
Photo: GRDC

Addressing crop nutrition proves profitable on sandy soils

Key facts

- Sandy soils are naturally low in fertility and require regular fertiliser applications to support agricultural production.
- Where required, address the factors that most limit agricultural production, such as water-repellence and subsoil compaction, before embarking on a fertiliser program.
- Variable rate technology enables targeted application of fertiliser, which is more cost-effective than blanket fertiliser applications.

Sandy soils lack natural fertility and rely heavily on regular fertiliser applications to supply the nutrients required for optimal crop production. The low fertility of sandy soils is due to a combination of low organic matter (OM) levels and poor cation exchange capacity (CEC).

While sandy soils often lack adequate nutrients to support optimal crop growth, growers often question, wisely, whether applying fertiliser will result in higher productivity, when a complex combination of factors can limit crop potential on sandy soils. Growers often are unsure whether the cost of fertiliser will be repaid in an associated increase in crop productivity.

In many cases, to maximise nutrient use efficiency, growers first need to address water repellence issues (see pages 10–15) and subsoil compaction (see pages 42-44). Unless plant roots can penetrate the soil and access nutrients dissolved in the soil solution at depth then fertiliser applications are likely to be a waste of time and money.

However, when these constraints have been addressed, a strategic fertiliser program may be the next step towards boosting productivity and profitability on sandy soils.

Maximising the returns from fertiliser inputs requires a sound understanding of current soil nutrient status, other factors that may be limiting production and the nutrients required to deliver target yields across the range of crop types being sown.

The four major nutrients required by crops are: nitrogen (N), phosphorus (P), potassium (K) and sulphur (S). Plants also require a range of 'micro' nutrients, often referred to as trace elements including: zinc (Zn), copper (Cu) and manganese (Mn).

Nitrogen management

Nitrogen is the key nutrient driving crop and pasture productivity on sandy soils and can be supplied via nitrogen fixation (via legume crops or pastures), breakdown of OM in the soil, or nitrogen fertiliser. In the nitrate (plant available) form within the soil, nitrogen is highly soluble and is prone to leaching beyond the root zone in sandy soils.

Trials carried out by Mallee Sustainable Farming (MSF) Inc during 2015 at Karoonda, South Australia revealed that 40kg/ha of nitrogen (86kg urea/ha) applied at sowing produced the highest wheat yields and protein levels on sandy soils.

The uptake of nitrogen fertiliser applied at sowing was also far greater than when applied post crop emergence (around 50% recovery when applied at sowing, compared with 30% recovery when applied at stem elongation: GS30–GS40).

Grower feedback and anecdotal evidence indicates a rate of 40kg N/ha is higher than the commonly-used rate of 15kg N/ha. However, in these trials this higher rate of nitrogen increased the average net return by $136/ha and the additional investment in fertiliser delivered a return of 80 cents per dollar invested.

Increasing fertiliser rates to ensure crops grown on deep sands have an adequate supply of nitrogen also can increase the water use efficiency (WUE) by up to 91% compared with current district practice.

Variable rate technology

Soil types across a farm and even within paddocks can be highly variable. The use of variable rate technology (VRT), in combination with soil testing and paddock history, allows growers to better apply fertiliser at rates that match both crop and soil requirements.

The advantages of VRT are supported by trials carried out on the dune–swale systems of the Mallee, SA. Figure 5 shows the cumulative gross margin from 2009–15 for different nitrogen strategies at Karoonda, SA. High rates of nitrogen on the heavy soils cause the crop to hay-off, which lead to a decrease in yield. These trial results would indicate that reducing the rates of nitrogen applied to these areas and re-allocating nitrogen to areas that are low in clay (and nitrogen) would improve yields and the return on investment in fertiliser.

ABOVE: Legumes, such as lupins, add nitrogen to the soil and offer a critical disease break between cereal crops. Photo: Ruth Sommerville, UNFS

