Methods of estimating the amount of N required by a potato crop

R.J. Martin, M.D. Craighead [1,2], P.D. Jamieson and S.M. Sinton

New Zealand Institute for Crop & Food Research Limited, Private Bag 4704, Christchurch.
[1] Ravensdown Fertiliser Co-operative Limited, P.O. Box 1049, Christchurch
[2] (current address: Nutrient Solutions Ltd., 19 Aynsley Terrace, Christchurch)

Abstract

Methods of estimating potato (*Solanum tuberosum* L.) crop nitrogen (N) requirement were compared by measuring petiole nitrate, total plant N content, or leaf area using data from an experiment with cv. Russet Burbank at Lincoln in the 1999-2000 season. The petiole test and the total plant N uptake test were difficult to translate into the amount of N required by the crop or to use in order to predict final yield. The relationship between petiole nitrate and yield varied considerably among this and other experiments. There was a close linear relationship between N content of the whole plant and plant fresh weight, but the relationship depended on the rate and timing of fertiliser application. There was a linear relationship between leaf area and plant N uptake, and maximum leaf area index was also closely related to final yield, suggesting that measuring leaf area could be a way of predicting plant N requirements and final yield.

Additional key words: *petiole test, leaf area index, yield, nitrogen uptake*

Introduction

Potatoes are valuable crops that receive up to 500 kg N/ha as fertiliser. Because of this, there is a substantial probability that some N is wasted, but the financial penalty for not reaching potential yields if N is undersupplied can be hundreds of dollars/ha. Hence there is a need for methods of accurately assessing N requirements to maximise profit, use the fertiliser more efficiently, and minimise wastage through leaching and residual N after harvest. A close linear relationship between N uptake and yield is often observed in potato crops (Mackerron *et al*. 1993; Vos, 1997). However, regular measurement of N uptake by sampling whole plants is excessively time consuming and expensive. This has led to a search for rapid and cheap methods of predicting N requirements.

The objective of this research was to compare three methods of predicting N requirements for potatoes. These methods were tested with data from an experiment where the amount and timing of N were varied.

The petiole nitrate test (Gardner and Jones, 1975; Kleinkopf *et al*., 1984) has been used extensively overseas to estimate crop N requirement, and is being used in New Zealand to assist in determining side dressing N requirements (M Craighead, pers. comm.). The petiole test involves taking samples from the fourth fully expanded leaf and drying them before subsequent laboratory nitrate N analysis. The nitrate level is compared with overseas guidelines such as those of Kleinkopf *et al*. (1984).

A method developed by Mackerron *et al*. (1994) uses crop fresh weight to estimate crop N requirement. Mackerron *et al*. (1994) claimed that there is a linear relationship between crop fresh weight increase and N uptake by the crop, which depends on the amount and timing of N applications. From an estimate of potential final yield, a required rate of N uptake to achieve that yield can be calculated. The difference between the actual and required N uptake rate can then be related to a required N application. Calibration of the relationship would enable consultants to advise N requirements from the potential yield of the crop, the fresh weight at sampling and previous N supplied to the crop. It is claimed that this test is superior to the petiole test (Mackerron *et al*., 1994).

Another possible indicator of plant N requirement is leaf area index (LAI), which is the area of leaf per unit area of ground. Allison *et al*. (1999) showed that there is a linear relationship between leaf area and plant N uptake, and leaf area is closely related to radiation interception and yield (Allan and Scott, 1992).

Materials and Methods

The trial was carried out near Lincoln, 20 km south of Christchurch. The soil was a Templeton silt loam, and the crop followed barley after three years in pasture. The paddock was ploughed in the winter. Eradicane (6 l/ha) was applied in September, and the site was then power harrowed to incorporate the chemical.

Site soil test results (0-30 cm) taken in July were, in AgResearch Soil Fertility Quick Test Units, Ca 6, K 17, Olsen P 28, Mg 16, Na 11, and SO_4-S 13. The pH was 5.5, and total N 0.18. A basal fertilizer mix applying 150 kg P/ha, 150 kg K/ha and 33 kg Mg/ha as a mix of superphosphate, potassium chloride, potassium sulphate and calcined magnesite was machine broadcast over the plots on 19 October. The area was then maxi-tilled and the urea-at-planting treatments (see below) applied on the same day.

