31	131
	S.E.M.		4.8	4.1	4.2	12.2
11 April	Stubble	Unplanted	68	41	27	136
	Early Cultivation	Unplanted	64	36	35	135
	S.E.		13.0	7.9	7.8	18.5
30 April	Stubble	Unplanted	66	25	21	112
	Early Cultivation	Unplanted	76	26	21	124
	S.E.		27.6	6.6	3.3	35.9
29 May	Stubble	Unplanted	63	35	35	133
	Early Cultivation	Unplanted	103	38	27	168
	Mid Cultivation	Unplanted	137	39	30	206
	S.E.		15.1	8.3	7.1	20.6
10 July	Stubble	Unplanted	98	58	37	193
	Early Cultivation	Unplanted	154	53	38	244
	Mid Cultivation	Unplanted	200	69	48	317
	Late Cultivation	Unplanted	116	60	35	211
	S.E.		23.3	10.9	5.8	30.2
7 August	Stubble	Unplanted	126	72	55	253
	Early Cultivation	Unplanted	179	84	52	316
	Mid Cultivation	Unplanted	231	100	54	385
	Late Cultivation	Unplanted	156	90	53	299
	S.E.	Unplanted	18.5	13.7	8.6	34.1
23 September	Stubble	Unplanted	124	60	65	249
	Early Cultivation	Unplanted	202	100	65	366
	Early Cultivation	Planted	25	15	12	52
	Mid Cultivation	Unplanted	161	75	103	339
	Mid Cultivation	Planted	23	14	24	61
	Late Cultivation	Unplanted	145	149	67	361
	Late Cultivation	Planted	27	24	32	82
	S.E.		16.9	11.2	16.7	25.2

Figure 9. **Effect of time of cultivation on soil mineral N, CUF Farm Field 2002. Stubble □, Cultivated early ■, mid ▲, late ♦, arrows indicate date of ploughing for the early, mid and late cultivations**



For the treatment ploughed on 11 June, the increase in soil mineral N was found at the subsequent sampling and then continued at a rapid rate until the end of September. The soil samples taken at final harvest showed that the presence of a crop reduced the amount of soil mineral N from an average of 330 kg N/ha in the unplanted treatment to 65 kg N/ha where the plots had been planted. The amount of soil mineral N in the topsoil (0-30 cm) in the planted plots was similar irrespective of planting date. However, with early cultivations and planting the amount of soil mineral N in the sub soil (30-60 and 60-90 cm) was smaller than from the middle and late plantings. This indicates that there had been considerable scavenging of nitrate from the sub soil.

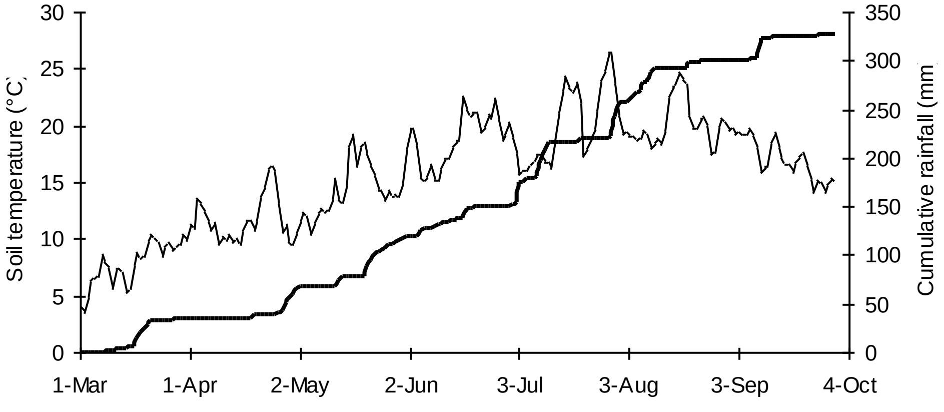
The soil mineral N data were analysed using a ‘split-line’ model to estimate the start date and rate of the rapid phase of mineralization. For the purpose of this analysis, the mean (120 kg N/ha) of the first four sampling dates was used since they were not statistically different and in addition the last sampling date was omitted since some curves were over-turning. As found in the 2001 experiment, the rate of net N mineralization was increased by cultivation (Table 20) and, when the errors were taken into account, there was evidence that the rate of mineralization increased as the date of cultivation was delayed. Without cultivation, there was little evidence of mineralization until mid-May. Despite a difference of over one month in the dates of ploughing of the early and mid cultivations, the regression analysis shows that the increase in mineralization rate occurred at similar times (late April/early May). Thus, the early cultivation began with ploughing on 26 March but there was no detectable increase in mineralization rate until early May. However, for mid and late cultivations, the increase in net mineralization rate occurred at approximately the same time as ploughing.

Table 20. Estimates of start date of rapid phase of mineralization and net mineralization rate using a split line function. CUF Farm Field 2002

Treatment	Date of ploughing	R^2	Estimated date of start of mineralization and S.E. (days)		Rate of mineralization and S.E. (kg N/ha/day)	
Stubble	-	98.8	22 May	5.6	1.7	0.18
Early cultivation	26 March	99.4	7 May	4.7	2.1	0.19
Mid cultivation	3 May	99.8	28 April	2.8	2.7	0.18
Late cultivation	11 June	99.6	14 June	3.3	3.0	0.22

Collectively, these data suggest that before a certain date, N mineralization rates are small irrespective of any cultivation. However, after this date, mineralization rates increase and the size of this increase is larger in soils that have been cultivated. In this experiment, the data show that this critical period is early May. Weather data, collected from an automated weather station *c.* 300 m from the experiment showed that from 20 March to 19 April there was only *c.* 9 mm of rain and thus, during this period the topsoil was relatively dry. In contrast, from the 19 April to the 18 May, when there was a rapid increase in N mineralization, there was *c.* 40 mm rain and thus the topsoil was generally moist. In addition, between March and May soil temperatures at 10 cm depth were increasing rapidly (Figure 10). Thus, on the first of March, April and May the mean soil temperature was 6.7, 9.5 and 13.5 °C respectively. The first cultivation on 26 March was therefore done in relatively cool and dry soil and the effect of the cultivation was minimal until the soil had warmed and wetted up. The mid and late cultivations were done when the soil was already warm and moist and this permitted the rate of mineralization to increase immediately.