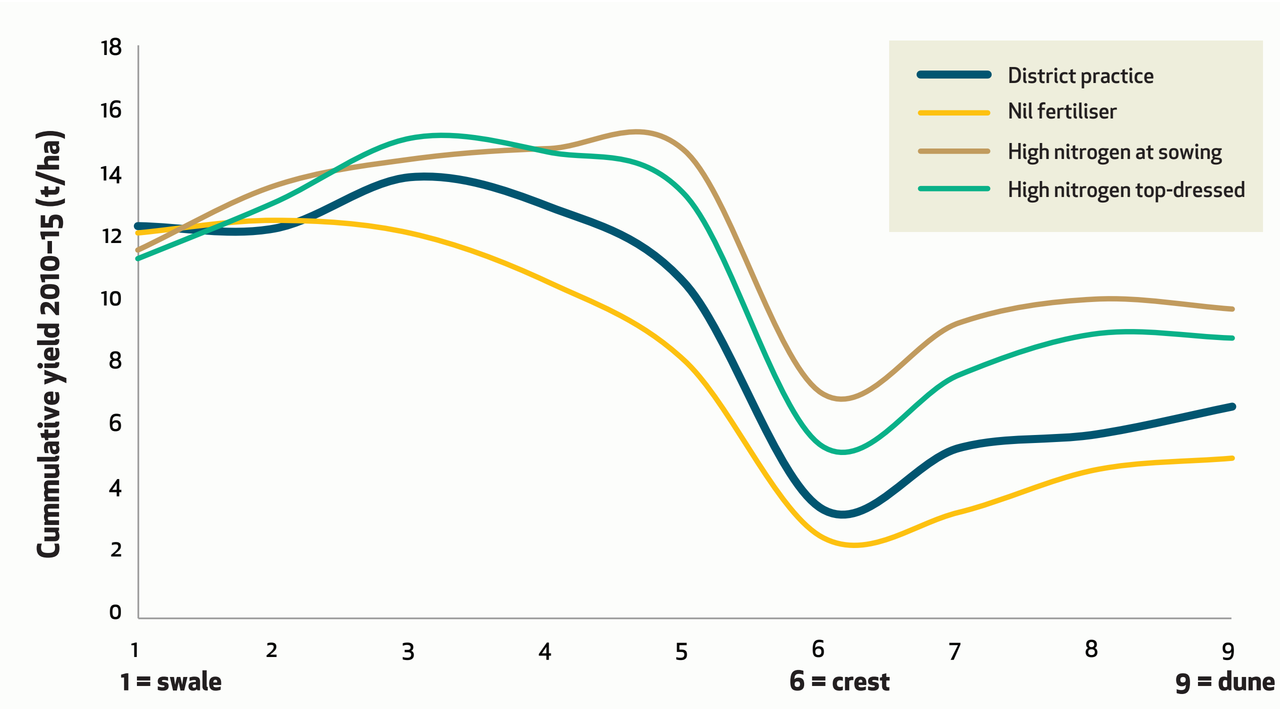
The role of legumes

Legumes play an important role in building soil nitrogen levels, as well as playing an important role in breaking the disease cycle and offering a broader range of weed control options.

When it comes to selecting a legume break crop, the best decision will depend on a range of factors. For example, in a mixed cropping and livestock system, a legume break crop may be a legume pasture, which may not have the same value in a cropping system as it does for an operation that includes livestock.

The inclusion of a non-cereal break, and even including a two-year break phase, can improve the accumulated yields of wheat by 1–2t/ha over the following two to three seasons. It can increase profitability by up to $100/ha/year for a four-year period when compared with continuous wheat.

Figure 5. Cumulative gross margin for the addition across nitrogen on a swale, mid-slope and dune system at Karoonda, SA 2009–15



Source: CSIRO, 2015

Yield Prophet – a tool to assist with nitrogen fertiliser decision making

Yield Prophet is an online production model designed to present growers with real-time information about the water and nitrogen use of their crops based on nitrogen and water measurements carried out at the start of the year.

Yield prophet can generate reports and assist management decisions, such as fertiliser applications and time of sowing. The modelling tool also can forecast yield based on historic yield data for a particular area, generate time of sowing reports, match inputs with the yield potential of a given crop, and manage scenarios based on weather forecasts.

