Seasonal soil moisture and nitrogen availability — Rutherglen and Boorhaman regions

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Key points

- Soils in the Rutherglen region of Victoria are highly variable.
- While most soils across the region increase in clay content in the subsoil, there is a vein of sandy subsoil that runs through the Boorhaman region.
- While soil moisture probes are a valuable management tool, accurate interpretation requires an understanding of the soil type, including any physical and chemical constraints that may restrict root and/or water movement to depth.
- Sampling for deep soil nitrogen (DSN) by combining all soil from 0-60cm depth does not give a clear picture of where nitrogen is located in the profile, and how readily plants can access it.

Background

During June 2015, the North East Catchment Management Authority (NECMA) provided funds to Riverine Plains Inc to install and monitor soil moisture probes in cropping paddocks at 11 sites across the Rutherglen region of Victoria through the *Soil moisture probe network* project.

The objective of this project was for growers to understand how knowledge of stored soil moisture can inform their decisions about applying fertiliser. For example, if the soil profile has sufficient moisture, growers might decide to apply enough nitrogen (N) during spring to satisfy the full crop requirement. However, if there is limited stored soil moisture, growers might only apply a smaller amount of fertiliser, as the crop would depend entirely on in-crop rainfall events to reach maturity.

The project also involved measurements of deep soil nitrogen (DSN) post-harvest and pre-sowing to account for the amount of nitrogen mineralised over summer.

Additional funding from the *Sustainable agriculture Victoria: Fast tracking innovation initiative*, made possible with the support of the Foundation for Rural and Regional Renewal (FRRR) through the William Buckland Foundation, allowed DSN sampling (broken into incremental depth samples) at each of these sites. By connecting the results from soil nitrogen sampling to soil moisture status, growers can predict if the stored nitrogen will be available to the crop through the year, or if it will be lost through leaching (due to accumulation of nitrogen at depth under high soil moisture conditions).

The *Benchmarking soil nutrient status in connection with soil water storage and soil type in cropping systems* project is supported by NECMA through funding from the Australian Government's National Landcare Program. This project commenced in 2016 and continued throughout 2017 to extend the work undertaken during 2015.

Some of the soil moisture probe sites from the original *Soil moisture probe network* project were relocated into the Boorhaman area through a partnership with the Boorhaman Landcare Group. Soil moisture monitoring and DSN sampling continued until pre-sowing 2017, with a full soil chemistry analysis undertaken at each site during June 2017 to assist in developing a network of benchmark sites through the region.

Aim

The aim of this project was to increase the understanding of nitrogen availability and movement across and between seasons, to understand how nitrogen availability is intimately related to soil moisture status and to understand the variability in soil chemistry within the Rutherglen–Boorhaman region.

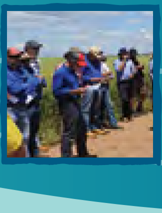
Method

Soil moisture monitoring

Soil moisture probes were installed at 11 sites across the Rutherglen region during June 2015. Probes were removed during harvest (November) and during late March 2016 in preparation for sowing. The results from this first year of soil moisture monitoring were presented in *Research for the Riverine Plains 2016* pages 66–75.

During July 2016, seven of these 11 soil moisture probes were re-installed at existing sites across the Rutherglen region and probes were installed at four new locations in the Boorhaman region. Results from this second year of soil moisture monitoring were presented in *Research for the Riverine Plains 2017,* pages 86–93.

Each probe measured up to four depth intervals (10, 30, 50 and 90cm below the soil surface), with values logged every two hours. The data was manually downloaded from each probe on a regular basis. Gaps in the dataset occurred during sowing and harvest, or if the probe was damaged.



Deep soil nitrogen sampling was carried out at each of the soil moisture probe locations during June and December 2015, April and July 2016, as well as during January, April and June 2017 (Figure 1).

The mid-season DSN sampling is timed to coincide with the typical programs of the region's growers, who use the results to identify how much nitrogen they need to apply to meet crop demand through spring. The post-harvest samplings provide a measure of post-crop residual nitrogen, while the post-sowing sampling provides information on the amount of nitrogen lost or mineralised during the summer months.

Deep soil nitrogen sampling at each of the 11 soil moisture probe sites consisted of one core sample, which was split into increments (0–10, 10–20, 20–30, 30–60 and 60–100cm) before being analysed for mineral nitrogen (nitrate + ammonium) and total nitrogen (includes organic and inorganic forms — i.e. the total nitrogen soil bank).

By measuring both mineral nitrogen and total nitrogen growers can better appreciate the role of organic forms of nitrogen in cycling and mineralisation processes.

The data from the nitrogen samples could not be statistically analysed because the collection was not replicated. While the results presented here provide an indication of nitrogen availability, they are sampled from one point in the paddock and there is the possibility the results are not representative of the rest of the paddock.

Soil chemistry benchmarking

Soil sampling for a full soil chemistry analysis (including nitrogen) was carried out during June 2017 in order to capture the key chemical constraints likely to impact on plant growth and root extraction of soil moisture. This analysis also provides key benchmarking figures on soil status in the Rutherglen-Boorhaman region, which will be of value over time.

Results

As there are now several years of data at most of the soil moisture monitoring sites, all results at each site have been compiled and evaluated *in toto* (as a whole). This has been done in order to 'step back' from the annual results to look at the soil system over several seasons.

Soil mineral nitrogen is comprised of both nitrate and ammonium, both of which are measured in standard soil tests, and when added together give a total *mineral nitrogen* value. As the ammonium fraction is sensitive to waterlogging (the value becomes elevated under anaerobic conditions), only the nitrate-nitrogen fraction is presented here. This allows comparison between wet and dry periods of sampling.

The monthly rainfall data for Rutherglen for the monitoring period is presented in Figure 2 and provides context to the soil moisture results presented. The 2015 season was characterised by high rainfall during the winter months, while the spring was dry. For the 2016 season, rainfall

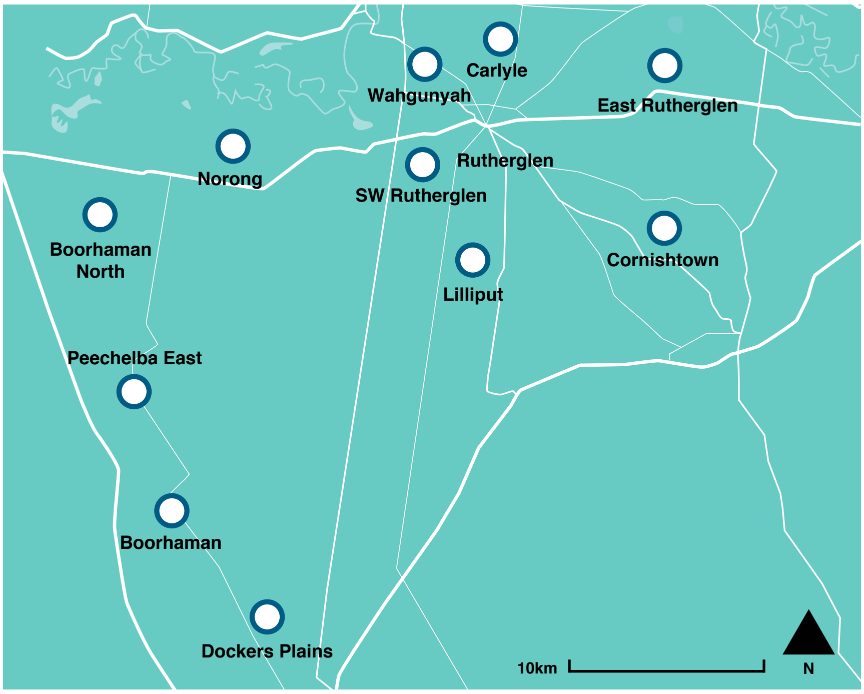


FIGURE 1 Locations of the 11 soil moisture probes installed across the Rutherglen and Boorhaman areas

during December 2015 and January 2016 helped replenish stored soil moisture reserves, however there was little follow-up rainfall during February and March 2016. The winter and spring of 2016 were extremely wet, with more than double the long-term median rainfall being received during September 2016. In comparison, the summer of 2016–17 was dry, with little soil moisture available to aid mineralisation (the microbial conversion of organic nitrogen into plant-available mineral nitrogen). High rainfall was recorded during autumn and winter 2017, while a dry spring saw crops draw heavily on soil moisture reserves. The summer of 2017–18 was characterised by intense rainfall events during harvest, followed by minimal summer and autumn rainfall.

Location: Carlyle

2015 crop and stubble practice: Wheat, cut for hay

2016 crop and yield: Triticale, cut for hay 6.9t/ha

2016 nitrogen applied: 10kg N/ha MAP, 69kg N/ha urea

Timing of 2016 in-crop nitrogen application: July

2016 stubble management (post-harvest): Multidisc

2017 crop and yield: Canola, 2.3t/ha, 43% protein (hail damage on 50%)

2017 nitrogen applied: 10kg N/ha MAP, 92kg N/ha urea

Timing of 2017 in-crop nitrogen application: July and August

2017 stubble management: Retained

The Carlyle site is a self-mulching grey clay. While the surface (0–10cm) is lighter textured and shows a clear response to rainfall and evapotranspiration, the subsurface layers do not show much response, due to the ability of heavy clay to strongly hold onto water (Figure 3).

