Plant & Food RESEARCH
RANGAHAU AHUMĀRA KAI

PFR SPTS No. 17957

Nitrogen - Measure it and manage it: Year 3 final science report

Norris M, Hunt A, Dellow S, Ward R, Arnold N, Liu J, Sorensen I, Tan Y

June 2019

Report for:
Foundation for Arable Research
X16-13

PUBLICATION DATA

Norris M, Hunt A, Dellow S, Ward R, Arnold N, Liu J, Sorensen I, Tan Y. June 2019. Nitrogen - Measure it and manage it: Year 3 final science report. A Plant & Food Research report prepared for: Foundation for Arable Research. Milestone No. 69738. Contract No. 33622. Job code: P/411120/01. SPTS No. 17957.

Report approved by:

Matthew Norris
Scientist, Cropping Systems and Environment
June 2019

Paul Johnstone
Science Group Leader, Cropping Systems and Environment – Sustainable Production
June 2019

CONTENTS

EXECUTIVE SUMMARY

Nitrogen - Measure it and manage it: Year 3 final science report

Norris M[1], Hunt A[2], Dellow S[3], Ward R[4], Arnold N[2], Liu J[2], Sorensen I[2], Tan Y[2]
Plant & Food Research: [1]Ruakura, [2]Hawkes Bay, [3]Lincoln, [4]Palmerston North

June 2019

Maintaining a balance between soil nitrogen (N) supply and crop N demand is central to the profitable and sustainable use of N fertiliser in New Zealand's cropping systems. To achieve this, growers need effective tools to help guide their N management decisions. In response to this, a 3-year Sustainable Farming Fund (SFF) project commenced in 2016 to develop a quick test mass balance (QTMB) approach for informing N applications in arable and vegetable production systems. In this approach, a simple N mass balance is used to calculate fertilizer N requirements as a function of crop N demand (determined from literature), soil mineral N levels (determined with the nitrate quick test) and N supply from mineralisation of N from organic matter (determined with the anaerobically mineralisable N (AMN) test).

Over the past 3 years, the approach has been tested and refined across 18 trial sites located on commercial cropping enterprises around New Zealand. Crops have included maize (five sites), potatoes (six sites), broccoli (two sites), cabbage (one site), lettuce (two sites) and spinach (two sites). At each site two N management approaches were compared (each replicated five times) and these included:

- A standard grower area where side-dressing N was applied at rates equivalent to the cooperating grower's application regime in the rest of the field
- A QTMB area where pre-planting and side-dressing N applications were based on outputs from the N mass balance.

Findings from the 18 trials completed over 3 years have demonstrated that the QTMB approach is an effective tool for informing N fertiliser decisions. At 14 of the 18 sites, application of the QTMB approach reduced N fertiliser inputs by 23–52% with no impact on yield (10 sites) or validated the grower's N management strategy (four sites). Application of the QTMB approach at two sites resulted in a yield deficit or the over application of side dress N, however this was related to inaccurate estimates of crop N uptake rather than a failure of the nitrate quick test to accurately determine soil mineral N supply. At the remaining two sites, complications with trial management meant we were not able to fully assess the utility of the approach. These trials were nonetheless important for quantifying crop N uptake and validation of the nitrate quick test.

As a key component of the N mass balance, quick test nitrate was found to be a suitable proxy for inorganic N supply and was strongly correlated with the standard laboratory measure for nitrate across a range of soil textures. Although less accurate than standard assessment by a commercial laboratory, the quick test was, nonetheless, found to provide sufficient precision for informing a N mass balance. Use of the nitrate quick test at our trial sites allowed us to identify when there was a mineral N surplus relative to crop N requirements. This resulted in considerable reductions in N fertiliser use (up to 52%) with no impact on crop yield or quality.

The test proved particularly effective at identifying high mineral N levels prior to side dressing and also the effects of background N supply from mineralisation which was enhanced following cultivation of long term pasture.

Overall, estimates of crop N uptake at harvest were comparable with predicted values (at 14 sites, actual N uptake was within 25% of the predicted value), although there were occasions where our predictions were considerably off. With the exception of two sites, differences between actual and predicted N uptake values did not adversely affect QTMB outcomes. Further refinement of crop requirements (these were collated from literature sources) is possible with the use of more complex modelling tools or systematic experience as the QTMB is applied within a field context.

In conclusion, findings from this study strongly suggest that in at least some of New Zealand's arable and vegetable production systems, there is potential to significantly reduce N fertiliser inputs without compromising yield or product quality. The QTMB approach is a simple and cost effective tool that can be used to enable a balance between N inputs and crop N requirements. In an effort to facilitate adoption, results from the study have been integrated into an electronic QTMB tool to help growers calculate fertiliser N requirements (at the time of soil testing) from nitrate quick test results and estimates of crop N demand (based on yield potential). One of the benefits of the tool is that estimates of N supply are automatically calculated from standard input information (soil texture, soil moisture and nitrate quick test results). This removes the need for users to determine and apply relevant soil correction factors for converting volumetric quick test values (mg/L) to a gravimetric basis (mg/kg dry matter; DM).

For further information please contact:

Matthew Norris
Plant & Food Research Ruakura
Private Bag 3230
Waikato Mail Centre
Hamilton 3240
NEW ZEALAND

Tel: +64 7 959 4430
DDI: +64 7 959 8974
Fax: +64 7 959 4431
Email: matthew.norris@plantandfood.co.nz

1 INTRODUCTION

Maintaining a balance between soil nitrogen (N) supply and crop N demand is central to the profitable and sustainable use of N fertiliser in New Zealand cropping systems. To achieve this, growers need effective tools to help guide their N management decisions. In response to this, a 3-year Sustainable Farming Fund (SFF) project (404944) commenced in 2017 to develop a quick test mass balance (QTMB) approach for informing N applications in arable and vegetable production systems. In this approach, a simple N mass balance is used to calculate fertilizer N requirements which are determined as a function of crop N demand, soil mineral N levels and supply from mineralisation of organic matter:

$$N_{\text{fertiliser}} = N_{\text{crop demand}} - N_{\text{mineral}} - N_{\text{mineralisable}} \qquad \textbf{(Equation 1)}$$

In the mass balance, $N_{\text{crop demand}}$ values are assumed from established uptake norms while N_{mineral} and $N_{\text{mineralisable}}$ values are determined by soil testing. A key component of the approach is the nitrate quick test which is used to estimate N_{mineral}. The quick test is a quick (results are obtained within a couple of hours) and cost effective (~ $1 a sample) alternative to the standard laboratory testing for mineral N, thereby removing a major constraint to estimating a simple N mass balance. Laboratory testing is still required to determine the $N_{\text{mineralisable}}$ component (the most common approach has been the anaerobically mineralisable N (AMN) test, although for in-season N recommendations, the quick test will capture mineralised N up to the point of testing, thereby accounting for some of N supplied from the organic N pool.

In Year 1 (2016/17 season; Norris et al. 2017) and Year 2 (2017/18 season; Norris et al. 2018), the approach was used to inform N applications at 12 commercial sites across a range of crops including maize (four sites), process potatoes (four sites), fresh market brassica (two sites), fresh market lettuce (one site) and fresh market baby spinach (one site). At each site, a paired plot experimental design was used to compare two N management approaches, each replicated five times. The two N management approaches included:

- A standard grower approach where side-dressing N was applied at rates equivalent to the cooperating grower’s application regime in the rest of the field
- A QTMB approach where pre-planting and side-dressing N applications were based on outputs from the N mass balance.

Overall, the QTMB was found to be an effective tool for informing in-season N management decisions, but particularly in intensive vegetable systems with multiple crop sequences and high fertiliser inputs. At 9 of the 12 sites, application of the QTMB resulted in reduced N fertiliser use (23 to 52% with no impact on yield or crop quality; six sites) or validation of the grower’s standard N management practice (three sites). At the remaining sites, the N side-dressing applications recommended by the QTMB either did not improve yields (two sites, where higher fertiliser rates were recommended) or resulted in a yield penalty (one site, where lower fertiliser rates were recommended) relative to the grower treatment. These negative results were related directly to a discrepancy between actual crop N uptakes and the N uptakes assumed in the mass balance, which were derived from initial estimates from the scientific literature. Importantly, and across both years, the nitrate quick test was found to be an appropriate means of informing an N mass balance, despite the apparent underestimation of soil nitrate-N by the quick test in Year 2.

In this report, we provide a final summary of results from the 3-year research programme and also report on findings from Year 3 of the study where six more field trials were established to further refine the QTMB approach and to demonstrate its application in a larger, field scale context.

2 YEAR 3 METHODS AND MATERIALS

2.1 Experimental design

A large-scale, strip trial design was used to compare two N management approaches at six commercial cropping sites across New Zealand. There were four crop types including maize silage (one site), potatoes (two sites), fresh market brassicas (one site) and fresh market leafy greens (two sites) which included baby spinach and head lettuce.

The two N management approaches were:

- A standard grower approach where side-dressing N was applied at rates equivalent to the cooperating grower's application regime in the rest of the field
- A QTMB approach where side-dressing N applications were based on outputs from a simple N mass balance.