Figure 10. Soil temperature (thin line) and cumulative rainfall (thick line) at CUF 2002



Overall, rates of net mineralization were faster in 2002 than in 2001. For example, the average rate of mineralization in the uncultivated plots was 0.8 kg N/ha/day in 2001 compared with 1.7 kg N/ha/day in 2002. This difference is unlikely to be due to soil temperatures since average soil temperature was slightly warmer in May 2001 than in 2002. However, the difference in mineralization rates may be due to differences in soil organic matter and clay content. The 2001 experiment was done on Dry Field which had an organic matter content of *c.* 7.5 % and a clay content of *c.* 16 %. The 2002 experiment was done on Farm Field, a soil with 4.6 % organic matter and 7 % clay content and, it might be expected, that Dry Field with the larger organic matter content would mineralize N at a faster rate than Farm Field. However, clay minerals tend to protect organic matter from mineralization and this protection may result in less N being mineralized during the season than might be expected if only the soil organic matter content is considered. A split-line analysis on bare plots in the 2002 BPC Reference Crop at CUF showed the average mineralization rate was only 1.0 (± 0.12) kg N/ha/day, with the start date of rapid mineralization on 24 April (± 7.0 days). The Reference Crop was located in Cage Side Field that had a slightly larger organic matter content than Dry Field but also a larger clay content. In the 2001 experiments, there was no delay between the cultivations and the stimulation of rapid mineralization. However, both cultivations were relatively late (11 May and 9 July), soil temperatures were already high (*c.* 14 and 21 °C, respectively) and the soils were moist owing to a wet March and April. If both seasons are taken together, it seems that for mineralization to be rapid the soil needs to be relatively moist and warm (> *c.* 13 °C) and possibly have a small clay content.

To date this work had shown that soils with moderate organic matter concentrations can mineralize substantial amounts of N. The amount of soil mineral N measured (and in consequence N recommendation) will depend upon the timing of that soil sample in relation to the timing of soil cultivations <u>and</u> on soil temperature and moisture content. Thus, a soil sample taken in mid-March at planting could underestimate the amount of N mineralized since soil temperatures were still cool. This may result in over applications of N fertilizer resulting is reductions in marketable yield.

Effect of variety, nitrogen application rate and planting density on canopy form and function in 2001 and 2002

Previous work has shown that for similar lengths of growing seasons varieties differ in their N requirements and knowledge of these differences has been exploited in the latest edition of *Fertiliser Recommendation for Arable and Horticultural Crops (RB209)*. However, the physiological basis for varietal differences in response to N remains uncertain. The purpose of the experiments reported here was to generate, by using extreme treatments, a wide range of canopy architectures and observe how these relate to N uptake, DM production and DM partitioning and tuber yields. Some results from 2001 have already been presented (CUPGRA Annual Report for 2001 p 69-74). This report will present data from the 2002 experiment and discuss them with reference to the 2001 data to make some general inferences about crop canopy form and function.

Both experiments tested, in factorial combination, two contrasting varieties (Cara and Estima), two plant spacings (15 and 60 cm) and two N application rates (0 and 300 kg N/ha). Each treatment combination was replicated four times and allocated at random to blocks. The experiments were planted, by hand, on 16 May in 2001 and 3 April 2002. Crop emergence was measured every 3 to 4 days until 100 % emergence and ground covers were recorded weekly from 50 % emergence until the canopy had totally senesced. At each harvest (2.28 m^2 area during the season and 4.56 m^2 at final harvest) graded tuber FW and DW yield was measured. In addition, the haulm was divided into its component parts (main-axis leaf and stems and branch leaf and stems). Leaf area indices (LAI) on main-axes and branches were also measured. Sub samples of tubers and haulm components were analyzed for N concentration.

Emergence and ground covers

The time taken from planting to 50 % emergence was *c.* 30 days in 2001 (23 June) and *c.* 43 days in 2002 (17 May). In both seasons, Cara attained 50 % emergence two days before Estima. In 2001, close spacing emerged 1 day ahead of the wide spacing but this effect was not seen in 2002. Conversely, N application rate had no effect on emergence in 2001 but applying 300 kg N/ha delayed 50 % emergence by *c*. 2 days in 2002. The effects of the treatments on ground cover development and on total integrated ground cover for both seasons are shown inTable 21 and Figure 11. In both seasons, Cara produced more extensive canopies than Estima, nitrogen prolonged canopy persistence and wider spacing delayed achievement of maximum ground cover when compared with closer spacing. When comparing between seasons, Cara produced a more persistent canopy in 2002 than in 2001 whilst the opposite was true for Estima.

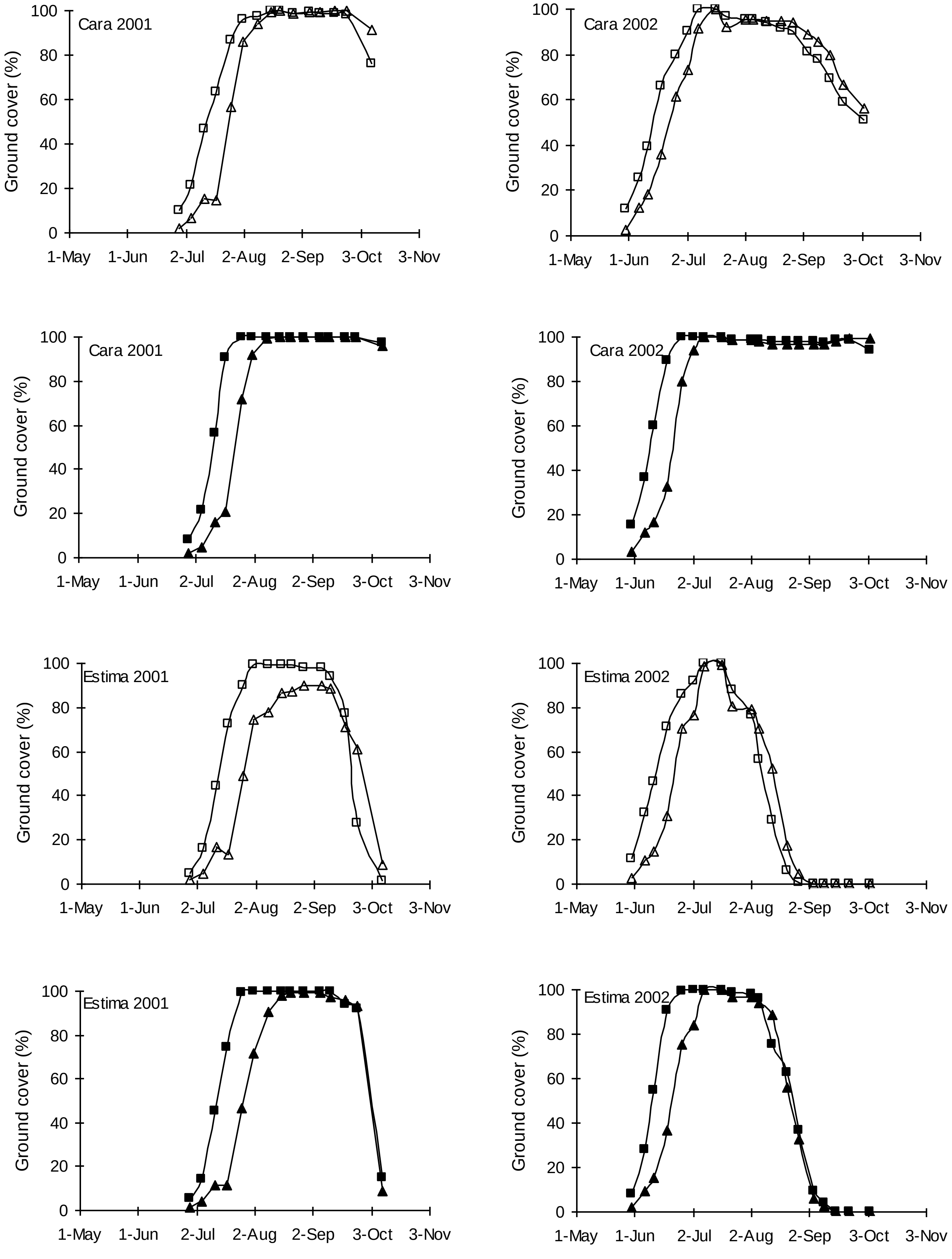
Table 21. Effect of variety, N application rate (kg N/ha) and plant spacing (cm) on total integrated ground cover (% days) in 2001 and 2002