During 2015 there was limited movement of soil moisture at depth, while the entire profile was full during the 2016 season. All moisture probe results at depth were closely aligned and this, along with soil pit observations of soil texture, support the determination that the soil is uniformly high in clay to depth.

During the period from June 2015 to harvest 2017, the only time plant roots were observed to strongly extract water at depth was during October 2017, when a lack of rain and high plant demand combined to result in the measurable extraction of water down to 50cm. While excavation of a soil pit during spring 2017 showed roots had penetrated into the 70–80cm zone, their contribution to water extraction may have been low.

Results from the moisture probe sensors showed that this soil dried out to depth during the summer of 2018. However, given this type of heavy clay would not naturally dry out to such low levels, the drying could only be due to the development of deep cracks near the soil moisture probe sensor locations.

Nitrogen movement at the Carlyle site was mostly restricted to the 0–10 and 10–30cm layers, with only minimal nitrogen movement down to 60cm (Figure 4). As most of the nitrate-nitrogen is in the top soil layers this nitrogen, along with additional in-crop nitrogen, was likely utilised by the crop.

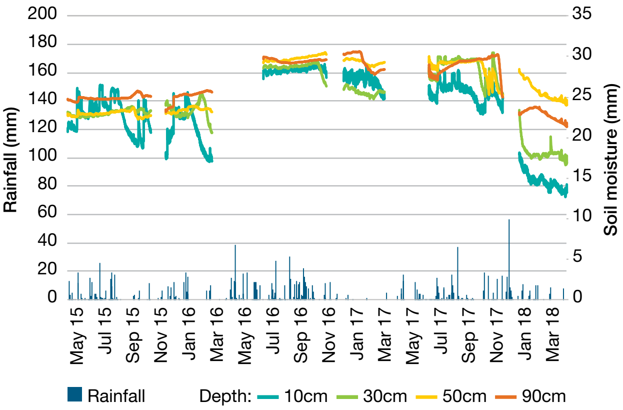


FIGURE 3 Soil moisture levels at Carlyle, Victoria May 2015 – March 2018

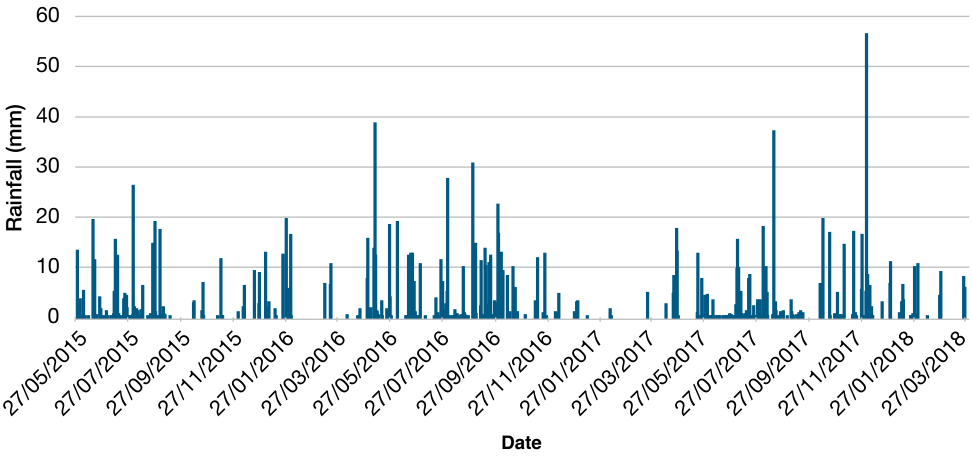


FIGURE 2 Monthly rainfall recorded at Rutherglen, 27 May 2015 – 31 March 2018

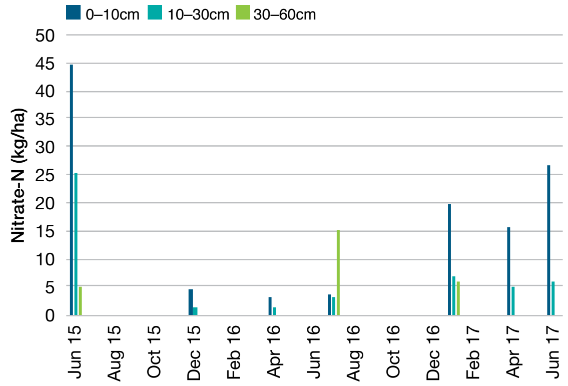


FIGURE 4 Plant-available (nitrate) soil nitrogen levels at Carlyle, Victoria June 2015 – June 2017.

The exception to this involves the July 2016 measurements, when nitrate likely leached downwards under the saturated conditions. It is also likely that significant denitrification (gaseous-nitrogen loss) occurred on this site during the 2016 winter, which probably experienced prolonged waterlogging due this soil's inability to drain water. While some mineralisation of organic nitrogen occurred before sampling in January 2017, this did not further increase in the interval to sowing, suggesting that some of this nitrogen may be left over from in-crop applications.

Soil chemistry results at Carlyle (Table 1) show a pH_{Ca} of 4.8, indicating an acidic topsoil. At this pH, aluminium (Al) toxicity becomes a risk to growing plants; if the pH value continues to decrease, aluminium availability in the soil will increase, which may limit plant growth. Sodium levels are low at this site, indicating that sodicity/dispersion is not a limiting factor. The soil organic carbon value of 1.2% should support an active microbial population.

TABLE 1 Soil chemistry results at Carlyle, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.8	5.1	6.5
EC (dS/m)	0.07	0.02	0.03
Chloride (mg/kg)	11	<10	<10
Nitrate N (kg/ha)	26.6	5.9	0
Mineral N (kg/ha)	28.8	8.4	2.7
Colwell P (mg/kg)	42	5	<5.0
PBI (Colwell)	94	40	47
CEC*	7.7	6.7	11.8
ESP#	1.5	1.1	2.8
Aluminium % of cations	3.7	<1	<1
Sulphur (KCl40)	6.2	1.6	1.7
Organic carbon (%)	1.2	0.2	<0.15
Available potassium (mg/kg)	240	120	230

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: South-west Rutherglen

2015 crop and stubble practice: Wheat, burned

2016 crop and yield: Canola, 1.7t/ha

2016 nitrogen applied: 10kg N/ha MAP, 69kg N/ha urea

Timing of 2016 in-crop nitrogen application: Mid-July

2016 stubble management (post-harvest): Burnt patches

2017 crop and yield: Wheat, 5.5t/ha

2017 nitrogen applied: 10kg N/ha MAP, 115kg N/ha

Timing of 2017 in-crop nitrogen in application: Early July, early August, late August

2017 stubble management: Burn stubble before lupins.

The soil moisture profile of the south-west (SW) Rutherglen site indicates this soil has a high capacity to store and release water for plant growth, as shown by the variance of soil moisture measured within each profile (Figure 5). Moisture probe readings show that during spring 2017 plants accessed moisture down to at least 90cm. Similarly to other soils in the region, this soil has a lighter-textured layer at 30cm depth, which has less capacity to store water than the 10cm layer.

The 2015 season moisture probe data indicated effective extraction of moisture below 50cm, with plant roots drawing down much of the available stored water during October. Several heat stress events were experienced during October, increasing the demand for moisture. Compared with the heavy clay soil of the Carlyle site, the lighter-textured soil present to 50cm depth at this site allowed the paddock to drain well during the wet winter of 2016. Data from the 2017 season showed roots accessed moisture down to 90cm during the dry spring period.