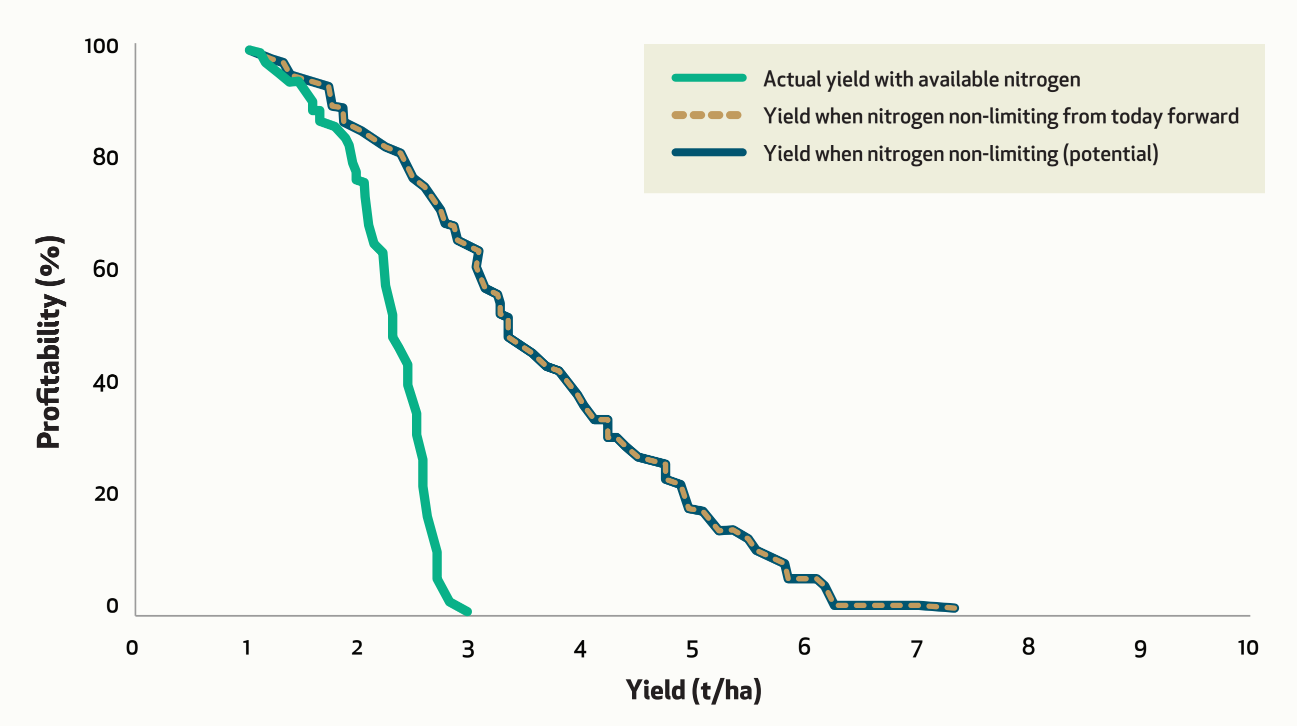
Figure 6 shows an output from Yield Prophet on 16 July, 2014 for Lameroo, SA. Based on this information, in a decile 5 (average) rainfall year, with current available nitrogen, the crop yield potential for this site is 2.2t/ha. However, when nitrogen is non-limiting, there is the potential to increase yield by an additional 1t/ha.

From this output, the decision to top-dress nitrogen may seem straight forward, however it is unlikely applying the amount of nitrogen needed to be 'non-limiting' would be economic. The decision to apply additional nitrogen needs to be weighed against other factors including seasonal forecast (i.e. La Niña or El Niño), historic nitrogen applications from previous seasons and other climatic risks such as frost.

Yield prophet sures up 'gut feeling' and is a useful support tool for nitrogen decision making.

Cost per paddock is around $170 per paddock, plus costs for soil testing.

Figure 6. A report from Yield Prophet displaying current yield potential against yield potential with nitrogen non-limiting



Although it has been repeatedly demonstrated that including break crops provides rotational benefits and increase the profitability of farm businesses, break crops are not widely grown in low-rainfall districts. Less than 10% of the cropping area in the SA-Victorian Mallee was sown to non-cereals during 2010. The major challenge is to develop suitable broadleaf crop types and specific agronomy technologies that are adapted to sandy soils in low-rainfall districts. However, despite these challenges, the longer-term benefits and value of including break crops in a rotation is worth considering.

Trace element and nitrogen interactions

Trace element deficiencies are often associated with a deficiency in nitrogen. Correcting these deficiencies is important for maximising the return on dollars invested in fertiliser inputs.

Trial work conducted at Karoonda by SARDI during 2013 showed the addition of nitrogen and trace elements (copper, manganese and zinc) increased yields by 77% compared with the no fertiliser treatments and yields were 40% higher than nitrogen (urea) only treatments.

Phosphorous management

Phosphorus is relatively immobile and when applied as fertiliser any phosphorus that is excess to crop requirements remains available for the following crop, assuming it is not tied up due to acidic or alkaline soil conditions. Although in extreme cases, phosphorus can be leached from a coarse sand.

Because it is relatively immobile, phosphorous testing is easily carried out with a 0–10cm soil test.

Phosphorus is commonly applied based on the amount removed by the crop in the previous year. This approach is appropriate if soil phosphorus reserves are adequate.