		Cara				Estima				
		0		300		0		300		
Year	Mean	15	60	15	60	15	60	15	60	S.E.
2001	7618	8519	7639	9106	7915	7115	5843	8134	6672	159.6
2002	8203	9848	9311	11653	10520	5584	4989	7418	6298	207.3

Yields and N uptake at final harvest

Final harvests were taken on 16 October in 2001 (115 DAE) and 4 October in 2002 (140 DAE). When averaged over all treatments, the total number of stems was similar in both years once errors had been taken into account (Table 22). On average, tuber FW yields were slightly higher in 2002 than 2001. In both seasons, yields were increased in crops grown at 15 cm than at 60 cm. In 2001, due to the shorter season, the main effect on N was to reduce yield and this effect was most noticeable in Cara. Conversely, in 2002, the main effect of N was to increase yield particularly in Estima. In agreement with the estimates of integrated ground cover, total DM yields were higher in 2002 than 2001. Cara always produced a larger total DM yield than Estima and the close spacing always had a higher yield than the wide spacing. In 2001, the main effect of N was non-significant, although applying N reduced yield in Cara but increased it in Estima. In 2002, N increased total DM yields in both Cara and Estima. Despite total N uptake being larger in 2002 than in 2001 the effect of the treatments were similar: Cara had a larger uptake than Estima, applying N increased uptake (although the effect of N on uptake was larger in 2002) and planting density had no significant effect in either season.

Figure 11. Effect of variety, N application rate (0, open symbols; and 300 kg N/ha, closed symbols) and plant spacing (15 cm, squares; and 60 cm triangles) on ground cover in 2001 and 2002



In both seasons Cara produced more stems than Estima and 15 cm spacing produced *c.* 3.6 times more stems than the 60 cm spacing. In 2002, applying 300 kg N/ha had no effect on the number of stems but in 2001, N reduced the number of stems particularly at the 15 cm spacing. Overall, tuber populations were slightly higher in 2002. Applying 300 kg N/ha reduced tuber populations in 2001 but not in 2002. Cara produced more tubers than Estima in 2001 but fewer than Estima in 2002. In both seasons, increasing the planting density fourfold increased the number of tubers by a factor of only *c.* 2.2.

Table 22. Effect of variety, N application rate (kg N/ha) and plant spacing (cm) on number of stems and tubers, yields and N uptakes in 2001 and 2002

		Cara				Estima				
		0		300		0		300		
Year	Mean	15	60	15	60	15	60	15	60	S.E.
Number of stems (000/ha)										
2001	89	212	51	149	43	109	33	83	31	8.1
2002	100	153	36	143	37	155	49	178	51	8.2
Number of tubers >10 mm (000/ha)										
2001	304	514	215	331	225	345	209	388	200	19.4
2002	362	466	213	408	248	545	218	603	193	15.7
Tuber FW yield >10 mm (t/ha)										
2001	46.6	56.9	45.0	33.3	30.2	49.0	47.0	61.3	50.1	3.32
2002	53.6	56.5	48.3	64.2	49.4	42.8	42.4	73.1	51.7	4.21
Total DW yield (t/ha)										
2001	12.0	15.1	12.1	13.0	10.6	10.9	9.9	13.2	11.2	0.84
2002	13.6	15.5	13.1	19.8	16.0	8.9	8.9	15.6	11.0	1.18
Total N uptake (kg N/ha)										
2001	164	138	135	224	258	102	109	190	161	16.3
2002	205	177	159	299	302	129	115	268	193	22.4

Once experimental error has been taken into account, tuber yields and total DM yields from widely contrasting treatments were often similar. For example, in 2001, Cara grown at 60 cm without N and Estima grown at the same spacing with 0 or 300 kg N/ha gave similar tuber yields of 45-50 t/ha. Likewise, in 2002, the total DM yield for Cara grown at 15 cm spacing without N was similar to the yield of Estima grown at the same spacing with 300 kg N/ha. These similar outcomes were achieved by very different routes in terms of DM production and partitioning. Some of these differences, and their implications, will be discussed in the remainder of this section.

Relationships between leaf area index and nitrogen uptake

A key component in using N to control crop canopy size and, in turn, radiation absorption (i.e.

“canopy management”) is an assumption that each unit of leaf area is associated with a predictable amount of N. For cereals, this assumption is reasonably robust. For potatoes, however, earlier work at CUF (BPC project 807/182) has shown that the relationship is not sufficiently stable to be of practical use. The data from the 2001 and 2002 experiments were analyzed so that the reasons for this instability could be better understood. These data were analyzed using a quadratic function and from the fitted parameters, estimates of the amount of N associated with increasing amounts of leaf area were calculated. The data were restricted to the early part of the season so that leaf area indices were still increasing and leaf senescence was negligible. The relationships between total (i.e. main-axis and branch) leaf N and main-axis and branch leaf area index are shown in Table 23. To produce the first layer of leaves, a remarkably constant amount of leaf N was required (*c.* 23 kg N/ha) irrespective of season, variety, N application rate and planting density. For subsequent units of leaf area, the analysis shows that progressively smaller amounts of nitrogen were used and this effect was most noticeable where no N was applied. In practice, it is probable that N is moved from the lowermost to the uppermost strata of leaf area so that the protein concentration of leaves receiving full sunlight is maximized. To produce a leaf area index of three and thereby absorb most of the radiation incident on the crop, an average leaf N uptake of 56 kg/ha was needed. Whilst there was some effect of season and N application rate on the amount of N associated with a leaf area index of three, these effects were small and thus, this value was reasonably stable. In some cases, for example unfertilized Estima, the maximum leaf area index only reached three.

The relationship between main-axis and branch stem N and leaf area are shown in Table 24. When compared with leaf N, the amount of stem N associated with each unit of leaf area was much more variable. For example, the amount of stem N associated with the first unit of leaf area varied by a factor of nearly two (10 to 18 kg N/ha) and the amount of stem N associated with a leaf area index of three had a three-fold variation (22 to 66 kg N/ha). These data suggest that much of the variation in the relationship between leaf area index and N uptake may be caused by the variation in the N content of stems. The next section will discuss the role of stem and leaf N in relation to canopy growth and DM partitioning.

