The effect of nitrogen fertilizer on the recovery of nitrogen by a potato crop

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Abstract

The objective of this trial was to determine how much soil and fertilizer nitrogen (N) is taken up by a potato crop and the consequences for yield and quality. A Russet Burbank potato crop was grown at Lincoln, New Zealand, with 4 rates of N fertilizer. The crop was sampled during growth for yield and N content of leaves, stems and tubers. Soil N status in the top 30 cm in the row was also measured every 2 weeks. Without N fertilizer, the soil provided 168 kg N/ha to the crop. N fertilizer recoveries ranged from 100% for 75 kg fertilizer N/ha to 58% for 300 kg N/ha. Fertilizer N increased leaf area and the amount of radiation intercepted, but did not alter the efficiency of radiation interception. The rate of N application had no effect on the rate of N uptake by the crop or the rate of tuber bulking, but the duration of these processes was increased by increasing N, resulting in higher tuber yields, but reduced percentage dry matter.

Additional key words: *soil nitrate N, radiation interception, yield, dry matter.*

Introduction

Efficient use of soil and fertilizer nitrogen (N) is desirable in potato crops because N can considerably improve yield and tuber size (Westermann and Kleinkopf, 1985; Porter and Sisson, 1991). However, excessive N can decrease tuber specific gravity (Painter and Augustin, 1976; McCann and Stark, 1989), and can also be leached from the root zone and cause groundwater pollution (Rourke, 1985).

Potatoes in Canterbury have traditionally been grown with relatively low rates of N fertilizer, around 100 kg N/ha (Jamieson and Genet, 1985). Recently, processors have introduced the cultivar Russet Burbank from the United States, and initially applied American fertilizer management strategies to the crops grown here, applying up to 350 kg N/ha, similar to levels in the United States (Rourke, 1985; Tyler *et al.*, 1983; Lauer, 1985).

So how much N does a processing potato crop require in Canterbury? Overseas literature (Harris, 1978; Ojala *et al.*, 1990) has suggested that between 2 and 4 kg N/ha is required for each t/ha tuber yield, i.e., 120 to 240 kg N/ha for the 60 t/ha Russet Burbank crop in a previous trial (Martin *et al.*, 1992).

In this trial, 4 rates of N fertilizer application were studied to determine how much N is taken up by a potato crop, and the consequences for yield and quality. Also, the amount of nitrate N in the soil was measured to examine how well the soil and fertilizer supply of N met the demand of the crop.

Materials and Methods

A field experiment was conducted in the 1992-93 season on a Templeton silt loam overlying sand (New Zealand Soil Bureau, 1968) (*Udic Ustochrept*, USDA Soil Taxonomy) at Lincoln, New Zealand. The experiment followed a short term (19 months) pasture after fallow. The fertility status of the top 300 mm of soil, determined by AgResearch Quick Tests (Cornforth and Sinclair, 1984) was pH 6, Ca 10, K 11, P 17, S 4, nitrate N 5, and total N 0.23. Soil physical characteristics on an adjacent area have been given by Martin *et al.* (1992).

The N treatments were nil (0N), 75 kg N/ha (75N), 150 kg N/ha (150N), and 300 kg N/ha (300N). Fertilizer was applied either all at planting, or split with 20% at planting plus 80% spread over 4 applications every 3 weeks from tuber initiation. However, only results from the rates of N application are presented in this paper.

A randomised block design was used with 4 replicates, with each plot 7 rows x 13 m long. N was applied as urea (46% N). The fertiliser applied at planting was broadcast by hand on November 3, the day before planting, and then cultivated in. Subsequent fertilizer applications were broadcast by hand along the rows on 17 December, 6 January, 1 February, and 15 February, and were followed within 1-4 days by at least 50 mm of sprinkler irrigation using a side roll system.

Cut and treated sprouted seed tubers of Russet Burbank potatoes were planted using a 2 row planter on November 4. The crop emerged between 23 and 27 November, and was moulded on 3 December. Tuber initiation occurred around 14 December. From 11 December to 9 March, the crop was sprayed at approximately 3-weekly intervals with a fungicide and insecticide to prevent any damage from blight and aphids.