Many soils have accumulated phosphorus over time because rates of phosphorus applied as fertiliser have been relatively high compared with the amounts removed by crop production. In this case, the soil is no longer responsive to an application of phosphorus and the replacement strategy can be employed.

Adopting a replacement strategy for a phosphorus-responsive deep sand can result in under-fertilisation. These soils tend to lack the ability to build nutrition due to leaching. The highly alkaline nature often associated with phosphorus-responsive deep sands can result in low nutrient availability. If the soils also are water repellent, the soil remains dry, and plants cannot access nutrients.

Based on CSIRO trials carried out at Karoonda, SA an application of a minimum of 5kg/ha of phosphorus is required to avoid deficiency.

To determine the potential for a response to the application of phosphorus fertiliser, leave a strip of crop where no phosphorus fertiliser is applied at sowing. If crop growth and subsequent yield from this nil-phosphorus treatment strip is less than the surrounding phosphorus treatment, the soil and crop are likely to respond to additional phosphorus fertiliser.

As discussed in *Row spacing, inter-row sowing and phosphorus*, (GRDC, 2010) wider row spacing increases the concentration of phosphorus in each row, allowing higher yields to be achieved with lower phosphorus rates compared with narrow row spacings.

Sulphur management

There is growing concern about sulphur deficiency on sandy soils. As a result some agronomists are recommending top-dressing with sulphate of ammonia (SOA), as opposed to urea (to address nitrogen deficiency).

Sulphur deficiency can be confused with nitrogen deficiency as physical crop symptoms are similar. Therefore, it is important to use soil or plant nutrient analyses to measure the availability of sulphur to diagnose any deficiency. This will ensure the maximum value can be extracted from the investment in fertiliser.

CSIRO trial work at Karoonda, SA during 2015 (Figure 7) found additional nitrogen applied to canola produced higher yields compared with the addition of sulphur. This is particularly interesting given canola is considered to be a crop with a high sulphur requirement and sulphur in the top 10cm, and at depth, were below the critical values.

The most cost effective and efficient long-term option for correcting a sulphur deficiency is to apply gypsum before sowing. A rate of 500kg/ha of gypsum equates to approximately 85kg/ha of sulphur, which will supply adequate sulphur for several years given about 2kg of sulphur is removed per tonne (wheat) of grain produced.

Recent trials indicate more barley crops grown on sandy soils in the SA Mallee responded to nitrogen than sulphur. Only one out of four sites was sulphur responsive, despite sulphur levels at these sites being below the critical value for sulphur (4–6mg/kg) in the top 0–10cm of soil. Crops treated with SOA yielded more than crops treated with gypsum and urea. This would, suggest the importance of looking deeper (i.e 0–40cm or 0–60cm) when soil testing for sulphur.

Nitrogen remains the main nutrient driving crop growth. If concerned about the lack of response to nitrogen applications look further than sulphur alone, as there may be other underlying nutritional limitations including trace elements.

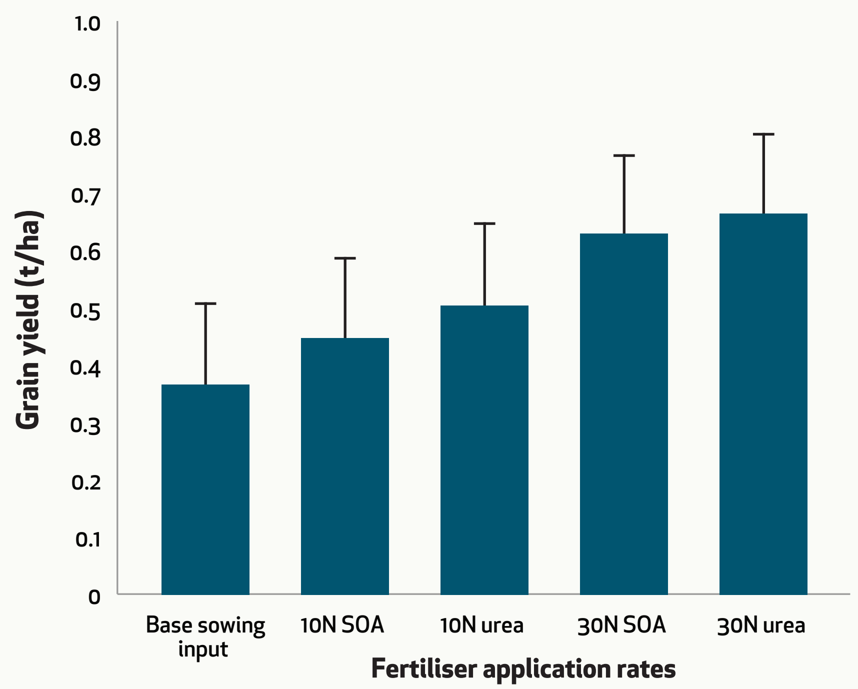
Sulphur can leach in a similar way to nitrogen, and while crops may appear deficient early in the season, this deficiency may be overcome later in the season as the root system develops and the roots can extract sulphur at depth..