Table 23. Total (main-axis and branch) leaf N associated with the production of each new increment of total (main-axis and branch) LAI and the amount of leaf N associated with an LAI of three

Variety	N rate (kg N/ha)	Spacing (cm)	Year	Nitrogen (kg N/ha) associated with each layer of leaf area					Total N for LAI=3
				1st	2nd	3rd	4th	5th	
Cara	0	15	2001	20	15	11	7	3	47
Cara	0	60	2001	20	16	12	8	4	48
Cara	300	15	2001	22	21	18	15	12	62
Cara	300	60	2001	21	19	17	15	13	56
Estima	0	15	2001	20	16	12	-	-	48
Estima	0	60	2001	21	15	7	-	-	43
Estima	300	15	2001	22	21	18	16	13	61
Estima	300	60	2001	24	19	12	6	-	55
Cara	0	15	2002	24	16	9	-	-	48
Cara	0	60	2002	23	17	11	-	-	51
Cara	300	15	2002	25	24	23	22	20	72
Cara	300	60	2002	26	24	21	19	17	71
Estima	0	15	2002	23	15	7	-	-	45
Estima	0	60	2002	23	19	15	-	-	57
Estima	300	15	2002	23	23	22	22	-	69
Estima	300	60	2002	25	20	16	11	-	61

Table 24. Total (main-axis and branch) stem N associated with the production of each new increment of total (main-axis and branch) LAI and the amount of stem N associated with an LAI of three

Variety	N rate (kg N/ha)	Spacing (cm)	Year	Nitrogen (kg N/ha) associated with each layer of leaf area					Total N for LAI=3
				1st	2nd	3rd	4th	5th	
Cara	0	15	2001	11	8	6	4	2	26
Cara	0	60	2001	13	12	9	6	3	35
Cara	300	15	2001	13	16	19	22	25	48
Cara	300	60	2001	18	25	23	21	18	66
Estima	0	15	2001	12	7	-	-	-	-
Estima	0	60	2001	10	7	5	-	-	22
Estima	300	15	2001	14	14	14	13	14	42
Estima	300	60	2001	15	14	10	7	-	39
Cara	0	15	2002	12	7	3	-	-	22
Cara	0	60	2002	12	8	5	-	-	25
Cara	300	15	2002	17	18	18	19	20	53
Cara	300	60	2002	16	15	14	14	13	45
Estima	0	15	2002	11	8	5	-	-	24
Estima	0	60	2002	10	3	-	-	-	-
Estima	300	15	2002	16	13	11	8	-	40
Estima	300	60	2002	14	11	8	5	-	33

Timing and rate of N uptake by main-axis, branches and tubers

Nitrogen uptake data from each harvest were analyzed using a split-line function. This function is useful for analysing data which show two distinct slopes (in this case rate of N uptake). The model produces estimates of the two slopes, the time when the slopes change (as DAE) and an estimate of the response variate (N uptake) at the change point. The function was fitted on a plot-by-plot basis and the estimated parameters were then subjected to analysis of variance. For much of our data the change point corresponded to a cessation of N uptake since the secondary slope was not significantly different from zero.

The effect of the treatments on parameters of N uptake by main-axes, branches and tubers in 2001 and 2002 are shown in Table 25 and Table 26. On average, the period of rapid N uptake by mainstems was slightly longer in 2002 (49 days) than in 2001 (40 days). In both seasons, the duration of N uptake was longer in Cara than Estima. However, in both seasons planting density and N application rate had no effect on duration of N uptake.

The rate of N uptake by the main-axis was slightly faster in 2001 than 2002. In both seasons, the main-axis of Cara took up N faster than Estima and the uptake rate was faster in the 15 cm spacing treatments and where 300 kg N/ha had been applied. The overall average quantity of N in the main-axis at the change in uptake rate was remarkably similar in both seasons (*c.* 81 kg N/ha) as were the main effects of the treatments on main-axis N uptake. In both seasons N uptake at the change in uptake rate was increased by use of Cara, N and close plant spacing.

On average, N uptake by the branches started 20 DAE in 2001 and 28 DAE in 2002. The estimates in both years were biased by extreme values from Estima grown at 15 cm spacing without N (which produced very limited branching). If these values are omitted, then, in both seasons, N uptake by branches started *c.* 24 DAE and there were no significant effects of variety, N rate or plant spacing. When averaged over both seasons, the change in rate of branch N uptake occurred *c.* 60 DAE, about 2 weeks after the change in rate of N uptake by the main-axis. In both seasons the change in rate of N uptake was later in Cara than in Estima. The rate of branch N uptake was larger in Cara than in Estima and was increased by applying N. However, in contrast to the rate of N uptake by the main-axes, the rate of branch N uptake was fastest at the widest spacings. In consequence, branch N uptake at the change in rate of N uptake was faster at the wide spacings than the narrow.

Table 25. Effect of treatments on parameters of N uptake up by main-axes, branches and tubers in 2001

			Main-axis			Branch				Tubers	
Variety	N rate kg/ha	Spacing (cm)	Change DAE	Rate kg/ha/day	Amount kg N/ha	Start DAE	Change DAE	Rate kg/ha/day	Amount kg N/ha	Start DAE	Rate kg/ha/day
Cara	0	15	39	2.2	78	23	65	0.9	42	21	1.2
Cara	0	60	46	1.2	52	24	62	1.9	69	25	0.7
Cara	300	15	41	5.0	185	22	65	3.1	126	30	0.5
Cara	300	60	46	1.8	77	26	58	4.7	165	25	0.6
Estima	0	15	41	1.7	71	9	56	0.2	11	20	1.7
Estima	0	60	34	0.9	30	19	55	1.2	43	27	1.4
Estima	300	15	34	3.1	105	18	56	2.7	99	23	2.6
Estima	300	60	42	1.0	42	20	53	2.5	90	26	1.8
S.E.			2.6	0.21	7.0	3.0	4.2	0.29	7.1	2.6	0.11
Mean			40	2.1	80	20	59	2.1	81	25	1.3
Cara			43	2.5	98	24	62	2.6	101	25	0.8
Estima			38	1.7	62	17	55	1.7	61	24	1.9
0 kg N/ha			40	1.5	58	19	59	1.0	41	23	1.3
300 kg N/ha			41	2.7	102	22	58	3.3	120	26	1.4
15 cm			39	3.0	110	18	60	1.7	70	24	1.5
60 cm			42	1.2	50	22	57	2.6	92	26	1.1
S.E.			1.3	0.11	3.5	1.5	2.1	0.14	3.5	1.3	0.06

Table 26. Effect of treatments on parameters of N uptake up by main-axes, branches and tubers in 2002