The two N management approaches were restricted to adjacent rectangular zones or 'strips' which varied in size based on site factors and grower preference. Strips were approximately 50 m wide by 100 m long (~ 0.5 ha) for the maize and potato sites, 13 m wide (equivalent to six beds) by 120 m long (~ 0.12 ha) for the fresh market brassica site, 13 m wide (equivalent to six beds) by 50 m long (~ 0.06 ha) for the baby spinach site and 8 m wide (equivalent to four beds) by 60 m long (~ 0.05 ha) for the head lettuce site. There were five monitor plots located within each management zone. These were 5 m long by six rows wide for the maize sites (23 m^2), 5 m long by four bed widths for the potato sites (36 m^2), 5 m long by one bed width for the fresh market brassica site (11 m^2), 5 m long by one bed width for the baby spinach site (9 m^2) and 5 m long by one bed width for the head lettuce site (11 m^2). Plots were separated by a 10–20 m buffer area at each end.

2.2 Trial sites

The six trial sites were located on commercial properties located in Auckland, Waikato, Gisborne and Canterbury regions of New Zealand (Figure 1), and were selected to provide a range of production systems in which to test the QTMB approach. All management activity (including side-dressing N applications) was carried out by the co-operating growers using their equipment. The exceptions were at Site 1 where all N fertiliser was hand applied to the trial area, and at Site 5 where magnesium sulphate was hand applied to the trial area at side dressing 1.

2.2.1 Site 1 — Baby spinach (Auckland)

Site 1 was located in the Auckland region near Pukekohe on a soil mapped as a Morrinsville clay (Typic Orthic Granular soil, Landcare Research, 2018). The site had a history of long term intensive vegetable production (> 5 years). Spinach was sown on 16 January 2019 and harvested on 12 February 2019, 27 days after sowing (Table 1). The grower's seasonal N application rate was 212 kg N/ha applied as a single application at planting. Fertiliser was surface applied and the site was irrigated.

2.2.2 Site 2 — Maize silage (Waikato)

Site 2 was located in the Waikato region near Cambridge on a soil mapped as an Otorohanga clay loam (Typic Orthic Allophanic soil, Landcare Research, 2018). The site was previously under pasture (4 years) used for dairy grazing. The 2018/19 crop was sown on 5 October 2018 and harvested on 19 February 2019, 137 days after sowing (Table 1). The grower's seasonal N application rate was 23 kg N/ha applied as a single application at planting. All fertiliser was incorporated and the site was not irrigated. We note that a seed treatment issue reduced biomass productivity in certain areas of the field. These 'non-uniform' areas were avoided when selecting final harvest plots.

2.2.3 Site 3 — Broccoli (Gisborne)

Site 3 was located near Gisborne on a soil mapped as a Flaxton silt loam (Typic Orthic Gley soil, Landcare Research 2018). The site had a history of long term intensive vegetable production (> 5 years). Broccoli was planted on 5 February 2019 and selectively harvested from 6 April 2019, 60 days after planting (Table 1). The grower's seasonal N application rate was 111 kg N/ha applied as 35 kg N/ha 15 days prior to planting (base dressing), 36 kg N/ha at side dressing 1 (28 days after planting) and 40 kg N/ha at side dressing 2 (44 days after planting). Base dressing fertiliser was incorporated while all side dressing fertiliser was surface applied. The site was irrigated.

2.2.4 Site 4 — Potatoes (Manawatu)

Site 4 was located in the Manawatu region near Opiki. Soil mapping information was not available for the site, however, soil coring revealed a silt loam top soil (0-30 cm) overlying a denser clay loam subsoil (30-60 cm). The site was under long term dairy pasture (> 5 years) prior to establishment of a process potato crop which was sown on 19 October 2018 and harvested on 20 March 2019, 152 days after sowing (Table 1). The grower's seasonal N application rate was 104 kg N/ha applied as 50 kg N/ha at sowing and 54 kg N/ha at side dressing (53 days after planting). Fertiliser applied at cultivation was incorporated, while fertiliser applied at side dressing was broadcast. The site was not irrigated.

2.2.5 Site 5 — Potatoes (Canterbury)

Site 5 was located in the Canterbury region near Pendarves on a soil mapped as a Lismore shallow silt loam (Pallic Firm Brown soil, Landcare Research 2018). The site was under long term dairy pasture (> 5 years) prior to establishment of a process potato crop which was sown on 18 October 2018 and harvested on 15 April 2019, 179 days after sowing (Table 1).
The grower's seasonal N application rate was 230 kg N/ha applied as 40 kg N/ha at pre-plant (3 days prior to sowing) and 68 kg N/ha at sowing, 34 kg N/ha at side dressing 1 (26 days after sowing), 20 kg N/ha at side dressing 2 (53 days after sowing), 27 kg N/ha at side dressing 3 (63 days after sowing) and 41 kg N/ha at side dressing 4 (77 days after sowing). Fertiliser applied at pre-planting and sowing was incorporated while fertiliser applied at side dressing was broadcast. The site was irrigated.

2.2.6 Site 6 — Lettuce (Canterbury)

Site 6 was located in the Canterbury region near Chertsey on a soil mapped as a Lismore shallow silt loam (Pallic Firm Brown soil, Landcare Research 2018). The site had a history of long term intensive vegetable production (> 5 years) and was irrigated. Head lettuce was planted on 10 January 2019 and harvested on 19 March 2019, 68 days after planting (Table 1). The grower's seasonal N application rate was 113 kg N/ha applied as 32 kg N/ha at planting, 81 kg N/ha at side dressing (15 days after planting). All fertiliser was surface applied to the beds.

Table 1. Summary of key management dates at the six trial sites for the 2018/19 season.

Site	Region	Location	Crop	Sowing/planting	Harvest date[1]
1	Auckland	Pukekohe	Baby spinach	16 January 2019	12 February 2019
2	Waikato	Cambridge	Maize (silage)	5 October 2018	19 February 2019
3	Gisborne	Gisborne	Broccoli	5 February 2019	6 April 2019
4	Manawatu	Opiki	Potatoes (process)	19 October 2018	20 March 2019
5	Canterbury	Pendarves	Potatoes (process)	18 October 2018	15 April 2019
6	Canterbury	Chertsey	Lettuce	10 January 2019	19 March 2019

[1] Date that the harvest samples were taken from the trial sites.

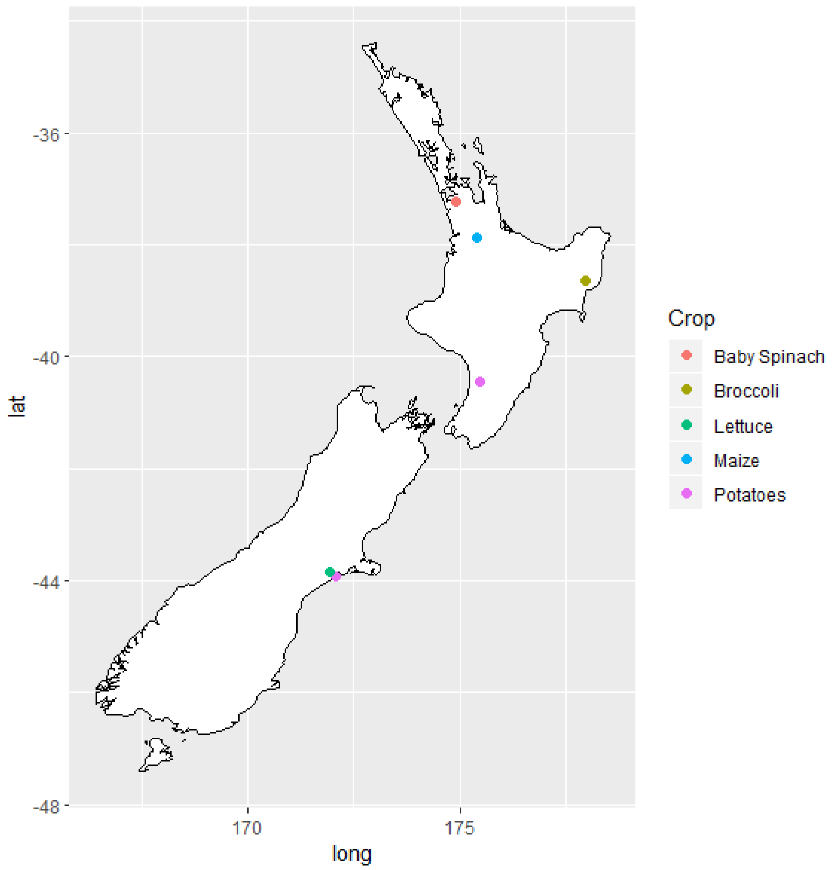

Figure 1. Location of the six trial sites for the 2018/19 growing season.

2.3 Measurements

2.3.1 Soil

Soil sampling protocols and laboratory analyses were the same as the Year 1 and Year 2 studies; a full description of these is provided in Norris et al. (2017). In brief, soil samples from each treatment plot were taken prior to crop establishment and at final harvest and analysed for mineral N (nitrate-N + ammonium-N), gravimetric moisture content and quick test nitrate-N. Sampling depths were 0–30 and 30–60 cm at the maize, broccoli and process potato sites and 0–15 and 15–30 cm at the baby spinach and head lettuce sites. At planting, the 0–30 cm sampling depths were analysed for AMN, while a separate set of 0–15 cm cores were taken for analysis of basic fertility (pH, Olsen P, exchangeable cations, cation exchange capacity and base saturation). Basic fertility samples were comprised of four composite samples (eight cores per composite) taken from across the trial area. We did not compare measures of base fertility between the treatment management zones, however, across all sites, measures of basic fertility were generally within or above optimum ranges for crop production (Appendix 1). At side dressing, samples were taken from the 0–30 and 30–60 cm (maize, broccoli and process potato sites) and 0–15 and 15–30 cm (baby spinach and head lettuce sites) depths and analysed only for quick test nitrate-N (to determine treatments).