Potassium management

Most soils across south-eastern Australia's agricultural regions are abundant in potassium, although low potassium levels have been found in isolated cases on the deep sands in the southern Mallee and south-east regions and parts of Mt Lofty ranges and Kangaroo Island. Almost all potassium deficiencies occur on sandy, light-textured soils.

As hay production expands potassium deficiency may become an increasing problem, as up to 10 times the amount of potassium is removed in hay compared with grain.

Figure 7. Canola grain yield on a dune site in response to urea and SOA applied at the eight-leaf growth stage



P=0.05, LSD= 0.14 t/ha with LSD represented by the error bars

ABOVE: Carrying out regular soil tests to measure and monitor nutrient levels will ensure fertiliser applications meet the demands of the crop without over-fertilising. Photo: Matt McCallum, McAg Consulting

Before applying potassium fertiliser it is first important to establish if there is a potassium deficiency using deep soil and tissue testing. If a deficiency is detected, an application of muriate of potash is the most cost-effective strategy. Best results have seen when muriate of potash is banded at a rate of 50–100kg K/ha below the seed at sowing, however effects will vary depending on current soil potassium levels.

In situations where soil tests show potassium to be below the critical value, it is assumed an application would give an economic response. However, trial results have been variable and often the cost of the potassium fertiliser is greater than the value of the additional yield.

Trace element management

The accuracy of soil testing to determine trace element levels is variable. Exercise caution when developing micronutrient strategies based on soil test results in isolation. A far more accurate option to detect a micronutrient deficiency is with a plant tissue test.

Zinc: Zinc deficiency is widespread on sandy soils across the south-eastern Australian cropping zone, with 80% of SA's agricultural lands potentially zinc responsive.

Options for applying zinc include:

- ***Soil application via spraying:*** Spray applications of zinc pre-sowing can correct deficiencies if the product is incorporated at a rate of 2kg Zn/ha. A single application at these rates can be expected to last 5–10 years if adequate distribution occurs following application.
- ***Foliar application:*** Zinc can be applied as a foliar spray, every year, or second year, at a rate of 200–330g Zn/ha for cereals. Beware of some product claims and always read the label carefully to see how much zinc will actually be being applied given the recommended rate.
- ***Granular fertilisers:*** Combining zinc with other nutrients on a granular fertiliser can be an effective option, as long as zinc is applied to every fertiliser granule. This can be done on farm by coating high analysis fertiliser with zinc oxide at a rate of 1.4kg/ha (1kg Zn/ha). Avoid granular zinc-blended fertilisers as they often have poor distribution, even if used annually.

  Note: Canola is a an efficient and effective scavenger of zinc in the soil due to its tap root, and may not require additional zinc. Confirming adequate zinc levels with a tissue test will confirm if a zinc application is required.

Manganese: Manganese deficiency is usually isolated to deep siliceous sands and, more recently, sands that have been ameliorated with clay with a high lime content. Foliar applications are the best option for rectifying a manganese deficiency. Soil applications of manganese are not recommended, particularly when soils are alkaline as the manganese quickly becomes tied up and unavailable to plants.

A rate of 4kg/ha (930g Mn/kg) of manganese sulphate will correct most manganese deficiencies

Check product labels for amount of manganese being applied.

Copper: Wheat grown on deep siliceous sands, calcereous sand, sand over clay and soils with ironstone granules on the Eyre Peninsula and Murray Mallee of SA require copper fertiliser applications every 5–10 years. High rates of nitrogen fertiliser can induce copper deficiency, and this is worth considering when planning application rates.

Options for applying copper include:

- ***Soil application via spraying:*** Spray applications of copper pre-sowing at a rate of 1kg Cu/ha followed by full incorporation usually supply sufficient copper for crop production for a number of years.
- ***Foliar application:*** Foliar applications of copper during the vegetative stages of crop growth are inexpensive and effective. In severe situations, a second spray before pollen formation may be required. A trial on the Eyre Peninsula on a copper-deficient crop produced yield increases from 0.7t/ha to 3t/ha with two applications of 90g Cu/ha (copper sulphate at 360g/ha): at early stem elongation and then prior to pollen formation.