The lighter texture of this soil means nitrate-nitrogen can move easily down to 60cm, as seen in the nitrogen results (Figure 6). As such, split applications of urea during the season are of value in reducing movement of nitrogen to

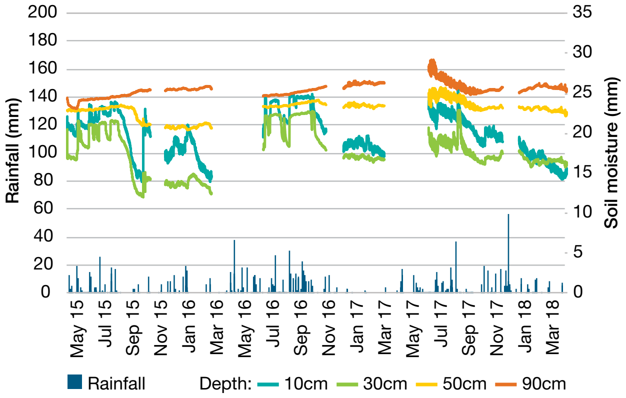


FIGURE 5 Soil moisture levels at south-west Rutherglen, Victoria May 2015 – March 2018

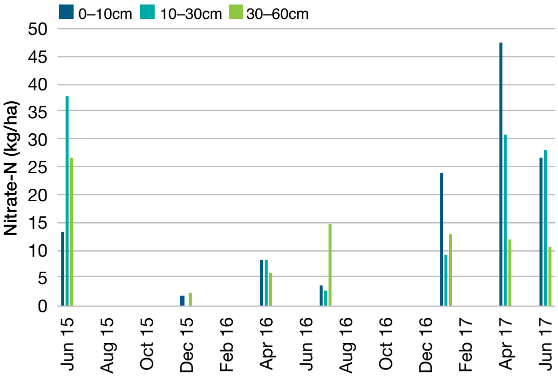


FIGURE 6 Plant-available (nitrate) soil nitrogen levels at south-west Rutherglen, Victoria June 2015 – June 2017

depth in this soil. Early summer rainfall during 2016–17 saw a large increase in mineralisation of nitrogen compared with the low mineralisation levels observed during the summer of 2015–16. Early summer rainfall during 2017–18 also saw high levels of mineralised nitrogen measured at the 10–30cm depth during summer, which moved down the profile with rainfall due to the light soil texture.

The soil chemistry results from the south-west Rutherglen site show this site is acid to depth (pH_{Ca} 4.9 at 30–60cm depth) (Table 2). The lighter texture of the soil, with its lower cation exchange capacity (CEC) and low carbon values, means it has a poor ability to withstand chemical change. High aluminium levels at the 10–30cm depth are related to the low pH values, with subsoil acidity likely to be the most limiting factor for growth of species sensitive to aluminium.

TABLE 2 Soil chemistry results at south-west Rutherglen, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.9	4.4	4.9
EC (dS/m)	0.06	0.04	0.03
Chloride (mg/kg)	<10	<10	<10
Nitrate N (kg/ha)	26.6	28.0	10.5
Mineral N (kg/ha)	28	28	10.5
Colwell P (mg/kg)	89	14	<5.0
PBI (Colwell)	61	71	120
CEC*	4.67	3.77	6.28
ESP[#]	0.65	0.74	4.2
Aluminium % of cations	3.3	14	3.8
Sulphur (KCl40)	6.3	5.2	9
Organic carbon (%)	0.91	0.21	<0.15
OM (%)	1.6	0.36	0.26
Available potassium (mg/kg)	200	130	150

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

[#] Exchangeable sodium percentage of CEC

Location: Wahgunyah

2015 crop and stubble practice: Wheat, burned

2016 crop and yield: Triticale, 4.2t/ha

2016 nitrogen applied: 10kg N/ha MAP, 92kg N/ha urea

Timing of 2017 in-crop nitrogen application: Early June, late August

2016 stubble management (post-harvest): Burnt

2017 crop and yield: Canola, 3.0t/ha

2017 nitrogen applied: 10kg N/ha MAP, 16.8kg N/ha SOA, 115 kg N/ha urea

Timing of 2017 in-crop nitrogen application: SOA end May, urea end June and August

2017 stubble management: Knocked down with harrows.

The soil at the Wahgunyah site is lighter textured than many of the soils in the region, being free draining down to 50cm (Figure 7). The large range between the upper and lower soil moisture limits (field capacity and permanent wilting point respectively) at the 50cm layer also indicates a lighter soil texture. The soil moisture probe results show that water can be extracted by plants down to a depth of 90cm. Clay content increases incrementally with depth in this soil, but it lacks the strong duplex texture contrast between the 10cm and 30cm depth increments commonly found at other sites in the region.

Soil moisture probe data indicated that this site maintained high levels of soil moisture throughout the 2015 season until October, when high temperatures and high crop demand saw the crop run soil moisture levels down (Figure 7). The wet conditions experienced during 2016 meant the profile was at field capacity for most of the season, with some drying to 50cm depth from October 2016. The 2017 season began with high levels of stored soil moisture, which was again drawn upon during the subsequent dry spring.

The nitrate-nitrogen measurements at the Wahgunyah site were generally low, with the exception of the June

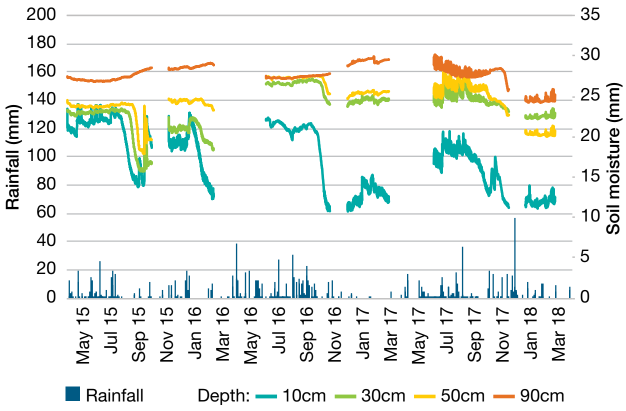


FIGURE 7 Soil moisture levels at Wahgunyah, Victoria May 2015 – March 2018

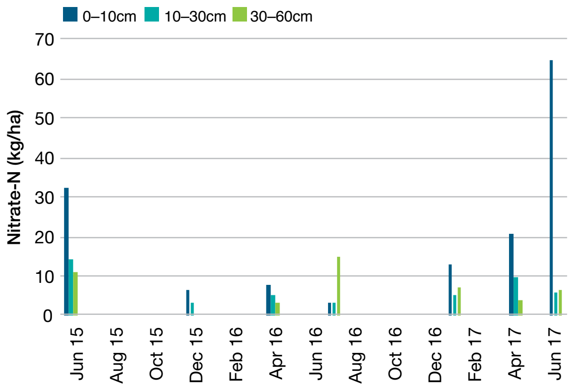


FIGURE 8 Plant-available (nitrate) soil nitrogen levels at Wahgunyah, Victoria June 2015 – June 2017

2015 and 2017 samples (Figure 8). These low numbers suggest most of the in-season fertiliser was used by the crop. As the soil moisture results show active root uptake of moisture to depth, it is likely that while some nitrogen moved to depth, this nitrogen was taken up by plant roots. Some mineralisation of nitrogen was measured between the December 2016 and April 2017 sampling. The spike in nitrogen observed during June 2017 in the 0–10cm layer would be due to in-crop nitrogen application.

The soil chemistry results for Wahgunyah show that while the 0–10cm depth is acid (pH$_{Ca}$ 4.9), pH increases with depth and is neutral at 30–60cm depth (pH$_{Ca}$ 7.1) (Table 3). Although there is measurable sodicity at depth (ESP 11–19%), this does not appear to limit root exploration to depth. The organic carbon value of 1.4% is good and possibly reflects a history of pasture in this paddock.

TABLE 3 Soil chemistry results at Wahgunyah, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH (CaCl$_2$)	4.9	5.8	7.1
EC (dS/m)	0.13	0.05	0.15
Chloride (mg/kg)	19	<10	13
Nitrate N (kg/ha)	64.4	5.88	6.72
Nineral N (kg/ha)	81.2	5.88	9.37
Colwell P (mg/kg)	85	<5.0	<5.0
PBI (Colwell)	76	49	150
CEC*	6.14	5.53	16.1
ESP#	1.1	11	19
Aluminium % of cations	2.7	2.3	0.69
Sulphur (KCl40)	12	9.4	26
Organic carbon (%)	1.4	0.18	0.24
OM (%)	2.4	0.31	0.41
Available potassium (mg/kg)	270	110	250

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

Exchangeable sodium percentage of CEC

Location: East Rutherglen

2015 crop and stubble practice: Wheat, burnt

2016 crop and yield: Canola, 2t/ha

2016 nitrogen applied: 7.5kg N/ha MAP, 101kg N/ha urea

Timing of 2016 in-crop nitrogen application: Late May, early July

2016 stubble management (post-harvest): Retained

2017 crop and yield: Wheat, 6.5t/ha

2017 nitrogen applied: 7kg N/ha MAP, 92kg N/ha urea

Timing of 2016 in-crop nitrogen application: Sowing, July

2017 stubble management: Burnt

The east Rutherglen site is characterised by increasing clay content to depth, changing from a loam texture in the surface to a medium–heavy clay beyond a depth of 60cm.

During 2015, the east Rutherglen site maintained high soil moisture levels for most of the growing season, until mid-September 2015 when the season turned dry (Figure 9). Soil pit observations showed wheat roots penetrated more than 1m during the 2015 season. The profile was re-wet by plentiful rains over the 2015–16 summer, which was followed by a wet winter and spring 2016. While the 10cm depth layer stayed wet until mid-October 2016 (when it started to drain), the 30cm layer appeared to remain in a saturated state from July onwards, due to increasing clay content to depth which slowed drainage. The 2016 pre-harvest soil moisture probe results show higher soil moisture than the post-harvest results at the 50cm sensor depth, indicating the canola crop may have actively extracted moisture down to 50cm depth before harvest. There was plenty of soil moisture available at depth during the 2017 season, with roots extracting water down to 90cm during the dry spring.