Seed tubers of potato cv. Russet Burbank were cut by hand to an estimated 50 g, then dressed with Gaucho (insecticide) and Monceren (fungicide), and dusted with fir bark dust to keep the cut surface dry.

There were four replicates of four N treatments (see below) in a randomised complete block trial. Plots were 9 or 10 rows by 10 m long. Row spacing was 77 cm and the tuber spacing within the row was 33 cm, giving a planned population of 39,350 tubers/ha. The trial area was planted with a 2-row planter on 21 October 1999. The crop was grubbed on 15 and 24 November to control weeds, and was moulded on 1 December.

The N fertiliser treatments, applied as urea, were:

1. no N fertiliser,
2. 150 kg N/ha at planting,
3. 300 kg N/ha (150 kg at planting plus 150 kg at moulding (1 December)),
4. 275 kg N/ha (100 kg at planting, 25 kg at moulding and on 13 December, and 12.5 kg applied on 10, 17, 24, 31 January, 7, 14, 21, 28 February and 1 and 6 March).

The N-at-moulding treatments were applied by hand immediately prior to moulding. Subsequent urea N applications were broadcast over the crop by hand. The crop was sprayed frequently to control diseases and aphids, and the trial was irrigated seven times with a total of 280 mm water applied.

Plant samples were taken from all treatments on 15 and 28 December, 11 and 24 January, 7 and 21 February, 6 and 20 March and 3 April. At each sampling, 4 plants in each of 2 adjacent rows were dug and separated into tubers and tops. The roots were discarded. The tops were weighed in the field and a subsample of a main stem from each of three plants brought back to the laboratory, and washed if necessary to remove any soil. All tubers were brought back to the laboratory.

In the laboratory the top subsample was weighed, and then the leaf area of the first fully expanded branchlet was determined on a Delta-T Image Analysis System. Laminas and petioles of the sixth branchlet, along with stems and leaves of the rest of the sub sample were then weighed and dried. The tubers were washed, allowed to dry and weighed. For later harvests, the % dry matter of the tubers was determined from their specific gravity, using a conversion table provided by the potato breeders at Crop & Food Research.

Petiole samples were taken on 22 December then at weekly intervals from 13 January until the tops had died, which varied from 1 to 15 March, according to treatment. The petiole of the first fully expanded leaf on each of 10-12 plants/plot was cut off, the leaflets stripped off, and the petiole dried at 80^{o}C and stored before all samples were forwarded to ARL Laboratories in Napier for nitrate (NO_3) analysis.

The data were analysed by analysis of variance using the Genstat statistical package (Genstat 6 Committee, 2000).

Results and Discussion

Weather

The 1999-2000 season was cooler and wetter than usual. After emergence, mean temperature in all months averaged 1.2^{o}C below the long-term average, but solar radiation was close to or above average. Rainfall over the life of the crop was close to average, but was below average in December and February, and above average in January. On 6 February, there were very strong NW winds all day, resulting in plants being blown over and a lot of leaf and leaf tip death.

During the growing season, 280 mm of irrigation were applied to the crop; at no stage did the crop experience drought conditions. Irrigation volumes of 38 to 50 mm were often followed within 24 hours by significant rainfall events. On two occasions, in December and early January, irrigations were closely followed by heavy rainfall events, resulting in the crop receiving 75-100 mm of water in less than a week.

Crop growth and leaf area

First emergence was noted on 8 November. The first flower buds were noticed on 13 December.

All treatments had reached an LAI of 3 - 4 by 15 December. The LAI of nil N plots stayed around 3.2 until 24 January and then declined until 6 March when all the tops had died (data not presented). The LAI of the other treatments was significantly higher over summer, increasing to between 4 and 6 in January and then declining steadily to zero (data not presented). By 6 March only 300 kg N/ha plots had any green leaf (LAI 0.6), but by 20 March all of the tops had died. Top weights showed a similar pattern of increase and decline to leaf area index. On 28 February, some late blight infection was noted on the southern two replicates, particularly in the nil N and 150 kg N/ha plots.