			Main-axis			Branch				Tubers	
Variety	N rate kg/ha	Spacing (cm)	Change DAE	Rate kg/ha/day	Amount kg N/ha	Start DAE	Change DAE	Rate kg/ha/day	Amount kg N/ha	Start DAE	Rate kg/ha/day
Cara	0	15	59	1.4	86	27	70	0.4	17	29	1.0
Cara	0	60	54	0.8	43	28	73	1.6	72	35	1.1
Cara	300	15	57	3.8	205	28	61	4.6	170	31	1.3
Cara	300	60	48	1.3	58	28	79	5.4	229	39	1.3
Estima	0	15	40	1.6	62	42	54	0.2	1	21	1.1
Estima	0	60	46	0.8	33	27	56	2.1	22	32	1.4
Estima	300	15	43	2.8	122	22	55	1.4	20	24	2.6
Estima	300	60	49	0.9	44	24	46	4.0	45	33	2.8
S.E.			4.3	0.21	15.7	4.7	9.4	1.19	16.2	2.5	0.26
Mean			49	1.7	82	28	62	2.5	72	30	1.6
Cara			55	1.8	98	28	71	3.0	122	33	1.2
Estima			44	1.5	65	29	53	1.9	22	27	2.0
0 kg N/ha			50	1.2	56	31	64	1.1	28	29	1.2
300 kg N/ha			49	2.2	107	25	60	3.9	116	32	2.0
15 cm			50	2.4	119	29	60	1.6	52	26	1.5
60 cm			49	0.9	44	27	64	3.3	92	35	1.6
S.E.			2.2	0.11	7.9	2.3	4.7	0.59	8.1	1.3	0.13

On average, N uptake by the tubers started 25 DAE in 2001 and 30 DAE in 2002. In 2001, the treatments had no effect on the timing of N uptake by tubers. However, in 2002, the onset of tuber N uptake was *c.* 6 days later in Cara than in Estima and *c.* 9 days later in crops grown at the wide spacing. The rate of tuber N uptake by Cara was *c.* half that of Estima. Applying 300 kg N/ha increased the rate of N uptake by tubers of Estima, but either had no effect or slowed the rate of tuber N uptake in Cara. The effects of plant spacing were less consistent. In 2001, the rate of tuber N uptake was reduced at the wider spacing but in 2002 there was no significant effect.

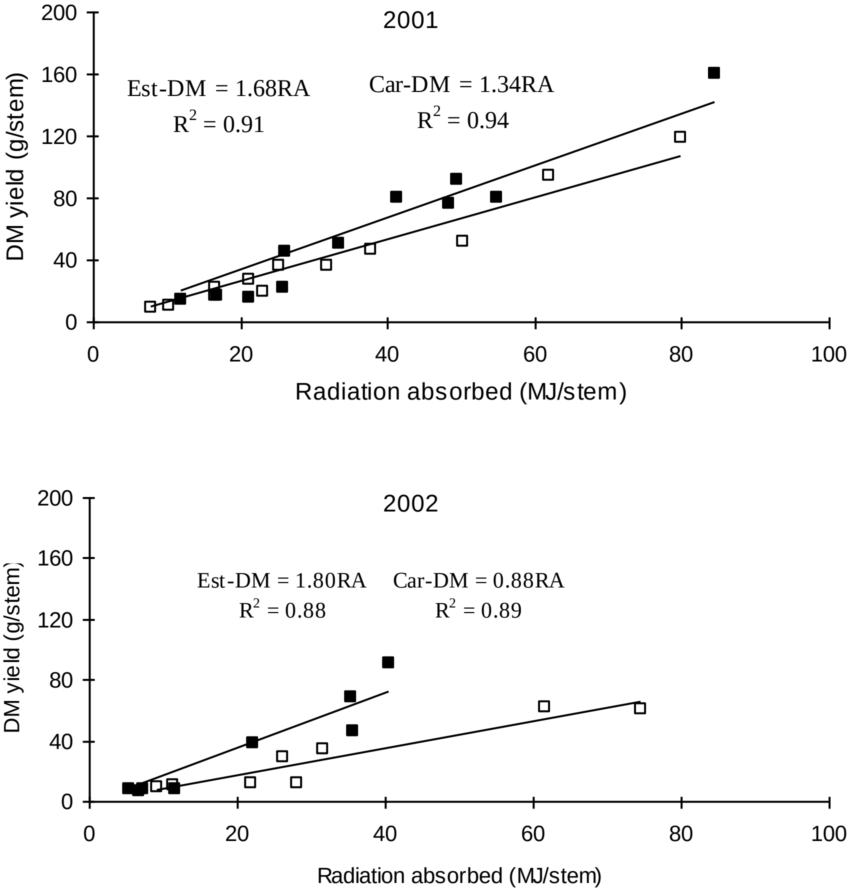
These data show that N uptake by tubers and branches starts simultaneously at *c.* 25-30 DAE. The data also show that treatments associated with large uptake rates by branches (Cara and wide spacings) tend to be associated with small rates of N uptake by tubers. Collectively, these data suggest that branches and tubers are competing for N and the outcome of this competition may be influenced by factors such as variety, N application rate and planting density. To test this hypothesis a simple model was devised, with a key parameter within the model being the proportion of N, from new uptake or from senescence of the main-axis, allocated to branches at the expense of the tubers. The model relied on inputs measured in the experiment and in consequence, the model may be self-fulfilling and inferences made using the model must be treated with caution. However, the principal measured input was maximum main-axis N uptake which occurred *c.* 45 DAE and for the remainder of the season the model relied on estimates of N partitioning and senescence. Furthermore, the model was also tested with independent data from a Maris Piper crop (Millard & MacKerron 1986). Results from the model are consistent with the hypothesis of tuber/branch competition and allocation of N to tubers (for example in Estima, without N and at close spacings), limits branch growth and canopy longevity. Conversely, allocation of N to branches (typically in Cara, with N and at wide spacings) increased canopy longevity. An important component of the model was the peak amount of main-axis N and how fast this pool of N was made available to branches or tubers. Work is continuing to further understand the factors controlling this variable.

Factors controlling N uptake and DM production

In a review of literature, Grindlay (1997) claimed that when N is not limiting the rate of N uptake is driven by the rate of DM production (i.e. the integral of the product of leaf area index and incident radiation). Data from the experiments in 2001 and 2002 were used to test this assertion.

