QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

MISCELLANEOUS BULLETIN No. 2

ACCUMULATION OF RESIDUAL SOIL NITROGEN AND ITS RELATION TO THE NITROGEN REQUIREMENTS OF BEETROOT (BETA VULGARIS L.) IN THE LOCKYER VALLEY

By S. Visuttipitakul, M.S., D.T.A., M.Agr.St. and S. A. Waring, B.Sc.Agr., Ph.D.

SUMMARY

Ammonium nitrate was broadcast in equal applications of 0, 75, 150 and 300 kg ha^{-1} to beetroot (*Beta vulgaris* L.) at 20 and 60 days after planting. The soil mineral nitrogen at planting was 284 kg N ha^{-1} for the 0 to 60-cm depth.

Most of the nitrogen in the applied fertilizer was left after harvest as residual mineral nitrogen in the form of nitrate at the depth of 0 to 60 cm in the soil profile. There was little evidence of either accumulation or uptake of mineral nitrogen below 60 cm. Increasing rates of applied fertilizer increased top yield and percentage nitrogen in both plant roots and tops, but did not increase root yield. This suggested that there was adequate nitrogen for root production already present.

The results indicate that where there is more than 250 kg ha^{-1} of mineral nitrogen in the top 60 cm of soil it may be wasteful to apply nitrogen fertilizer. Alternatively if mineral nitrogen in the soil at planting is very low application of 300 kg ha^{-1} of nitrogen fertilizer may be required. Determination of mineral nitrogen at planting associated with an estimate of potential yield may allow more accurate prediction of nitrogen fertilizer requirements.

I. INTRODUCTION

Associated with the development of modern technology and improved farming systems, the yield of many crops has increased rapidly. As a result, nitrogenous fertilizers have become more and more important for high yields. However, the price of fertilizer also has rapidly increased since the energy crisis in 1973 (Tanaka 1975). Thus fertilizer waste must be minimized, and more attention paid to residual nitrogen in the soil (Chang 1975). In particular the initial content of mineral nitrogen can be important in determining the amount of nitrogen fertilizer required to attain maximum yield and the recovery of fertilizer nitrogen by crops. For example Shannon *et al.* (1967) found that beetroot did not show yield response to applied nitrogen in a field which had been fertilized in the past resulting in high residual mineral nitrogen in the soil.

In the Lockyer Valley region of south-east Queensland considerable quantities of beetroot are grown for canning. High rates of nitrogen fertilizer (up to 450 kg N ha^{-1}) are applied for each crop but little is known about actual crop needs. A preliminary investigation at sites on a number of farms found residual mineral nitrogen accumulated in the soil (1-m depth) in individual borings ranging from 90 to 160 kg N ha^{-1}.

The objective of the work reported was to investigate the accumulation of residual mineral nitrogen and its relation to the nitrogen requirement for the growing of beetroot in the Lockyer Valley.

II. MATERIALS AND METHODS

The experiment was carried out on a farm in the Lockyer Valley area approximately 1 km north of Forest Hill and 85 km west of Brisbane. The soil on the experimental site was a Black Earth (Stace *et al.* 1968) typical of the soils used for horticulture in the area. Some of the important properties are shown in table 1.

TABLE 1

SOIL CHARACTERISTICS OF THE EXPERIMENTAL SITE

Soil Depth (cm)	pH*	Total N† (%)	Organic Carbon‡ (%)	C : N Ratio	Available P.‖ ($\mu g\ g^{-1}$ O.D. Soil)	Particle Size[g]			B.D.[a] ($g\ cm^{-3}$)
						Sand	Silt	Clay	
0– 10	8·6	0·149	1·76	11·8	11·6	13	32	35	1·20
10– 20	8·6	0·142	1·67	11·8	10·0	12	32	55	1·20
20– 40	8·1	0·131	1·38	10·5	7·7	18	25	56	1·44
40– 60	8·0	0·097	1·02	10·5	9·7	29	22	49	1·43
60– 80	8·0	0·073	0·74	10·1	9·7	37	19	43	1·43[b]
80–100	8·0	0·072	0·49	6·8	10·4	33	23	45	1·43[b]
100–120	8·7	0·044	0·38	8·6	9·8	34	16	50	1·43[b]
120–140	8·8	0·040	0·17	4·2	9·8	25	21	53	1·43[b]

* 1 : 5 soil water ratio; † Kjeldahl method (Waring, unpublished data);
‡ Walkely and Black method (Piper 1950); ‖ B.S.E.S. method (Kerr and von Stieglitz 1938);
[g] Hydrometer method (Piper 1950); [a] (Method of W. E. Fox, unpublished data);
[b] Assuming B. D. the same as for the 40 to 60-cm depth.