Soil organic carbon and nutrition

Soil and crop nutrients are inextricably linked with soil organic carbon (SOC) levels. Historically, much of the low-rainfall environment has been dominated by a two-year rotation of medic pasture followed by a wheat or barley crop. In this system, the medic pasture phase fixed and supplied nitrogen required by the subsequent cereal crops. Over time growers have shifted to a more continuous cropping system and reduced livestock numbers.

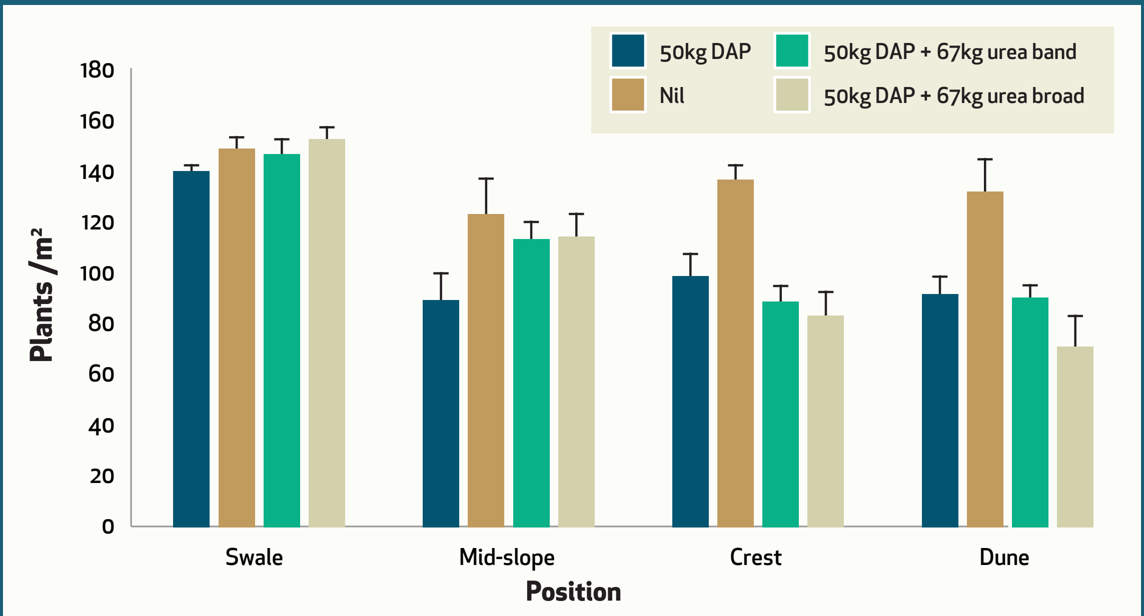
If a random paddock was selected in the low-rainfall zone and a nutrient audit was carried out to calculate nutrition applied, nutrient fixed and nutrient removed or lost, it would be likely that more nutrients have been removed than applied, particularly in the case of nitrogen. In other words, during the past 20 years or so, paddocks have been mined of some key nutrients. For phosphorus the simple strategy of replacing what is removed can be applied relatively easily. However, this is not the case with nitrogen.

Fertiliser management tips

- Soil testing for trace elements is paramount for getting the most out of your fertiliser budget.
- A standard benchmark from the FM500 performance summit is for fertiliser costs to be 12% or less of total farm income.
- Increasing the proportion of legumes in the crop rotation can increase the supply of organic nitrogen.
- Numerous trials have confirmed that variable rate technology is a useful tool to enable nitrogen fertiliser to be applied where it will have the greatest economic impact.
- Regular soil testing is required to measure and monitor nutrient levels and ensure fertiliser applications will meet the demands of the crop.
- Supplying adequate crop nutrition at or before sowing improves nutrient use efficiency. While post-emergent nitrogen applications can assist in managing risk, the opportunities and conditions are often limited. High rates at sowing are the most economical option. Beware of applying too much fertiliser at sowing on sandy soils, particularly when dry. Severe reductions in plant numbers can occur from either ammonia toxicity (high nitrogen content fertiliser) or osmotic effect where moisture is drawn to the fertiliser and away from the seed.