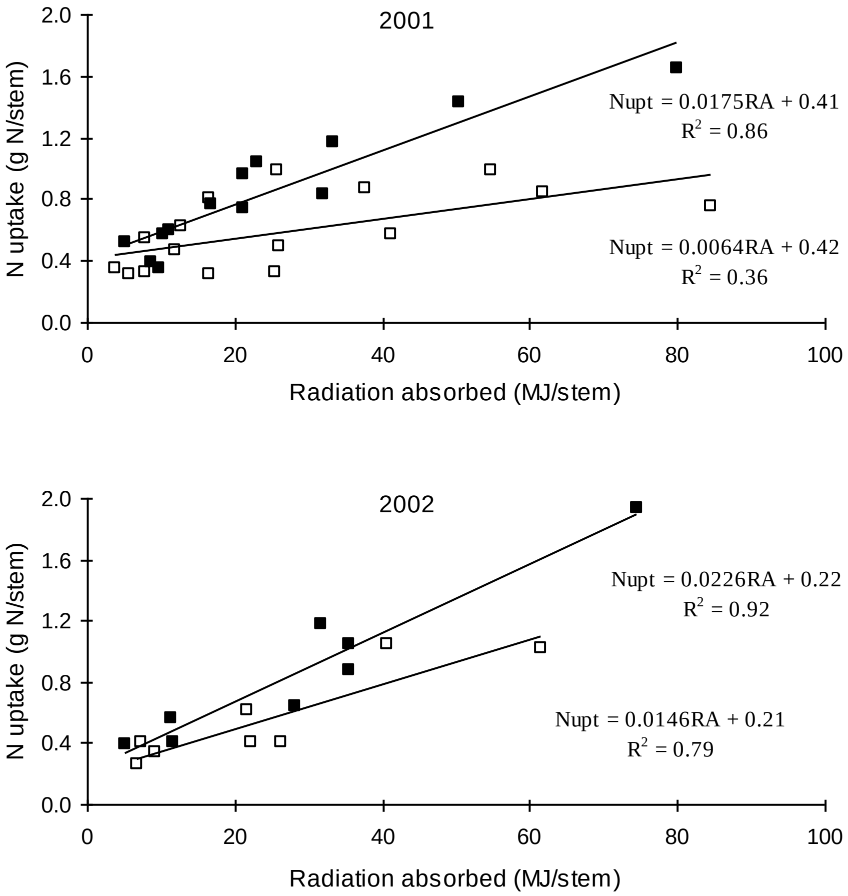
Data were analysed on a per stem basis and the data restricted to < 53 DAE. Main-axis leaf area data were interpolated using a cubic polynomial to estimate the leaf area index on each day. The proportion of incident radiation absorbed was estimated using the Monteith relationship described by Firman and Allen (1989). Measurements of incident radiation (as MJ/m2) were scaled to a per stem basis by diving by the average number of stem/m^2 found in each treatment. Cumulative radiation absorbtion was then calculated for each treatment and each harvest date. As a check on the methodology, total DW yield per stem was plotted against radiation absorbed per stem (Figure 12).

Figure 12. Relationship between DM yield and radiation absorbtion for Cara (■) and Estima (□) in 2001 and 2002 at Cambridge University Farm



Regression of DM yield against radiation absorbtion showed these two variates were correlated (i.e. R^2 of *c.* 0.90) and, as has been found in other experiments the conversion efficiency of Estima was slightly larger than that of Cara. These data suggest that the methods to estimate leaf area index and, in turn, radiation absorbtion were valid. Regressions of N uptake against radiation absorbtion are shown in Figure 13.

Figure 13. Relationship between N uptake and radiation absorbtion for crops of Cara and Estima receiving 0 kg N/ha (□) and 300 kg N/ha (■) in 2001 and 2002 at Cambridge University Farm

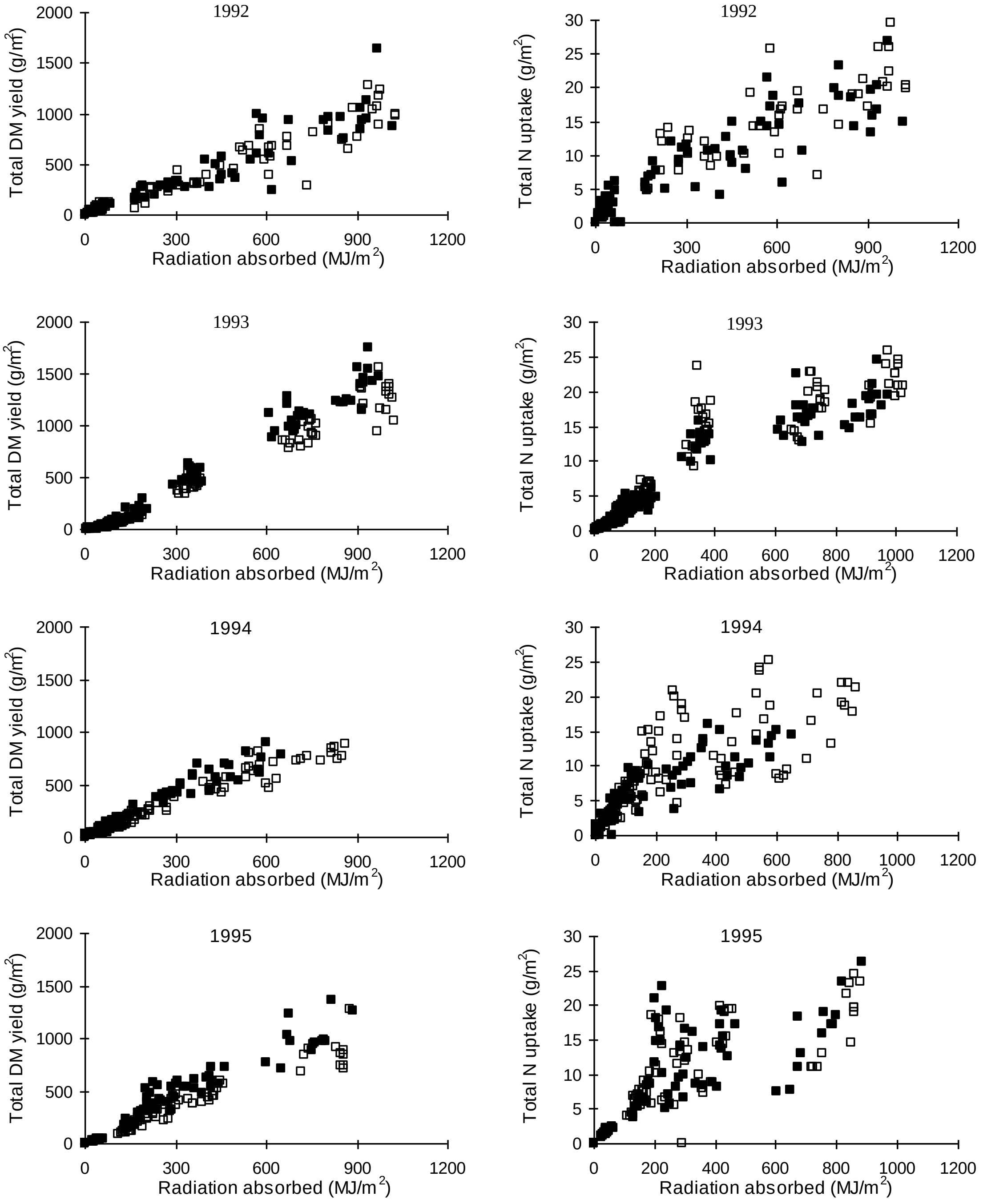


In both seasons increasing the N application rate increased the quantity of N absorbed per MJ of radiation absorbed. For crops receiving 300 kg N/ha, regressions against radiation absorbtion explained a large amount of the variation in N uptake, and this suggest that there is a causal link between N uptake and radiation absorbed as suggested by Grindlay (1997). For crops receiving 0 kg N/ha the relationship between N uptake and radiation absorbtion differed between the two seasons. In 2001, the regression explained little of the variation in N uptake, implying that N uptake was more or less independent of radiation absorbtion and therefore yield production. In 2002, however, the regression still explained a large proportion of the variation in N uptake. Closer, examination of the data showed that, in both seasons, the relationship between N uptake and radiation absorbtion may be better described by a two phase process. In the initial phase, N uptake and radiation absorbtion were closely associated with the slope of the relationship determined by N application rate. In the second phase, there was little association between N uptake and radiation absorbtion irrespective of variety, planting density or N application rate. The data sets collected in 2001 and 2002 did not contain sufficient data points to determine, with any precision, the timing of the change from the initial phase of N uptake to the secondary. To study this, data sets from BPC sponsored experiments at CUF 1992 to 1995 were examined. These older experiment tested the effects of N application rate (0-240 kg N/ha) on the growth and yield of Estima and Cara. During each season, harvests were taken to assess total DM yield, N uptake and leaf area index. Similar methods as before were used to estimate daily leaf area index and radiation absorbtion. The exception were data from 1992, where ground covers were used to estimate radiation absorbtion instead of leaf area index. The relationship between total DM yield and radiation absorbtion for Estima and Cara in 1992-1995 are shown in Figure 14 and in Table 27. As found with the 2001 and 2002 data, there was a good correlation between DM yield and radiation absorbtion with Estima having, with the exception of 1992, a significantly larger conversion efficiency.