The experimental design employed was a randomized complete block consisting of 6 blocks with 4 treatments (0, 150, 300 and 600 kg N ha^{-1}). Planting was by a standard commercial machine at a spacing of 7 x 30 cm except for a 50-cm spacing after each 5 rows to allow for the tractor wheel. The plot size was 3·4 x 10 m so that each plot consisted of 10 rows of plants. The applied fertilizer (ammonium nitrate) was split into halves, and broadcast by hand when the plants were 20 and 60-days old. Weeding and irrigation followed the normal field practice. Rainfall and irrigation during the experimental period are shown in table 2. Germination was adversely affected by the heavy rainfall on 26 February giving a more variable and less dense stand than normal.

Two plant harvests were made during the experimental period. For the first harvest two plants per row from the middle rows of the plot (3rd to 8th row) were randomly harvested. For the second harvest six rows of plant (3rd to 8th row), 4 m in length at the middle of each plot were harvested. Dry weight of plant material was determined by drying at 60°C to constant weight.

Soil samples were taken using a Jarrett auger which cut a 12-cm-diameter hole. Three soil samplings were made as shown in table 2. For the initial soil sampling there were 3 holes per block located at random and for the samplings under crop 2 holes per plot, one at the middle of the inter-row and another

TABLE 2

WATER RECEIVED BY PLANTS AND SCHEDULE OF OPERATIONS

Date	Water Received (mm)		Operation
	Rainfall	Irrigation	
2.2.75	51	19	
17.2.75	..	..	Initial soil sampling
22.2.75	..	..	Planting
26.2.75	102	..	
10.3.75	..	17	
12.3.75	5	..	
14.3.75	..	..	First fertilization
22.3.75	30	..	
5.4.75	36	..	
12.4.75	..	25	
16.4.75	..	..	First soil sampling under crop
17.4.75	..	..	First plant harvesting
22.4.75	..	19	
23.4.75	..	..	Second fertilization
8.5.75	..	19	
24.5.75	..	19	
9.6.75	..	..	Second plant harvesting
10.6.75	..	..	Second soil sampling under crop
Totals ..	224	118	

at the row position with each position being located randomly. For the samplings under crop, soil samples at the same depth of the two holes per plot were composited and sub-samples taken for determination of moisture and mineral nitrogen.

For mineral nitrogen determination approximately 100 g of soil (weighed to $\pm 0 \cdot 01$ g) was placed in a screw-top jar and 200 ml 2M KCl added on the same day that the soil was sampled. The jars were stored overnight at 5°C and extracted the next day by shaking and filtration. Filtrates were stored at 5°C and analysed for mineral nitrogen by the distillation method of Bremner and Keeney (1965).

III. RESULTS AND DISCUSSION

Mineral nitrogen in the soil at the various samplings

Values for mineral nitrogen are shown in table 3. Tests showed only trace quantities of nitrite nitrogen (NO_2-N) at all samplings. Ammonium nitrogen (NH_4-N) values for individual depths were very low (less than 1 kg N ha^{-1}) at the initial soil sampling. Thus almost all the mineral nitrogen present was in the nitrate form (NO_3-N). Cumulative totals from the surface to 60, 100 and 140-cm depths were 284, 383 and 479 kg N ha^{-1} respectively. These figures were well above figures in the preliminary investigation indicating substantial accumulation of residual mineral nitrogen presumably due to applications of nitrogen fertilizer in excess of plant needs over previous seasons.

At the first sampling under-crop NH_4-N values were very low (1 to 4 kg N ha^{-1}) indicating rapid nitrification of ammonium from the ammonium nitrate in the fertilized treatments. At the second sampling under-crop NH_4-N values were again very low (1 to 3 kg N ha^{-1}) except for the surface of the

TABLE 3

MINERAL NITROGEN (NH_4–N + NO_2–N + NO_3–N) AT VARIOUS SOIL DEPTHS AVERAGED OVER SIX BLOCKS (kg N ha^{-1})