Yields

Tuber yields increased with increasing amounts of N applied early, from 59 t/ha for nil N to 85 t/ha for 300 kg N/ha (Table 1). The yield from the split application of 275 kg N/ha did not differ from that of 150 kg N/ha applied early. These yield responses to N were up to 21% higher than those in a previous trial (Martin, 1995b). Tuber dry matter percentage decreased with increasing N fertiliser application. They were not as high as that found by Martin (1995b), but tubers in that crop were left to mature in the field. They were still, however, considerably higher than the 20% assumed in potato models (Mackerron and Waister, 1985). Overall, the potatoes had a good appearance, with no sign of uneven growth and no sign of hollow heart or incipient hollow heart during the growth of the crop. Crop N uptake and N uptake/tonne of tuber yield both increased with increasing N application (Table 1). The fertiliser taken up by the plant as a percentage of that applied was 66% for the two early N treatments, similar to equivalent treatments reported by Martin (1995b), and 47% for the split applications (Table 1).

Petiole nitrates

Changes in petiole nitrate are shown in Fig. 1. The background levels separated by the dotted lines are those recommended for potatoes in Idaho (Kleinkopf *et al.*, 1984). The level of petiole NO_3^- in the no N treatment would, according to the Idaho recommendations, have been deficient over the whole course of the trial. When 300 kg/ha N/ha was applied early, petiole NO_3^- levels were adequate according to Idaho guidelines, but the 150 kg and split 275 kg N/ha applications produced petiole NO_3^- levels that were well into the inadequate range at the start of sampling, and in the deficient range thereafter.

Petiole NO_3^- levels in this trial were around 10,000 ppm lower than for Russet Burbank in a previous trial (Martin, 1995a), but tuber yields were 8-11 t/ha higher than for equivalent fertilizer levels in the 1995 trial (Table 2). In contrast, a winter potato crop at Puke-

Table 1. Mean potato tuber yield, dry matter percentage, maximum crop N uptake, and crop N uptake/t of tubers.

Treatment (kg N/ha)	Tuber yield (t/ha)	Dry Matter %	Maximum crop N uptake (kg/ha)	Crop N uptake (kg/t tubers)	Difference (%) in crop N uptake over control
Nil	59.4	24.3	148	2.50	0
150 early	73.4	22.2	240	3.27	99
300 early	85.2	21.4	336	3.95	188
275 split	74.9	21.6	276	3.69	128
LSD (P<0.05) (df=9)	5.36	0.61	27.9	0.251	