Table 27. Effect of season and variety on net conversion efficiency 1992-1995 at Cambridge University Farm

Year	Variety	R^2	g DM/MJ	S.E.
1992	Cara	0.91	1.03	0.025
	Estima		1.09	0.037
1993	Cara	0.97	1.25	0.016
	Estima		1.49	0.023
1994	Cara	0.96	1.05	0.015
	Estima		1.34	0.028
1995	Cara	0.93	1.08	0.024
	Estima		1.43	0.035

Figure 14. Relationship between DM yield and radiation absorbtion and N uptake and radiation absorbtion for Cara (□) and Estima (■) in 1992-1995 at Cambridge University Farm



The relationships between N uptake and radiation absorption are also shown in Figure 14, and in all seasons there was evidence of an initial rapid phase of N uptake followed by second phase where radiation was absorbed but with little or no N uptake.   These data were analysed using a ‘split-line’ function to estimate the initial and final rate of N uptake and the point (as radiation absorbed) where the rates change. The analyses for 1992-1995 are shown in Table 28, Table 29, Table 30 and Table 31 respectively.   The effect of variety on the initial rate of N uptake was inconsistent over seasons: in 1992 and 1993 Cara had a larger initial rate than Estima, whilst in 1994 and 1995 there were no significant differences between varieties. Increasing the N application rate from 0 to 240 kg N/ha increased the rate of uptake, the exception being 1992 where the rate appeared abnormally small after application of 240 kg N/ha. The final rate of N uptake was always smaller than the initial rate and in some treatments was not significantly different from zero i.e. after the breakpoint radiation was being absorbed but there was no net uptake of N. The total amount of N accumulated at the break point was larger in Cara than in Estima and generally increased as the amount of N applied increased. The total amount of radiation absorbed at the breakpoint was generally increased by the first increment of N but not thereafter and the effect of variety on radiation absorption was small and inconsistent.

Using estimates of radiation absorption it is possible calculate the breakpoint in terms of days after planting and, when combined with emergence data, as days after emergence. When averaged over treatments, the breakpoint ranged from 63 DAP (for a late planted crop in 1994) to 94 DAP (for an early planted crop in 1993). Similarly, the breakpoint ranged from 34 DAE (1994) to 53 DAE (1993). Converting days after planting to a calendar date shows that the change in rate of N uptake occurred at a remarkably consistent date (Table 32). Furthermore, this change in rate was not overly affected by factors such as planting date, variety or N application rate. Of particular interest are the data from 1994 where due to excessive sprouting Cara emerged *c.* 3 weeks before the Estima but for both varieties, the change in rate of N uptake occurred 63 DAP (23 June).

Table 28. Parameters of N uptake in relation to radiation absorbtion. CUF Variety*N 1992, planted 10 April 1992

Variety	N rate	Initial Rate (g N/MJ)	Final Rate (g N/MJ)	Breakpoint (g N/m^2)	Breakpoint (MJ/m^2)	Breakpoint DAP	Breakpoint DAE	GC to BP (% days)	GC after BP (% days)	Total GC (% days)
Cara	0	0.044	0.009	14.3	165	72	40	822	8143	8964
Cara	60	0.063	0.011	10.0	288	73	41	1600	8455	10055
Cara	120	0.080	0.017	8.1	115	64	31	592	9781	10373
Cara	180	0.119	0.022	19.4	11	55	21	130	10928	11058
Cara	240	0.063	0.002	9.6	348	78	43	1806	8758	10563
Estima	0	0.043	0.004	10.8	174	72	39	957	2968	3925
Estima	60	0.026	0.001	11.7	501	88	55	2766	3261	6027
Estima	120	0.033	0.001	12.5	517	90	54	2887	4053	6940
Estima	180	0.085	0.012	6.6	97	65	28	501	6600	7100
Estima	240	0.036	0.016	10.0	363	89	51	2145	4817	6962
S.E.		0.0160	0.0037	3.19	89.5	5.8	6.3	512.1	501.5	249.4
Mean		0.059	0.010	11.3	258	75	40	1420	6776	8197
Cara		0.074	0.012	12.3	186	69	35	990	9213	10203
Estima		0.045	0.007	10.3	331	81	45	1851	4340	6191
S.E.		0.0071	0.0017	1.43	40.0	2.6	2.8	229.0	224.3	111.5
0		0.043	0.007	12.6	170	72	40	889	5556	6445
60		0.045	0.006	10.9	395	81	48	2183	5858	8041
120		0.056	0.009	10.3	316	77	42	1740	6917	8657
180		0.102	0.017	13.0	54	60	25	315	8764	9079
240		0.050	0.009	9.8	356	84	47	1975	6787	8763
S.E.		0.0113	0.0026	2.25	63.3	4.1	4.5	362.1	354.6	176.3

Table 29. Parameters of N uptake in relation to radiation absorbtion. CUF Variety*N 1993, planted 10 March 1993

Variety	N rate	Initial Rate (g N/MJ)	Final Rate (g N/MJ)	Breakpoint (g N/m^2)	Breakpoint (MJ/m^2)	Breakpoint DAP	Breakpoint DAE	GC to BP (% days)	GC after BP (% days)	Total GC (% days)
Cara	0	0.034	0.011	10.1	310	89	46	1591	8449	10040
Cara	60	0.039	0.011	13.4	363	91	47	1930	8661	10591
Cara	120	0.043	0.011	15.5	389	91	48	2034	9181	11215
Cara	180	0.049	0.001	20.5	442	96	52	2520	8117	10637
Cara	240	0.057	0.007	19.4	369	92	47	2003	9248	11252
Estima	0	0.030	0.004	12.2	418	96	59	2352	2932	5284
Estima	60	0.036	0.006	15.3	450	97	59	2697	3346	6043
Estima	120	0.037	0.007	14.2	404	93	55	2435	4548	6982
Estima	180	0.039	-0.004	18.6	501	102	63	3143	3609	6752
Estima	240	0.039	0.014	13.0	363	93	54	2035	5562	7597
S.E.		0.0021	0.0029	1.15	25.5	2.3	2.4	216.9	394.7	315.8
Mean		0.040	0.007	15.2	401	94	53	2274	6365	8639
Cara		0.044	0.008	15.8	375	92	48	2016	8731	10747
Estima		0.036	0.006	14.7	427	96	58	2532	3999	6532
S.E.		0.0010	0.0013	0.51	11.4	1.0	1.1	97.0	176.5	141.2
0		0.032	0.007	11.1	364	93	52	1971	5691	7662
60		0.038	0.008	14.4	407	94	53	2314	6003	8317
120		0.040	0.009	14.9	397	92	51	2234	6865	9099
180		0.044	-0.001	19.5	471	99	57	2832	5863	8694
240		0.048	0.011	16.2	366	92	51	2019	7405	9424
S.E.		0.0015	0.0020	0.81	18.1	1.6	1.7	153.4	279.1	223.3

