NORTHERN
SEPTEMBER 2018

GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

CANOLA

SECTION 5

NUTRITION AND FERTILISER

DECLINING SOIL FERTILITY | NEW NUTRITION THINKING FOR THE NORTHERN REGION | CROP REMOVAL RATES | SOIL TESTING | NITROGEN | PHOSPHORUS | SULFUR | POTASSIUM | MICRONUTRIENTS | TOXICITY | NUTRITION EFFECTS ON FOLLOWING CROP

Nutrition and fertiliser

5.1 Declining soil fertility

The natural fertility of cropped agricultural soils is declining over time, and so growers must continually review their management programs to ensure the long-term sustainability of high quality grain production. Paddock records, including yield and protein levels, fertiliser test strips, crop monitoring, and soil and plant tissue tests all assist in the formulation of an efficient nutrition program.

Pasture leys, legume rotations and fertilisers all play an important role in maintaining and improving the chemical, biological and physical fertility of soils, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed. Increasing fertiliser costs means growers are increasing pulses within their crop rotation and even the use of ley pastures to complement their fertiliser programs and possibly boost soil organic matter. [1]

5.1.1 Soil organic matter

Soil organic matter (SOM) is a critical component of healthy soils and sustainable agricultural production. Growers understand that crops grown in healthy soils perform better and are easier to manage. Soil organic matter is '*all of the organic materials found in soils irrespective of its origin or state of decomposition'* [2] that is anything in or on the soil of biological origin, alive or dead. It is composed mainly of carbon (approximately 60%) as well as a variety of nutrients (including nitrogen, phosphorus and sulfur). It is difficult to actually measure the SOM content of soil directly so we measure the soil organic carbon (SOC) content and estimate SOM through a conversion factor:

Soil organic matter (%) = organic carbon (%) × 1.72

It is important to understand the role of plants in the SOM cycle. Photosynthesis is the process by which plants take in carbon dioxide (CO_2) from the atmosphere, combine with water taken up from the soil, and utilising the energy from the sun, form carbohydrate (organic matter) and release oxygen (O2). This is the start of the SOM cycle. When the leaves and roots (carbohydrate) die they enter the soil and become SOM. These residues are decomposed by soil organisms which provides them with the energy to grow and reproduce. The SOM cycle is a continuum of different forms (or fractions) with different time frames under which decomposition takes place. Over time SOM moves through these fractions; particulate, humic and resistant fractions. As SOM decomposes carbon is released from the system along with any nutrients that are not utilised by the microorganisms. These nutrients are then available for plants to utilise. Eventually a component of these residues will become resistant to further decomposition (resistant fraction Figure 1).

1 QDAF (2010) Nutrition management. Overview. Department of Agriculture, Fisheries and Forestry Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

2 JA Baldock, JO Skjemstad (1999) Soil organic carbon/Soil organic matter. In KI Peverill, LA Sparrow, DJ Reuter (eds). Soil analysis: An interpretation manual. CSIRO Publishing, Collingwood Australia.

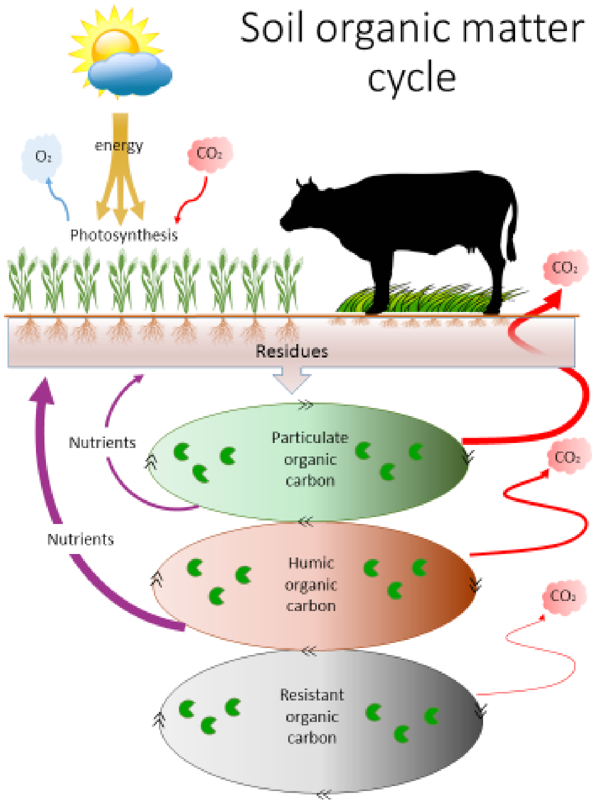


Figure 1: *Organic matter cycle.*

Source: J Gentry, QDAF

Organic matter is fundamental to several of the physical, chemical and biological functions of the soil. It helps to ameliorate or buffer the harmful effects of plant pathogens and chemical toxicities. It enhances surface and deeper soil structure, with positive effects on infiltration and exchange of water and gases, and for keeping the soil in place. It improves soil water-holding capacity and, through its high cation-exchange capacity, prevents the leaching of essential cations such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na). Most importantly, it is a major repository for the cycling of nitrogen and other nutrients and their delivery to crops and pastures.

Australian soils are generally low in SOM. Initial SOM levels are limited by dry matter production (and so climate) for each land type/location. SOM levels have declined under traditional cropping practices. On-farm measures (sampled 2012–15) from over 500 sites in Queensland and northern NSW confirm that soil organic matter, measured as soil organic carbon, declines dramatically when land is cleared and continuously cropped. This decline affects all soils and land types but is most dramatic for the brigalow–belah soils because their starting organic carbon levels are so high (Figure 2). [3]

3 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

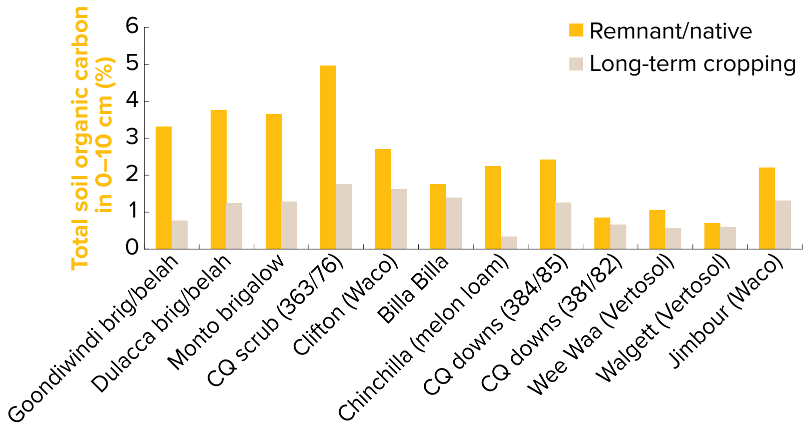


Figure 2: *The decline of soil organic carbon in long-term cropping systems.* [4]

Declining levels of SOM have implications for soil structure, soil moisture retention, nutrient delivery and microbial activity. However, probably the single most important effect is the decline in the soil's capacity to mineralise organic nitrogen (N) to plant-available N. Past research (1983) has shown that N mineralisation capacity was reduced by 39–57%, with an overall average decline of 52% (Figure 3). [5] This translated into reduced wheat yields when crops were grown without fertiliser N.

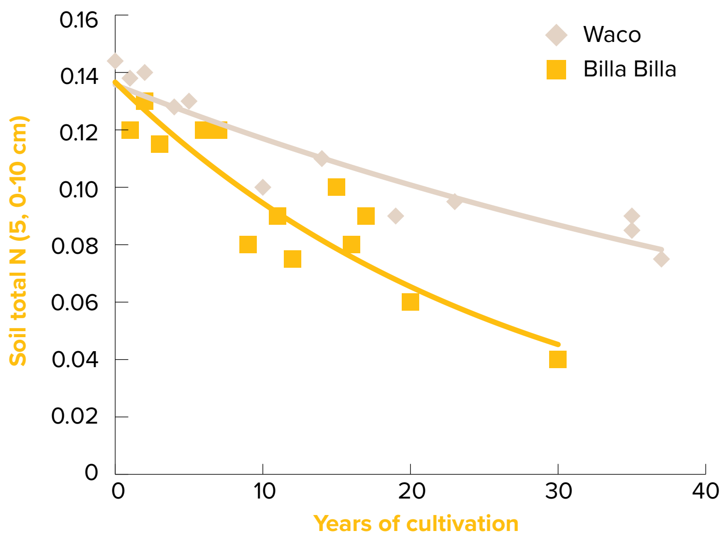


Figure 3: *Graph of decline in soil total N with years of cropping. The decline was greater for the Billa Billa soil (clay content 34%) than the Waco soil (clay content 74%).* [6]

Source: based on Dalal & Mayer (1986a,b)

4 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

5 RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

6 RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

5.1.2 Current situation

Soil organic carbon levels are simply a snapshot of the current balance between inputs (e.g. plant residues and other organic inputs) and losses (e.g. erosion, decomposition) constantly happening in each soil and farming system. The decline over time is overwhelmingly driven by the extent of fallowing in our farming systems. Most fallow rain in the northern region (as much as 75–80% in a summer fallow) is lost as runoff or evaporation. This wasted rain does not grow dry matter to replenish the organic matter reserves in the soil. However, increasing moisture in the fallowed soil continues to support microbial decomposition. This helps accumulate available nitrogen for the next crop, but reduces soil organic carbon. The soil organic matter and carbon levels will continue to decline until they reach a new lower level that the dry matter produced by the new farming system can sustain. Put simply,

'Crops may make more money than trees and pastures, but do not return as much dry matter to the soil.'

Total soil organic carbon levels vary within a paddock, from paddock to paddock and from region to region. Comprehensive sampling was under taken throughout the northern region, with over 900 sites sampled and analysed for total organic carbon at 0–10 cm depth. These results varied enormously across sites. The average was 1.46% however it varied from under 0.5% to over 5% (Figure 4). [7] A selection of these data from representative soil types throughout the northern grains region clearly indicates how soil carbon levels can be significantly different due to soil type (Figure 5). [8]

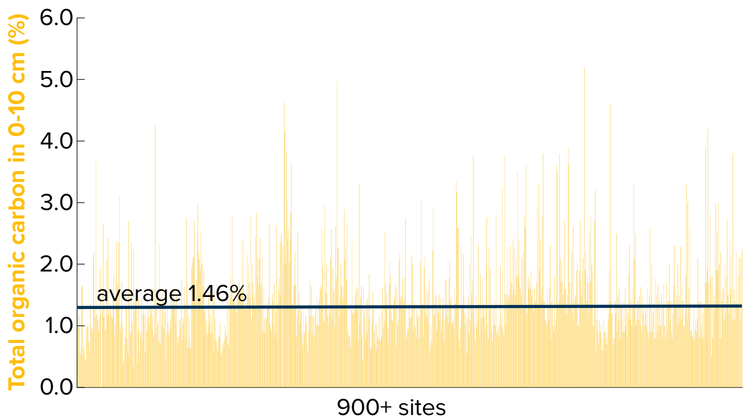


Figure 4: *Soil organic carbon levels on mixed farms within the GRDC Northern Region.* [9]

7 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112 – 117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