2.3.2 Crop measurements

At final harvest, crop biomass samples were taken from each plot to assess final yields and crop N uptake under the different treatment regimes. Crop harvest procedures were as follows:

- Baby spinach (Site 1): Total fresh weight (above ground component) was recorded from a 0.25 m^2 harvest quadrat from within each plot. Subsamples were subsequently taken for dry matter percentage (DM)% and plant tissue N analysis.
- Maize silage (Site 2): A 2 m x 2 row area (3.04 m^2) was harvested at ground level and population and total fresh weight recorded. A subsample of five plants was taken for analysis of DM % and plant tissue N in the residue and cob components.
- Broccoli (Site 3): Population and head size diameter were recorded from a 2 m x 3 bed area (10.8 m^2). A four plant subsample was then harvested at ground level and the fresh weights of the residue and floret components recorded. Only plants within the commercial grade floret size (125–150 mm) were sampled. A subsample from each of the residue and floret components was taken for DM% and plant tissue N analysis.
- Potatoes (Sites 4 and 5): Total tuber number and total tuber fresh weight were recorded from the harvest plots which were 2 m x 2 rows (3.7 m^2). Tubers were separated into either marketable or waste product. The marketable component was defined by the grower as non-rotten and greater than 45 mm diameter at Site 4 and greater than 60 mm diameter at Site 5. A subsample of 10 tubers was taken from each plot for DM% and plant tissue N analysis.
- Lettuce (Site 6): Population and total fresh weight were recorded from a 1 m x 1 bed area (2.1 m^2). Samples were subsequently graded into marketable and reject product and subsamples taken from each class for DM% and plant tissue N analysis. The proportion of marketable and reject lettuces were determined by visual assessment on a 5 m x 1 bed area (10.5 m^2).

2.4 Nitrogen quick test mass balance model

A full explanation of the N mass balance model used to predict fertiliser N requirements is provided in the Year 2 report (Norris et al. 2018). In brief, N requirement at planting and at side dressing were determined using the following equation:

$$\text{N Fert} = [\text{Crop N}_{\text{Total}} - \text{Crop N}] - \text{Soil Min N} - \text{Soil Org N supply} \quad \text{(Equation 2)}$$

Where 'N Fert' is the N fertiliser requirement, 'Crop N Total' is the seasonal whole crop N uptake, 'Crop N' is the whole crop N uptake at the time of soil testing, 'Soil Min N' is the soil mineral N concentration in the crop rootzone at the time of soil testing (estimated with the nitrate quick test) and 'Soil Org N supply' is the seasonal supply of N from mineralisation of organic N (estimated with the AMN test using samples taken at planting).

Seasonal whole crop N uptake values were derived using the QTMB tool which estimates crop N uptake as a function of yield potential. Target yield potential values and associated whole crop N uptake values for each of the Year 3 crops are summarised in Appendix 2. For vegetable crops, specific details on the data sets used to inform the N uptakes curves in the QTMB model are provided in Norris et al. (2019). A document summarising the N input data for arable crops is currently being drafted (N uptake information for maize and potatoes is derived from Li et al. (2009) and Jamieson et al. (2005) respectively).

2.5 Statistical analyses

Data were analysed using 1-way analysis of variance (ANOVA) for each individual trial using GenStat (version 17, 2014, VSNi Ltd, Hemel Hempstead, UK). There were five plots (five replicates of the two management approaches) giving a total of four degrees of freedom. F probabilities < 0.05 were considered significant, between 0.05–0.10 weakly significant, and > 0.10 not significant. Standard regression techniques were used to assess the relationship between quick test nitrate and laboratory-determined nitrate and mineral N.

3 YEAR 3 TRIAL SITE RESULTS

3.1 Summary of N applications

Across the six sites, the amount of N fertiliser applied to the respective grower and QTMB treatments ranged from 104 to 240 kg N/ha and from 23 to 142 kg N/ha (Table 2). At Site 1, incorrect information was obtained from the grower relating to N application rates which resulted in lower rates being applied to the grower treatment compared to standard grower practice. Following this, five additional monitor plots were established in an adjacent area (termed 'rest of field') which was under standard management. At Site 2, the QTMB recommendation for the side dressing application was the same as the grower rate which was to apply no N fertiliser. Consequently, to implement a treatment, N was applied to the grower treatment at a typical industry rate of 90 kg N/ha. With the exception of Site 1, N fertiliser was applied at standard rates for base and pre-planting applications. This occurred because we could not withhold the N component from the mixed fertiliser products in use which contained a range of additional nutrients required in both treatments to maintain a balanced trial design.

Table 2. Nitrogen applications for the grower and quick test mass balance (QTMB) treatments at the six trial sites for the 2018–19 season.

Site	Crop	Treatment	Nitrogen applied (kg/ha)			
			Base	Planting	Side dressing	Total
1	Baby spinach *	Grower	0	0	106	106
		QTMB	0	0	92 [1]	92
		Rest of field	0	212	0	212
2	Maize (silage) **	Grower	0	23	92	115
		QTMB	0	23	0	23
3	Broccoli	Grower	35	0	76 [2]	111
		QTMB	35	0	30	65
4	Potatoes (process)	Grower	0	50	54	104
		QTMB	0	50	0	50
5	Potatoes (process)	Grower	40	68	122 [3]	230
		QTMB	40	68	34 [4]	142
6	Head lettuce	Grower	0	32	81	113
		QTMB	0	32	27	59

[1] Applied as two split applications of 50 and 42 kg N/ha. [2] Applied as two split applications of 36 and 40 kg N/ha. [3] Applied as four split applications of 20 to 41 kg N/ha. [4] Applied as two split applications of 20 and 14 kg N/ha.
***** Additional measurements were taken from this site ('Rest of field') to quantify productivity in the area outside the trial area which was managed differently to the grower treatment.
****** QTMB recommendation was the same as the grower rate which was to apply no side dress N fertiliser. Consequently, to implement a treatment N was applied to the grower treatment at a typical industry rate.

3.2 Results from each site

This section summarises results from each of the sites as they relate to the different N management approaches in the grower and QTMB treatments. Key summary data are presented in Figure 2, while supplementary data relating to crop productivity and site N balances are provided in Appendices 2 and 3 respectively.

3.2.1 Site 1 — Baby spinach (irrigated)

Site summary: We were not able to fully assess the utility of the QTMB approach at the site due to complicating factors associated with a lack of rainfall and irrigation inputs during critical growth periods. However, under current management practice, N applications are more than three times plant N requirements. Application of the QTMB approach could reduce this N surplus while ensuring sufficient N supply to maintain productivity.

At this site, fresh weight (FW) yields and crop N uptakes were significantly lower ($p < 0.05$) in the grower and QTMB treatments compared to the yields and N uptakes in the rest of field (RF) plots (Appendix 2) which received about double the amount of fertiliser N. The marked difference in productivity between the trial area and the rest of the field was most likely due to the timing of fertiliser application rather than reduced N application rates over the trial area. Fertiliser was hand applied to the trial area one week after sowing (plants had just emerged) at 106 and 50 kg N/ha to the grower and QTMB treatments respectively. Following this application, there was very little rainfall, while irrigation was delayed due availability of irrigation equipment. This meant that fertiliser N was not 'washed in' and thus available for uptake during a period of critical plant N demand (soil mineral N levels at planting were very low; Figure 2). A secondary side dressing application to the QTMB treatment (42 kg N/ha) was apparently too late to mitigate this N deficit. In contrast, the rest of field was subject to a large application of N (212 kg N/ha) at planting which was immediately 'washed in' with irrigation. Thus, N was not limiting in this management zone and crop N uptake at harvest (61 kg N/ha) was comparable to predicted uptake (56 kg N/ha) at the target yield potential of 13 tons (t) FW/ha (actual yield was 14.7 t FW/ha) (Figure 2).

A positive outcome for the QTMB approach would almost certainly been achieved in the absence of these complicating factors due the large difference between standard practice N inputs (212 kg N/ha) and resulting plant N uptakes which are generally low for baby spinach crops (< 70 kg N/ha). Evidence for surplus N in the system relative to crop N requirements is seen in the high mineral levels at harvest in the RF plots (101 kg N/ha; 0-30 cm).

3.2.2 Site 2 — Maize silage (dry land)

Site summary: The QTMB confirmed that the grower's N application rate was sufficient to meet crop N demand and reduce the risk of oversupply. Side dressing the site (previously under long term pasture) at a standard industry rate of 92 kg N/ha did not significantly increase yields or plant tissue N concentrations.

The target yield for the site was 24 t DM/ha with an associated whole crop N uptake (above ground component) of 240 kg N/ha (Figure 2). The QTMB recommendation was to apply no N at side dressing, so to implement a comparative treatment N was applied at 92 kg/ha to the grower area (Figure 2). This additional N did not significantly increase yields in the grower treatment which averaged 25 t DM/ha compared to 23 t DM/ha in the QTMB treatment while final harvest plant tissue N concentrations were also similar between treatments (0.91%; Appendix 2). Whole crop N uptake averaged 230 and 210 kg N/ha in the respective grower and QTMB treatments, slightly lower than the QTMB predicted value of 240 kg N/ha. Overall, crop N uptakes were higher than the seasonal sum of mineral N supply (Figure 2; Appendix 3), consistent with the supply of additional N from mineralisation of organic matter. Anaerobically mineralisable N concentrations at planting were high (~ 140 kg N/ha), consistent with the site coming out of long term pasture. At final harvest, soil mineral N levels (0-60 cm) were significantly higher ($P < 0.05$) in the QTMB (41 kg N/ha) compared to the grower (26 kg N/ha) treatment (Appendix 3), although for both treatments levels were considered to be low and thus differences inconsequential on a field scale.

3.2.3 Site 3 — Broccoli (irrigated)

Site summary: Using the QTMB approach, N application was reduced by 41% (equivalent to 46 kg N/ha) with no reduction in above ground biomass or marketable yield.

The target yield for the site was 65 t FW/ha total above ground biomass with an associated harvestable yield (floret component) of 14 t FW/ha. Whole crop N uptake (above ground component) was assumed to be 199 kg N/ha (Figure 2). The QTMB treatment received 65 kg N/ha over the growing season, 41% less N than the grower treatment which received 111 kg N/ha (Figure 2), nevertheless at harvest, yields (total biomass and harvestable component) and crop N uptakes were comparable between the two treatments (Figure 2, Appendix 2). This suggests that the additional N applied to the grower treatment did not improve overall productivity although there was some evidence to suggest that the rate of floret development was slightly advanced under standard management (15% fewer florets in the < 125 mm size range; data not shown). Whole crop N uptake averaged 255 and 237 kg N/ha in the respective grower and QTMB treatments, higher than the QTMB predicted value of 199 kg N/ha. This discrepancy may reflect luxury uptake by the crop, particularly in the grower treatment where plant tissue N concentrations were significantly higher compared to the QTMB treatment (Appendix 2) despite comparable yields. Floret yields (10–11 t FW/ha) were lower than target values (14 t FW/ha), most likely due to early harvest of the trial area (the site was selectively harvested 2 days following harvest of the trial area). Overall, the QTMB was found to be an effective tool for reducing side dressing N application rates in response to high mineral N levels at planting (140–142 kg N/ha; Appendix 3) and considerable background N supply from mineralisation (AMN ranged from 87–116 kg N/ha; Appendix 3).

3.2.4 Site 4 — Potatoes (dryland)

Site summary: Using the QTMB approach, N application was reduced by 52% (equivalent to 54 kg N/ha) with no reduction in total yield, marketable yield or tuber N uptake.

The target yield for the site was 55 t FW/ha with an associated whole crop N uptake (including tuber component) of 186 kg N/ha (Figure 2). Side dress N was withheld from the QTMB treatment which received a total of 50 kg N/ha over the growing season, 52% less N than the grower treatment which received 104 kg N/ha (Figure 2). Omission of side dress N from the QTMB treatment did not negatively affect total or marketable tuber yields which averaged 48 and 54 t FW/ha and 45 and 52 t FW/ha in respective grower and QTMB treatments (Appendix 2). There was a significant treatment effect ($p < 0.05$) on tuber N concentrations which were lower in the QTMB (1.32%) compared to the grower (1.56%) treatment (Appendix 2). However, net tuber N uptake remained comparable between treatments (144–145 kg N/ha; Figure 2) and lower than the predicted crop N uptake value (186 kg N/ha). Lower than predicted crop N uptake was consistent with slightly lower than expected yields (average of 51 t FW/ha across treatments) and the fact that remaining above ground biomass at the time of harvest was not quantified. Overall, crop N uptakes were higher than the seasonal sum of mineral N supply (Figure 2; Appendix 3), consistent with the supply of additional N from mineralisation of organic matter (AMN concentrations at planting were moderate at ~ 107 kg N/ha; Appendix 3).

3.2.5 Site 5 — Potatoes (irrigated)

Site summary: Using the QTMB approach, N application was reduced by 48% (equivalent to 88 kg N/ha) with no reduction in total yield, marketable yield or tuber N uptake.

The target yield for the site was 75 t FW/ha with an associated whole crop N uptake (including tuber component) of 255 kg N/ha (Figure 2). The QTMB treatment received 142 kg N/ha over the growing season, 48% less N than the grower treatment which received 230 kg N/ha (Figure 2). At final harvest all measures of plant productivity including total and marketable yield, tuber N uptake and tuber N concentrations were comparable between the QTMB and grower treatments (Appendix 2). At 93-94 t FW/ha, total yields were considerably higher than target values, probably due to favourable growing conditions and also the availability of irrigation. Resulting tuber N uptakes were higher than predicted at 324-325 kg N/ha. As at Site's 2 and 4 which had also come out of long term pasture, crop N uptakes were higher than the seasonal sum of mineral N supply (Figure 2; Appendix 3), particularly for the QTMB treatment where crop N uptakes exceeded supply by 139 kg N/ha. This 'extra' N was supplied from mineralisation of organic matter as reflected in the high pre-planting AMN concentrations (194–198 kg N/ha; Appendix 3). Overall, the QTMB was found to be an effective tool for confidently reducing side dressing N application rates in response to considerable background N supply from mineralisation.

3.2.6 Site 6 — Lettuce (irrigated)

Site summary: Using the QTMB approach, N application was reduced by 48% (equivalent to 54 kg N/ha) with no reduction in total or marketable yield.

The target yield for the site was 55 t FW/ha total above ground biomass with an associated harvestable yield (head component) of 42 t FW/ha. Whole crop N uptake (above ground component) was assumed to be 108 kg N/ha (Figure 2). The QTMB treatment received 59 kg N/ha over the growing season, 48% less N than the grower treatment which received 113 kg N/ha (Figure 2). At final harvest, all measures of plant productivity including total and marketable yield, crop N uptake and plant tissue N concentrations were comparable between the QTMB and grower treatments (Appendix 2). Total yields averaged 68 and 66 t FW/ha in respective grower and QTMB treatments and were higher than the target yield values.
In contrast, marketable yield at 26–29 t FW/ha were lower than targeted (42 t FW/ha). This difference likely reflects the variability in fresh weight yields for lettuce crops which can vary considerably with different varieties and growing conditions (in the QTMB tool a default harvest index of 76% is assumed). Crop N uptakes (112–119 kg N/ha) were generally comparable or slightly higher than predicted. Reduced N application to the QTMB resulted in significantly lower ($p < 0.05$) residual mineral levels (0–30 cm) at harvest (116 kg N/ha) compared to the grower treatment (181 kg N/ha) (Figure2; Appendix 3). These residual mineral N levels were surprisingly high in both treatments, although consistent with additional N supply from mineralisation of organic matter. AMN concentrations at planting were high for an intensive vegetable production site (~ 91 kg N/ha across treatments).

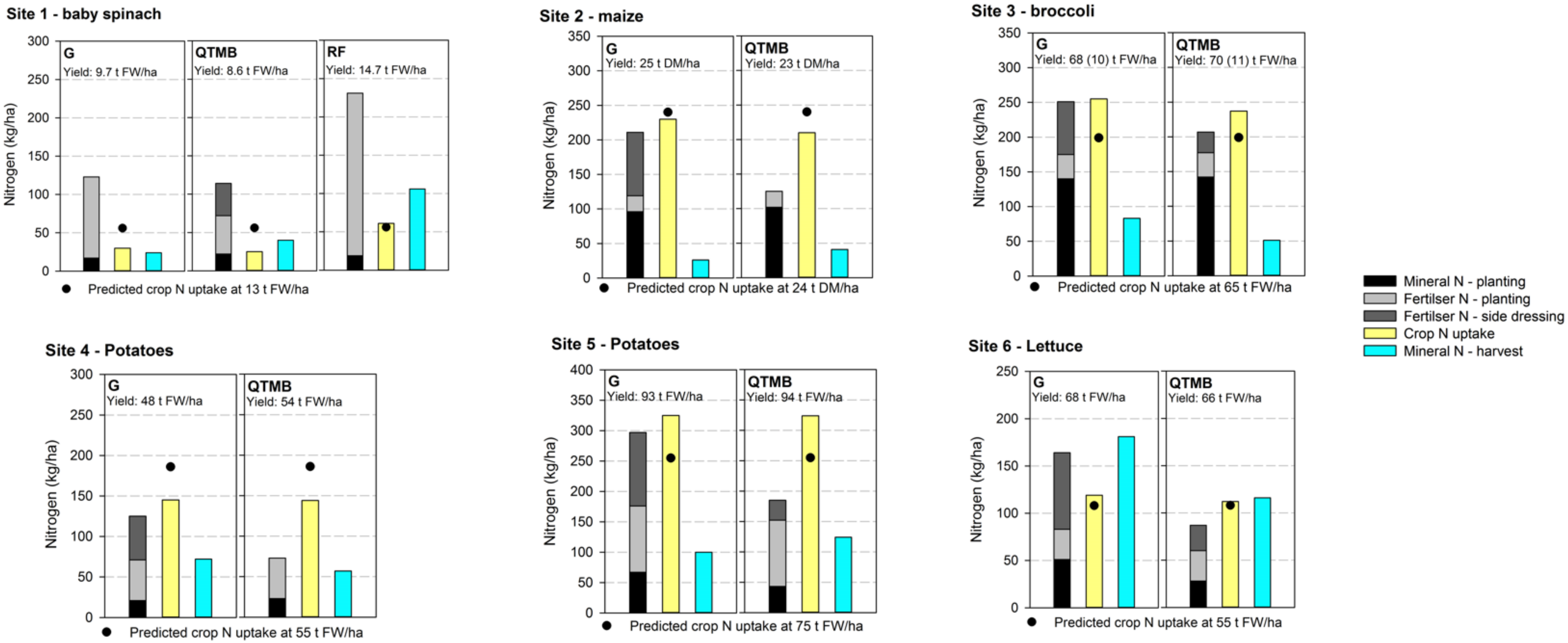

Figure 2. Nitrogen (N) mass balance information for the Grower (G) and Quick Test Mass Balance (QTMB) treatments at the six trial sites for the 2018/19 growing season. At Site 1 an additional monitoring zone (RF) was included in the trial. Graphs show mineral N levels at planting and harvest (0–30 cm at Sites 1 and 6; 0–60 cm at Sites 2 to 4), fertiliser N applied at base/planting and side dressing and crop N uptake at harvest (above ground at Sites 1, 2, 3 and 6; tubers at Sites 4 and 5). The predicted crop N uptake values (●) used to inform the N mass balance are also shown.

4 EVALUATION OF THE NITRATE QUICK TEST FOR PREDICTING SOIL MINERAL N SUPPLY

4.1 Is nitrate-N the predominant form of mineral N in cropping soils?

Soil mineral N is the sum of nitrate-N and ammonium-N and represents the inorganic N pool which is available for plant uptake. In the QTMB approach we assume that nitrate-N is the predominant form of mineral N in well aerated, cropping soils and therefore quick test nitrate is a suitable proxy for assessing soil inorganic N supply. The primary risk with this assumption is that inorganic N supply may be underestimated if ammonium-N concentrations are elevated. Based on our 3-year data set, where over 900 soil samples were analysed, this risk is typically low with nitrate-N shown to be the primary contributor to soil mineral N supply (~98 %, Figure 3) across a range of soil types, sampling depths and production systems. Recommendations to reduce the risk of samples with elevated ammonium concentrations include:

- Sampling before the application of fertiliser N or allowing at least 10n days post fertiliser application before sampling (assuming rainfall or irrigation has occurred to 'wash' fertiliser into the soil). This time frame should be extended to 2 weeks in winter, particularly if ammoniacal-based fertiliser products are being used (e.g. calcium ammonium nitrate).
- Avoid sampling when soils are waterlogged.

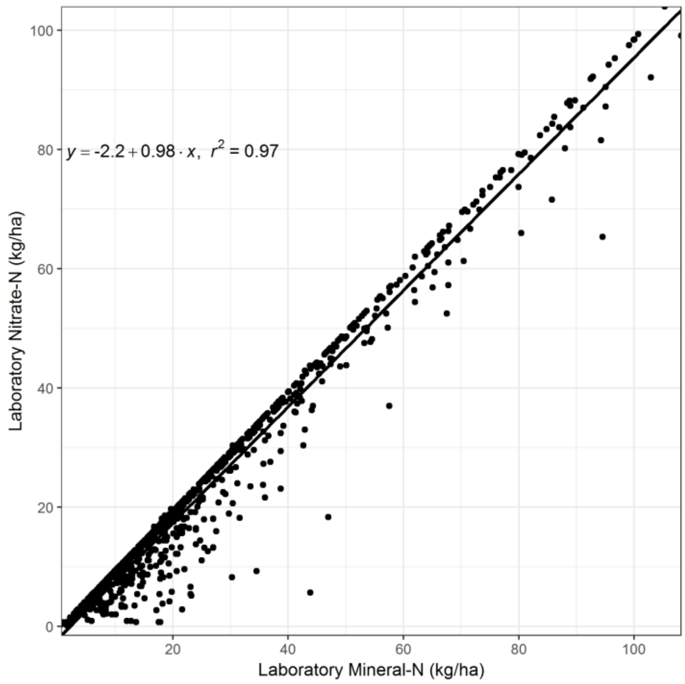

Figure 3. Relationship between nitrate-nitrogen (N) and mineral-N for soil samples taken from 17 commercial cropping sites over 3 years. Samples were analysed at a commercial soil testing laboratory.

4.2 How well does quick test nitrate predict laboratory nitrate?

The standard method for quantifying soil mineral N supply is the 1.7 M potassium chloride (KCl) extraction where samples are extracted for 60 min in a 1:5 soil:solution ratio and the solution analysed for nitrate-N and ammonium-N using automated colourimetric methods (results are reported on a mg/kg DM basis). In the quick test approach, samples are extracted for 5 min in a dilute calcium chloride ($CaCl_2$) solution (0.01 M) at a 1:3 soil: solution ratio with nitrate-N measured using a semi-quantitative, visual colour scale approach. With the difference in methodology between the two methods, validation of the nitrate quick test is an important step in determining whether this approach may be used as a substitute for the standard method.

Results from regression analyses show that quick test nitrate is strongly correlated with laboratory nitrate (r^2 = 0.84-0.86; Figure 4) across a range of soil textures and for a range of sampling depths. However, there was some evidence to suggest that the quick test may underestimate soil nitrate supply as seen in a slope value of 0.77 for the Year 2 data set (Figure 4C). This did not appear to be an issue in Years 1 and 3 where the quick test apparently overestimated supply by a slight margin (m = 1.1; Figure 4B and D). Considering the entire data set (Figure 4A), we conclude that quick test nitrate is a suitable proxy for laboratory nitrate, providing sufficient precision to inform a N mass balance. This is demonstrated well in Figure 5 which shows the relationship between quick test nitrate and laboratory nitrate on a field basis (kg/ha). The quick test results presented here represent the information used to inform N management decisions across each of the six sites in each year (18 sites in total). Thus, strong positive correlations with laboratory nitrate (r^2 = 0.89–0.91) and proximity of slope values to 1 (0.85–1.1) provide confidence that estimates of field nitrate supply made with the quick test are indeed comparable with those made using standard analytical procedures. The strong correlations observed here also indicate that the correction factors used to convert quick test values from a volumetric (mg nitrate/L) to gravimetric basis (mg nitrate-N/kg DM) are working well. Correction factors, which have been have refined and validated over the course of this study, are listed in Appendix 4.

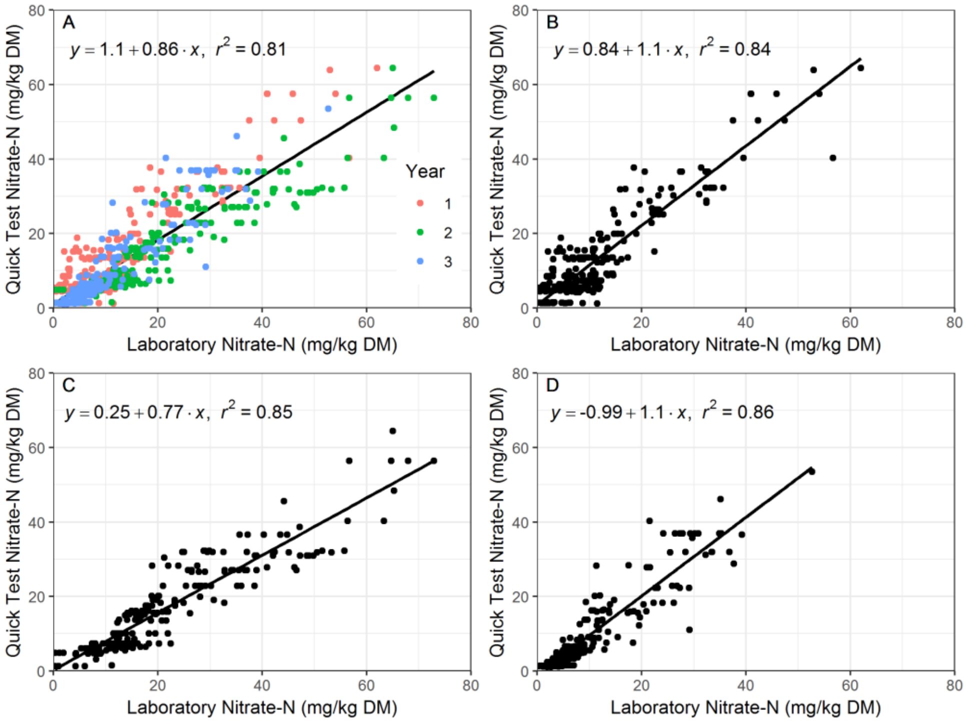

Figure 4. Relationship between quick test and laboratory nitrate-nitrogen (N) on a dry soil basis (mg/kg dry matter; DM) for the (A) combined Year 1, 2 and 3 data sets, (B) Year 1 data set, (C) Year 2 data set and (D) Year 3 data set.

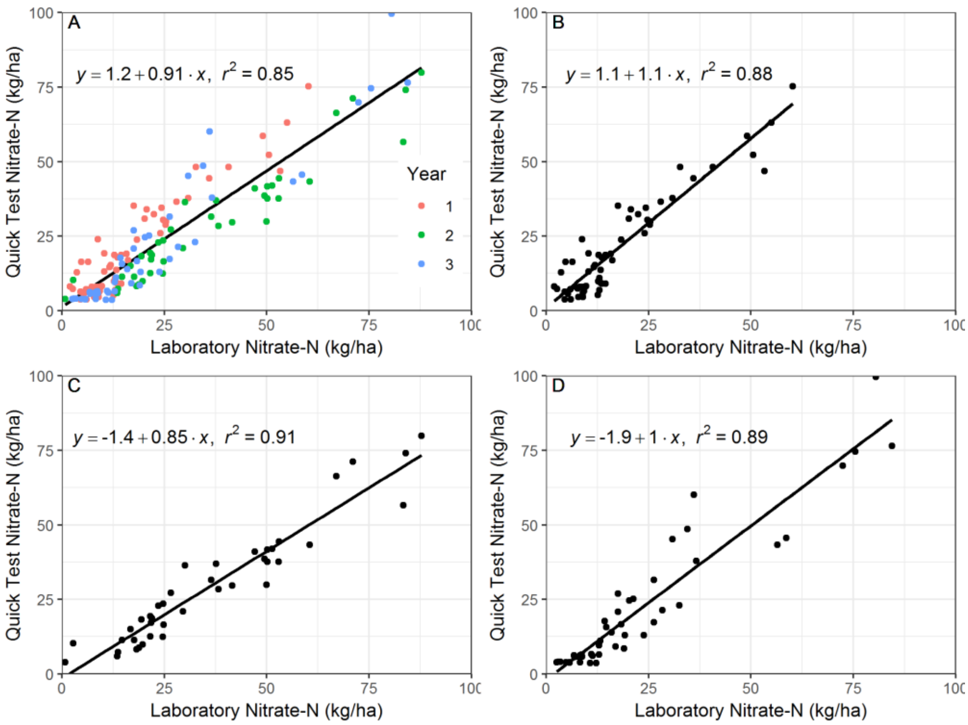

Figure 5. Relationship between quick test and laboratory nitrate-nitrogen (N) on a field basis (kg/ha) for the (A) combined Year 1, 2 and 3 data sets, (B) Year 1 data set, (C) Year 2 data set and (D) Year 3 data set. Each data point is the average mineral N value across the five treatment replicates at each trial site and for each sampling depth.

4.3 Can we estimate whole profile nitrate-N supply from top soil samples?

Soil sampling can be a laborious process, particularly if samples are extracted from depth (>30 cm), and this can be a practical barrier to the adoption of soil testing approaches such as the nitrate quick test. With this in mind, we sought to evaluate whether nitrate-N concentrations in top soil samples (typically 0–15 or 0–30 cm) could be used to predict whole profile (0–60 cm) nitrate-N supply, potentially removing the need for deep soil sampling. Because the rooting zone for most arable and vegetable crops (including deep rooted crops such as maize) is predominantly in the 0–60 cm depth, quantifying N supply in this zone will give a good indication of total N supply at the time of testing.

Results from our 3-year data set show that there may be potential to predict whole profile (0–60 cm) nitrate-N supply using results from 0–30 cm soil cores with a strong positive correlation observed between these two variables ($y = 3.7 + 1.3x$; $r^2 = 0.83$; Figure 6B). In contrast, whole profile (0–60 cm) nitrate-N supply was more weakly correlated with 0–15 cm nitrate-N supply ($y = 17 + 1.7x$; $r^2 = 0.67$; Figure 6A) indicating a less useful predictive relationship. A strong positive correlation was also observed between 0–30 cm and 0–15 cm nitrate-N supply ($y = 8.5 + 1.3x$; $r^2 = 0.87$; Figure 6A) which has implications for shallow rooted crops (< 30 cm) where deep coring (> 30 cm) is not required. We note that the data set reflects a range of cropping systems (generally spring planted and autumn harvested) with samples taken both before and after the application of fertilser. While these relationships are potentially useful, it is evident from Figure 6 that variability exists, particularly as nitrate-N concentrations increase. Therefore, soil testing remains the most reliable means of determining supply, especially after significant rainfall where nitrate will be redistributed down the soil profile. Where resource constraints exist, sampling should be focussed on the 0–30 cm sample depth where most of the soil nitrate-N supply is distributed (> 75%) and the concentration of plant roots is the highest.

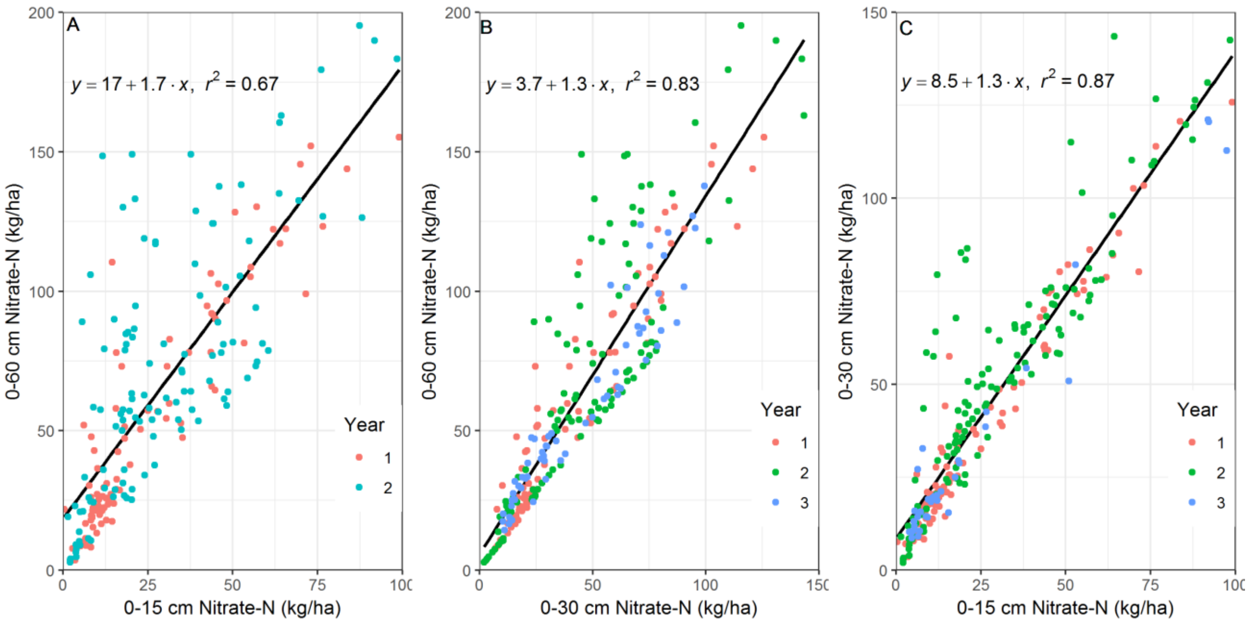

Figure 6. Relationship between whole profile nitrate-nitrogen (N) supply (0–60 cm) and nitrate-N in the (A) 0–15 cm and (B) 0–30 cm sampling depths for respective Year 1 and 2 and combined three year sets. Figure C shows the relationship between 0–30 cm and 0–15 cm nitrate-N supply for the combined 3-year data set.

5 FINAL SUMMARY AND CONCLUSIONS

The overall aim of this project has been to develop and validate a QTMB approach for the sustainable management of N fertiliser in arable and vegetable production systems. The basic premise of the approach is that in accordance with good management practice, N fertiliser applications should be determined with respect to the crop's demand for N and the supply of N from the soil. To this end, the research programme has focussed on the following:

1. Validating the nitrate quick test as a substitute for the more costly and time consuming lab-based mineral N test.
2. Collating information on crop N demand for a range of arable and vegetable crops.
3. Testing QTMB approach across a range of arable and vegetable production contexts (18 field trials over 3 years).

Key findings from the 3-year programme are summarised below.

- Findings from the 18 trials completed over 3 years have demonstrated that the QTMB approach is an effective tool for informing N fertiliser decisions. At 14 of the 18 sites, application of the QTMB approach reduced N fertiliser inputs by 23–52% with no impact on yield (10 sites) or validated the grower's N management strategy (four sites) (Figure 7). Application of the QTMB approach at two sites resulted in a yield deficit (potatoes Year 1 (4); Figure 7) or the over application of side dress N (broccoli Year 1 (5); Figure 7), however this was related to inaccurate estimates of crop N uptake rather than a failure of the nitrate quick test to determine soil mineral N supply. At the remaining two sites, complications with trial management meant we weren't able to fully assess the utility of the approach. These trials were nonetheless important for quantifying crop N uptake and validation of the nitrate quick test.
- The QTMB approach requires estimates of crop N requirement and soil N supply (determined with the nitrate quick test). Because it is difficult to accurately predict crop N demand (there are many variables that influence this parameter), our approach in this study has been to collate biomass N uptake information for a range of crops, thereby providing an initial estimate of crop N demand for use in the mass balance. Our estimates of crop N uptake at harvest were generally comparable with predicted values (at 14 sites actual N uptake was within 25% of the predicted value), although there were occasions where predictions were considerably off (Figure 8). On the whole, differences between actual and predicted N uptake values didn't adversely affect QTMB outcomes. We note that estimates of crop N uptake may be further refined through more complex modelling tools or systematic experience as the QTMB is applied within a field context.
- Quick test nitrate is a suitable proxy for soil mineral N supply in well aerated, cropping soils and may be used as a substitute for standard laboratory measures when informing a N mass balance. Use of the nitrate quick test at our trial sites allowed us to identify when there was a mineral N surplus relative to crop N requirements. This resulted in some considerable reductions in N fertiliser use (up to 52%) with no impact on crop yield or quality. The test proved particularly effective at identifying high residual mineral N levels prior to side dressing and also the effects of background N supply from mineralisation which was enhanced following cultivation of long term pasture.

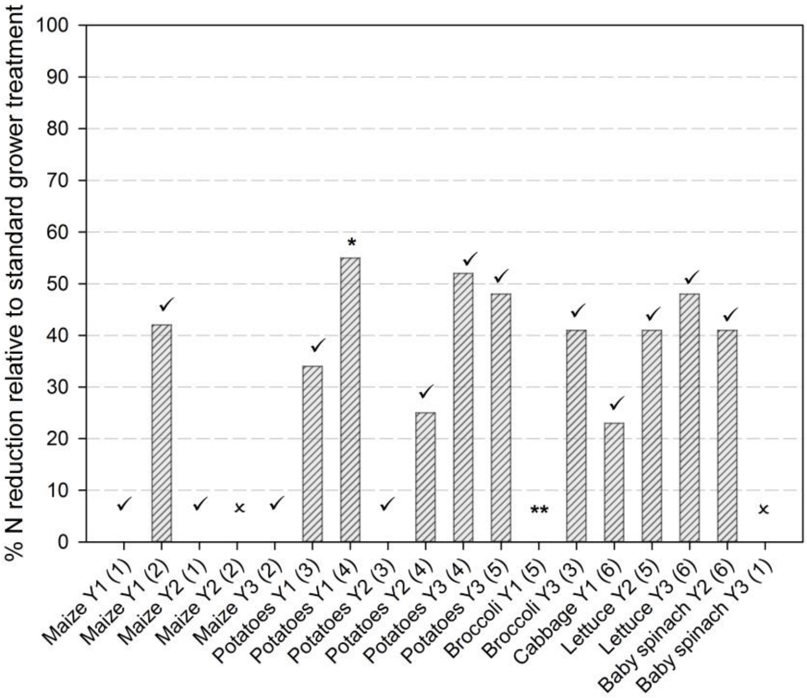

Figure 7. Summary of outcomes from the 18 trials sites where the quick test mass balance (QTMB) approach was applied. Bars represent the percentage reduction in fertiliser use in the QTMB treatments relative to the grower treatments where nitrogen (N) was applied at standard rates. Tick marks (✓) indicate a positive outcome for the QTMB approach (no reduction in yield or validation of the grower's N management strategy) while crosses (×) indicate where an assessment of the QTMB approach was compromised due to complications with trial management. Stars indicate a negative outcome for the approach as seen in a yield deficit (*) or the over application of side dress N (**)

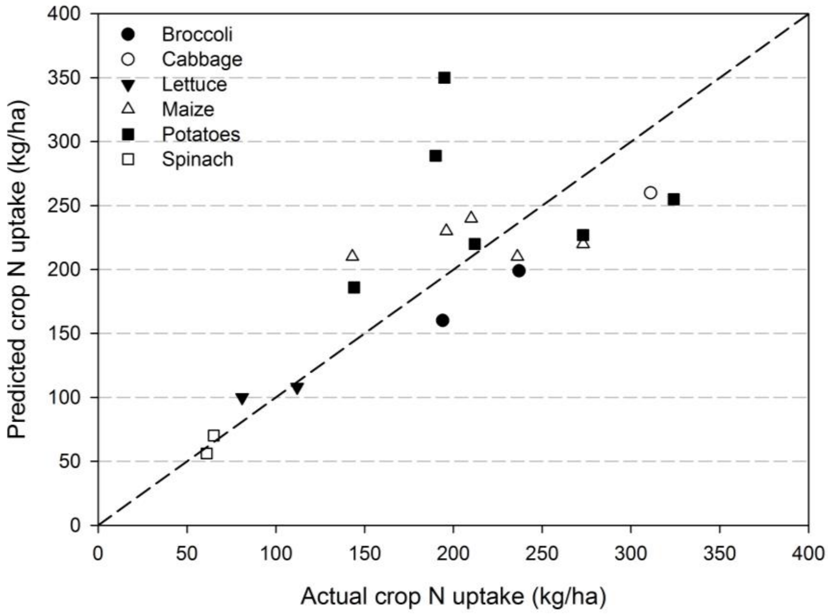

Figure 8. Plot of predicted crop nitrogen (N) uptake against actual crop N uptake each crop across the 18 trial sites. Predicted values were those used in the quick test mass balance to inform N fertiliser decisions. The dashed line represents a 1:1 relationship.

- Data from the past 3 years has demonstrated that for crops planted in spring after an extended winter fallow or cover crop period, pre-planting fertiliser N application will often be required to meet early season crop N demand. The one exception is if a site is coming out of long term pasture and subject to increased N supply from mineralisation of organic N. In this regard, efforts are best focused on using the QTMB to inform in-season side dressing N applications. On intensive vegetable cropping sites with multiple crop sequences and high fertiliser inputs, the QTMB is useful for informing all fertiliser N applications, particularly pre-planting applications where residual mineral N levels may still be high from the previous crop. Findings from this study demonstrate that there is potential to significantly reduce N fertiliser inputs in many arable and vegetable production systems. Under standard management practice, N fertiliser was applied well in excess of crop N demand at 13 of the 18 trial sites.
- Results from the study have been integrated into an electronic QTMB tool to help growers calculate fertiliser N requirements (at the time of soil testing) from nitrate quick test results and estimates of crop N demand (based on yield potential) (Figure 9s). One of the benefits of the tool is that estimates of N supply are automatically calculated from standard input information (soil texture, soil moisture and nitrate quick test results). This removes the need for users to determine and apply relevant soil correction factors for converting volumetric quick test values (mg/L) to a gravimetric basis.

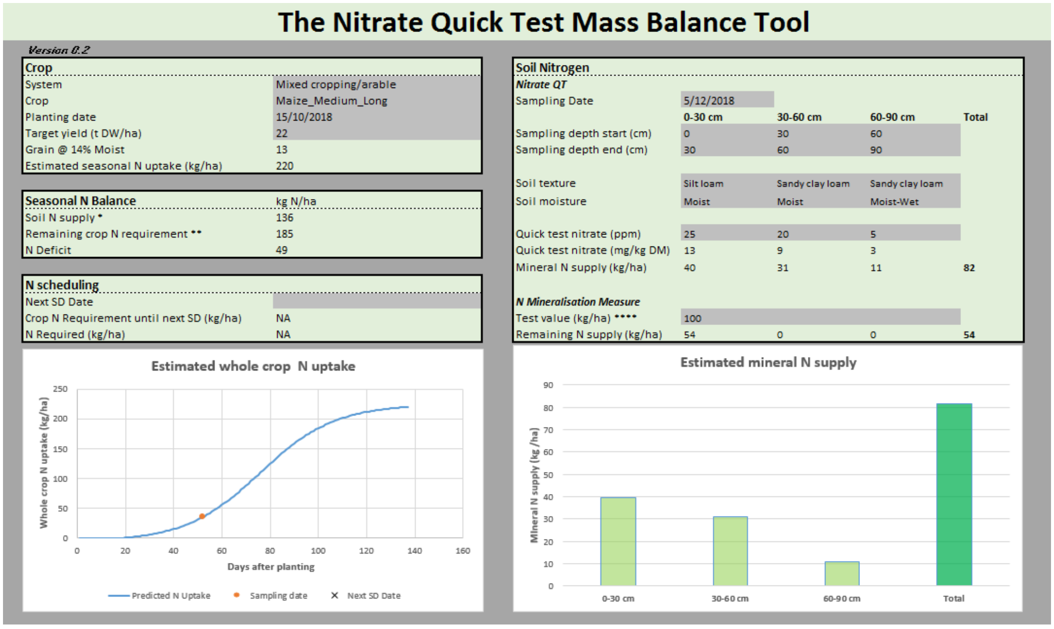

Figure 9. Screen shot of the quick test mass balance user tool.

6 ACKNOWLEDGEMENTS

Funding for this project was from the Ministry for Primary Industry's Sustainable Farming Fund (404944), Foundation for Arable Research, Potatoes New Zealand, HortNZ's Vegetable Research & Innovation Board, Waikato Regional Council, Ravensdown and Ballance Agri-Nutrients. We are thankful to the involved growers for their cooperation and interest in the project.

7 REFERENCES

Jamieson P, Zyskowski R, Sinton S 2005. The potato calculator, New Zealand Institute for Crop & Food Research Limited.

Landcare Research 2018. S-map Online. http://smap.landcareresearch.co.nz/home [accessed October 2018]

Li FY, Johnstone PR, Pearson A, Fletcher A, Jamieson PD, Brown HE, Zyskowski RF 2009. AmaizeN: A decision support system for optimizing nitrogen management of maize. NJAS - Wageningen Journal of Life Sciences 57(1): 93–100.

Norris M, Hunt A, Dellow S, Arnold N, Liu J, Sorensen I, Tan Y, Johnstone P 2017. Nitrogen - Measure it and manage it: Year 1 summary report. A Plant & Food Research report prepared for: Foundation for Arable Research. Milestone No. 69731. Contract No. 33622. Job code: P/411120/01. SPTS No. 15170.