The June 2015 nitrate-nitrogen sampling results showed a large amount of nitrogen (170kg/ha) was available at 0–10cm depth (Figure 10). During late July – early August, 101kg N/ha was applied as urea, which meant the wheat crop potentially had access to 271kg N/ha during late winter. As it was quite wet at this time, it is likely some of this nitrogen was lost as gaseous-nitrogen due to denitrification, while the rest was taken up by the crop. Mineralisation over the 2015–16 summer resulted in almost 40kg N/ha becoming available to the following crop. The wet winter of 2016 saw a large amount of nitrate moving into the 30–60cm depth by July 2016 (67kg N/ha), however about two-thirds of this nitrogen was likely extracted by plant roots throughout the season.

The high clay content of this soil at depth would minimise further leaching of nitrogen, as shown by the reduced concentrations available at depth post-harvest. The 2016–2017 mineralisation results showed that about 25kg

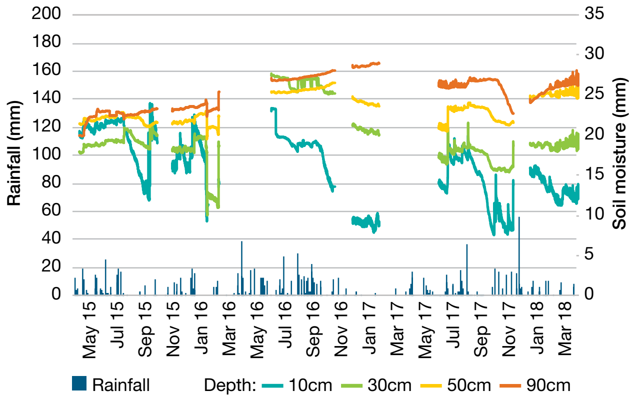


FIGURE 9 Soil moisture levels at east Rutherglen, Victoria May 2015 – March 2018

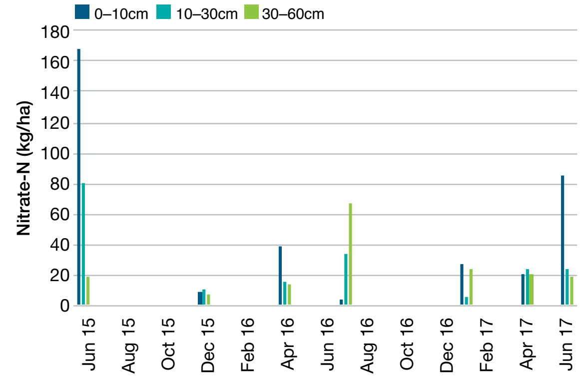


FIGURE 10 Plant-available (nitrate) soil nitrogen levels at east Rutherglen, Victoria, June 2015 – June 2017

N/ha of organic nitrogen became available post-harvest at the 0–10cm depth, which was comparable with most other sites (although it appears less due to the scale of the graph) (Figure 10). The high concentration of nitrate-nitrogen measured at the 0–10cm depth during June 2017 can be attributed to 100kg urea (46kg N/ha) applied at sowing with MAP.

The soil chemistry results for east Rutherglen show mid-range pH values due to a regular liming history (Table 4). The high Colwell phosphorus measurement (120mg P/kg) at the 0–10cm depth would be due to MAP application at sowing, as well as the accumulation of residual phosphorus as a result of stubble breakdown over many years of no-till cropping. The 10–30cm layer in this soil has been depleted due to years of prolific root growth in this zone. This includes pH (the depletion of alkali makes conditions more acidic) and CEC (cation exchange capacity). Regular monitoring and a proactive lime application will support amelioration of this layer over the long term.

TABLE 4 Soil chemistry results at east Rutherglen, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5.8	5.2	5.5
EC (dS/m)	0.17	0.05	0.1
Chloride (mg/kg)	19	<10	<10
Nitrate N (kg/ha)	85.4	24.36	18.06
Mineral N (kg/ha)	88.06	26.26	21.38
Colwell P (mg/kg)	120	25	6.7
PBI (Colwell)	43	71	190
CEC*	7.27	5.8	8.85
ESP#	0.44	1.1	4.8
Aluminium % of cations	<1	<1	<1
Sulphur (KCl40)	15	14	42
Organic carbon (%)	1.1	0.36	0.2
OM (%)	1.9	0.62	0.34
Available potassium (mg/kg)	340	210	170

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: Cornishtown

2015 crop and stubble practice: Wheat, burnt

2016 crop and yield: Faba beans, 3t/ha

2016 nitrogen applied: 14kg N/ha DAP

Time of 2016 in-crop nitrogen application: None

2016 stubble management (post-harvest): Sheep grazed, then burnt

2017 crop and yield: Wheat, 6.5t/ha

2017 nitrogen applied: 10kg N/ha MAP

Time of 2017 in-crop nitrogen application: None

2017 stubble management: Burnt

The soil at the Cornishtown site gradually increases in clay content with depth, as is shown by the differences between soil moisture levels at each depth (Figure 11).

The high temperatures experienced during October 2015 saw wheat roots draw down moisture from past 50cm depth, though soil water content was replenished to saturation point by the wet winter and spring of 2016. The soil profile remained quite full during the 2017 season until the dry spring, during which moisture extraction by roots was observed down to 90cm.

The nitrate-nitrogen values were relatively low at the Cornishtown site (Figure 12). Mineralisation over the 2015–16 summer resulted in at least 40kg N/ha becoming available after the wheat crop had been harvested, while almost 60kg N/ha was mineralised after the faba bean crop of 2016 was harvested. Of particular interest is the increase in available nitrogen, which was measured



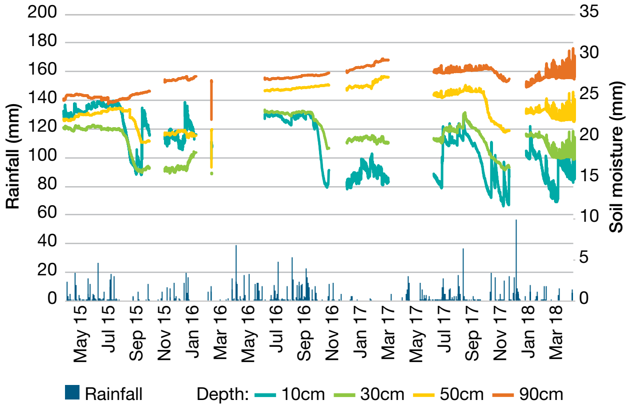


FIGURE 11 Soil moisture levels at Cornishtown, Victoria May 2015 – March 2018

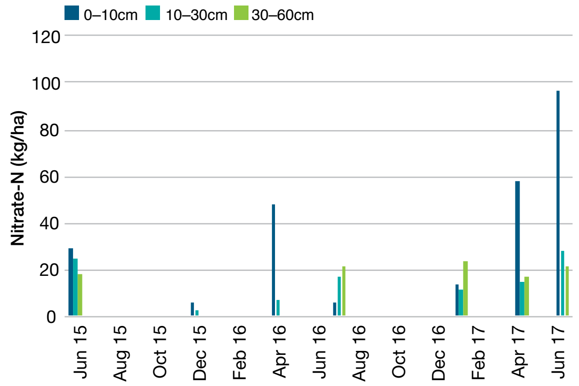


FIGURE 12 Plant-available (nitrate) soil nitrogen levels at Cornishtown, Victoria June 2015 – June 2017

mostly between January and April 2017, during a time of low rainfall. This likely coincides with the period of sheep grazing, demonstrating the potential for the combination of pulse crop production and sheep grazing of pulse stubble to increase mineral nitrogen values over summer. The high value of nitrate-nitrogen in June 2017 was due to the applied MAP in addition to the high levels of mineralised nitrogen.

The soil chemistry results for Cornishtown show that while the pH in the 0–10cm depth is acidic (pH_{Ca} 5.1), very low pH at the 10–30cm depth (pH_{Ca} 4.7) will likely be associated with an increase in aluminium availability (Table 5) and could limit plant growth of sensitive species, such as canola in the coming years. The organic carbon level of 1.4% is a good result for this soil. The 10–30cm layer shows a reduction in the phosphorus buffering index (PBI) compared with the 0–10cm layer. This suggests the 10–30cm layer has a slightly lower clay content, which also aligns with the slight drop in CEC at this depth (clay being a major provider of exchange sites as part of CEC).