8 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

9 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

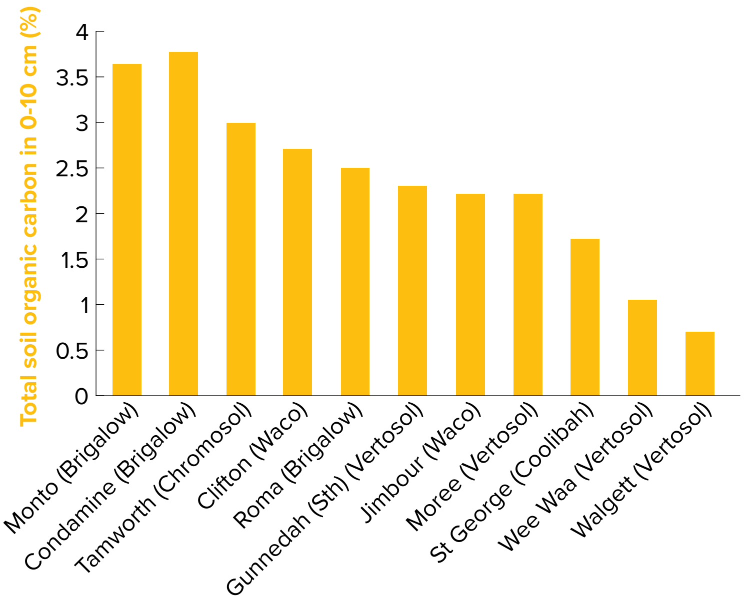


Figure 5: *Impact of land-type on total soil carbon levels (0–10 cm) across the northern region.* [10]

5.1.3 Options for reversing the decline in soil organic matter

Soil organic matter is an under-valued capital resource that needs informed management. Levels of SOC are the result of the balance between inputs (e.g. plant residues and other organic inputs) and losses (e.g. erosion, decomposition, harvested material) in each soil and farming. [11] So maximising total dry matter production will encourage higher SOC levels, and clearing native vegetation for grain cropping will typically reduce SOC and SOM levels. [12]

Modern farming practices that maximise Water Use Efficiency for extra dry matter production are integral in protecting SOM. Greater cropping frequency, crops with higher yields and associated higher stubble loads, pasture rotations and avoiding burning or baling will all help growers in the northern region to maintain SOM.

Research in the past has shown the most direct, effective means of increasing SOM levels is through the use of pastures, however these pasture have to be productive. A grass only pasture will run out of N especially in older paddocks, which is normally the reason why these paddocks are retired from cropping. As a result, a source of nitrogen is required to maximise dry matter production, this can be supplied via a legume or N fertiliser. The rotation experiments of I. Holford and colleagues at Tamworth, NSW and R. Dalal and colleagues in southeast Queensland provide good evidence of this (Table 1).

The greatest gains in soil carbon and nitrogen, relative to the wheat monoculture, were made in the 4-year grass–legume ley, with increases of 550 kg total N/ha and 4.2 t organic C/ha. The chickpea–wheat rotation fared no better than the continuous wheat system. The shorter (1–2-year) lucerne and annual medic leys resulted in marginal increases in soil organic C and N (Table 1).

10 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

11 FC Hoyle, JA Baldock, DV Murphy (2011) Soil organic carbon: Role in rainfed farming systems. In PG Tow, I Cooper, I Partridge, C Birch (eds). Rainfed farming systems. Springer, pp. 339–361.

12 RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

Clearly, time and good sources of both carbon and nitrogen are required to build up SOM, which is exactly what the 4-year grass–legume ley provided. Nitrogen was supplied via N_2 fixation by the lucerne and annual medic in the pasture, with most of the carbon supplied by the grasses, purple pigeon grass and Rhodes grass. There were no inputs of fertiliser nitrogen in any of the treatments in Table 1. [13]

Table 1: *Effects of different rotations on soil total N and organic C (t/ha) to 30 cm and as gain relative to continuous wheat.*

Rotation	Wheat crops	0–30 cm	Gain	0–30 cm	Gain
Grass/ legume ley 4 years	0	2.91	0.55	26.5	4.2
Lucerne ley (1-2 years)	2-3	2.56	0.20	23.5	1.2
Annual medic ley (1-2 years)	2-3	2.49	0.13	23.1	0.8
Chickpeas (2 years)	2	2.35	0.00	22.0	0.0
Continuous wheat 4 years	4	2.36	-	22.3	-

Further research was initiated in 2012 to identify cropping practices that have the potential to increase or maintain soil organic carbon and soil organic matter levels at the highest levels possible in a productive cropping system. Paired sampling has shown that returning cropping country to pasture will increase soil carbon levels (Figure 6). However, there were large variations in carbon level increases detected, indicating not all soil types or pastures preform the same. Soil type influences the speed by which carbon levels change, i.e. a sandy soil will lose and store carbon faster than a soil high in clay. As too does the quality and productivity of the pasture, maximising dry matter production by ensuring adequate nutrition (especially in terms of nitrogen and phosphorus) will maximise increases in soil carbon over time. Current research in Queensland being undertaken by the Department of Agriculture, Fisheries and Forestry (QDAF) is indicating that the most promising practice to date to rebuild soil carbon stocks, in the shortest time frame, is the establishment of a highly productive pasture rotation with annual applications of nitrogen fertiliser, however, adding an adapted legume is also effective. [14]

13 D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, https://grdc.com.au/uploads/documents/Managing-N-for-Northern-Grains-Cropping.pdf

14 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

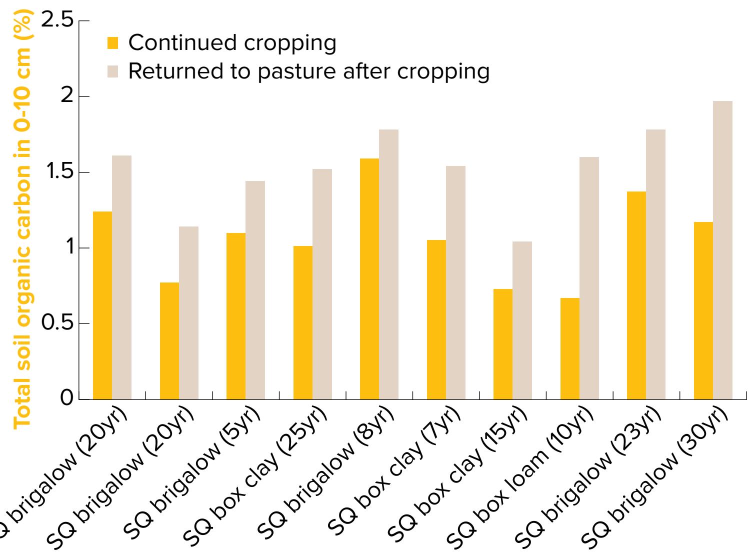


Figure 6: *Total organic carbon comparisons for croplands resown to pasture.* [15]

Impact of fertiliser N inputs on soil

If the rates of fertiliser N are sufficiently high, the effects can be positive. In the Warra experiments, both soil organic C and total N increased marginally (3–4%) over an 8-year period when no-till, continuous wheat, fertilised at a rate of 75 kg N/ha, was grown. This is in contrast with decreases of 10–12% in soil organic C and N in the non-fertilised, continuous wheat and chickpea–wheat plots. The result was much the same in NSW Department of Primary Industries experiments in northern NSW. At the Warialda site, for example, SOM increased during 5 years of cropping but only where fertiliser N had been applied to the cereals.

It is clear from the above examples that building SOM requires N. It works in two ways. First, the fertiliser or legume N produces higher crop/pasture yields and creates more residues that are returned to the soil. Then, these residues are decomposed by the soil microbes, with some eventually becoming stable organic matter or humus. The humus has a C/N ratio of about 10:1, i.e. 10 atoms of C to 1 atom of N. If there are good amounts of mineral N in the soil where the residues are decomposing, the C is efficiently locked into microbial biomass and then into humus.

If, on the other hand, the soil is deficient in mineral N, then more of the C is respired by the soil microbes and less is locked into the stable organic matter. [16]

5.2 New nutrition thinking for the northern region

Canola best management recommendations from the southern region have been a useful starting point; however, they are now being fine-tuned and adapted for conditions and soil types in the northern region.

Research into optimal fertiliser rates, particularly for nitrogen (N), phosphorus (P) and sulfur (S), has generated useful data. The relationship between crop nutrition and production of consistent oil content is also under investigation (see Section 5.7 Sulfur)

MORE INFORMATION

GRDC Update Paper: Harnessing the benefit of crop residues and tillage to enhance the supply of nitrogen phosphorus and sulfur in the soil

15 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

16 D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, https://grdc.com.au/uploads/documents/Managing-N-for-Northern-Grains-Cropping.pdf

MORE INFORMATION

Economics and management of P nutrition and multiple nutrient decline

Nitrogen and sulfur for wheat and canola—protein and oil.

Previous recommendations considered S to be non-negotiable and N applications more seasonally dependent. New research indicates this approach needs to be reversed; S application may not be needed and attention should be refocused and effort redirected to getting N rates right.

Trials over 3 years in the central and northern regions of NSW indicate that the previous recommendation of 20–25 kg S/ha independent of soil nutritional status is unwarranted, with no trial demonstrating a response.

Sulfur deficiency in canola, if it occurs, can be severe but this is not always the case. The frequency of such deficiency is most likely lower than thought and can be rectified early in-crop without ongoing penalty.

Canola has abundant fine roots with the ability to branch and proliferate in zones of higher nutrient content, such as around fertiliser bands or granules. In addition, canola roots can increase their root hair number and length in response to low P conditions.

Strong responses to N have been observed. Savings in S fertiliser costs may be better used to increase N rates. [17]

5.3 Crop removal rates

Canola requires high inputs per tonne of grain for the major (macro-) nutrients N, P and S compared with other crops (Table 2). However, on a per-hectare basis, canola's nutritional requirements are similar to cereals, because yields are usually about 50% of wheat. [18]

Table 2: *Comparison of the average amount of major nutrients removed (kg/ha) per tonne of grain and stubble for a range of crops, including canola and wheat.*

	Nitrogen		Phosphorus		Potassium		Sulfur	
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble
Canola	40	10	7	2	9	26	3.5–5	3.2
Wheat	21	8	3	0.7	5	21	1.5	1.5
Barley	20	7	2.5	0.7	4.5	18	1.5	1.5
Oats	20	7	2.5	0.6	4.5	18	2	1
Lupins	51	10	4.5	0.4	9	16	3	2.5

MORE INFORMATION

GRDC Update Paper: The what where and why of soil testing in the northern region

5.4 Soil testing

In Australia, canola is not recommended for soils of pHCaCl <4.5, and preferably not <4.7 if exchangeable aluminium (Al) levels exceed 3%. Many soils where canola is grown have a pH <5.0, with some as low as 4.0. Although most of these soils were naturally acidic, their acidity has been increased by agricultural activities. The acidity may occur in the surface soil or subsoil, or in both. Soil tests for pH are recommended before growing canola. Samples are taken from the surface (0–10 cm), as well as at depth (10–30 cm) to check for subsoil acidity.