Table 30. Parameters of N uptake in relation to radiation absorbtion. CUF Variety*N 1994, planted 21 April 1994

Variety	N rate	Initial Rate (g N/MJ)	Final Rate (g N/MJ)	Breakpoint (g N/m^2)	Breakpoint (MJ/m^2)	Breakpoint DAP	Breakpoint DAE	GC to BP (% days)	GC after BP (% days)	Total GC (% days)
Cara	0	0.031	0.006	6.3	177	62	44	845	7771	8616
Cara	60	0.036	-0.007	12.5	319	67	47	1522	10983	12505
Cara	120	0.053	-0.006	17.9	335	66	49	1843	11777	13620
Cara	180	0.069	-0.007	20.1	292	61	41	1325	12081	13406
Cara	240	0.078	0.002	20.2	265	61	43	1417	12388	13806
Estima	0	0.061	0.005	5.0	84	62	18	414	4069	4484
Estima	60	0.057	-0.005	11.2	194	65	28	935	5292	6228
Estima	120	0.075	0.003	10.8	157	62	26	711	5749	6460
Estima	180	0.060	0.003	11.4	191	65	28	876	6636	7511
Estima	240	0.071	0.002	10.6	143	63	21	658	8121	8779
S.E.		0.0059	0.0057	1.86	33.7	2.5	2.9	197.7	559.4	526.4
Mean		0.059	0.000	12.6	216	63	34	1055	8487	9541
Cara		0.054	-0.002	15.4	278	63	45	1391	11000	12391
Estima		0.065	0.002	9.8	154	63	24	719	5973	6692
S.E.		0.0026	0.0025	0.83	15.1	1.1	1.3	88.4	250.2	235.4
0		0.046	0.005	5.7	130	62	31	630	5920	6550
60		0.047	-0.006	11.8	256	66	38	1229	8138	9366
120		0.064	-0.002	14.4	246	64	37	1277	8763	10040
180		0.065	-0.002	15.8	242	63	34	1100	9358	10459
240		0.074	0.002	15.4	204	62	32	1038	10255	11292
S.E.		0.0041	0.0040	1.31	23.9	1.8	2.0	139.8	395.6	372.2

Table 31. Parameters of N uptake in relation to radiation absorbtion. CUF Variety*N 1995, planted 4 April 1995

Variety	N rate	Initial Rate (g N/MJ)	Final Rate (g N/MJ)	Breakpoint (g N/m^2)	Breakpoint (MJ/m^2)	Breakpoint DAP	Breakpoint DAE	GC to BP (% days)	GC after BP (% days)	Total GC (% days)
Cara	0	0.037	0.008	7.1	201	70	40	1042	6879	7920
Cara	120	0.061	0.010	13.4	231	71	42	1351	7595	8946
Cara	240	0.065	0.009	16.5	272	74	45	1703	7453	9156
Estima	0	0.039	0.008	7.6	197	70	43	1076	3596	4672
Estima	120	0.064	0.008	12.5	209	69	42	1282	4024	5306
Estima	240	0.068	0.008	15.0	234	71	44	1582	4346	5928
S.E.		0.0044	0.0032	0.94	26.3	2.3	2.2	196.0	199.4	120.4
Mean		0.056	0.008	12.0	224	71	43	1339	5649	6988
Cara		0.055	0.009	12.3	235	72	42	1365	7309	8674
Estima		0.057	0.008	11.7	213	70	43	1313	3989	5302
S.E.		0.0026	0.0019	0.54	15.2	1.3	1.3	113.2	115.1	69.5
0		0.038	0.008	7.3	199	70	41	1059	5238	6296
120		0.063	0.009	12.9	220	70	42	1316	5809	7126
240		0.067	0.009	15.7	253	73	44	1643	5899	7542
S.E.		0.0031	0.0023	0.67	18.6	1.6	1.6	138.6	141.0	85.2

These data are of interest for several reasons. The data clearly demonstrate that in the early part of the season (i.e. up to *c.* mid June) N uptake by the crop is driven by radiation absorption and the rate of N uptake was a function of how much N had been applied. Collectively, these data imply that N uptake is largely a passive process. Transpiration of water as a consequence of radiation absorption and photosynthesis will also result in the absorption of nitrate dissolved in the soil water and the concentration of the nitrate is dependent on the amount of N applied. After *c.* mid June, nitrogen uptake slows and appears to become independent of radiation absorption and thereby independent of yield production. This is of considerable significance since many models of crop growth assume that crop N content and productivity are intimately linked (Greenwood *et al.* 1985, Booij *et al.* 2001). The analysis done on the 1992-1995 and the 2001 and 2002 data demonstrate that this is not the case and inferences based on models which link yield production as a function of N uptake are likely to be unreliable.

Table 32. Estimated date of change from rapid to slow N uptake. Cambridge University Farm

Year	Estima	Cara
1992	30 June	18 June
1993	14 June	10 June
1994	23 June	23 June
1995	13 June	15 June
Mean	20 June	17 June

Furthermore, it is of interest to understand why the rapid phase of uptake finishes in mid June. It is possible that day length (either as an absolute value or the rate of change of day length) is acting as a signal that results in a slowing or cessation of N uptake. Thus, June 21st is the longest day and the rate of change of day length about the equinox is at its slowest. An alternative explanation for the similarity in the date of change in N uptake rate is that all crops attained a similar stage of development by mid June. It is possible that the change in rate corresponds to flowering and thus a cessation of development of the mainstem. However, at present, our data do not allow this hypothesis to be tested reliably . A planting date experiment is planned for 2003 to separate out environmental signals (day length) from physiological ones (e.g. flowering).

Other experiments (i.e. the Cultivation experiment, p. 38) have shown that DM and N are translocated in variable ratios from haulm to tubers. Furthermore, the experiments reported here have demonstrated that haulm N uptake, leaf area and, therefore, production of yield are poorly related. On-going analyses of the relationships between the N content of haulm components, branch production and canopy persistence suggest that the effects of N may be qualitative as well as quantitative. Thus, a certain quantity of main-axis N may be needed to trigger branch production and thereby produce persistent canopies. This observation is consistent with the poor relationship between N uptake and yield seen in many experiments: if the effect of N were purely quantitative then these relationships would be expected to be much closer. Further analysis has also shown that rates and timings of main-axis leaf area expansion show a similar pattern to that of main-axis N uptake. In consequence, a better understanding of the factors that control main-axis N uptake will lead to better understanding of leaf area production, DM production and formation of marketable yield.

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