Figure 8 shows that even at low rates on the crest and dune soils (i.e. 50kg DAP), crop establishment can be reduced. The cause for reduced establishment in Figure 8 is likely to be from osmotic stress, where moisture is drawn away from the germinating grain. The amount of fertiliser that can be applied with the seed at sowing depends on row spacing, soil type and seed bed utilisation. Refer to the 'Further Reading' section to determine what is safe in your system.

Figure 8. Effect of fertiliser across four zones at Karoonda in the Southern Mallee



Note: It is likely osmotic stress is the cause of reduced plant numbers in both the dune and crest zones

The nitrogen content of a soil is highly dependent on the amount of SOC contained within that soil. SOC is a large and complex molecule that provides the basic food source to microbes. Microbes breakdown the SOC, releasing (mineralising) nutrients that can then be taken up by plants. If nutrients are not removed then this system would be in an equilibrium and the mineralisation process slows. When nutrients are removed, this drives the further breakdown of SOC, and over time this SOC pool is slowly eroded.

When the historical farming system of south-eastern Australia shifted from a medic–wheat system to continuous cropping, the number of legumes within the system reduced, increasing the reliance on the SOC nitrogen pool and supplementary fertiliser to meet crop nitrogen requirements. Due to the higher demands for nutrition with continuous cropping, the system is relying heavily on the SOC pool to supply crop nitrogen, resulting in the erosion of this pool. The reduced SOC pool in the soil results in lower microbial activity and a lower capacity to mineralise nitrogen.

The drawdown on soil organic nitrogen reserves from SOC needs to be balanced, particularly where nitrogen inputs are low, in order to halt the depletion of these organic reserves in fragile sands.

When organic nitrogen reserves become exhausted it is particularly difficult and expensive to re-build nitrogen levels in a low-rainfall environment, because ultimately, the environment will dictate organic carbon, and therefore, chemical and biological fertility. While no-till farming practices will slow organic carbon depletion, any increase is somewhat restricted by rainfall.

ABOVE: Numerous trials investigating the incorporation of organic matter, such as chicken manure, have seen productivity benefits emerge. Photo: Evan Collis, GRDC

Deep placement of nutrients

Growers are often frustrated at the amount of unused moisture in sandy soils at harvest, which represents a lost opportunity for achieving the yield potential. Generally, crop growth is in fact limited by poor soil fertility at depth and not inadequate soil moisture.

In many sands an infertile layer can occur anywhere from 10cm through to 40cm beneath the soil surface. Roots require a combination of moisture and nutrition to exert the energy to grow deeper in the profile, and in the absence of one or the other, roots tend not to reach these infertile layers. The rooting depth of crops is substantially reduced, and subsequent performance is impacted.

Numerous trials have investigated the viability of the deep placement of fertiliser into these 'nutritional deserts. Results have been mixed and remain inconclusive.

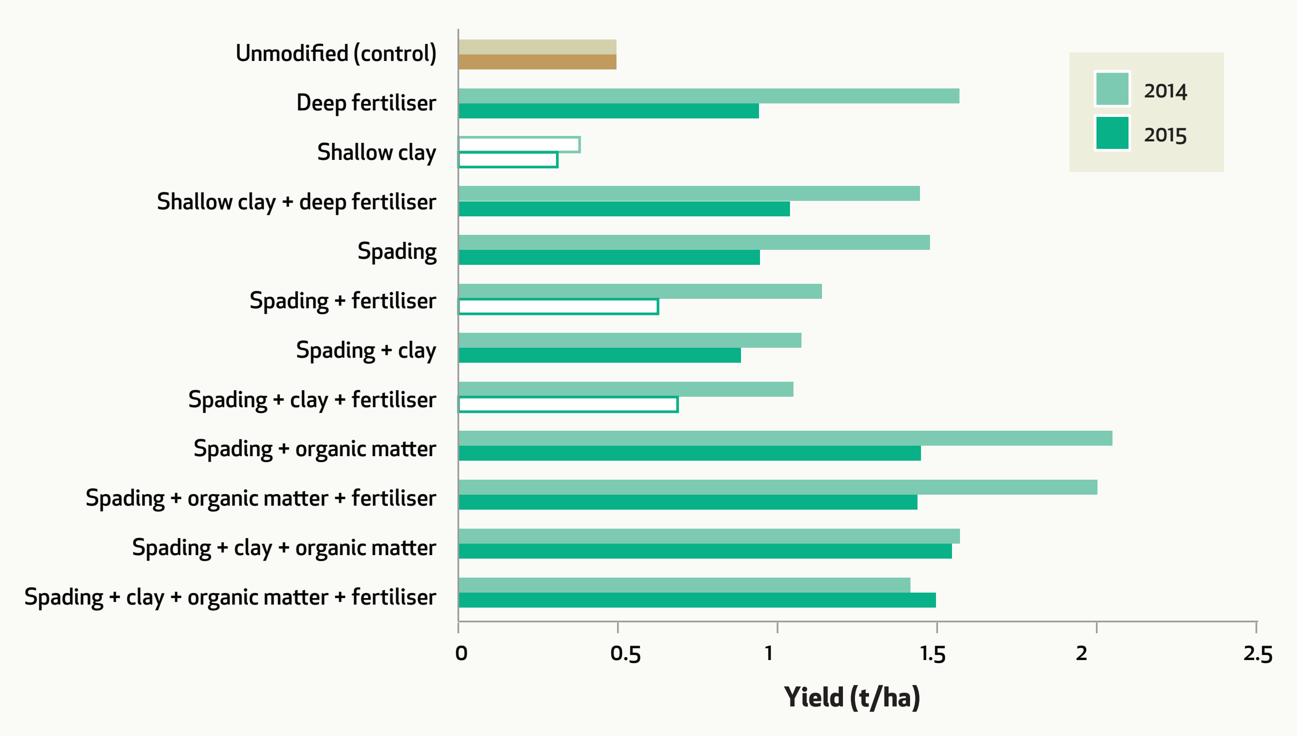
The PIRSA 'New Horizons' program continues to assess the effects and cost-benefit of incorporating organic matter and nutrients to depth across a range of treatments to address the issue of the bleached A2 horizon.