Where the soil is pH is ≤5, Al and manganese (Mn) toxicities can be a problem for canola. Aluminium is much more detrimental than Mn because it kills root tips, the sites of root growth. Plants with Al toxicity have a shallow, stunted root system that is unable to exploit soil moisture at depth. The crop does not respond to available nutrients, and seed yield is drastically reduced. Severe Mn toxicity reduces yield because

17 GRDC (2014) Canola nutrition in the northern region. GRDC Media Centre, 28 April 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Canola-nutrition-in-the-northern-region

18 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

entire leaves become chlorotic and distorted. Mild to severe Mn toxicity is often seen sporadically or in patches and often associated with waterlogged parts of fields. [19]

NSW DPI soil testing

5.5 Nitrogen

Canola has a high N demand, twice that per ton of wheat. One ton per ha of canola will remove approximately 40Kg/ha of N but the crop will require at least twice this amount. For a crop with a targeted yield of around 2 t/ha the crop will require around 160 kg/ha of N. This can be supplied through soil reserves but additional N fertiliser will be needed in many cases. Depending on the amount of soil N available to the crop, ~80–100 kg/ha of fertiliser N would be needed. In general, a canola crop requires an amount of N similar to a high-protein wheat crop.

Deep soil testing for N and S is recommended for all growers, particularly first-time growers. This will allow N budgeting.

Canola seed is very sensitive to fertiliser burn. No more than 10 kg/ha of N should be in direct contact with the seed at sowing in narrow (18-cm) rows and proportionally less at wider row spacings. The majority of the N should be either drilled in before sowing or banded 2–3 cm below and beside the seed at sowing (Figure 7). An alternative is to apply N to the growing crop. Application timing should aim to minimise losses from volatilisation, that is, time the topdressing for when the crop has good groundcover and before a rain event. Losses can be high on dry, alkaline soils. [20]

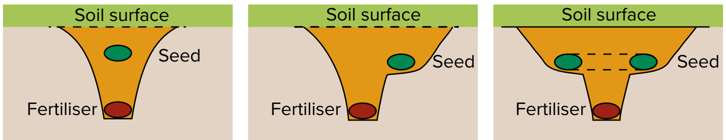
WATCH: Interview with central west NSW grain growers Dave and Nigel Newbigging

MORE INFORMATION

GRDC Update Paper: Budgeting crop nitrogen supply better estimation better decisions

19 P Hocking, R Norton, A Good (1999) Crop nutrition. 10th International Rapeseed Congress, http://www.regional.org.au/au/gcirc/canola/p-05.htm

20 L Serafin, J Holland, R Bambach, D McCaffery (2009) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf



A. Single outlet with centre banding
Pros: Sub-seed soil disturbance, fertiliser separation banded at depth.
Cons: High draft and breakout force required compared with tillage at seeding depth, seed placement quality variable.

B. Single outlet with side banding
Pros: Sub-seed soil disturbance, fertiliser separation banded at depth, improved seed placement, good moisture transfer to seed.
Cons: High draft and breakout force required, potentially higher soil and residue disturbance.

C. Dual outlet paired row and ribbon sowing systems
Pros: Sub-seed soil disturbance, fertiliser separation, good seed placement except over centre section, higher seed-bed utilisation.
Cons: High draft and breakout force required, higher soil and residue disturbance influencing seeding depth uniformity.

Figure 7: *Three arrangements of split seed and fertiliser banding with tillage below the seeding point that illustrate the different types of seed and fertiliser separation achieved.*

The N content of a canola plant (expressed as a percentage of dry matter) is highest at the full rosette stage, when deficiency symptoms are often visible.

Generally, the older leaves become pale green to yellow, and may develop red, pink or purple colours (Figure 8). Plants will be stunted and the crop will not achieve full groundcover by 8–10 weeks after sowing. Once stem elongation commences, a deficiency is then characterised by a thin main stem and restricted branching. This results in a thin and open crop. Flowering will occur over a shorter period, reducing the number of pods per unit area.

Figure 8: *Nitrogen deficiency symptoms show as smaller leaves, which are more erect, and leaf colours from pale green to yellow on older leaves and pinkish red on others.*

Photo: S. Marcroft, MGP

Unfortunately, some visual symptoms are similar to other nutrient deficiencies (e.g. P and S), which can result in incorrect diagnosis. [21]

N deficiency affects older leaves first, while sulfur deficiency affects younger leaves first. [22]

Tissue tests combined with a good knowledge of the paddock's history (including past fertiliser use and crop yields) will assist in a more accurate assessment of the most likely deficiency. [23]

Diagnosing nitrogen efficiency in canola

5.5.1 Estimating nitrogen requirements

Canola is ideally grown in soils of high N fertility; for example, as the first or second crop following several years of legume-dominant pasture. However, paddock fertility is often inadequate, so additional N is required to produce both high yields and good seed quality.

Canola removes 40 kg N/t grain, but the crop requires up to three times this amount of N to produce this yield (referred to as the efficiency factor). This is because the plants must compete for N with soil microorganisms, and some of the N taken up by the plants is retained in the stubble, and senesced leaves and roots. A good canola crop will produce twice as much stubble as grain (by weight), giving a harvest index (HI) of about 33%.

The best way to determine a crop's potential N requirement is through a combination of N removal (total N in the estimated grain yield × efficiency factor) and the amount of N estimated to be available in the soil. Deep soil tests (to a depth of 60 or 90 cm) can be taken prior to sowing. Most deep soil tests are taken to 60 cm in the major canola-producing areas. They can also be done during the growing season to determine whether topdressing is required.

Example

Available soil N (calculated from deep N test + estimate of in-crop mineralisation) = 125 kg/ha

As a rough 'rule of thumb', the in-crop mineralisation is calculated as:
Growing season rainfall (mm) × organic carbon (%) × 0.15

Fertiliser N required for crop = total N required – available soil N (kg N/ha)
= 200 – 125 kg N/ha
= 75 kg N/ha

Nitrogen requirement calculator

Nitrogen removed in grain = target yield × 40 (kg N/t grain)

Total N required = N removed in grain × 2.5 (efficiency factor of 40%)

In the example:
Estimated target yield = 2 t/ha
N removal in grain 2 × 40 kg N/t = 80 kg N/ha
Total N required = 80 × 2.5 kg N/ha
= 200 kg N/ha [24]

Nitrogen fertiliser rates

Fertiliser N required for crop = total N required – available soil N (kg N/ha)

21 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

22 Diagnosing nitrogen deficiency in canola, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-canola

23 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

24 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Using the example:

Available soil N (calculated from deep N test + in-crop mineralisation) = 125 kg/ha

Fertiliser N required for crop = 200 – 125 kg N/ha
= 75 kg N/ha (or 163 kg/ha of urea)

As the above calculations indicate, about 75 kg/ha of additional N is required as fertiliser to achieve the anticipated yield. The N can be applied in several combinations pre-sowing, at sowing or as topdressing(s) before stem elongation during the season.

Other formulae are available for calculating N requirements; however, these need more detailed inputs, which can be provided by consultants or agronomists. [25]

IN FOCUS

5.5.2 Northern Grower Alliance trials

Recent GRDC-funded Northern Grower Alliance (NGA) research has demonstrated strong yield responses to N in situations with ~25–70 kg N/ha available from soil testing (excluding any mineralised N). Nitrogen removal in grain was ~60–80 kg N/ha at yields of ~1.5–2.0 t/ha. This supports a total crop-available N target of ~120–160 kg N/ha where yield targets are in the range of 1.5–2.0 t/ha. It also corresponds to a total crop-available N target of ~80 kg N/ha for each tonne of grain. [26]

Other key findings included:

- Nitrogen was the key nutrient limiting grain yield, with significant yield responses at all sites and net returns of $120–200/ha compared with nil N applied.
- Oil content significantly decreased (by 1–3%) with additional N at three of the four sites, but financial impact was more than compensated by yield increases.
- No interaction between N and S was detected at any site. [27]

Yield

Key points

- Significant yield response to N was found at all sites.
- Yield response to N had plateaued at Yallaroi and Bellata but not at Moree and Blackville.
- No yield response to addition of S was detected at any site.
- There was a yield response to P at both Yallaroi and Bellata.

There was no significant N × S interaction for yield at any trial. The results presented in Tables 3 and 4 show the main effects of N or S. The factorial experimental design means that each result for a single rate of N or S is based on 32 individual plots at Moree and Blackville and 12 plots at Yallaroi and Bellata. The results for yield response to P (Table 5) and oil content (Tables 6–8) are based on a smaller subset of treatments at

25 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

26 GRDC (2014) Canola nutrition in the northern region. GRDC Media Centre, 28 April 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Canola-nutrition-in-the-northern-region

27 R Daniel, M Gardner, A Mitchell, R Norton (2013) Canola nutrition: what were the benefits from N, S and P in 2012? GRDC Update Papers, 5 March 2013, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Canola-nutrition-what-were-the-benefits-from-N-S-and-P-in-2012

Yallaroi and Bellata with a factorial of two rates of P and three combinations of N and S.[28]

Table 3: *Grain yield response to different rates of nitrogen addition at four sites.*

Moree		Blackville		Yallaroi		Bellata	
N added (kg N/ ha)	Grain yield (t/ha)	N added (kg N/ ha)	Grain yield (t/ha)	N added (kg N/ ha)	Grain yield (t/ha)	N added (kg N/ ha)	Grain yield (t/ha)
0	0.73d	0	0.99c	34	1.58b	34	1.25b
40	1.08c	50	1.51b	84	1.89a	84	1.40a
80	1.31b	100	1.69b	134	1.91a	134	1.45a
120	1.47a	200	1.99a				
l.s.d. (*P* = 0.05):	0.14		0.19		0.21		0.12
CV	6.4 %		4.8%		14.0%		10.7%

CV, Coefficient of variation. Within columns, means followed by the same letter are not significantly different at P = 0.05

Table 4: *Grain yield at different rates of sulfur addition at four sites.*

Moree		Blackville		Yallaroi		Bellata	
S added (kg S/ ha)	Grain yield (t/ha)	S added (kg S/ ha)	Grain yield (t/ha)	S added (kg S/ ha)	Grain yield (t/ha)	S added (kg S/ ha)	Grain yield (t/ha)
1	1.16	1	1.53	1	1.75	1	1.32
11	1.14	11	1.52	16	1.77	16	1.40
21	1.12	21	1.56	31	1.85	31	1.38
41	1.16	41	1.54				

There were no significant differences

Table 5: *Grain yield response to different rates of phosphorus addition at two sites.*

Yallaroi		Bellata	
P added (kg P/ ha)	Grain yield (t/ ha)	P added (kg P/ ha)	Grain yield (t/ ha)
0	1.54b	0	1.26b
20	1.83a	20	1.43a
l.s.d. (*P* =0.05)	0.19		0.12
CV	12.2%		12.0%

CV, Coefficient of variation. Within columns, means followed by the same letter are not significantly different at P = 0.05

Oil content

Key points

- Significant reduction in oil content occurred with increasing N rates at three of the four sites.
- No oil content response was detected to addition of S at any site.

28 R Daniel, M Gardner, A Mitchell, R Norton (2013) Canola nutrition: what were the benefits from N, S and P in 2012? GRDC Update Papers, 5 March 2013, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Canola-nutrition-what-were-the-benefits-from-N-S-and-P-in-2012

- There was no significant oil content response to addition of P at either site.