Commencing at tuber initiation, the crop was sampled at 2-weekly intervals until all the tops had died down (early April). In each plot, 2 rows were selected for intermediate sampling and 2 rows for a final harvest. The middle and outside rows of the 7-row plot were left as guard rows. Four plants were sampled at each sampling, 2 from each sampling row; 1-2 plants were left as guards between successive sampling. For each plot, leaf areas were measured using a leaf area meter, and leaf, stem and tuber dry weights were determined after drying for 12-24 hours in a forced draft oven. Dried samples were retained from selected harvests for subsequent analysis for total plant organic N using a Kjeldahl digestion and a modified version of the auto-analyzer method of Kamphake *et al.* (1967).

N concentrations in stems, leaves, dead top material, and tubers were measured for the second, fourth, sixth and eighth sampling, i.e., in late December, late January, late February and late March. The N yield of the top components were calculated and then combined for determination of top N concentration. Linear interpolation of the N concentration data over time was used to calculate top and tuber N yields for the other sampling.

Within a day of the crop being sampled, soil samples were taken from the 0-150 and 150-300 mm depths within the row for each plot. These were then bulked according to treatment and frozen until analysis for soil nitrate N using a modified version of the auto-analyzer method of Kamphake *et al.* (1967).

Light interception by the crop canopy was measured using a plant canopy analyzer (Li-Cor LAI-2000). Other meteorological data were obtained from the Lincoln Meteorological Station, c. 200 m from the experimental site.

The N uptake was calculated for each treatment for the harvest when total plant N was maximal to avoid any losses from the tops as they died down. The N balance (net N gain or loss to the pool of total N in the plant plus the nitrate N in the top 30 cm of soil, assuming no volatilization or runoff), were calculated as:

N gain = change in nitrate N in top 30 cm of soil plus change in plant total N minus any addition of fertilizer N.

In the 0N treatment, it was assumed that all the nitrate N in the soil was derived from mineralization, and that this level of mineralization was the same in the other treatments.

On 1 and 3 June the 2 final harvest rows were lifted with a single row potato harvester, bagged and stored in a cool dark shed until 8 and 9 July, when the potatoes were passed over a grading table where they were separated into table grade (passing over a 55 mm screen) and others. Specific gravity measurements, assessment for deformities such as secondary growth and cracks, and cutting for estimates of hollow heart and other internal defects were made on sub-samples of table potatoes.

Results

Timing of N fertilizer had very little effect on final N uptake and yield, and so, because of space limitations, only rates of N fertilizer are considered in this paper.

Season

The season was considerably cooler and slightly wetter than average (Table 1). Four irrigations of 50 mm water each were applied during the growing season, and the crop was never under water stress during growth.

Table 1. Actual and long-term mean temperatures and rainfall at Lincoln, New Zealand.

	Mean temperature (°C)		Rainfall (mm)	
Month (1992-93)	Actual	Long-term mean	Actual	Long-term mean
November	13.9	12.9	45.8	52.0
December	14.0	15.8	55.4	61.7
January	15.6	16.7	61.4	54.9
February	15.2	16.1	44.0	47.0
March	13.3	15.0	62.6	56.1
April	10.9	11.0	71.8	54.0
May	9.0	8.9	92.4	52.6

Soil Nitrate Nitrogen

Soil nitrate N levels increased in all treatments from sowing to December, especially in 300N (Fig. 1). The soil nitrate N in 0N then declined to similar levels to those at planting for the rest of the season. There was little difference between 75N and 150N in soil nitrate N, which declined to levels only slightly higher than 0N by February.

Plant Nitrogen

Total plant N yields for the 4 fertilizer rates are presented in Figure 2. Initially, N uptake rates were very similar irrespective of N treatment, and increased at a linear rate. However, N treatment had a strong effect on the duration of this linear uptake phase, which lasted until 68 days after planting for 0N, until 96 days for 75N and 150N, and until 110 days for 300N. After these dates, N uptake effectively ceased.

In Figure 3, top and tuber N yields are plotted for 3 rates of N. The 150N data have been omitted for clarity, but were between the 75N and 300N yield data for both tops and tubers. LSD's are given for those harvests where N concentration was measured, not interpolated. Top N yields increased up to late December for 0N and early January for plus N, thereafter declining. There was no significant ($P<0.05$) difference between plus N treatments until late March, but all had significantly higher top N yields than 0N.