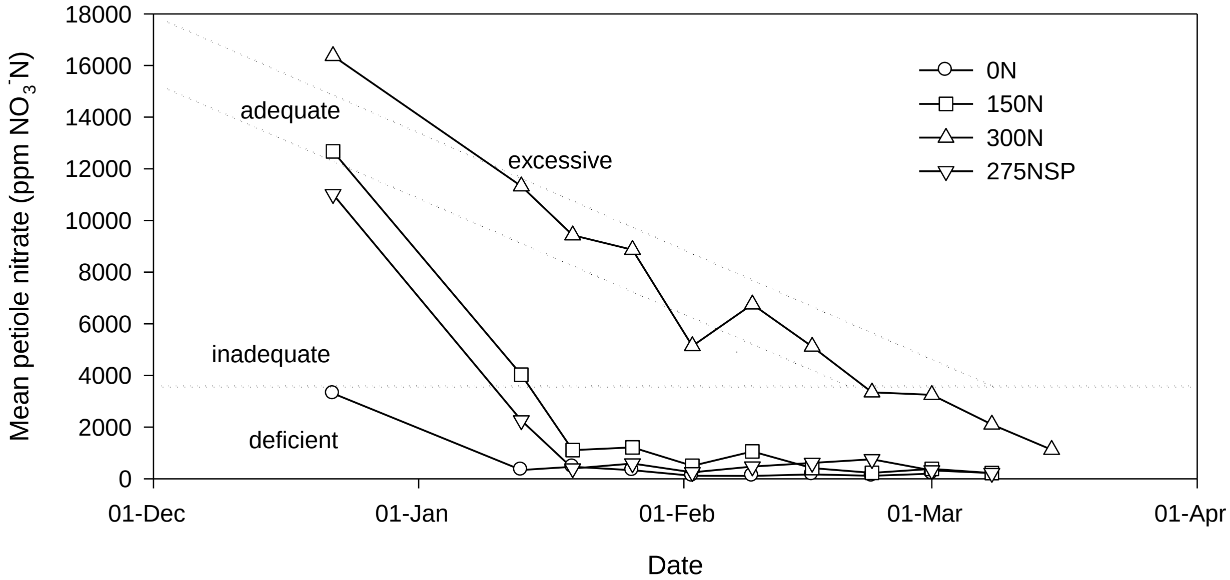

Figure 1. Mean potato petiole nitrate concentration (ppm) for all treatments at each petiole sampling time. The background levels separated by the dotted lines are those recommended for potatoes in Idaho (Kleinkopf *et al.*, 1984).

Table 2. Tuber yields (t/ha) at final harvest from trials with contrasting petiole NO_3 ranges.

Petiole N range[1]	This study	Martin (1995b)	Martin *et al.* (2001)
Deficient	59	54	-
Inadequate	74	62	-
Adequate	85	63	13
Excessive	-	70	28

[1]according to Kleinkopf *et al*. (1984).

kohe had very high petiole NO_3^- levels, but produced very low yields (Martin *et al.*, 2001). This indicates that petiole NO_3^- levels will need to be calibrated for New Zealand conditions in order to take into account other agronomic factors and to avoid recommending excess N fertilizer. Sampling timing and technique may also reduce variability between crops (Martin, 1995a).

The first petiole samples were taken on 22 December, and the second on 13 January. If the first samples had been immediately sent away for analysis, it is unlikely, because of the Christmas-New Year close down, that the results would have been available before the second sampling, by which time the petiole NO_3^- levels in most of the treatments were deficient. A faster means of measuring plant N status at this critical stage of potato growth is, therefore, required. One possibility is the petiole sap test, described by Martin (1995a), although this technique requires careful sampling to achieve consistent results (Mackerron *et al.*, 1995).

Mackerron crop fresh weight test

There were close linear relationships between N uptake by the whole plant (in kg/ha) and the plant fresh weight (in t/ha) (r > 83%; Fig. 2), but the slope appears to vary with the rate and timing of the N application. In order for these relationships to be of predictive value, they must hold for different sites and years. Figure 2 also shows data for nil or plus N fertiliser treatments from a winter grown potato crop at Pukekohe (Martin *et al.*, 2000), where the crop received high N applications but had low yields. In contrast, Allen and Scott (1992) found that similar yielding crops might have very different N contents. This suggests that using the relationship between N uptake

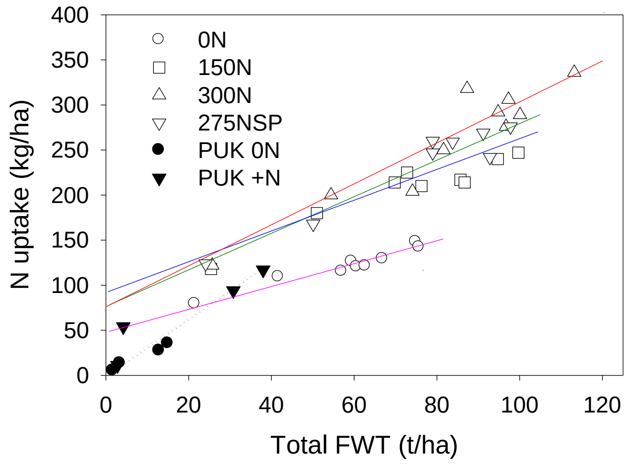

Figure 2. Potato crop N uptake (kg/ha) plotted against total fresh weight (including tubers) (t/ha) for successive harvests for this trial (open symbols) and from Pukekohe (closed symbols). Slopes of the regression lines are no N = 1.14, 150 N early = 1.59, 300 N early = 2.37, and 275 N split = 2.09, and for Pukekohe, combined no N and plus N data = 2.74.