Table 6: *Oil content response to different rates of nitrogen application at four sites.*

Moree		Blackville		Yallaroi		Bellata	
N added (kg N/ ha)	Oil content (%)	N added (kg N/ ha)	Oil content (%)	N added (kg N/ ha)	Oil content (%)	N added (kg N/ ha)	Oil content (%)
0	43.9a	0	45.5b	34	44.5	34	47.3a
40	44.3a	50	46.2a	84	44.4	84	46.0b
80	43.2b	100	45.8b	134	44.6	134	44.5c
120	42.3c	200	44.7c				
l.s.d. (*P* = 0.05)	0.5		0.4		n.s.		0.8

Within columns, means followed by the same letter are not significantly different at P = 0.05; n.s., not significant

Table 7: *Oil content at different rates of sulfur at four sites.*

Moree		Blackville		Yallaroi		Bellata	
S added (kg S/ ha)	Oil content (%)	S added (kg S/ ha)	Oil content (%)	S added (kg S/ ha)	Oil content (%)	S added (kg S/ ha)	Oil content (%)
1	43.6	1	45.5	1	44.4	1	46.0
11	43.6	11	45.6	16	44.6	16	46.0
21	43.7	21	45.6	31	44.5	31	45.7
41	43.7	41	45.6				

There were no significant differences

Table 8: *Oil content at different rates of phosphorus addition at two sites.*

Yallaroi		Bellata	
P added (kg P/ ha)	Oil content (%)	P added (kg P/ ha)	Oil content (%)
0	44.8	0	45.4
20	44.4	20	46.1

There were no significant differences

Although the Bellata result in Table 8 was not significant (*P* = 0.11) with respect to P addition, there was an apparent trend to improved oil content, particularly when combined with lower N rates (~0.7–0.9% oil content). This may be experimental noise but appears worthy of further investigation. [29]

For more details about the trial sites and experimental design, read the 2013 Update Paper: Canola nutrition: what were the benefits from N S and P in 2012?

http://www.farmtrials.com.au/

29 R Daniel, M Gardner, A Mitchell, R Norton (2013) Canola nutrition: what were the benefits from N, S and P in 2012? GRDC Update Papers, 5 March 2013, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Canola-nutrition-what-were-the-benefits-from-N-S-and-P-in-2012

5.5.3 Diagnosing nitrogen deficiency in canola

Nitrogen deficiency is the most common nutrient deficiency in canola, especially during cold, wet conditions and in sandy soils in high-rainfall areas. Hybrid varieties can display leaf purpling with adequate nutrient levels (Figure 9).

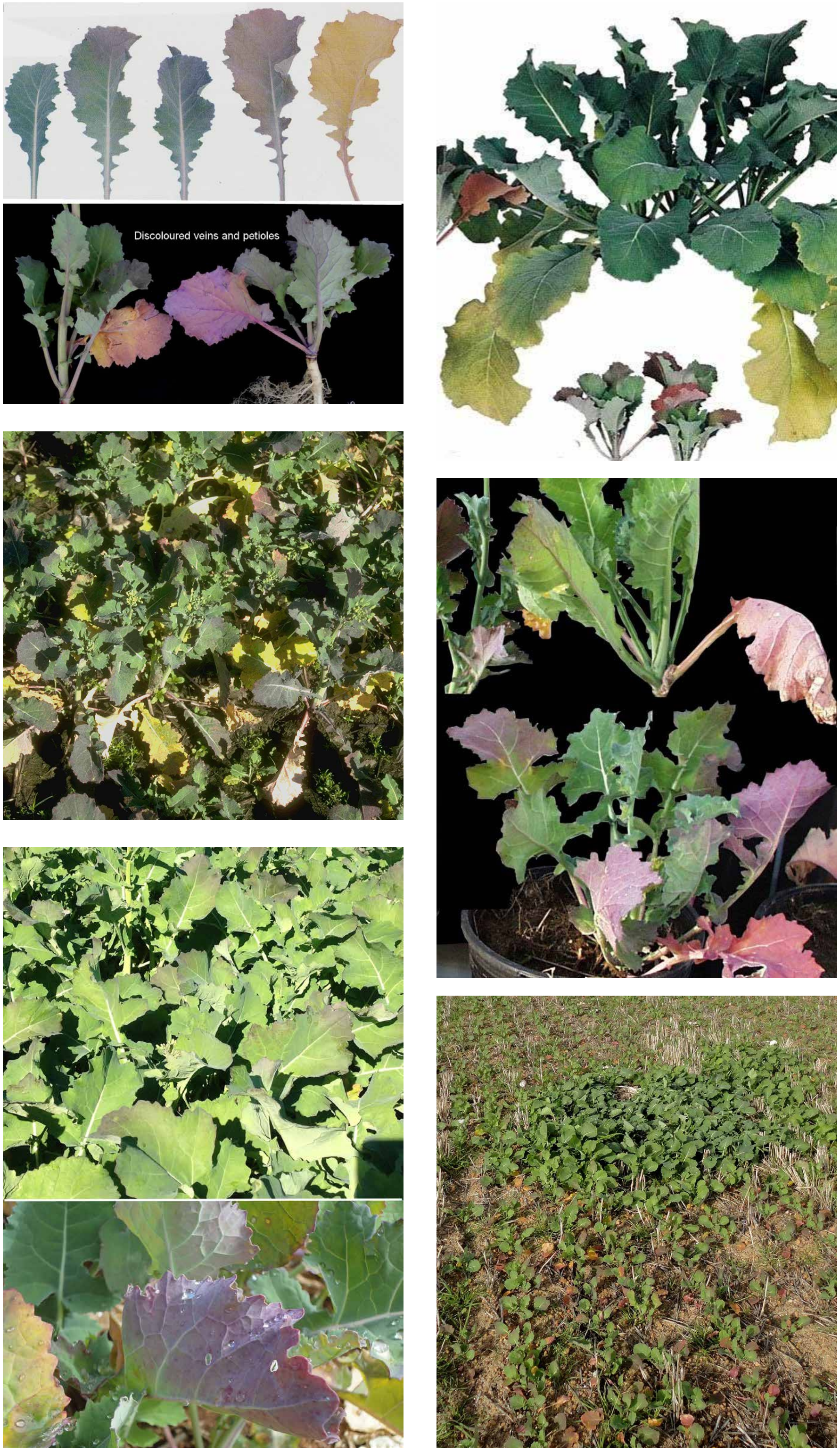


Figure 9: *Images of nitrogen deficiency in canola.*

What to look for

Paddock

- Plants are smaller and less branched with red to purple or yellow leaves.
- Symptoms are worse in wetter seasons, on lighter soil areas and sometimes on non-legume header rows.

Plant

- Mildly deficient plants are smaller with paler green and more erect leaves. Deficient seedlings have reddened cotyledons.
- Oldest leaves develop whitish purple veins and mild purple pigmentation that starts at the end of the leaf and progresses to the base on both sides of the leaf. (See Table 9 for conditions with similar leaf symptoms.)
- The whole leaf then turns yellow or pinkish purple. Developing leaves are narrow and more erect.
- Established plants that become N-deficient develop yellowing on leaf margins that spreads in toward the midrib between the veins. The midrib becomes discoloured then the leaf dies.
- From stem elongation, the main stem is thinner and branching is restricted. Flowering time and pod numbers are reduced.

What else could it be?

Table 9: *Conditions that result in symptoms similar to nitrogen deficiency.*

Condition	Similarities	Differences
Beet western yellow virus in canola	Purple-red colours spreading from end of oldest leaves	Affected plants are stunted rather than smaller and thinner
Damping off in canola	Reddened cotyledons and seedling older leaves	Damping off causes stunted plants with pinched roots or hypocotyls. Often plant death occurs
Sulfur deficiency in canola	Purple leaves	Sulfur deficiency affects younger leaves the most
Phosphorus deficiency in canola	Purplish older leaves	Phosphorus-deficient plants have purpling on leaf margin, then the leaf turns bronze

Where does it occur?

Nitrogen deficiency can occur on most soils but is most common in the following situations:

- cold, wet conditions that slow N mineralisation and uptake of N
- soils with very low organic matter
- after high rainfall on sandy soils, which can result in nitrogen leaching.

Management strategies

- Nitrogen fertiliser or foliar spray can be applied. However only N can be absorbed through the leaf so you will still be reliant on rainfall to move the nitrogen into the root zone, economics of liquid vs solid fertilisers should be taken into account.

- There is a risk of volatilisation loss from urea or nitrate sources of N. Loss is greatest from dry alkaline soils with dewy conditions, but new GRDC-funded research shows this may not be as high as traditionally thought. [30]
- The yield potential for canola is established during stem elongation and the budding stage, so all N should be applied before this stage of growth (8–10 weeks).
- Unlike cereals, canola does not 'hay off' when too much N has been applied, but N reduces oil content, particularly with late application.

Nitrogen volatilisation: Factors affecting how much N is lost and how much is left over time

How can it be monitored?

Tissue test

- Use whole top-of-plant test to diagnose suspected deficiency. Critical N levels vary with plant age and size, but as a rough guide, 2.7% (seedling) to 3.2% (rosette) indicates deficiency.
- Nitrogen soil testing by itself is of little value for most soils.
- Models that combine Nitrate, Ammonium, soil organic carbon, soil type and legume history are valuable for N fertiliser calculation.
- Leaf-colour symptoms are not a reliable guide for hybrid varieties. [31]

MORE INFORMATION

GRDC Update Paper: Improving fertiliser decisions for P on the Western Downs

GRDC Update Paper: Phosphorus and potassium nutrition

5.6 Phosphorus

Research in northern NSW has shown that P application is more critical for canola than for wheat grown under the same conditions. Results have consistently shown greater responses to P in canola than wheat, and responses have occurred in situations where wheat has not responded. Hence, it is critical that P be applied to canola unless soil tests indicate that the soil is well supplied with this nutrient. [32]

With grain removal of ~10 kg P/ha, application of ~15–20 kg P/ha appears warranted from both an agronomic and a financial viewpoint. [33]

For more details about the trial sites and experimental design, read the 2013 Update Paper: Canola nutrition: what were the benefits from N S and P in 2012?

30 G. Schwenke, Nitrogen volatilisation: Factors affecting how much N is lost and how much is left over time (2014), http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Factors-affecting-how-much-N-is-lost-and-how-much-is-left-over-time

31 DAFWA (2015) Diagnosing nitrogen deficiency in canola. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-canola

32 L Serafin, J Holland, R Bambach, D McCaffery (2009) Canola: Northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

33 GRDC (2014) Canola nutrition in the northern region. GRDC Media Centre, 28 April 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Canola-nutrition-in-the-northern-region/Details

Figure 10: *Severe phosphorus deficiency showing plant stunting and delayed maturity.*

Photo: R. Colton, NSW DPI

5.6.1 Role and deficiency symptoms

Phosphorus plays an important role in the storage and use of energy within the plant. Lack of P restricts root development (resulting in weaker plants) and delays maturity (Figure 10), both of which affect yield potential and seed oil content, particularly in dry spring conditions. Low P levels also restrict the plant's ability to respond to N. Even a mild deficiency can significantly reduce plant growth without any symptoms. In cases of severe deficiency, the older leaves will often appear dull blue or purple (Figure 11). Phosphorus is a very mobile nutrient within the plant, and if a deficiency occurs, it moves rapidly from older leaves to the young leaves or developing pods.

Figure 11: *Phosphorus deficiency shows as distinct pink purpling of the tips and margins of older leaves.*

Photo: P. Hocking, CSIRO

Fertiliser placement

In the soil, P is immobile, so fertiliser should be banded close to the seed at sowing. This ensures that the developing seedling is able to take up a good supply during the early growth stage when requirement for P is at its highest. Many soils (particularly if exchangeable Al is present) are able to tie up P, making it unavailable to plants. Banding the fertiliser can reduce the amount of P tied up because less fertiliser is in contact with the soil than occurs with broadcasting.