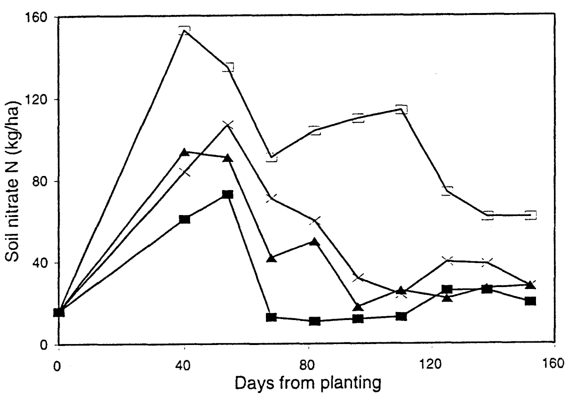

Figure 1. Soil nitrate N (kg/ha) in top 30 cm of soil over the life of the potato crop under 4 rates of N fertilizer. ■ = no fertilizer N, ▲ = 75 kg N/ha, × = 150 kg N/ha, □ = 300 kg N/ha.

In late December, tubers in the 0N treatment had significantly ($P<0.05$) higher N yield than those in plus

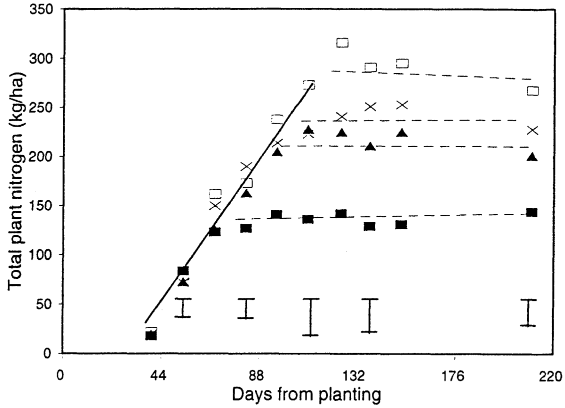

Figure 2. Total plant N yield (kg/ha) under 4 rates of N fertilizer. Legend as in Figure 1. The slope of the regression line using data from first 3 harvests for treatment 0N, first 5 harvests for 75N and 150N, and first 6 harvests for 300N is 3.56($\pm$ 0.15) (r^2=0.97, $P<0.001$). Vertical bars are LSDs ($P<0.05$). Broken lines show response plateaux to the four level of applied N.

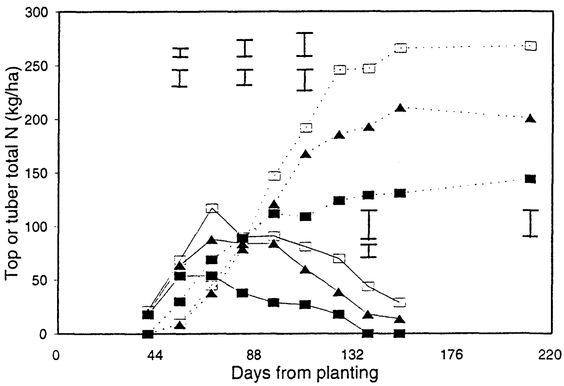

Figure 3. Top (solid line) and tuber (dotted line) N yield (kg/ha) under 3 rates of N fertilizer. Legend as in Figure 1; no data for 150 kg N/ha. Vertical bars are LSDs ($P<0.05$), lower set of bars for tops and upper for tubers.

N treatments. From early February, tuber N yield in 0N treatments levelled off, and was significantly lower than in plus N treatments. Tubers in the 300N treatment had significantly higher N yield than 75N or 150N, but there was no significant difference between the latter 2 N rates. The proportion of total plant N in the tubers was initially higher in the 0N treatment, but thereafter differed by less than 2% between treatments.

Nitrogen balance

When total plant N was maximal, the 0N treatment had accumulated 142 kg N/ha in the crop and 26 kg nitrate N/ha still in the soil, a total of 168 kg N/ha (Table 2). It was assumed that all of this N came from mineralization, or from more than 30 cm depth, and that the same amount became available to all treatments. So 168 kg N/ha became available to the plant-soil system in addition to any N fertilizer added.