TABLE 5 Soil chemistry results at Cornishtown, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5.1	4.7	5.9
EC (dS/m)	0.16	0.05	0.04
Chloride (mg/kg)	19	<10	<10
Nitrate N (kg/ha)	96.6	28	21.84
Mineral N (kg/ha)	100.24	30.52	25.41
Colwell P (mg/kg)	37	6.5	<5.0
PBI (Colwell)	78	68	120
CEC*	6.88	5.16	7.83
ESP#	1.2	2	6.2
Aluminium % of cations	<1	4.9	<1
Sulphur (KCl40)	11	11	7.5
Organic carbon (%)	1.4	0.27	<0.15
OM (%)	2.4	0.46	0.26
Available potassium (mg/kg)	210	170	140

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: Lilliput

2015 crop and stubble practice: Wheat, burnt

2016 crop and yield: Faba beans, 2.5t/ha

2016 nitrogen applied: None

2016 stubble management (post-harvest): Retained

2017 crop and yield: Canola, 3t/ha

2017 nitrogen applied: 8kg N/ha MAP, 16.8kg N/ha SOA, 115kg N/ha

Timing of 2017 in-crop nitrogen application: May, early July

2017 stubble management: Retained

The Lilliput site is relatively free draining, both at the surface (0–10cm) and subsurface (10–50cm) layers (Figure 13). The 30cm layer contains more clay than the surface layer, but is still readily accessed by plant roots, as seen by the range of soil water values. The 50cm depth layer is lighter again, as indicated by the 50cm probe soil water readings, which are lower than those measured at the 10cm depth. This soil is a grey-coloured material, which occurs through the landscape around Black Dog creek, before moving into a heavy clay at 90cm.

Soil moisture was non-limiting throughout most of the 2015 cropping season. During September 2015 conditions dried off and soil moisture started to be drawn down to 50cm. Rainfall during November 2015 somewhat wet the profile to a depth of 30cm, however by sowing (2016), the soil had dried out in the top 10cm. Although the soil profile was close to saturation during the wet season of 2016, the lighter-textured soil at this site meant plants could extract water

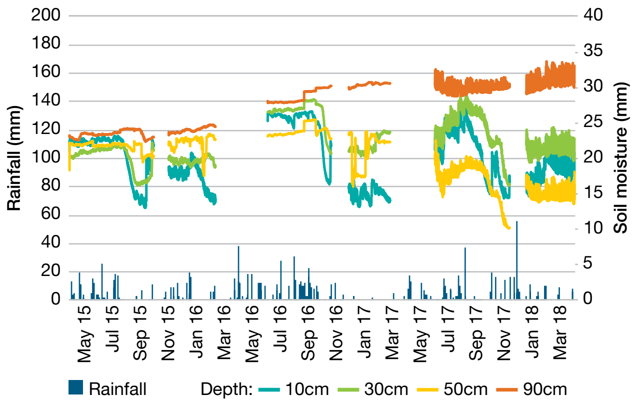


FIGURE 13 Soil moisture levels at Lilliput, Victoria May 2015 – March 2018

throughout the winter. The profile dried out quickly after the wet conditions eased during October, which highlighted the texture contrast between the 10 and 30cm layers.

Stored moisture reserves were high at the start of the 2017 season, but the dry spring period meant most of the available stored water was used to bring the crop to harvest. While rainfall over the summer of 2017–18 helped restore some soil moisture, the light texture of the 30cm and 50cm layers meant most of the moisture moved down into the 90cm zone. This stored moisture may only become accessible later in the 2018 season.

The June 2015 nitrogen sampling showed a large 'bulge' of nitrate (plant-available nitrogen) at 30–60cm depth, which is likely due to accumulation of nitrogen over time (Figure 14). This bulge had largely disappeared by the post-harvest sampling, with limited nitrogen remaining by the pre-sowing sampling. While the crop may have used some of this DSN, it is likely at least some of the nitrogen was lost to the deeper layers through leaching given soil moisture levels were high throughout the season. Low levels of nitrate-nitrogen were measured during July 2016, with the highest levels observed at 30–60cm (which is in line with other sites) due to the wet conditions. The low levels of nitrogen measured during the 2016 season were expected given there was no nitrogen applied to the 2016 faba bean crop. As with the Cornishtown results, the faba bean crop at Lilliput resulted in significant nitrogen mineralisation over the following summer – autumn (40kg N/ha), even with low summer rainfall. The higher levels of nitrogen measured in June 2017 would be partly due to the fertiliser added at sowing and partly due to further in-crop mineralisation of nitrogen.

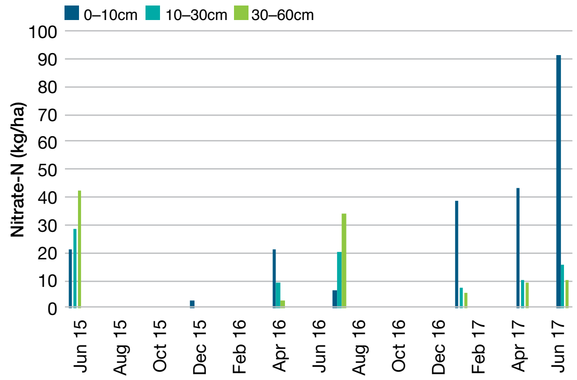


FIGURE 14 Plant-available (nitrate) soil nitrogen levels at Lilliput, Victoria June 2015 – June 2017

The soil chemistry results at Lilliput show that lime was needed to amend the low pH (pH_{Ca} 4.6) in the topsoil (Table 6). The soil carbon value of 1.3% is good for this soil and will contribute towards the ongoing sustainability of this site for cropping. The lower PBI in the 10–30cm zone (48), compared with the 0–10cm layer (72) supports the observation of a lower clay content at this site. Increases in the CEC with depth are likely due to increasing silt content (not clay). The exchangeable sodium percentage (ESP) results are only of concern at the 30–60cm depth, however at this point they are beyond the reach of management options.

TABLE 6 Soil chemistry results at Lilliput, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.6	5.5	6.7
EC (dS/m)	0.16	0.03	0.06
Chloride (mg/kg)	23	<10	<10
Nitrate N (kg/ha)	107.8	8.96	5.04
Mineral N (kg/ha)	119	11.45	8.53
Colwell P (mg/kg)	63	5.9	<5.0
PBI (Colwell)	72	48	80
CEC *	7.03	9.59	16.4
ESP#	2	3.3	8
Aluminium % of cations	3.2	<1	<1
Sulphur (KCl40)	11	3.3	2.1
Organic carbon (%)	1.3	0.22	0.16
OM (%)	2.2	0.38	0.28
Available potassium (mg/kg)	290	140	280

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: Norong

2015 crop and stubble practice: Wheat, retained

2016 crop and yield: Canola, 1.1t/ha

2016 nitrogen applied: 10kg N/ha MAP, 92kg N/ha urea

Timing of 2016 in-crop nitrogen application: Sowing, mid-July

2016 stubble management (post-harvest): Some burnt

2017 crop and yield: Wheat, 5.4t/ha

2017 nitrogen applied: 8kg N/ha MAP, 105.8kg N/ha urea

Timing of 2017 in-crop nitrogen application: Sowing, May, early July

2017 stubble management: Burnt

The soil at Norong showed a high capacity to store and release moisture from the 10cm depth, due to a light-textured topsoil (Figure 15). There is an increase in clay content below the 10cm layer, which would explain why the moisture release range of the 30cm and 50cm soil layers are similar. A further increase in clay content at 90cm resulted in higher stored soil moisture, with only a small range in results observed between wetting and drying.

Plants had access to adequate soil moisture during the 2015 season, with soil moisture drawn from at least 50cm depth during the period of heat stress during mid-October 2015. The site was wet throughout the 2016 season, however post-harvest results show some difference in moisture content between of the soil layers; this indicates that roots extracted water from the 30cm layer as well as some water from the 50cm layer in the lead-up to harvest (after the probe was removed). This soil has a large texture change into the subsoil; the large increase in clay content means water and nutrients move only slowly into the subsoil. Adequate moisture was present during the 2017 season, until the dry spring period when plant roots extracted water down to 50cm depth. While significant rainfall during the 2017 harvest increased stored soil moisture levels, the 2018 season started with a soil moisture profile at less than field capacity.