Phosphorus fertiliser banded above and below the seed gives better yield responses than P broadcast before sowing. In sandy soils, which are prone to drying in the surface layer, banding some of the fertiliser below the seed at sowing may improve the efficiency of P uptake.

Phosphorus requirements

If a wheat crop responds to P, then a rate at least equivalent should be used when sowing canola at that site. Topdressing is ineffective, so it is important to get the P rate right at sowing. A maintenance application of 7–8 kg P/ha is needed for every tonne of canola you expect to harvest.

If a soil-test indicates a high soil P level, then lower rates of P could be applied. In some situations, where soil P levels are very high, it may be uneconomic to apply P. If more is applied than is removed by the grain, it will be added to the soil P bank and may be available for following crops or pastures to utilise. However, a significant proportion (up to 50%) of applied fertiliser P can ultimately become 'fixed' into organic and inorganic forms that are largely unavailable for crop uptake in the short-medium term but can add to the P pool in the longer term with a proportion of the P becoming available over time.

Depending on your location there are a few laboratory analysis available for P. The Olsen P test (Bicarb) is often recommended on acid soils. The Colwell P test is more useful on alkaline clay soils, however each of these tests only measures a proportion of the P status of a soil. The Phosphorus Buffering Index is also important as it can indicate how available the phosphorus in the soil is to plants, whilst the BSES-P is recommended as a baseline of the pool P status. Using a qualified soil nutrition advisor will help you decide which tests are applicable on your soil type.

MORE INFORMATION

Economics and management of P nutrition and multiple nutrient decline

If tests indicate <20 mg/kg, then P is considered low (depending on soil type and rainfall) and a response is likely. If the soil P level is high (>40 mg/kg P) a response to P is less likely, unless the soil is acidic (pHCa <4.8) and has a low cation exchange capacity (<5 cmol(+)/kg); in such cases, significant yield responses have been obtained in southern NSW. Soil P tests are less reliable in low-rainfall zones or on alkaline soils, and so a nutrient budget is better for making P fertiliser decisions. A Colwell P level of ~40 mg/kg provides opportunity for some seasonal adjustment to fertiliser rates. [34]

Table 10 shows the critical P soil test values based on data from the Better Fertiliser Decisions for Crops (Bell et al. 2013). Values differ by soil type and crop, and the values indicate that canola is less responsive than wheat or barley on many soils. However, the dataset is incomplete so true comparisons are difficult to make. There is a suggestion that wheat after canola is more P responsive than wheat after wheat, possibly because the canola is quite efficient at accessing soil P.

34 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Table 10: *Critical Colwell soil test values and ranges as taken from the Better Fertiliser Decisions for Crops database (Bell et al. 2013).* [35]

Crop	Soil type	Critical value (mg/kg)	Critical range (mg/kg)
Wheat and barley	Vertosol	17	12–25
	Chromosol/ Sodosol	22	17–28
	Calcarosol	34	26–44
	Brown/Red Chromosols	25	18–35
Barley	Ferrosols	76	46–130
Canola	All soils	18	16–19
Field pea	All soils	24	21–28

FAQ

5.7 Sulfur

Traditional thought was that canola requires about 10 kg sulfate-S/t grain. The standard recommendation in southern NSW is to apply 25–30 kg sulfate-S/ha. However, while the standard 'rule of thumb' has been commonly extended on northern clay soils as early as 1992, commercial trials indicated a lower requirement on soil types that have naturally occurring gypsum at depth, typically the grey and black clay soils. This was identified in a deep (60–90 cm) soil test.

Recent research suggests that growers in southern Queensland and central/northern parts of NSW can reconsider routinely adding sulfur (S) to canola where there is good soil fertility and plant roots can access subsoil S reserves.

Is sulfur over-rated?

- Canola has a high profit potential as well as farming system benefits, such as reducing disease load (e.g. crown rot, take-all).
- Canola is considered by many growers to be a high risk and expensive crop to grow, mainly due to concerns about high inputs, including fertiliser.
- Crop nutrition is a major determinant of profitable crop production, with both under- and over-fertilisation leading to economic losses.
- Field trials in central and northern NSW over five years have shown no significant responses to added S for yield and oil percentage. [36] This has prompted new advice for growers.
- Where canola is grown more intensively in southern NSW and crop removal of S is higher, sulfur requirements should be determined by deep soil testing, using test strips and keeping accurate records of previous S applications.
- N deficiency is far more common than sulfur deficiency. N and P are crucial nutrients to get right.
- S responses are most likely when soil or seasonal conditions limit root access to deeper soil reserves. In this case, S applied at the surface is more likely to generate a response. S is more mobile in the soil and susceptible to leaching from the topsoil and accumulating at depths below 60 cm.

Key points

- Recent research indicates that blanket early applications of 20 kg/ha of S to soil in central/northern NSW and southern Queensland are not warranted.

35 R Norton (2016) Phosphorus – are we going to hit the wall and how much P in 2015? GRDC Update Papers 21 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Phosphorus

36 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Sulfur-strategy-to-improve-profitability-in-canola-in-the-central-west-of-NSW

- S deficiencies can be significant when they occur but occurrences are rare.
- Growers can adopt a watch-and-see approach. Be ready to fertilise in-crop if signs of deficiency occur as 100% of yield and oil percentage can be recovered if sulfur is applied before stem elongation.
- Savings from S fertiliser costs may be better used to increase N rates.
- Most soils in the regions researched would have sufficient S in the profile to meet the requirements of most crops.
- Conducting KCl-40 soil tests before growing canola may be useful, however the currently recommended critical soil test levels are, in most cases, higher than needed.
- Soil requirements for sulfur should be determined by deep soil tests. Shallow soil tests are unreliable. [37]

5.7.1 A new paradigm in sulfur thinking

Advice for growers based on best-available, past research into fertiliser rates (N, P and S) was to always apply a base level of S and to apply N depending on the season.

New research indicates this approach needs to be reversed. More than 20 trials across several seasons and locations in central and northern NSW have shown no yield or oil percentage responses to added S. They also showed no significant N S interaction for yield. Getting N rates right is most important and S application may not be needed. Furthermore, S deficiency can be identified early on and rectified early in-crop. [38]

Grain removal rates lower than thought

Commonly quoted grain-removal rates used in nutrient budget are overestimates. Average crop removal rates do not support the requirement of 20 kg S/ha universally. While current industry references suggest 10 kg S/t grain removal rates, it is less than half this. Therefore, planning S fertilisation for maintenance levels of 4 kg to 5 kg S/t of grain removed might be more suitable as a general rule. If soil levels are adequate, this may be reduced even further.

However, it is important to note that more research is needed to calibrate soil test critical levels to enable greater confidence in soil testing for S in canola.

Canola requires higher inputs per tonne of grain for the major (macro-) nutrients N, P and S compared with other crops (Table 11). However, on a per hectare basis, canola's nutritional requirements are similar to cereals, because yields are usually about half that of wheat. [39]

37 GRDC (2016) Canola nutrition and sulfur. GRDC Tips and Tactics, https://grdc.com.au/Resources/Factsheets/2016/04/Canola-nutrition-and-sulfur

38 GRDC (2016) Canola nutrition and sulfur. GRDC Tips and Tactics, https://grdc.com.au/Resources/Factsheets/2016/04/Canola-nutrition-and-sulfur

39 GRDC (2016) Canola nutrition and sulfur. GRDC Tips and Tactics, https://grdc.com.au/Resources/Factsheets/2016/04/Canola-nutrition-and-sulfur

Table 11: *Comparison of the average quantity of major nutrients removed (kg/ha) per tonne of grain and stubble for a range of crops, including canola and wheat.*

	Nitrogen		Phosphorus		Potassium		Sulfur	
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble
Canola	40	10	7	2	9	26	3.5–5	3.2
Wheat	21	8	3	0.7	5	21	1.5	1.5
Barley	20	7	2.5	0.7	4.5	18	1.5	1.5
Oats	20	7	2.5	0.6	4.5	18	2	1
Lupins	51	10	4.5	0.4	9	16	3	2.5

Source: Canola best practice management guide for south-eastern Australia

See the GRDC Tips and Tactics fact sheet Canola nutrition and sulfur for FAQs.

Key points

- Five years of trials by GOA failed to demonstrate a consistent response to the addition of S for yield or oil content. Numerous recent trials by other organisations have also failed to demonstrate responses to S in canola.
- Sulfur deficiency occurs in canola and can be quite severe, but the frequency of such deficiency is most likely lower than thought and it can be rectified early in the crop without ongoing penalty.
- Unwarranted applications of 20 kg S/ha are reducing the profitability of some canola crops and rates should be reviewed to maintenance levels of 4 kg S/t grain removed. If soil levels are adequate, this may be reduced even further.
- Canola is more frequently responsive to N applications and at least some expenditure on fertiliser may be better redirected from S to N applications.
- Soil-test critical levels for S are uncalibrated, are most likely too high, and should be reviewed. [40]

Reducing rates of sulfur fertiliser

When considering fertilising canola, its requirement for S distinguishes it from most other field crops. As such, S is often the first nutrient addressed after starter P fertiliser applications in fertiliser programs, and the requirement for N then follows.

More than 20 trials run over three seasons, mentioned above, have failed to demonstrate responses to added S in either yield or oil percentage. Average crop removal rates do not support the requirement of 20 kg S/ha universally.

Given this scenario, reducing the current recommended practice (CRP) of 20 kg S/ha to rates that more closely match crop yields and subsequent removal rates would be a more economical approach, whilst being sustainable in the longer term.

However, the lack of response to S in recent trials raises the possibility of completely removing intended S applications, as it is done in wheat. Because there is often no yield or oil percentage response, profitability in the short term will only decline with any additions of S.

If growers are to take this approach, soil tests may be still useful to predict potential responsiveness when using removal rates. If soil levels and subsequent calculations of soil-available S outstrip the predicted conservative crop requirements of 4–5 kg S/t crop potential, the likelihood of crop responses or a deficient situation developing is low.

In situations where no S is applied, growers do risk deficiencies developing despite prediction to the contrary. The frequency of such a deficiency based on recent trial work is low but not zero. If deficiency is identified prior to stem elongation and S

40 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

is applied, research by Hocking *et al.* (1996) has shown that both final yield and oil percentage will not be penalised. [41]

5.7.2 Nitrogen versus sulfur canola trials

The results of more than 30 trials spread over five years in central west NSW have shown a stark difference in canola yield responses to N fertiliser and S. The response to N was significant, compared with negligible responses to S, even in areas where S levels were otherwise low. Experiments included sites as far west as Nyngan, to east around Coolah and centres in between.

Researchers found no evidence of N fertiliser leading to premature haying-off in canola or reduced yields in dry spring years. There appeared to be a close relationship between greater biomass produced from N fertiliser and greater yield, despite the difficult seasonal conditions. Economic N response was also improved by factors such as timely sowing, good weed and disease control, and good subsoil stored moisture at sowing.