Trials in this program have found:

- Crop productivity on infertile sandy soils can be greatly improved by incorporating organic matter deep into the soil (>30 cm).
- In some cases, crop yields are further boosted by incorporating clay and/or fertiliser to depth.
- Two years of recent research shows the best soil modification treatments can increase crop yields by 70–200 %, even in season of below-average rainfall.
- Treatments that address multiple constraints in these soils provide greater benefit than those addressing an individual issue.
- Crop yields are reduced when clay is poorly incorporated into the soil (Figure 9).

This is a 'proof-of-concept' trial and the application of treatments in the trial would not be economical on a broadacre scale, given even the moderately-priced treatments start from around $500/ha, and in some cases the cost of treatments are even more than the value of the land itself.

Figure 9. Comparison of wheat yield at the New Horizons site, Karoonda, SA (2014 and 2015)



Note: Solid bars denote significance. The clay rate used at this site was 600t/ha, and the organic matter source was lucerne pellets at 10t/ha. The delivery of fertiliser was using commercial fertilisers, surface applied and spaded or deep banded to 20–40cm. The unmodified treatment was district practice, and were provided with fertiliser to match the crops likely potential.

Further information

- Closing Mallee yield gaps using nutrition and break crops at Karoonda (CSIRO, 2015) http://www.msfp.org.au/wp-content/uploads/2014-Karoonda-FD-Booklet.pdf
- Low risk strategies for low-rainfall canola (CSIRO, 2015) https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-117-Optimising-canola-profitability/Low-risk-strategies-for-low-rainfall-canola
- Mallee Crop Sequencing Project (Mallee Sustainable Farming Project, 2013) http://www.msfp.org.au/wp-content/uploads/2013-Karoonda-FD-Booklet.pdf
- Deep placement of nutrients — Few excuses left not to recommend it (Minnipa Ag Centre, 2004)
- The value of break crops in low rainfall farming systems, (Mallee Sustainable Farming Project, 2016) https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/The-value-of-break-crops-in-low-rainfall-farming-systems-and-which-ones-perform-the-best
- 2013 Barley Agronomy Update (SARDI 2013) http://www.msfp.org.au/wp-content/uploads/2013-Karoonda-FD-Booklet.pdf
- Match nitrogen to soil type to lift crop profits (CSIRO, 2013) (GRDC, Ground Cover supplement March–April, 2013) https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS103/Match-nitrogen-to-soil-type-to-lift-crop-profits
- New Horizons — the next revolution in agriculture (PIRSA,2015) http://pir.sa.gov.au/major_programs/new_horizons
- Do we need to revisit potassium? (GRDC Updates, 2014) https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Do-we-need-to-revisit-potassium
- Fertiliser Toxicity- Fact Sheet, GRDC https://grdc.com.au/Resources/Factsheets/2011/05/Fertiliser-Toxicity
- Row spacing, inter-row sowing and phosphorus, (GRDC, 2010) https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/ROW-SPACING-INTER-ROW-SOWING-AND-PHOSPHORUS