Norris M, Hunt A, Dellow S, Arnold N, Liu J, Sorensen I, Tan Y, Hedderley D. June 2018. X16-13 Nitrogen - Measure it and manage it: Year 2 summary report. A Plant and Food Research report prepared for: Foundation for Arable Research. Milestone No. 69735. Contract No. 33622. Job code: P/411120/01. SPTS No. 16566.

Norris M, Hunt A, Reid J. May 2019. Quick test vegetable nitrogen uptake review (FAR–PFR contract #33622). A Plant and Food Research report prepared for: Foundation for Arable Research. Milestone No. 81316. Contract No. 33622. Job code: P/411120/01. SPTS No. 17808.

APPENDIX 1. MEASURES OF BASE FERTILITY

Measures of base fertility at the six trial sites for the 2018–19 growing season.

Site	pH	Olsen P (mg/L)	Calcium (me/100g)	Magnesium (me/100g)	Potassium (me/100g)	Sodium (me/100g)	Base sat (%) [1]	CEC (me/100g) [2]
1 (baby spinach)	6.6	225	10.3	1.95	2.29	0.12	70.9	20.5
Optimum range [3]	*5.6–6.8*	*50–90*	*7.8–11.6*	*0.86–1.29*	*0.72–0.96*	*0.02–0.19*		
2 (maize)	5.6	24	7.7	0.74	0.35	0.12	66.1	13.5
Optimum range	*5.6–6.2*	*15–30*	*4.8–9.6*	*0.48–0.77*	*0.56–0.70*	*0.02–0.19*		
3 (broccoli)	7.0	159	25.1	3.79	1.49	0.20	93.5	32.8
Optimum range	*6.0–7.2*	*35–75*	*9.6–14.3*	*0.96–1.44*	*0.70–1.05*	*0.02–0.17*		
4 (potatoes)	5.6	9	7.4	1.80	0.38	0.12	56.4	17.3
5 (potatoes)	5.8	19	8.8	1.02	0.31	0.20	64.3	16.0
Optimum range	*5.1–6.0*	*35–55*	*7.6–14.3*	*0.38–1.44*	*0.42–1.05*	*0.02–0.19*		
6 (lettuce)	7.0	47	10.1	0.28	0.47	0.10	86.5	13.0
Optimum range	*6.3–7.0*	*35–90*	*9.3–14.0*	*0.86–1.29*	*0.48–0.72*	*0.02–0.19*		

[1] Percentage base saturation. [2] Cation exchange capacity. [3] Optimum ranges are based on values supplied in ARL soil test reports.

APPENDIX 2. CROP PRODUCTIVITY

Planting population and crop yield data at the six trial sites (2018–19 growing season) including a comparison of predicted yields and crop nitrogen (N) uptakes with actual yields and crop N uptakes for the grower and quick test mass balance (QTMB) treatments. t FW/ha = tons of fresh weight per hectare. t DM/ha = tons of dry matter per hectare.

Site	Treatment	Population (plants/ha)	Target yield [1]	Actual yield [1]	Predicted crop N uptake (kg N/ha) [1]	Actual N uptake (kg N/ha) [1]	Plant tissue N concentration (%) [1]
1 (baby spinach) [2]	Grower	-	13 t FW/ha	9.7 t FW/ha	56	30	3.7
	QTMB	-		8.6 t FW/ha		25	3.9
	Rest of field	-		14.7 t FW/ha		61	5.3
	P value [3]		-	*< 0.001 *****	-	*< 0.001 *****	*< 0.001 *****
	LSD [4]		-	*2.1*	-	6.9	0.44
2 (maize)	Grower	104331	24 t DW/ha	25.4 t DM/ha	240	230	0.91
	QTMB	104987		23.2 t DM/ha		210	0.91
	P value	*0.83*	-	*0.14*	-	*0.29*	*0.96*
3 (broccoli) [5]	Grower	45537	65 (14) t FW/ha	68 (10) t FW/ha	199	255	4.1
	QTMB	45537		70 (11) t FW/ha		237	3.7
	P value	*1.0*	-	*0.72 (0.93)*	-	*0.37*	*0.015 *****
4 (potatoes) [6]	Grower	35795	55 t FW/ha	48 (45) t FW/ha	186	145	1.65
	QTMB	34091		54 (52) t FW/ha		144	1.32
	P value	*0.17*	-	*0.29*	-	*0.95*	*0.028 *****
5 (potatoes) [6]	Grower	33333	75 t FW/ha	93 (81) t FW/ha	255	325	1.56
	QTMB	31111		94 (87) t FW/ha		324	1.55
	P value	*0.31*	-	*0.73 (0.23)*	-	*0.93*	*0.85*
6 (lettuce) [6]	Grower	42254	55 (42) t FW/ha	68 (26) t FW/ha	108	119	3.42
	QTMB	42254		66 (29) t FW/ha		112	3.35
	P value	-	-	*0.59 (0.27)*	-	*0.16*	*0.36*

[1] Yield, N uptakes and plant tissue N concentrations are for the above ground plant component at Sites 1, 2, 3, 6 and the tuber component at Sites 4 and 5. [2] Crop was direct seeded at high density so population was not quantified. [3] P values of below 0.05 (**) and 0.10 (*) indicate respective significant and weakly significant differences in means between treatments. [4] The least significant difference (LSD) is shown for Site 1 only, this for comparison of treatment means. [5] Values in parenthesis are for the broccoli floret component. [6] Values in parenthesis represent the marketable yield.

APPENDIX 3. SITE NITROGEN BALANCES

Nitrogen (N) balance for the grower and quick test mass balance (QTMB) treatments at the six trial sites for the 2018–19 season.

Site	Treatment	AMN at planting [1]	Soil mineral N at planting [2]	Fertiliser N applied at base/planting	Total mineral N supply at planting	Fertiliser N applied at side dressing	Seasonal sum of mineral N supply [3]	Crop N uptake [4]	Soil mineral N at harvest [2]
1 (baby spinach)	Grower	29	17	106	123	0	123	30	24
	QTMB	27	22	50	72	42	114	25	40
	Rest of field		19	212	231	0	231	61	106
	***P Value* [5]**	*0.71*	*0.51*		*< 0.001 *****		*< 0.001 *****	*< 0.001 *****	*0.001 *****
	***LSD* [6]**	*10*	*9*		*9*		*9*	*7*	*37*
2 (maize)	Grower	145	96	23	119	92	211	230	26
	QTMB	145	102	23	125	0	125	210	41
	P Value	*1.0*	*0.83*		*0.83*		*0.006 *****	*0.29*	*0.040 *****
3 (broccoli)	Grower	116	140	35	175	76	251	255	83
	QTMB	87	142	35	177	30	207	237	51
	P Value	*0.52*	*0.86*		*0.86*		*0.003 *****	*0.37*	*0.35*
4 (potatoes)	Grower	111	21	50	71	54	125	145	72
	QTMB	103	23	50	73	0	73	144	57
	P Value	*0.81*	*0.73*		*0.73*		*<0.001 *****	*0.95*	*0.33*
5 (potatoes)	Grower	198	67	109	176	121	297	325	100
	QTMB	194	43	109	152	33	185	324	124
	P Value	*0.87*	*0.013 *****		*0.013 *****		*<0.001 *****		*0.31*
6 (lettuce)	Grower	101	51	32	83	81	164	119	181
	QTMB	81	28	32	60	27	87	112	116
	P Value	*0.003 *****	*0.14*		*0.14*		*<0.001 *****		*0.007 *****

[1] Anaerobically mineralisable nitrogen (0–30 cm sampling depth). This is a suggested proxy for new N mineralisation from soil organic matter and is not an indication of mineral N already in the soil at the time of sampling.[2] 0-30 cm at Sites 1 and 6; 0-60 cm at Sites 2 to 4. [3] Represents the sum of mineral N at planting and the total amount of N fertiliser applied. [4] For the spinach, maize, broccoli and lettuce crops (Sites 1, 2, 3 and 6) this is the total N uptake in above ground biomass. For the potato crops (Site 4 and 5), this is the N uptake by the tuber component. [5] P values of below 0.05 (**) and 0.10 (*) indicate respective significant and weakly significant differences in means between treatments. [6] The least significant difference (LSD) is shown for Site 1 only, this for comparison of treatment means.

APPENDIX 4. QUICK TEST CORRECTION FACTORS

Nitrate quick test correction factors for converting solution nitrate-nitrogen (N) results (mg nitrate/L) to a dry soil basis (mg nitrate-N/kg dry matter).

Texture	Dry	Dry-Moist	Moist	Moist-Wet	Wet
clay	1.77	1.60	1.45	1.39	1.33
clay loam	1.69	1.52	1.35	1.32	1.28
loam	2.02	1.76	1.52	1.40	1.29
loamy sand	1.80	1.67	1.54	1.47	1.40
sand	1.80	1.67	1.54	1.47	1.40
sandy clay	1.81	1.62	1.43	1.37	1.30
sandy clay loam	1.92	1.74	1.57	1.49	1.41
sandy loam	2.05	1.91	1.77	1.64	1.51
silt	1.88	1.63	1.38	1.34	1.30
silt loam	1.74	1.55	1.37	1.33	1.28
silty clay	1.92	1.75	1.57	1.49	1.40
silty clay loam	1.85	1.66	1.47	1.41	1.35

DISCOVER. INNOVATE. GROW.