Key points

- Five years of research in central west NSW noted large and economical canola responses to 40 to 100 kilograms of N per hectare.
- Common dry spring conditions did not result in canola crops burning off with yield penalties from N fertiliser application.
- There was no response to S fertiliser over the five years and more than 30 experiments, despite generally low soil S levels (Figure 12). [42]

Figure 12: *Canola responds well to nitrogen but new research shows no response to sulfur, even in low sulfur soils.*

Photo: Bob Freebairn

41 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

42 B Freebairn (2016) Nitrogen versus sulfur canola trials. GRDC Update Papers 14 July 2016, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-123-JulyAugust-2016/Nitrogen-versus-sulfur-canola-trials

IN FOCUS

5.7.3 GRDC Grain Orana Alliance (GOA) research

Canola has been generally accepted as having high requirements for S, much higher than wheat. Sulfur deficiency was first identified in 1988 and 1989, but was only noted as a significant problem in 1990 (Coulton and Sykes 1992). Deficient situations lead to significant yield and oil penalties where it occurred.

In 2010, GOA established four trial sites to investigate the effect of S fertiliser form and timing on canola performance, in particular, on final seed oil percentage. None of the trials demonstrated any response to S fertiliser in terms of yield or oil percentage, regardless of form or timing.

Following this result, GOA questioned why responses were not seen despite prediction that three of the sites would respond. Was it because of changes in our farming systems, a consequence of the trial season being one of the wettest on record, or because our understanding of S nutrition of canola and its occurrence was incorrect?

In 2011 and 2012, GOA established eight and four trials, respectively, to improve our understanding and better identify situations where S deficiency or responses will occur. None of these trials showed any responses to S in yield or oil percentage.

During this period, several other agencies also conducted trials investigating S nutrition in canola. These trials too have failed to realise any responses to S.

The results from these recent trials should challenge our understanding and approach to S nutrition in canola, in particular:

- the frequency and likelihood of deficiencies in the Central West of NSW
- critical soil test levels
- grain removal rates and nutrient budgeting
- new approaches to S nutrition in canola. [43]

Background

Unreliable yields and crop failures of canola in the late 1980s and early 1990s were suspected to be due to S deficiency. Consequently, a series of 14 trials was established in 1992 in collaboration with CSIRO, University of New England, Incitec and NSW Department of Primary Industries (DPI). These trials investigated whether there was an interaction of N and S, and whether higher N rates were exacerbating S deficiency (Sykes 1990).

A report by ACIL Consulting (1998) states that the trials' responses in 1992–93 were 'dramatic', particularly when following pasture. It also states that the trial collaborators reported from the series of trials that 'applying 20–30 kg/ha is sufficient to achieve maximum yields' and is 'the best practice for maximising yield with the least risk versus cost trade off'. Probably, all subsequent recommendations for S application to canola in most industry resources are sourced from this statement.

This recommendation was widely adopted and is still accepted, as quoted in the 2009 Canola best management practice guide for south-eastern Australia:

43 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

'All paddocks sown to canola should receive 20 kg/ha of sulfur in the form of available sulfate. On lighter soil with a history of deficiency symptoms, increase rates to 30 kg/ha.'

This practice will be referred to as the CRP. The adoption of this recommendation was rapid; it was estimated that even before the completion of the trials, 90% of canola was receiving the additional levels of S recommended. A key factor supporting this rate of adoption was that the relatively low cost of S fertilisers at the time was outweighed by the risk of penalty in deficient situations (ACIL Consulting 1998).

During the same period in the early 1990s, the KCl-40 soil test for S was introduced and was adopted as a more appropriate test method than the existing MCP (mono-calcium phosphate) method; however, this superiority was demonstrated primarily on pasture sites (ACIL Consulting 1998)

The KCl-40 test was then widely used for estimating soil S levels, particularly for canola. Very little literature was available for NSW until Anderson *et al*. (2013) reviewed past trial yield performance against soil tests. Presumably, soil critical levels were based upon values extrapolated from critical levels for pasture situations and/or simply on the base blanket recommendations of 20–30 kg S/ha.

Trials conducted by CL Mullen and SJ Druce between 1993 and 1998 demonstrated that responses to S were not common on heavy grey soils of upper central NSW, owing to S contained in the subsoil. Because of this work, S fertiliser is not commonly applied on these soil types, but all other soils in the GOA region commonly still receive the standard 20 kg S/ha.

More recently, research by Khan *et al*. (2011) has questioned the suitability of gypsum as a source of S for growing of canola compared with sulfate of ammonia (SOA). Gypsum is a commonly used fertiliser in the GOA region, and perhaps this was contributing to lower oil percentages in the region's crops and/or suppressing yields because of S deficiencies.

This was the basis of four trials run by GOA in 2010 investigating sources of S and timing of applications. None of the trials showed response to S in any form or with any timing despite predictions by soil analysis and experience to the contrary. This work is briefed in Sulfur nutrition in canola—gypsum vs. sulphate of ammonia and application timings (Street 2011).

Following this outcome and other questions raised in above-mentioned paper, GOA continued the research. Trial design was revised to replicate better the earlier trials, with the simple aims of quantifying a response and helping to build on the predictability of response. [44]

Recent findings

Tables 12–18 summarise the findings from recent trials investigating S responses in canola. [45]

GOA trials

2010

Four sites were selected in winter 2010 across the GOA region. Three sites were identified through recent KCl-40 soil tests as being low–moderate in S. The fourth site was deemed adequate in S by way of KCl-40 soil tests.

44 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

45 M Street (2013) Sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 26 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Sulfur-strategy-to-improve-profitability-in-canola-in-the-central-west-of-NSW

Table 12: *Canola yield and oil percentage in response to applied sulfur fertiliser, GOA 2010.*

Site	Total S 0–60 cm (kg/ha)	Site av. yield (t/ha)	Yield response to S	Oil % response to S
Nyngan	1.4 kg	2.5	n.s.	n.s.
Narromine	85 kg	2.2	n.s	n.s
Curban	39 kg	2.8	n.s	n.s
Wellington	23 kg	2.2	n.s	n.s

Calculated S total = (KCl-40 × bulk density × depth). Statistical analyses are reported at P = 0.05; n.s., not significant

Treatments addressed three rates of S applied: 0, 15 or 30 kg/ha, in two forms (gypsum or SOA), applied at five different timings from pre-seeding to early flowering.

There was no significant difference between any treatment and the untreated control for yield or oil percentage as assessed by ANOVA (Table 12).

2011

Four plot-sown sites and four farmer-sown replicated trials were established in 2011. All sites were selected for low soil S.

The small-plot trial protocol was changed in 2011 to a full factorial trial design with two N rates (50 and 100 kg N/ha) and five S rates (0, 5, 10, 20 and 30 kg S/ha). All fertiliser treatments were predrilled immediately prior to sowing. The S was supplied in the form of granular SOA (20% N, 24% S) and the N rates adjusted using urea (46% N).

Oil percentage was not available for this set of trials. Yield results were analysed by factorial analysis (Table 13).

Table 13: *Canola yield response to increasing applied sulfur or nitrogen fertiliser, GOA 2011.*

Site	Total N 0–70 cm (kg/ha)	Total S 0–70 cm (kg/ha)	Trial av. yield	Yield response	
				N	S
Geurie	62	35	1.68	+0.28 t/ha	n.s.
Curban	37	40.4	0.84	+0.3 t/Ha	n.s.
Warren	39	30.1	0.97	+0.26 t/ha	n.s.
Narromine	44	42	2.03	n.s.	

Calculated N or S total = (soil test value × bulk density × depth). Statistical analyses are reported at P = 0.05; n.s., not significant

There was no response to added S in yield or oil percentage. Three of the sites demonstrated strong positive, statistically significant responses to increased N rates from 50 to 100 kg/ha. Yield responses were an increase of 18% at Geurie, 32% at Warren and 42% at Curban.

The four farmer-sown trials were small-plot replicated trials. The trials were established on farmer-sown paddocks on soils of low S background. These trials were designed only to provide further support to the more comprehensive, plot-sown trials, and treatments were reduced to plus and minus S.

The treatments were broadcast ahead of rain during the vegetative stage and comprised: no N or S added (control); S added in the form of SOA at 100 kg/ha (21 kg N and 24 kg S/ha); N added as urea at 45 kg/ha (21 kg N/ha) to supply the equivalent amount of N contained in the SOA treatment. The outcomes analysed by ANOVA are presented in Table 14.

Table 14: *Canola yield and oil percentage in response to applied sulfur or nitrogen fertiliser, GOA 2011.*

Site	Total soil S (kg/ha)	Trial average yield (t/ha)	Yield effect	Oil effect
Wongarbon	No S applied in 14 years	1.7	n.s.	n.s.
Coolah Black	33	0.9	Urea or SOA suppressed yield over control	n.s.
Coolah Red	31	1.06	n.s.	n.s.
Arthurville	24	2.3	n.s.	n.s.

Calculated S total = (soil test value × bulk density × depth). SOA, Sulfate of ammonia. Statistical analyses are reported at P = 0.05; n.s., not significant

The only interaction achieved in these trials was a reduction in yield to applied S at Coolah Black. This reduction, however, was achieved with both urea and SOA, so it may have been primarily due to the added N in both treatments, not the S. The resulting reduction in yield could be attributed to the dry conditions in late winter and spring experienced in 2011 at this site and over-fertilisation with N, supported by the low average trial yield.

2012

GOA repeated the same plot-sown protocol employed in 2011 on a further four sites in 2012. Yield and oil percentage results were analysed by factorial analysis (ANOVA) with the outcome listed in Table 15.

Table 15: *Yield and oil percentage in response to increasing applied sulfur or nitrogen fertiliser, GOA 2012.*

Site	Total N 0–70 cm (kg/ha)	Total S 0–70 cm (kg/ha)	Trial average yield (t/ha)	Yield response		Oil % response	
				N	S	N	S
Narromine	75	18.3	2.79	n.s.		n.s.	
Curban	88	33.8	1.27	n.s.		n.s.	
Wellington N	32	37	0.61	+ 0.13 t/ha	n.s.	n.s.	
Wellington S	71	50	1.4	+ 0.1 t/ha	n.s.	n.s.	

Calculated N or S total = (soil test value × bulk density × depth). Statistical analyses are reported at P = 0.05; n.s., not significant

In 2012, there was no response to added S in yield or oil percentage. In two of the trials there was a significant yield response to increasing the N from 50 to 100 kg/ha. At the Wellington N site, yield was increased by 24% with the increased N rate, and at Wellington S, by 7%. [46]

46 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

TABLE OF CONTENTS FEEDBACK

DPI collaborative trials 2012

In 2012, in collaboration with the NSW DPI, two trials were undertaken at Trangie and Coonamble. The trials were a factorial design with four N rates (0, 25, 50 and 100 kg/ha) and four S rates (0, 10, 20 and 30 kg/ha) and two canola varieties, Pioneer 43C80 and Pioneer 44Y84, sown at the Trangie site, but only Pioneer 44Y84 sown at the Coonamble site. Yield and oil percentage results were analysed by factorial analysis (ANOVA) with the outcome listed in Table 16.

Table 16: *Canola yield and oil percentage in response to increasing applied sulfur or nitrogen fertiliser, NSW DPI/GOA 2012.*

Site	Total N 0–90 cm (kg/ha)	Total S 0–90 cm (kg/ha)	Trial average yield (t/ha)	Yield response		Oil % response	
				N	S	N	S
Coonamble	73	20	2.56	n.s.		n.s.	
Trangie	113	141	1.81	+ 0.35 t/ha	n.s.	–1.60%	n.s.