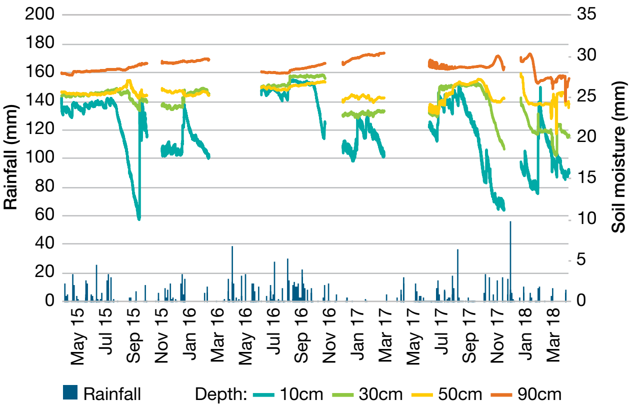


FIGURE 15 Soil moisture levels at Norong, Victoria May 2015 – March 2018

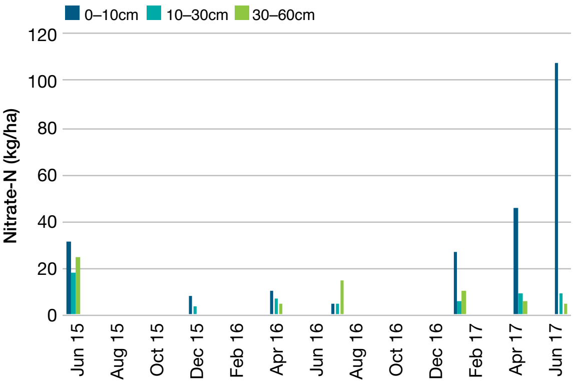


FIGURE 16 Plant-available (nitrate) soil nitrogen levels at Norong, Victoria June 2015 – June 2017

A soil pit excavated during February 2018 showed wheat roots from the 2017 season had penetrated past the 50cm zone, however this was not reflected in the moisture probe data. This suggests there may not have been a high enough density of roots in this zone to change the soil moisture profile to the extent it could be detected by the soil moisture probe.

The nitrate-nitrogen results were low throughout 2016, indicating that any nitrogen not used by plants was likely lost through denitrification (Figure 16). Any leaching of nitrate-nitrogen to depth would have been detected during the January 2016 sampling as high levels within the subsurface layers. As these levels were low, this suggests leaching is not a significant issue in this soil. Some mineralisation of nitrogen occurred over the summer of 2016–17, with more than 40kg N/ha mineralised by April 2017. The increase in nitrate-nitrogen measured during June 2017 reflects the combined effect of mineralised nitrogen and urea applied during May.

The soil chemistry results for Norong showed that while the pH in the surface soil was low (pH_{Ca} 4.8), it increased rapidly with depth (Table 7). The CEC for this soil also increases with depth as does the ESP, meaning that dispersion and sodicity are issues at depth. However, as this cannot be practically ameliorated it needs to be considered in terms of future soil management (i.e. a return to deep inversion ploughing would bring dispersive sodic subsoil up to the surface, which would reduce the surface soil quality). The organic carbon content is high (1.8%) at this site and would add further value to nutrient cycling processes.

TABLE 7 Soil chemistry results at Norong, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.8	5.9	7.2
EC (dS/m)	0.16	0.06	0.1
Chloride (mg/kg)	26	<10	<10
Nitrate N (kg/ha)	91	15.96	10.08
Mineral N (kg/ha)	94.36	18.76	13.82
Colwell P (mg/kg)	44	<5.0	<5.0
PBI (Colwell)	78	66	70
CEC*	7.86	11.9	17.5
ESP#	1.2	7.4	11
Aluminium % of cations	<1	<1	<1
Sulphur (KCl40)	13	4.1	7.5
Organic carbon (%)	1.8	0.35	0.23
OM (%)	3.1	0.6	0.4
Available potassium (mg/kg)	350	220	260

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: Dockers Plains

2015 crop and stubble practice: Wheat, stubble burnt

2016 crop and yield: Wheat, 4t/ha

2016 nitrogen applied: 8kg N/ha MAP, 92kg N/ha urea

Timing of 2016 in-crop nitrogen application: June, August

2016 stubble management (post-harvest): Sown to lucerne

2017 crop and yield: Lucerne

2017 nitrogen applied: 8kg N/ha MAP

2017 stubble management: Will be four years of lucerne pasture

The Dockers Plains soil moisture probe was installed during July 2016, along with the other moisture probes in the Boorhaman region. While the 2016 cropping season was extremely wet, the soil moisture probe data indicates the soil appears to be free draining down to 30cm, with the 10cm sensor showing short increases in moisture content after rainfall, before returning to a steady level (Figure 17). The soil moisture measurements for the 10cm and 30cm layers indicate they are both quite light textured (low clay content), with plants extracting water from these layers with ease after conditions started to dry out during October 2016. Plants accessed soil moisture in the 50cm layer from mid-October onwards, as seen by the decrease in soil moisture in the 50cm layer by the end of the season. The 90cm layer likely has a higher clay content, with no measurable water uptake shown by plants. The 2017 soil moisture probe data indicates the 10–30cm layer is a lighter texture than the 10cm layer, with the 30cm depth retaining less water than the 10cm layer for most of the 2017 season. The dry spring of 2017 resulted in the drawdown of soil moisture in the 10cm and 30cm layers, with indications of root extraction of water down into the 50cm layer.

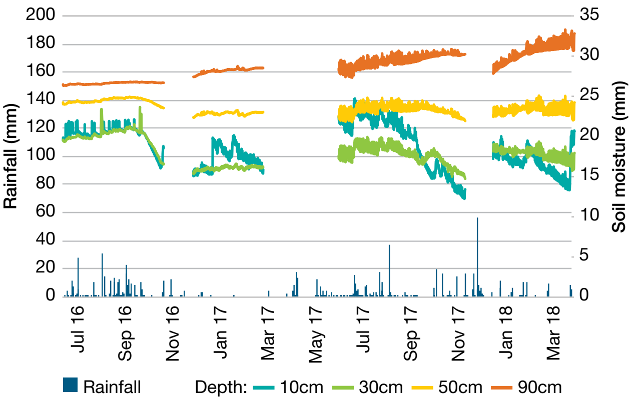


FIGURE 17 Soil moisture levels at Dockers Plains, Victoria July 2016 – March 2018

The July 2016 nitrate-nitrogen results show that nitrate moved down to 30–60cm depth with high winter rainfall (Figure 18). Subsequent post-harvest nitrogen sampling showed a reduction in nitrogen at this depth. This, when combined with higher clay content at depth (which would minimise further leaching), indicates the likely accessing of nitrogen by plant roots during the second half of the season. Mineralisation of organic nitrogen to nitrate-nitrogen was measured over summer and was particularly evident in the April 2017 sampling. The increased concentration of nitrate-nitrogen in the surface soil (observed in the absence of fertiliser) along with minimal nitrogen measured at depth, is indicative of mineralisation. The further increase in nitrate-nitrogen at all three depths during June 2017 is likely due to the contribution of MAP, which would move readily in this soil.

The soil chemistry results for Dockers Plains indicate that subsoil acidity is likely to be an ongoing issue at this site

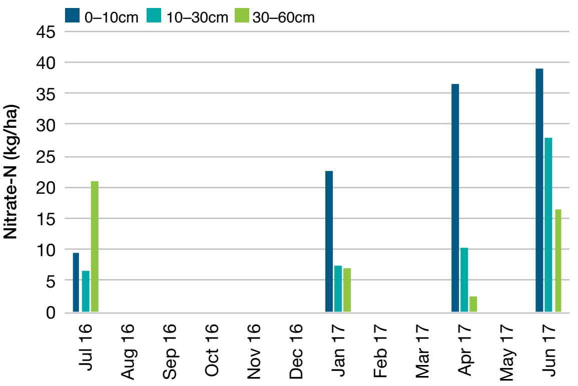


FIGURE 18 Plant-available (nitrate) soil nitrogen levels at Dockers Plains, Victoria July 2016 – June 2017

(Table 8). While the 0–10cm depth value of pH_{Ca} 5.7 is high, this drops to pH_{Ca} 4.4 in the 10–30cm layer and is associated with an increase in aluminium to 19%, which will limit the productivity of sensitive crops. Furthermore, the low CEC in this soil means it has limited capacity to resist chemical change, meaning the pH decline in the subsoil will continue if not addressed.

TABLE 8 Soil chemistry results at Dockers Plains. Sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5.7	4.4	5.3
EC (dS/m)	0.09	0.05	0.03
Chloride (mg/kg)	17	10	<10
Nitrate N (kg/ha)	39.2	28	16.38
Mineral N (kg/ha)	43.4	30.07	16.38
Colwell P (mg/kg)	28	13	5.9
PBI (Colwell)	33	53	64
CEC*	5.49	3.31	5.22
ESP#	<1	<1	<1
Aluminium % of cations	2.8	19	3
Sulphur (KCl40)	6.2	8.7	10
Organic carbon (%)	1.1	0.24	<0.15
OM (%)	1.9	0.41	0.26
Available potassium (mg/kg)	220	170	130

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

Exchangeable sodium percentage of CEC

Location: Boorhaman

2015 crop and stubble practice: Wheat, baled straw

2016 crop and yield: Canola, 2t/ha

2016 nitrogen applied: 8kg N/ha MAP, 115kg N/ha urea

Timing of 2016 in-crop nitrogen application: Early June, mid-July

2016 stubble management (post-harvest): Sheep grazed, harrowed, burnt

2017 crop and yield: Wheat, 4.5t/ha

2017 nitrogen applied: 9kg N/ha MAP, 115kg N/ha urea

Timing of 2017 in-crop nitrogen application: June, August

2017 stubble management: Baled straw, sown into remaining stubble

The Boorhaman site has a lighter-textured surface soil, with clay content increasing with depth.

The Boorhaman soil moisture probe was installed during July 2016, along with the other moisture probes in the Boorhaman region. The 2016 season was characterised by a high soil moisture content and the flat-lining of soil moisture probe sensor data at all depths until mid-October 2016, indicating the soil may have reached its capacity to store water and become waterlogged (Figure 19). The high clay content at depth would also have reduced the capacity for water to drain through the profile. The 2017 season started with a full profile of stored water and soil moisture probe data indicates water was only extracted by plant roots to a depth of 30cm (possibly to 50cm depth) during the dry spring.

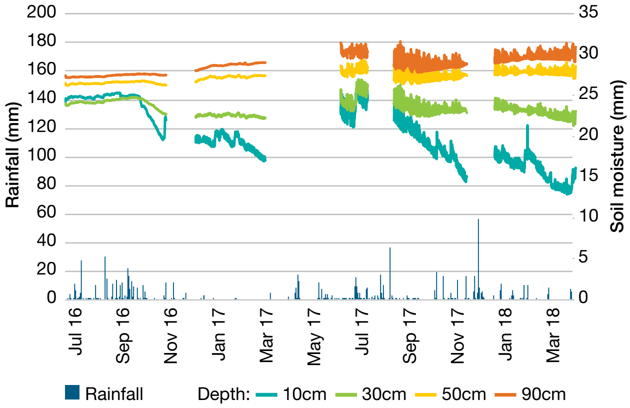


FIGURE 19 Soil moisture levels at Boorhaman, Victoria July 2016 – March 2018

The low nitrate-nitrogen values measured in the 0–10cm and 10–30cm layers during July 2016 indicate that urea applied during early June 2016 may have been largely lost through denitrification, with some also moving down the profile into the 30–60cm depth (Figure 20). This demonstrates the value of split applications, as a follow-up urea application during mid-July (after soil sampling) was needed to meet plant requirements for the rest of the season. There is some evidence of plant roots moving beyond the 30cm layer, as the bulge of nitrate-nitrogen measured in the 30–60cm depth in July 2016 had largely disappeared by January 2017, indicating it was utilised by the crop. Mineralisation of organic nitrogen to plant-available nitrogen during the 2016–17 summer was high at this site, with 95kg N/ha of nitrate-nitrogen measured in the 0–10cm depth at sowing.

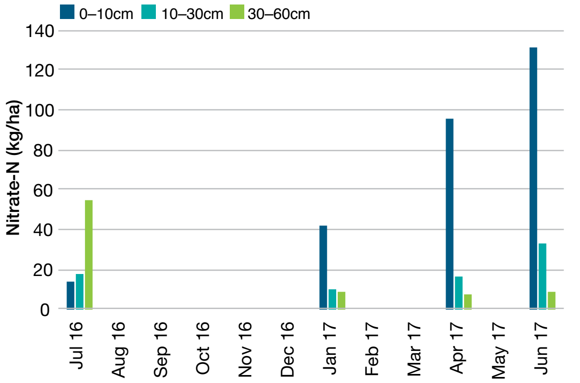


FIGURE 20 Plant-available (nitrate) soil nitrogen levels at Boorhaman, Victoria July 2016 – June 2017

The high value of nitrate-nitrogen measured during June 2017 likely resulted from the combination of mineralised nitrogen and urea applied in June 2017.

The soil chemistry results from the Boorhaman site show that subsoil acidity is an issue at this site (Table 9). The 10–30cm depth pH_{Ca} of 4.5 corresponds to 13% aluminium, which may impact on the growth of sensitive species. The drop in CEC in the 10–30cm depth (3.68cmol(+)/kg) also indicates this zone may be poorly buffered against pH change (i.e. the pH may decrease more quickly than at a higher CEC value).

TABLE 9 Soil chemistry results at Boorhaman, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5	4.5	5.4
EC (dS/m)	0.21	0.05	0.02
Chloride (mg/kg)	19	<10	<10
Nitrate N (kg/ha)	131.6	33.6	8.82
Mineral N (kg/ha)	134.82	33.6	8.82
Colwell P (mg/kg)	44	12	<5.0
PBI (Colwell)	38	45	100
CEC*	5.71	3.68	7.03
ESP#	0.41	<1	0.45
Aluminium % of cations	3.6	13	1.5
Sulphur (KCl40)	25	8.4	3.4
Organic carbon (%)	1.3	0.34	0.32
OM (%)	2.2	0.58	0.55
Available potassium (mg/kg)	270	160	170

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: Peechelba East

2015 crop and stubble practice: Wheat, burnt

2016 crop and yield: Wheat, 4.5t/ha

2016 nitrogen applied: 9kg N/ha MAP, 129kg N/ha urea

Timing of 2016 in-crop nitrogen application: Sowing, end June, mid-August

2016 stubble management (post-harvest): 50% retained, 50% burnt

2017 crop and yield: Canola, 3.36t/ha

2017 nitrogen applied: 9kg N/ha MAP, 128.8kg N/ha urea

Timing of 2017 in-crop nitrogen application: Pre-sowing, June, late July

2017 stubble management: Stubble broken up with a disc chain

The surface soil at Peechelba East is lightly textured. This is seen by the large fluxes in soil moisture levels in the 0–10cm layer as well as the low base level of soil moisture measured (less than 10mm by mid-March 2017) (Figure 21). The 30cm layer is a heavier soil type, which gradually increases in clay content and dispersiveness at depth (see soil chemistry notes on following page), as shown by the increase in soil moisture content and reduced flux in soil moisture with depth. While the soil moisture probe results show limited movement of water in the 50cm and 90cm depth zones during 2016, indicating they were at capacity, there was clear extraction of water to the 30cm zone in the period leading up to harvest 2016. This suggests roots did not penetrate much past 30cm during 2016. The 2017 season results showed the extraction of water down to 50cm, especially during the dry spring conditions. The 2018 season started with approximately 50% soil water capacity, available to a depth of 50cm.

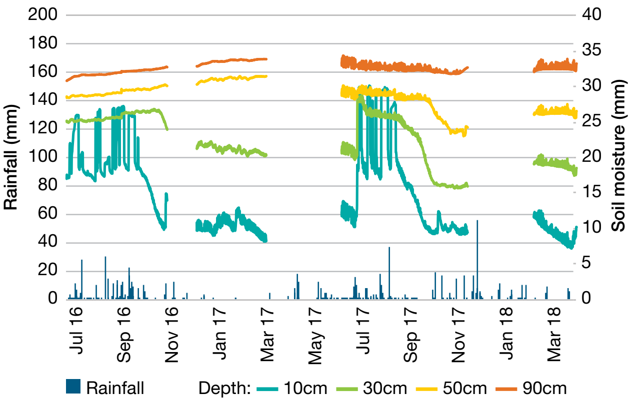


FIGURE 21 Soil moisture levels at Peechelba East, Victoria, July 2016 – March 2018

The nitrate-nitrogen levels measured during July 2016 show some of the urea applied at the end of June may have been lost by leaching or denitrification (gaseous nitrogen loss), with increased nitrogen measured in the 30–60cm depth (Figure 22). A follow-up urea application was needed during mid-August to replace the lost nitrogen and meet crop needs.

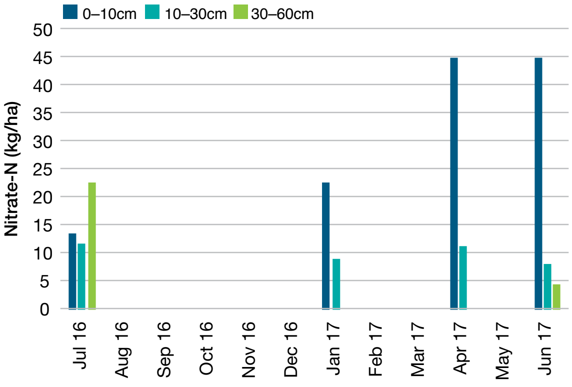


FIGURE 22 Plant-available (nitrate) soil nitrogen levels at Peechelba East, Victoria July 2016 – June 2017.

Note: An extraordinarily high nitrate reading (63kg N/ha) was measured for the 30–60cm depth during April 2017. Based on soil type, it was considered to be an analytical error and removed.

Summer mineralisation of nitrogen was also good at Peechelba East, assisted by rainfall during December 2016. While some nitrate-nitrogen was measured at depth during July 2016, this was not detected in the January 2017 sampling. The lack of change in the nitrate-nitrogen values between the April and June 2017 measurements suggest the June urea application may have been made after the soil sampling was done.

The soil chemistry results from Peechelba East indicate this soil type naturally increases in pH at depth (Table 10). This means that although the surface 0–10cm layer has a low pH (pH_{Ca} 4.7), the increased CEC value at the 10–30cm depth will assist in buffering against pH change. Ongoing lime application will be needed to increase the pH in the 0–10cm layer and maintain the higher pH values (pH_{Ca} 5.2) at the 10–30cm depth. The ESP also increases at depth, suggesting water movement to depth is compromised by dispersion as well as increased clay content.

TABLE 10 Soil chemistry results at Peechelba East, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	4.7	5.2	8.1
EC (dS/m)	0.09	0.06	0.37
Chloride (mg/kg)	16	<10	48
Nitrate N (kg/ha)	44.8	8.12	4.2
Mineral N (kg/ha)	48.44	9.88	6.89
Colwell P (mg/kg)	37	<5.0	<5.0
PBI (Colwell)	69	66	94
CEC*	5.73	8.48	23.5
ESP#	2.7	11	15
Aluminium % of cations	2.6	<1	<1
Sulphur (KCl40)	8.5	8.2	32
Organic carbon (%)	1.2	0.27	0.17
OM (%)	2.1	0.46	0.29
Available potassium (mg/kg)	160	90	190

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Location: North Boorhaman

2015 crop and stubble practice: Wheat, windrowed and baled

2016 crop and yield: Canola, 1.5t/ha

2016 nitrogen applied: 10kg N/ha MAP, 92kg N/ha urea

Timing of 2016 in-crop nitrogen application: Early June

2016 stubble management (post-harvest): Retained

2017 crop and yield: Wheat, 5t/ha

2017 nitrogen applied: 8kg N/ha MAP, 36.8kg N/ha

Timing of 2017 in-crop nitrogen application: July, August

2017 stubble management: Stubble burnt

The North Boorhaman site has a sandy loam surface soil, with a sand layer at 10–30cm depth.

The North Boorhaman soil moisture probe was installed during July 2016 and the soil moisture graph indicates good storage and extraction of water from the surface soil, but with lower soil moisture storage at 30cm depth (Figure 23). The lack of flux in the 30cm layer throughout the wet season of 2016 suggests this layer reached field capacity early during the season, with lateral drainage through the sand layer across the landscape. The soil did not dry out until late October 2016, after the 10cm layer started to be depleted.

The 2017 season results showed that while the soil moisture profile was full, the soil did not reach field capacity in the 10cm and 30cm layers as it did during 2016. The dry spring of 2017 caused the extraction of detectable amounts of water only to the 30cm depth. Further drying of these layers, measured during the summer of 2017–18, was likely caused by the capillary movement of water or by the development of cracks in the soil near the moisture probe.

Nitrate-nitrogen concentrations were very low during July 2016, likely due to high movement of nitrogen to depth and lateral movement through the sand layer (Figure 24). While some mineralisation was measured in the 0–10cm layer during January 2017, no increase in nitrate-nitrogen levels as a result of summer – autumn mineralisation was evident during April 2017. This was the only site not to show increased nitrate-nitrogen levels during April 2017 and suggests that April soil sampling at this site was either not representative of the paddock or that some of the 0–5cm soil (where most of the nitrogen is) had been accidentally removed. This is supported by the high nitrate-nitrogen results returned from June 2017, which being greater than the amount of MAP applied at sowing, indicates ongoing mineralisation.

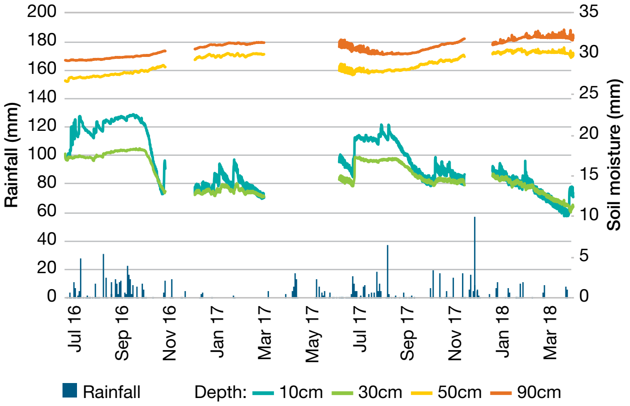


FIGURE 23 Soil moisture levels at North Boorhaman, Victoria, July 2016 – March 2018

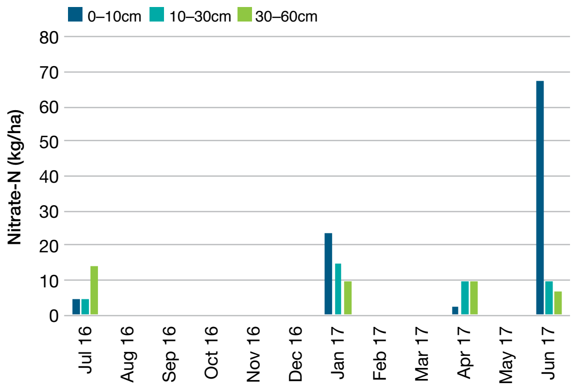


FIGURE 24 Plant-available (nitrate) soil nitrogen levels at North Boorhaman, Victoria, July 2016 – June 2017

The soil chemistry results at North Boorhaman indicate that root growth to depth would be limited by soil pH (Table 11), which is supported by an observed lack of change in the soil moisture profile at depth at this site. The low pH_{Ca} values of 4.5 (10–30cm) and 4.2 (30–60cm) also correspond to high aluminium values. Moreover, the sand layer at 10–30cm below the soil surface make it difficult to maintain high pH values at this depth due to the low CEC value in this zone (1.1cmol(+)/kg). An increase in clay content in the 30–60cm zone is reflected in the high CEC value and the associated increase in phosphate buffering index (PBI), which is related to higher phosphorus sorption with increasing clay content.

TABLE 11 Soil chemistry results at North Boorhaman, Victoria, sampled 22 June 2017

	0–10cm	10–30cm	30–60cm
pH ($CaCl_2$)	5.7	4.5	4.2
EC (dS/m)	0.12	0.02	0.06
Chloride (mg/kg)	<10	<10	<10
Nitrate N (kg/ha)	67.2	9.52	6.72
Mineral N (kg/ha)	68.6	9.52	6.72
Colwell P (mg/kg)	55	23	<5.0
PBI (Colwell)	33	21	150
CEC*	4.47	1.1	14.5
ESP#	1.1	2.6	6.9
Aluminium % of cations	2.6	27	10
Sulphur (KCl40)	12	2.1	8.5
Organic carbon (%)	0.93	0.21	<0.15
OM (%)	1.6	0.36	0.26
Available potassium (mg/kg)	120	40	250

* Cation exchange capacity, including aluminium (measured by ammonium acetate)

\# Exchangeable sodium percentage of CEC

Observations

A range of soil types exist across the Rutherglen–Boorhaman region. While the typical duplex soil type with a texture contrast (i.e. a sharp increase in clay content in the subsoil) dominates, a range of features is evident through the landscape, with a new adventure in every soil pit!

Some of the key features observed during local soil pit examinations include dispersive subsoils just below the surface, sand layers at depth and dense clays just below the surface. The key message is that understanding the variability of soil types and their behaviour is key to optimising management in different paddocks in difficult years (i.e. when it is too dry or too wet).

The challenge with these variable soil types is that soil moisture probe readings could be somewhat misleading if the underlying soil is not well understood. For example, measurements of soil moisture content may be high at a site with a highly dispersive, dense clay at depth. However, if the plants cannot access this stored moisture because of either physical or chemical constraints hindering root growth at depth, the moisture is not actually *plant-available.* This means the total soil water content measured using a probe must be interpreted through the lens of that particular soil and its inherent attributes and potential constraints. This is readily achieved by digging a soil pit during late spring to see where the roots are, measuring some soil chemical parameters and by making informed decisions about the rooting depth and associated depth of water extraction (and predicted stored soil water). These actions only need to be done once, after which a soil moisture probe can provide relevant, timely information across seasons and years, given the 'context' of the readings is already well understood.

The 2015–16 measurements, taken during the term of the previous project, showed that most of the soil nitrate-nitrogen was present in the surface soil, with generally little nitrogen measured at depth. By comparison, the 2016–17 measurements, taken during and after a wet season, showed how quickly nitrogen could move to depth even in clay-based soils, with a general depletion of nitrogen in the surface soil and accumulation of nitrate-nitrogen in the 30–60cm zone by July 2016.

While these two sets of measurements show different numbers, a key point is that if a general (bulked) 0–60cm depth soil sample for nitrogen had been collected in these soils, we may have received the same answer for the two different seasons! For example, in July 2016 the bulked soil test may have indicated adequate nitrogen, but if that nitrogen was present below a clay layer in a soil subject to waterlogging, it may be months until the soil dried out enough for roots to move to that depth. Splitting the soil

sample into two increments (i.e. a 0–30cm and a 30–60cm depth sample) provides more accurate information on the availability of nitrogen as the season progresses, supporting better and more timely fertiliser decisions.

The last point to note is that the soil chemistry results, supported by soil pit observations, show that the soils of this region have different origin. This is seen by differences in clay content, CEC and pH at depth, which means one size certainly does not fit all in these systems. While some soils have increased pH at depth, others are acid at depth and will require careful management to maintain the productivity of these systems.

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