The 75N treatment had no extra nitrate N left in the soil when total plant N was maximal, compared to 0N. However, the 75N crop contained 254 kg N/ha, an additional 11 kg N/ha over and above the combined N supply from soil (168 kg N/ha) and fertilizer (75 kg N/ha). 150N treatments had only 2 kg nitrate N/ha left in the soil over 0N treatments, and 75% of the fertilizer N had been taken up by the plant, but 25% (37 kg N/ha) was unaccounted for. 300N treatments only took up 58% of the fertilizer N, but 48 kg/ha was left as nitrate N in the top 30 cm of soil, so a similar percentage of applied N (26%) was unaccounted for, although this represented 78 kg N/ha.

Crop Growth and Leaf Areas

Leaf area measurements calculated by the canopy analyzer were closely correlated to measured leaf areas (r^2=0.84, P<0.001). After December, plants in the 0N treatment intercepted significantly less radiation than plus N (data not presented), but there was no significant difference between rates of N until the last set of measurements in late March, when 150N and 300N intercepted significantly more radiation than 0N or 75N.

The canopy analyzer data were used to calculate the amount of incoming radiation intercepted by the crop. There was a linear relationship between total dry weight at each harvest and cumulative radiation interception (Fig. 4). The 0N crop intercepted less radiation and produced less dry weight than plus N, but there was no significant (P<0.05) difference in slope between treatments, i.e., the efficiency of conversion of radiation to dry matter was the same.

Yield

Tuber bulking rates were linear from 54 days after planting (late December) to 110 days after planting for 0N (late February) and 125 days after planting (early March) for plus N treatments (Fig. 5). The bulking rate for all treatments over this period was 0.88 t/ha/day.

Increasing N significantly increased total and table yields, table percentage, and numbers and size of table grade tubers, but significantly decreased percentage dry matter (Table 3). There was no significant effect of N on hollow heart and deformities.

Table 2. Total plant N and soil nitrate N levels and the recovery of applied N fertilizer (kg N/ha) calculated when the N level in the plant was at maximum.

Fertilizer applied	(a)		0	75	150	300
Maximum N in plant	(b)		142	228	253	316
N in soil	(c)		26	26	28	74
N in soil and plant	(d)	(b)+(c)	168	254	281	390
N supply from soil	(e)	(d)0N	168	168	168	168
N supply from fertilizer left in soil	(f)	(d)-(e)	0	86	113	222
Fertilizer N left in soil	(g)	(c)-(c)0N	0	0	2	48
Fertilizer N in plant	(h)	(f)-(g)	-	86	111	174
Fertilizer N 'lost' from system	(i)	(a)-(f)	-	-11	37	78
Fertilizer N in soil as % N applied	(j)	100(g)/(a)	-	0	1	16
Fertilizer N in plant as % N applied	(k)	100(h)/(a)	-	115	74	58
Fertilizer N 'lost' from system as % N applied	(l)	100(i)/(a)	-	-15	25	26

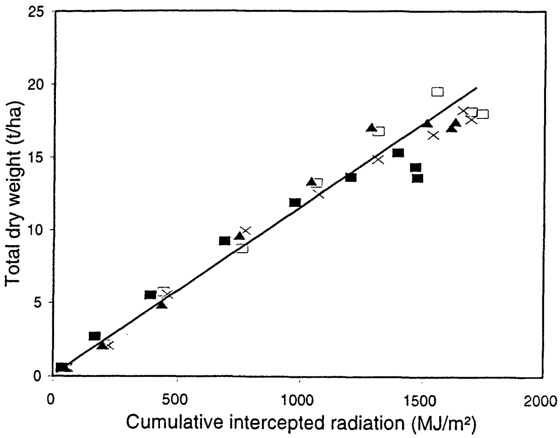

Figure 4. Total dry matter yield plotted against cumulative intercepted radiation under 4 rates of N fertilizer. Legend as in Figure 1. Slope of regression line for all rates of fertilizer N is 11.2(± 0.2) (r^2=0.97, P<0.001).

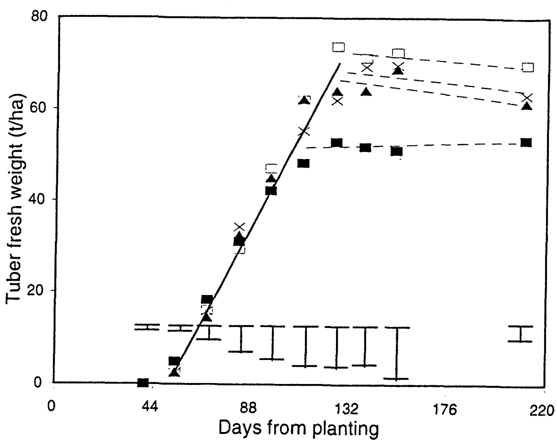

Figure 5. Fresh tuber yield (t/ha) under 4 rates of N fertilizer. Legend as in Figure 1. Slope of regression line for all treatments from harvests 2 to 6 for 0N, and harvests 2 to 7 for plus N is 884(±33) (r^2=0.97, P<0.001). Vertical bars are LSDs (P<0.05).

Table 3. Final harvest data.

Fertilizer applied	Total tuber yield (t/ha)	Table yield (t/ha)	Table as % total	Table numbers/m²	Weight/table tuber (g)	% dry matter	% table tubers deformed	% hollow heart
0	53.5	35.4	66.3	15.7	202	26.3	10.4	5.0
75	61.7	44.1	71.3	18.8	214	24.7	9.0	9.5
150	63.3	46.6	73.5	19.4	219	24.3	8.8	8.6
300	69.9	54.6	78.2	21.1	238	23.8	8.7	9.6
L.S.D.	3.8 ***	4.3 ***	4.1 ***	1.9 *	10 ***	0.4 ***	4.5 N.S.	4.3 N.S.

Discussion

Soil mineral N is present as either as ammonium or nitrate ions. Temperate arable soils have a fairly constant but low content of ammonium N, but a very variable and higher nitrate content (Russell, 1961). In the soil, urea fertilizer is broken down into ammonium ions, which are then converted into nitrate ions. This process is complete in 2 to 4 weeks during the warmer months in Canterbury (R.J. Haynes, pers. comm.). Like nitrate N, ammonium N can be taken up by the potato crop but the concentration of nitrate and ammonium N in the plant is very small compared to the organic N. Much of the ammonium is held on the exchange complex, and so is not available for leaching, unlike nitrates which are all dissolved in the soil solution.

In this trial, soil nitrate N was only measured to a depth of 30 cm. However, Lesczynski and Tanner (1976) showed that more than 85% of potato roots were in this layer, and Tyler *et al.* (1983) showed that most soil N after harvest was in the top 30 cm. Using ^{15}N as a tracer, Joern and Vitosh (1995) found that 83% of applied N fertilizer was in the top 30 cm of soil at harvest.

In this trial fertilizer N recoveries ranged from 58 to 115%. Westermann *et al.* (1988) had fertilizer N recovery efficiencies of 60 to 80%, but Tyler *et al.* (1983) reported recoveries as low as 39%. Joern and

Vitosh (1995) found that approximately 30-40% of applied fertilizer N was unaccounted for, either in tubers or vines not harvested, or lost by leaching or denitrification.

The 115% recovery of N in 75N may have been due to a greater growth of the roots, or the longer time available to take up N compared to 0N. Root growth was not measured in this trial, but the 75N crop took up N throughout the sampling period, whereas the 0N crop had effectively stopped N uptake by late February. So it is quite likely that this extra 11 kg N/ha would have been available to the other fertiliser treatments. Working through the N balance, this means that the percentage recovery of fertilizer N in 150N and 300N would have been 4-7% lower than in Table 2, and the % 'lost' similarly higher.

Figure 3 shows that the process of N uptake can be divided into 3 phases. Initially, the N in the tops is used to build up leaf area. From tuber initiation to the end of tuber bulking, there is usually a large increase in tuber N, and a steady reduction in top N, as a result of continued uptake of soil N and remobilization of reserve N. This is consistent with data from Millard and Robinson (1990) in Scotland. In the USA, however, this result would be indicative of a crop deficient in N (Lauer, 1985). In high fertility situations in the USA, tops may have higher N yields than tubers for a much greater proportion of their life (Kleinkopf *et al.*, 1981; Lauer, 1985). In this trial, N uptake by tubers was delayed in the N fertilizer treatments compared to 0N. Delayed tuber initiation and reduced partitioning to tubers early in the season with high N levels have also been reported by Kleinkopf *et al.* (1981) and Westermann and Kleinkopf (1985).

In the third phase, the canopy senesces and tuber bulking slows. During this phase, only about 24 kg N/ha was taken up by the tubers, and an equal or greater amount was lost from the tops over that period. Using ^{15}N, Millard *et al.* (1989) found that all N taken up by the potato crop initially goes to the tops, and is then relocated to the tubers. So any N application needs to be applied well in advance of this time to have any effect on growth and yield. Ojala *et al.* (1990) recommended that N uptake should be completed 2-3 weeks before the start of canopy senescence, which in this trial would have been the end of January.

Westermann and Kleinkopf (1985) suggested that there is sufficient N in the top soil to supply a potato crop when soil nitrate concentration exceeds 7.5 mg/kg. In this trial, this is equivalent to 14 kg nitrate N/ha in the top 30 cm of soil, and the only treatment which fell below this level was 0N during January and February. This low level of soil N resulted in N uptake by that treatment ceasing soon after tuber initiation, although initially there was continued translocation of N from tops to tubers over this period.

In this trial the maximum amount of N taken up by the crop for each tonne of tubers produced increased from 2.65 kg N/ha/tonne for 0N to 4.52 kg N/ha/tonne for 300N, very similar to uptakes reported for Russet Burbank in the USA (Kleinkopf *et al.*, 1981; Joern and Vitosh, 1995) and the 2-4 kg N/ha/tonne reported for other cultivars (Harris, 1978; Ojala *et al.*, 1990). This represents a decline in N use efficiency with increasing fertilizer N of nearly 50%.

According to Westermann and Kleinkopf (1985), a minimum uptake rate of more than 2.4 kg/ha/day is required to prevent N from being depleted from tops and roots during tuber growth, and at least 3.7 kg N/ha/day is required to produced a tuber growth rate of 0.75 t/ha/day. In the UK, N accumulation rates are lower, averaging around 2-2.5 kg/ha/day over mid part of the season (Harris, 1978). In this trial, the mean uptake rate over the linear phase of tuber bulking averaged 3.6 kg N/ha/day, very close to the rate recommended by Westermann and Kleinkopf (1985). Even so, under high fertilizer N, there must have been some N surplus to tuber growth requirements, as the longer duration of canopy cover and leaf area index was probably partly due to surplus N being stored in the foliage and used for new leaf production rather than being translocated to the tubers (Millard and Marshall, 1986).

Tuber yield in potatoes can be regarded as the product of 4 groups of processes: radiation interception, conversion of intercepted radiation to dry matter, partitioning of dry matter between tops and tubers, and regulation of tuber dry matter content (Millard and Marshall, 1986). In this crop, very little dry matter would have remained in the dead tops by harvest, so partitioning to tubers was assumed to be close to 100%. In this trial up to 1800 MJ/m^2 of radiation were intercepted, higher than in the United Kingdom (Allen and Scott, 1980; Millard and Marshall, 1986). The conversion efficiency to dry matter was 1.12 g/MJ, very similar to the 1.07 to 1.32 reported for other cultivars by Millard and Marshall (1986) and Spitters (1987), but lower than the 1.43-1.84 reported by MacKerron and Waister (1985). This suggests that growth may have been restricted in some way in this crop, or that respiration rates were higher in the warmer New Zealand environment. One potential reason for reduced yield was the quality of the seed. In this trial there was an average of 5 stems per seed tuber, possibly due to the seed tubers having been stored at higher than optimum temperatures (Iritani and Weller, 1987). Iritani and Weller (1987) found that Russet Burbank seed stored at lower temperatures produced only half the number of stems per tuber, but produced significantly higher yield, especially of large tubers.

The tuber bulking rate of 0.88 t/ha/day was similar to the .95 t/ha/day reported for Russet Burbank by Kleinkopf *et al.* (1981), and the up to 1 t/ha/day reported for other cultivars by Harris (1978). This crop was left to mature in the field, which may explain why dry matter contents in this trial are higher than reported previously for Russet Burbank in New Zealand (Admiraal, 1988) and the 20% assumed in potato models (MacKerron and Waister, 1985).

The major effect of increasing N on quality was through a reduction in tuber dry matter percentage, a common response (Painter and Augustin, 1976; Ojala *et al.*, 1990). There was no evidence that increasing N increased tuber deformities, in contrast to the results of Painter and Augustin (1976). The relatively high level of hollow heart in this trial may have resulted from the wet season combined with the irrigation applied to wash the fertilizer in (McCann and Stark, 1989), as Porter and Sisson (1991) found no evidence that hollow heart was increased by N fertilizer.

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