Calculated N or S total = (soil test value × bulk density × depth). Statistical analyses are reported at P = 0.05; n.s., not significant

At the Coonamble site there was no response to the addition of N or S in either yield or oil percentage. The Trangie site showed no significant response to S in yield or oil percentage, but that would not be expected given the soil S levels. There were significant responses to N in yield and oil percentage. Increasing N rates increased yields but decreased oil percentage. There was a significant variety response, with 44Y84 outperforming 43C80 in both yield and oil percentage (data not presented). [47]

DPI northern region trials 2012

NSW DPI established two trials in northern NSW investigating N and S interactions. The trials were a factorial design with four N rates of 0, 40, 80 and 120 kg/ha at Moree and 0, 50, 100 and 200 kg/ha at Blackville, both with four S rates of 0, 11, 21 and 41 kg/ha and two canola varieties. Nitrogen was applied as urea with S applied as granulated gypsum applied pre-sowing.

Yield and oil percentage results were analysed by factorial analysis (ANOVA) with the outcome listed in Table 17.

Table 17: *Canola yield and oil percentage in response to increasing applied sulfur or nitrogen fertiliser, DPI 2012.*

Site	Total N 0–90 cm (kg/ha)	Total S 0–90 cm (kg/ha)	Trial av. yield (t/ha)	Yield response		Oil % response	
				N	S	N	S
Blackville	28	130	1.54	+1 t/ha	n.s.	–0.79%	n.s.
Moree	46	94	1.15	+0.74 t/ha	n.s.	–1.60%	n.s.

Calculated N or S total = (soil test value × bulk density × depth). Statistical analyses are reported at P = 0.05; n.s., not significant

There was no response to added S at either site in yield or oil percentage, as would be expected with such high levels of soil S. Both sites responded strongly to the addition of N; the yield response was positive and the oil percentage response negative.

47 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

NGA trials 2012

NGA established two trials in 2012 to investigate nutrition of canola in the northern region. The trials investigated the interaction of N and S as well as P. The trials were a factorial design with three N rates of 34, 84 and 134 kg/ha and three S rates of 1, 16 and 31 kg/ha. Nitrogen was applied as urea with S applied as Gran Am (SOA) pre-sowing.

Yield and oil percentage results were analysed by factorial analysis (ANOVA) with the outcome listed in Table 18.

Table 18: *Canola yield and oil percentage in response to increasing applied sulfur or nitrogen fertiliser, NGA 2012.*

Site	Total N 0–90 cm (kg/ha)	Total S 0–90 cm (kg/ha)	Trial av. yield (t/ha)	Yield response		Oil % response	
				N	S	N	S
Bellata	69	164	1.37	+0.15 t/ha	n.s.	–2.80%	n.s.
Yallaroi	30	NA	1.79	+0.31 t/ha	n.s.	n.s.	

Calculated N or S total = (soil test value × bulk density × depth). Statistical analyses are reported at P = 0.05; n.s., not significant

There was no response to added S at either site in yield or oil percentage. At both sites, there was a positive yield response to increasing N rates, 13% at Bellata and 20% at Yallaroi. At Bellata, there was a negative response to increased N rates in oil percentage. The Bellata site responded to added P; at the Yallaroi site there was a non-significant trend to increase with added P (data not presented). [48]

Central West Farming Systems (CWFS)

CWFS have undertaken several trials at their regional sites investigating canola S nutrition over a number of seasons. Unfortunately, individual trial data are not yet available, but personal comments by John Small of CWFS regarding the trials over recent seasons are as follows:

'*There has been no clear or statistically significant response to the addition of S in terms of yield or oil performance in canola over a number of trials by CWFS over recent seasons*.'

Readers should seek further clarification and data from CWFS concerning these trials. The outcomes will be valuable to farmers in the Central West because the trials were generally undertaken on red soils of the region, which are more likely to respond than the heavier soils of the northern regions. [49]

http://cwfs.org.au/regional-sites/

Discussion

As indicated above, there has been no response to S in terms of yield or oil percentage in recent trial work. This work has been undertaken by several agencies across a range of soil types and three seasons. It should also be noted that all but one of GOA's trial sites were selected specifically for low soil S levels and were predicted to be responsive.

Why have responses not been achieved?

The CRP is that all canola paddocks should receive S fertiliser. However, of the original work that formed this recommendation, only six of the 14 sites

48 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

49 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

showed a yield response to S and only three an oil percentage response (Sykes 1990). Many of these sites did not respond despite prediction by soil tests.

The most commonly reported trial was at the Wellington site, where yields increased from 1 to 4 t/ha with the addition of S. At this site, 75% of the site maximum yield was achieved at an application rate of 10 kg S/ha, and 92% at 20 kg S/ha. A similar result was demonstrated at Baradine, but these could be described as the two most severe documented cases of S deficiency.

Many of the other responsive sites did not realise such a magnitude of improvement. At the Gollan site at the rate of 40 kg N/ha, increasing S from 0 to 20 kg/ha increased yields by only 590 kg. At 80 kg N/ha, there was a 325 kg/ha improvement by increasing the S rate from 0 to 20 kg/ha. At the Junee Reefs and Tamworth sites, a maximum response was achieved of ~400 kg/ha. These would still be worthy and economic responses at today's fertiliser prices, but the penalties are nowhere near the extent often promoted.

The ACIL Consulting (1998) report also mentions other previous work from 1990, commenting, 'A major field study of canola in NSW reported significant grain yield increases from the addition of N but no significant responses to S (Sykes and Coulton, 1990)'.

The more recent work detailed above shows no response to the addition of S over 3 years and in a range of soils predicted to respond.

In summary, the frequency of response to added S is quite low; considering the trials detailed above, <14% of trial sites were responsive (excluding the field study of 1990 and those of CWFS).

Industry-accepted grain-removal rates used in nutrient budgets may also lend support to the CRP. Current industry references suggest that removal rates are 10 kg S/t grain and that crop requirements of canola are much higher than of wheat (Coulton *et al*. 1992).

Analysis of grain samples from the GOA and NGA trial work has shown that grain removal is much lower than these levels. Janzen and Bettany (1994), Pinkerton *et al.* (1993) and Hocking *et al*. (1996) all measured grain S contents in their range of experiments. Grain S levels no greater than ~0.5% or 5 kg S/t grain were measured, even in treatments with adequate S. In many cases, the S levels were even lower, resulting in them being less than half of the industry benchmarks.

When considering this information for formulating crop requirements and fertiliser programs, there may be little difference in requirements between wheat and canola. For example, an average wheat yield for the GOA region may be 3 t/ha, removing ~1.8 kg S/t or 5.4 kg S/ha. Canola generally performs at 50% of comparable wheat yields, so 1.5 t/ha removing 3.6 kg S/t (critical threshold, Hocking *et al.* 1996) will remove only 5.4 kg S/ha, or similar amounts to the wheat crop.

So, as a possible explanation of the lack of responsiveness in all of these trials, the sites were simply predicted to respond when in fact that was not likely; there was adequate S contained in the soil profile and subsequent mineralisation to satisfy crop demands, a demand much lower than previously understood.

For example, using the highest achieved yield in the GOA trials of ~ 2.8 t/ha, the crop removal rate would be 9.8 kg/ha. If we assumed an arbitrary uptake or transfer efficiency of 50%, the crop would have a growing requirement of only 20 kg/ha. All of the sites detailed in this paper would have satisfied this requirement with starting soil levels and only a minimal amount of mineralisation; no additional fertiliser would be required.

So, what is the critical soil level to indicate when S addition may be required? To supply this requirement of 20 kg S/ha, a soil KCl-40 test would have a critical level of ~2.3 mg/kg averaged in the top 60 cm of soil. If this were indeed the soil critical level, few cropping soils would be lower. [50]

Re-focus investment on nitrogen instead of sulfur

By contrast, the majority of all trials have demonstrated response to N. Twelve of the 14 trials undertaken in 1992 resulted in significant and economic responses, with an average increase in response to 80 kg N/ha of 600 kg/ha (Sykes 1990). Of the two trials that did not show a response, one was following 5 years of grass-free legume-based pasture, and the other was compromised by frost, resulting in a high coefficient of variation.

Three of four GOA trials in 2011 responded significantly to increasing N application from 50 to 100 kg/ha. The average yield increase over the three sites was 280 kg/ha, returning around 200% on investment. Two of GOA's trials in 2012 also returned a significant yield response to increasing N. Returns were much lower with the dry spring conditions, with the yield increases only breaking even after additional costs.

Trials by NGA in 2012 demonstrated a 13% yield increase or ~150 kg/ha (break-even) by increasing N from 34 to 84 kg/ha in one trial. The second site saw an increase yield of 20% or ~310 kg/ha, resulting in approximately a 200% return on investment.

It should be noted that the GOA and NGA trials did not have nil N treatments, but they were all clearly N-responsive sites.

In the NSW DPI–GOA trials in 2012, treatments of nil N were included, and this allows a response curve to be generated. The Trangie site showed strong responses to N, with yield increasing by 0.35 t/ha or 21% by increasing N from 0 to 100 kg/ha. The economics of such applications are demonstrated in Figure 13.

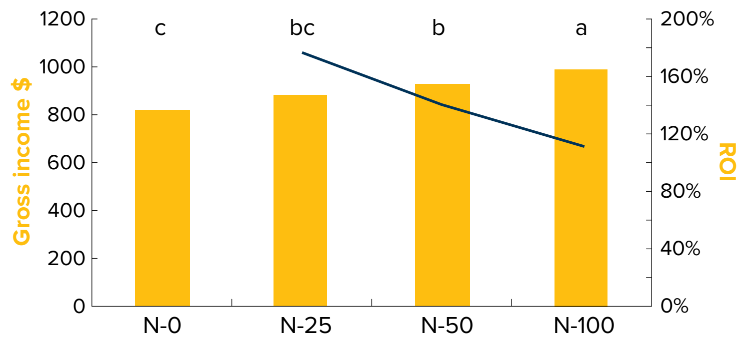


Figure 13: *Canola yield performance in relation to applied nitrogen rate and the corresponding return on investment (ROI), Trangie. Columns headed by the same letter are not significantly different.*

Source: NSW DPI–GOA 2012

Although the starting soil N at this site was high at 113 kg/ha, yield and resultant gross income increased almost in a linear response, and the treatments have not demonstrated a clear upper limit. The responsiveness of canola to high rates of N is reinforced at three other sites detailed in Figure 14; again there was no clear indication of a yield plateau even up to 200 kg N/ha.

50 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

Therefore, although canola will tend to respond to increasing N, the return on investment declined beyond the 25 kg/N rate but remained positive. This is only one trial in a dry spring, but it demonstrates that the most economical rate is not necessarily the point of yield maximisation. The economically optimum N rates may be different for each situation.

Determining the optimal N rate for canola through deep soil tests coupled with yield forecasting is one approach and probably the most reliable.