Soil Depth (cm)	Initial Soil Sampling	First Soil Sampling				Second Soil Sampling			
		Rate of Fertilization kg N ha^{-1}							
		0	75	150	300	0	75 + 75	150 + 150	300 + 300
0 –20	94	14a*	33b	89c	146d	10a′	28b′	76c′	243d′
20– 40	101	56a	66a	78a	126b	21a′	54b′	99c′	147d′
40– 60	89	76a	80a	68a	81a	49a′	68b′	79b′c′	92c′
60– 80	54	62a	63a	74a	82a	55a′	67a′b′	70a′b′	80b′
80–100	45	49a	53a	54a	60a	48a′	49a′	58a′	55a′
100–120	40	..	..	..	..	40a′	48a′	36a′	47a′
120–140	56	..	..	..	..	46a′	47a′	48a′	50a′
Total	479	257A	295B	363C	495D	269A′	361B′	466C′	714D′

* Figures followed by the same letter at the horizontal are not significantly different at 5% level.

plots receiving the 300 + 300 fertilizer treatment where the value was 12·4 kg N ha^{-1}. Thus at both samplings under crop almost all the mineral nitrogen was present in the nitrate form.

Mineral nitrogen in the soil at the first sampling showed depletion in the 0 to 40-cm soil depth for the zero and 75 kg N ha^{-1} fertilizer treatments and further accumulation for the 300 kg N ha^{-1} treatment. There was little change in depths below 40 cm. At the second soil sampling further depletion occurred in the 0 to 40-cm soil depth for the zero fertilizer treatment and some depletion at 40 to 60 cm whereas further accumulation occurred in the 0 to 40-cm depth for the 300 + 300 kg N ha^{-1} fertilizer treatment. There was little change in depths below 60 cm.

Depletion in the zero fertilizer treatment at both samplings is probably due mainly to plant uptake suggesting that such activity was minimal below the surface 60 cm. The further accumulation in surface soil for the 300 + 300 kg N ha^{-1} treatment indicated that this rate was well in excess of plant needs. The relatively stable values below 60 cm, even with large applications of nitrogenous fertilizer, suggest that there was little leaching of nitrate-nitrogen beyond this depth during the experiment. Thus the accumulations shown at depth in the initial sampling must have occurred as a result of stronger leaching conditions than those during the experiment.

Yield, nitrogen content and nitrogen uptake at the two plant harvests

As shown in table 4, there were no significant differences in either fresh or dry weight of roots among the nitrogen fertilizer treatments at either the first or second harvest. For the plant tops differences were not significant at the first harvest, but at the second harvest increases occurred which were significant at the higher levels of applied nitrogen fertilizer. The nitrogen percentages of plant roots and tops increased with rate of fertilizer application becoming significant at the higher rates at the second harvest. Nitrogen uptake by the plant increased with rate of fertilizer application becoming significant for tops and whole plants at the second harvest.

Estimates of the fate of the applied nitrogen fertilizer are shown in table 5. Apparent crop recoveries are low at both harvests whereas apparent soil recovery as mineral nitrogen was high ranging from 51 to 79% at the first harvest and 61 to 74% at the second harvest. Fertilizer nitrogen not accounted for by plant uptake or as soil mineral nitrogen was substantial, increasing with the amount of applied fertilizer but declining as a percentage of the applied fertilizer, as the fertilizer rate increased. A significant part of this unaccounted-for nitrogen would have been immobilized by the soil micro-organisms but it is probable that net gaseous loss either as ammonia or by denitrification occurred, particularly by the former mechanism in view of the alkaline pH of the soil (table 1). Clearly leaching was not an important mechanism of loss during the experiment.

An important consideration is the optimum rate of fertilizer application for maximum economic return. Results of this experiment indicated that the economic yield did not increase with fertilization due to the relatively high level of mineral nitrogen at planting. This points to the importance of considering the amount of mineral nitrogen present in the soil at planting. Measurement of mineral nitrogen at planting may allow estimation of whether additional nitrogen fertilizer is needed. One difficulty is that complete utilization of soil mineral nitrogen would not be expected. The results in this experiment suggest that where there is more soil mineral nitrogen than about 250 kg ha^{-1} (or 7·4 kg N t^{-1} or expected yield of fresh beet) in the top 60 cm of soil at planting it may be

TABLE 4

YIELD, N PERCENTAGE AND N UPTAKE BY PLANT ROOTS AND TOPS AT THE FIRST AND SECOND HARVESTS

—	First Harvest				Second Harvest			
	Rate of Fertilizer Application as kg N ha⁻¹							
	0	75	150	300	0	75 + 75	150 + 150	300 + 300
Fresh weight of plant roots (t ha^{-1})	13·69a*	13·98a	13·82a	13·86a	33·93a′	34·75a′	32·79a′	33·26a′
Dry weight of plant roots (t ha^{-1}) ..	1·34a	1·34a	1·33a	1·34a	3·31a′	3·38a′	3·32a′	3·21a′
Fresh weight of plant tops (t ha^{-1}) ..	13·42a	13·63a	14·01a	14·01a	15·20a′	15·30a′	15·49a′b′	16·85b′
Dry weight of plant tops (t ha^{-1}) ..	1·31a	1·33a	1·38a	1·37a	1·50a′	1·50a′	1·56a′	1·75b′
N in roots (%)	3·18a	3·39a	3·37a	3·50a	2·97a′	3·12a′b′	3·22b′c′	3·37c′
N in tops (%)	2·98a	3·07a	3·14a	3·52a	2·79a′	2·89a′	3·09b′	3·24b′
N uptake in roots (kg N ha^{-1}) ..	41·3a	45·6a	47·3a	48·1a	98·3a′	105·8a′	108·9a′	108·2a′
N uptake in tops (kg N ha^{-1}) ..	39·9a	41·4a	41·3a	46·8a	41·6a	43·8a′	48·3a′	56·6b′
N uptake in whole plant (kg N ha^{-1})	81·2a	87·0a	88·6a	94·9a	139·9a′	149·6a′b′	157·2b′	164·8b′

* Figures followed by the same letter are not significantly different at 5% level.

TABLE 5

PARTIAL BALANCE SHEET FOR APPLIED NITROGEN FERTILIZER AT THE FIRST AND SECOND HARVESTS

—	First Harvest				Second Harvest			
	Rate of N Application (kg N ha^{-1})							
	0	75	150	300	0	75 + 75	150 + 150	300 + 300
Recovery in Crop								
Uptake in total plant (kg N ha^{-1})	81·2	87·0	88·6	94·9	139·9	146·6	157·2	164·8
Increase from the zero treatment (kg N ha^{-1})	..	5·8	7·4	13·7	..	9·7	17·3	24·9
Apparent nitrogen recovery by plant*(%)	..	7·7	4·9	4·6	..	6·5	5·8	4·1
Recovery in soil								
Mineral nitrogen in the whole profile† (kg N ha^{-1})	247 (383)	295	363	495	269 (479)	361	466	714
Increase from the zero treatment (kg N ha^{-1})	..	38	106	238	..	92	197	445
Apparent recovery in soil (%) as mineral nitrogen‡	..	50·7	70·6	79·3	..	61·3	65·6	74·2
Unaccounted for in crop plus soil								
Amount (kg N ha^{-1})	..	31·2	36·6	48·3	..	48·3	85·7	130·1
As percentage of applied fertilizer	..	41·6	24·4	16·1	..	32·2	28·6	21·7

* 100 x increase from zero treatment ÷ applied fertilizer.
† To 100 cm depth for the first harvest and 140 cm for the second harvest. Bracketed figures are for the initial sampling.
‡ 100 x increase from the zero treatment ÷ applied fertilizer.

wasteful to apply nitrogen fertilizer. On the other hand if mineral nitrogen at planting is very low (< 50 kg ha^{-1}) a figure close to 300 kg N ha^{-1} (or 8·8 kg N t^{-1} of expected yield of fresh beet) of applied fertilizer may be required, since the results in table 5 showed no change in soil mineral nitrogen with this application of nitrogen fertilizer. Thus if the potential yield of fresh beet can be estimated and the residual mineral nitrogen measured, a more accurate estimate of nitrogen fertilizer requirement can be made. It is clear that the current practice of applying 450 kg N ha^{-1} on this particular farm is not necessary in terms of net yield.

Since it is not only the quantity but the quality of the beet yield that is also important in determining the maximum economic return for the beetroot grower, it is possible that nitrogen, additional to that needed for maximum root yield, may reduce or improve beet quality. Thus a more detailed examination of the effects of nitrogen fertilizer on beet quality is required.

IV. ACKNOWLEDGEMENTS

The authors wish to thank Mr R. McMahon, D.P.I., for assisting in site selection and general advice, Mr C. Litzow for providing the area for the experiment, Mr D. Mercer for help in conducting the field experiment, and finally the Australian Government for a Colombo Plan scholarship granted to the senior author.

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(Received for publication 23 June 1977)

This work was carried out in the Department of Agriculture, University of Queensland, St. Lucia, Q. 4067. Mr Visuttipitakul is currently with the ASRCT, Bangkok. Dr Waring is a Senior Lecturer, Department of Agriculture, at the University.

88884—S. R. Hampson, Government Printer, Queensland