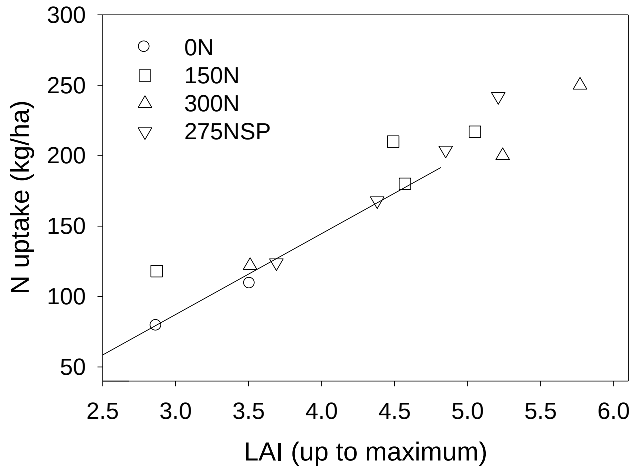

Figure 3. Potato leaf area index v N uptake (kg/ha) up to the maximum leaf area index for each treatment. Solid line is for previous data from Martin (1995b).

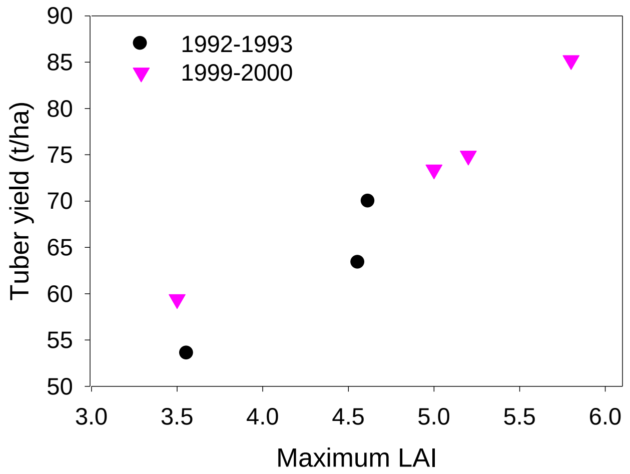

Figure 4. Final potato yield (t/ha) v maximum leaf area index for 1992-93 (data from Martin, 1995b) and this trial (1999-2000). Points represent different N treatments.

and total biomass to predict plant N requirements has the same problems as the petiole nitrate test, in that other seasonal or agronomic factors will affect the relationship (Allison *et al.*, 1999), and that there is still the problem of translating these relationships into final yield. This method may have value if it is coupled with models forecasting potential yields and hence optimum N requirements (Jamieson *et al.*, 2001).

LAI method

In this and a previous experiment (Martin, 1995b), increased N uptake resulted in increased leaf area (r^2 = 0.91, Fig. 3), and final yield was related to maximum LAI (r^2 = 0.92, Fig. 4). Similar relationships between N uptake and leaf area were shown by Allison *et al.* (1999). The fact that in both trials very similar patterns emerged between LAI and N uptake and between maximum LAI and final yield suggests a robust relationship. Such relationships may need to be calibrated for different cultivars, soil types and agronomic practices, and may also be affected by growing conditions which affect leaf expansion, such as temperature (Allison *et al.*, 1999).

Leaf area index can easily be measured in the field, but the equipment is expensive. However, consultants may be able to use such equipment in the way they schedule irrigation using a neutron probe. More easily measured possible proxies for LAI could include crop height, % ground cover, and date of canopy closure. Trials could indicate target times for, say, when a certain canopy height or ground cover should be achieved. Maximum LAIs were achieved in mid January in all treatments in both trials, indicating that any N applications to increase and maintain leaf area index would have to be applied before then.

Conclusions

These results, and those of Martin (1995a), indicate that there are currently no reliable field methods for predicting N requirements from potato crops. The three methods described all have limitations. The petiole N test needs calibration and fast turn around of results to be applicable. The fresh weight method of Mackerron *et al*. (1994) needs careful calibration and interpretation, and the leaf area method shows promise but involves using expensive equipment in the field. Modelling approaches for forecasting N requirements for potatoes, which may be possible to use in conjunction with the other methods above, are being developed (Jamieson *et al*., 2001).

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