It is worth noting that increasing N rates may have the effect of reducing oil percentage, as demonstrated in the Trangie, Bellata, Blackville and the Moree trials (Figure 14). Many of the trials from 1992 also showed statistically significant reductions in oil content from increased N rates. Increased N can lead to increased protein, and the relationship of protein to oil percentage is inverse, which can result in depressed levels of oil. However, in all cases the increased yield more than adequately offset this loss. [51]

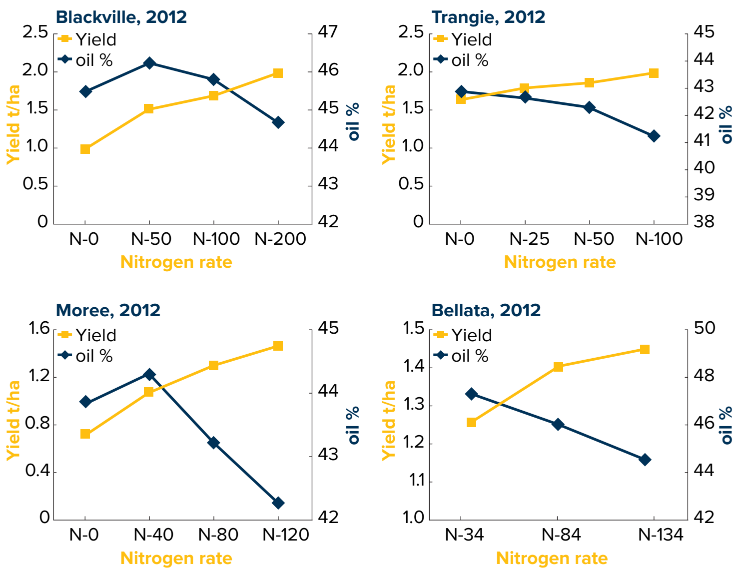


Figure 14: *Canola yield and oil percentage performance demonstrating the inverse relationship to applied nitrogen.*

Source: NSW DPI/NGA/GOA 2012

Summary

Twenty trials have recently been undertaken across several seasons and locations in NSW. None has demonstrated S responses in yield or oil percentage. This does not preclude deficiency and yield penalties from occurring but does highlight that the frequency and the likelihood is not high.

The results from the trial work in 1992 and the ensuing extension message regarding the need for S may have lost their original perspective. Within the original reports, the data suggested that N was paramount to achieving maximum profitability for canola in nearly all cases. The data also suggested that, in only some cases, canola responded to S as well.

51 M Street (2014) Review of sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 18 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Review-of-sulfur-strategy

The one extension message that persisted was that all canola crops needed 20 kg S/ha, and sometimes more. The then lower cost of S fertiliser and the significant penalties seen in deficient situations meant that this recommendation was adopted rapidly, needed or not. Declining terms of trade over the last 20 years do not allow for such a potentially wasteful approach.

Through the efforts of GOA, several shortcomings in the understanding of canola agronomy have been highlighted. Removal rates are over-estimated and the lack of calibrated soil critical levels is a major problem. Rectification in both of these areas may improve the predictability of S responsiveness.

With the reduced frequency of response and considering the reviewed S demand of canola, the CRP may need revision to match more closely the S removal rates. This will result in increased profitability and sustainability for growers.

Removal of S from fertiliser programs may be risky but will prove most profitable in many cases. However, wheat, which has a similar S requirement per hectare and is predominantly fertilised with mono- or di-ammonium phosphate (containing only minimal S), is not noted to suffer yield impacts through S deficiencies. It should also be remembered that deficient situations are easily corrected by in-crop applications.

There is a strong case for the savings in expenditure on S to be redirected to N, where a response is much more common. However, the optimal rate of N may need to be revisited or targeted through soil tests and nutrient budgets to ensure that return on investment is also maximised, not simply the yield. [52]

WATCH: Interview with grower Tom Quigley, Trangie NSW.

MORE INFORMATION

Canola research insight for Trangie farmer

Review of sulfur strategy

Sulfur strategy to improve profitability in-canola in the Central West of NSW

Sulfur nutrition in canola—gypsum vs sulphate of ammonia and application timing

Sulfur in northern Vertosols

5.8 Potassium

An adequate supply of potassium (K) is important to provide plants with increased resistance to disease, frost and drought, as well as increased carbohydrate production. Canola crops take up large amounts of K during growth but most of it remains in the stubble, with only a small proportion removed in the grain.

Although soil tests, especially the balance of exchangeable cations, can provide a guide to the K level, tissue tests are the most reliable method to determine whether

52 M Street (2013) Sulfur strategy to improve profitability in canola in the central west of NSW. GRDC Update Papers, 26 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Sulfur-strategy-to-improve-profitability-in-canola-in-the-central-west-of-NSW

MORE INFORMATION

[Do we need to revisit potassium]

[Economics and management of P nutrition and multiple nutrient decline]

K fertiliser is needed. Avoid sowing potassium fertiliser with the seed; it could affect germination. [53]

5.9 Micronutrients

5.9.1 Zinc

Although canola is a non-mycorrhizal crop, it requires zinc (Zn) on alkaline soils. The precise level of response in northern NSW is not known, but in the absence of better information, use wheat guidelines.

Zinc is best applied to the soil and thoroughly incorporated, but if this is not possible, apply it with starter fertiliser and place 2.5 cm beside and below the seed at planting. Zinc is highly competiative with soil moisture and the seed at planting so should not be added in the seed line.

Foliar spraying of zinc sulfate heptahydrate at 1 kg/ha plus wetting agent is an alternative application method if sprayed twice to deficient crops at 3 and 5 weeks after emergence. Zinc sulfate is incompatible with most herbicides and insecticides. Zinc seed treatments are not normally applied to canola, because insufficient Zn will be applied with the low seeding rate used. [54]

Deficiency symptoms

Zinc deficiency appears in crops as poor plant vigour, with areas of poorer growth alongside healthy, apparently normal plants, giving the crop a patchy appearance (Figure 15). Although there are few reports of Zn deficiency in canola, growers should be cautious. Zinc is routinely applied to the clay soils of northern NSW.

Zinc deficiencies can occur in the following situations:

- in strongly alkaline soils, pHCa >7.0
- with high P levels
- after long periods of fallow
- following land-forming where alkaline subsoil is exposed.

Other major and trace elements apart from Zn may also need special consideration in land-formed paddocks. [55]

Fertiliser strategies

Where responses to Zn are known to occur, incorporate Zn into the soil before sowing canola. In northern NSW and irrigation areas, broadcast rates of 10–20 kg Zn/ha are common where summer crops such as maize and sorghum are also grown. These rates supply enough Zn for ≥5 years.

On alkaline soils in south-western NSW, Zn is applied at 2–3 kg/ha every 3–5 years, usually as Zn-supplemented fertiliser at sowing.

Zinc oxide is the cheapest and most concentrated form of Zn and it is usually broadcast with fertiliser to ensure an even application. However, it is not water-soluble and is not an effective means of adding Zn if a quick response is required. When coated onto fertiliser, zinc oxide can flake off, resulting in problems with distribution. Foliar sprays are a short-term correction only and need to be applied before symptoms are obvious, soon after crop emergence or if Zn deficiency has been identified through tissue analysis. [56]

53 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

54 L Serafin, J Holland, R Bambach, D McCaffery (2009) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

55 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

56 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Figure 15: *Zinc deficiency appears as bronzing on the upper leaf surface and may occur in neutral to alkaline soils.*

Photo: B. Holloway, SARDI

5.9.2 Molybdenum

Role and deficiency symptoms

Molybdenum (Mo) is important in enabling plants to convert nitrates from the soil into a usable form within the plant. Deficiency is more common when soil acidity falls (pHCa <5.5) but is difficult to diagnose other than by a tissue test. Deficiency can be avoided by applying Mo at a rate of 50 g/ha every 5 years. The most common practice is the application of 150 g/ha of the soluble form sodium molybdate (39% Mo) sprayed onto the soil surface. Molybdenum is compatible with pre-emergent herbicides and can be thoroughly incorporated into the soil before sowing. [57]

Fertiliser requirements

Although fertilisers containing Mo can be used at sowing, the concentration of Mo they contain is less than recommended and they are more expensive than using sodium molybdate.

Molybdenum-treated single superphosphate applied during the pasture phase is cost-effective and it should supply enough Mo for the canola crop. [58]

5.9.3 Magnesium

In recent years, magnesium (Mg) deficiency has been reported in a number of seedling crops. As the crop grows and develops a deeper root system, the deficiency symptoms disappear because most soils have adequate Mg deeper in the profile. Low surface levels of Mg are probably due to low levels of sulfonylurea herbicide residues and the harvesting of subterranean clover hay, where large quantities of Mg are exported from the paddock.

Lime–dolomite blends can be used when liming acid soils if there is a history of deficiency symptoms, and other dry and foliar applied fertilisers are available. [59]

57 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

58 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

59 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

5.9.4 Calcium

Calcium (Ca) is important in plants because it assists in strengthening cell walls, thereby giving strength to plant tissues. Calcium is not readily transferred from older to younger tissue within a plant, so if a deficiency occurs it is first seen in the youngest stems, which wither and die, giving rise to the term 'withertop' to describe Ca deficiency (Figure 16).

Calcium deficiency is not common but it can occur in acid soils, especially if the level of exchangeable Ca is low. The use of lime (calcium carbonate) on acid soils and gypsum on sodic soils has meant only an intermittent occurrence of 'withertop' in canola. [60]

Figure 16: *Death of the canola flower head from calcium deficiency.*

Photo: D. McCaffery, NSW DPI

5.10 Toxicity

The most effective treatment for Al and Mn toxicity (Figure 17) is liming to raise the soil pH to >5.0. Lime rates depend on the pH to depth and the cation exchange capacity of the soil. Microfine lime is usually applied at 2.5–4.0 t/ha. Shallow incorporation of lime is sufficient to ameliorate surface soil acidity, but deep ripping is required to incorporate the lime, reduce soil strength and improve drainage where there is the more serious problem of subsoil acidity.

In many respects, the sensitivity of canola to soil acidity has had beneficial spin-offs in that it forced Australian growers to implement liming programs before their soils became too acidic for less sensitive crop and pasture species.

There are breeding programs to improve the Al and Mn tolerance of Australian canola, by using both conventional technology and genetic engineering. The rationale for increasing the tolerance of canola to soil acidity is to broaden management options for growers while they implement liming programs. [61]

60 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

61 P Hocking, R Norton, A Good (1999) Crop nutrition. 10th International Rapeseed Congress, http://www.regional.org.au/au/gcirc/canola/p-05.htm

Figure 17: *Symptoms of severe manganese toxicity in young canola on an acid soil.*

5.11 Nutrition effects on following crop

Canola has provided the opportunity for more reliable responses to N in subsequent cereals by reducing cereal root diseases. However, growers of grain sorghum and cotton on alkaline soils in northern NSW have reported low yields and poor growth following canola, particularly on the Liverpool Plains. [62]

This is due to the depletion of soil microorganisms called arbuscular mycorrhizal fungi (AMF; previously known as VAM fungi). They are beneficial soil fungi that assist the uptake of P and Zn that would otherwise be unavailable to the crop. Canola does not need these fungi to help it take up P and Zn, so under canola the fungal population declines to a low level. To avoid this problem, follow canola with a short-fallow crop such as wheat or another cereal crop rather than pulses or long-fallow crops such as sorghum and cotton that depend on AMF. [63]

62 R Norton, J Kirkegaard, J Angus, T Potter. Canola in rotations. Australian Oilseed Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0014/2705/Chapter_5_-_Canola_in_Rotations.pdf

63 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf