INTERNATIONAL
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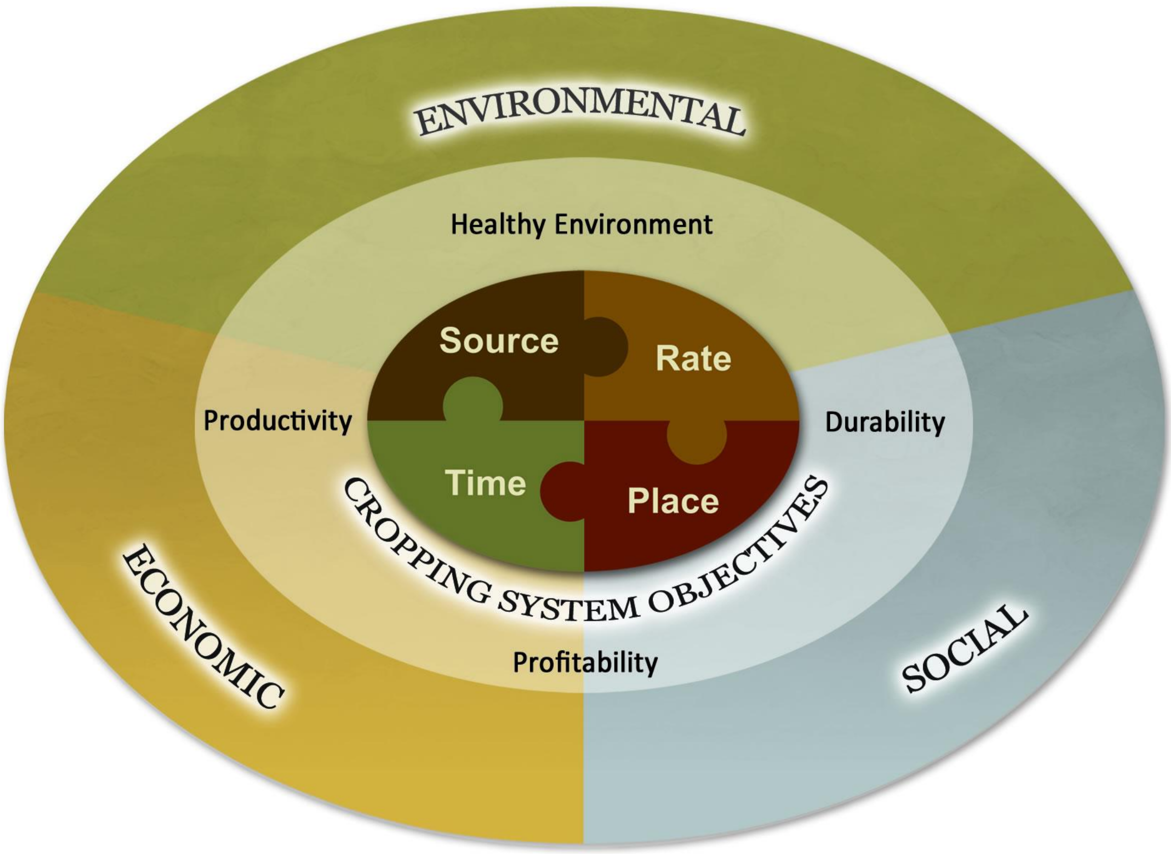
INSTITUTE

4R Canola Nutrition Guide



NUTRIENT MANAGEMENT

Aim

The aim of this module is to identify the major steps in developing a balanced nutrition program for a canola crop.

Learning Outcomes

After completion of this module, participants will be better able to:

- Understand the importance of estimating canola N, P, K and S nutrient demand based on yield potential.
- Use soil test values to assess if nutrient supply will be sufficient to meet crop demand.
- Use key soil parameters to assess, and then address, particular secondary and micronutrient deficiencies.
- Have strategies in place to assess the effectiveness of a nutrition program.

About the Author

Dr Rob Norton is the Australia New Zealand Regional Director for the International Plant Nutrition Institute (IPNI), which is a not-for-profit, science based research and education institute that operates in more than 50 countries. He is based in Horsham Victoria, where his role is to identify and undertake plant nutrition research projects that will improve nutrient management, as well as developing education programs to capitalise on these opportunities.

He has written extensively on canola agronomy and nutrition and has authored over 100 refereed publications. He has supervised many undergraduate and postgraduate students who now help drive the innovation that has been the backbone of Australian agriculture.

CONTENTS

1. DEVELOPING NUTRIENT MANAGEMENT STRATEGIES

Canola has secured a place in cropping systems, as a profitable crop in its own right, as well as conferring rotational benefits on subsequent crops. Canola is grown in a wide range of soils, from deep, leached sands in Western Australia, highly calcareous soils in South Australia, alkaline self-mulching clays in Victoria, and acidic red duplex soils in central New South Wales. Certain soil types will have particular needs for additional macronutrients (Nitrogen, Phosphorus, Potassium and/or Sulfur) and/or micronutrients (Copper, Manganese, Boron and Zinc).

In any given situation, one or more of these nutrients may be limiting yield and so care should be given firstly to diagnosing where a response will occur if additional nutrients are supplied. Soil type, paddock history and soil tests will all help with the diagnosis, but in most situations, under good agronomic practice, attention should first be given to getting the macronutrients "right", and then addressing any potential micronutrient issues.

The higher yield potential of newer canola varieties places larger demands on nutrient supply and where soil organic matter is relatively low, supply from the soil may not be sufficient to meet crop demand. Compared to most other grain crops in Australia, canola has a greater requirement for nutrient inputs to achieve high yields. Canola needs about 25% more N, P and K, and over twice the amount of S than wheat to balance fertiliser inputs with nutrient removal in grain (Table 1).

Crop	Yield	N kg/ha	P kg/ha	K kg/ha	S kg/ha
Canola	kg/t	40	6	8	4
	2.5 t/ha	100	15	20	10
Wheat	kg/t	21	3	3.5	1
	3.5 t/ha	75	11	12	4

Table 1: nutrient removal (kg/ha) in grain of a 2.5 t/ha canola crop compared to a 3.5 t/ha wheat (kg/ha)

A 2.5 t/ha canola crop will remove in grain the equivalent of about 80 kg/ha of mono-ammonium phosphate, di-ammonium phosphate or triple superphosphate in P, and up to 170 kg of urea to balance the N removal. However, there is quite a bit more to developing a balanced nutrition program because the soil can supply some of these nutrients, while the season and the soil properties may mean that extra nutrients will be needed to account for losses and soil fixation.

Fertiliser *Best Management Practices* (BMPs), for canola or any other crop, can be described as the application of the right source (or product) at the right rate, right time and right place. The linkage of source, rate, time and place sits within good agronomic practice, such as effective weed, pest and disease control, and good and timely crop establishment. Under the Global "4R" Nutrient Stewardship Framework, the four "rights" (4R) convey how nutrient management, including fertiliser and manure use, can be managed to achieve economic, social and environmental goals (see Figure 1). While economic goals may dominate many of our production systems other aspects such as managing nutrient run-off or restricting nitrous oxide losses can moderate the optimum source, rate, time, place combination.

In estimating the fertiliser requirements for canola, Australian growers use a range of techniques including shallow and deep soil tests, field cropping history, plant testing for nutrient status, balance sheets based on nutrient removal, and test strips in fields to see whether adequate fertiliser has been applied. These tools are best be used in combination rather than in isolation from each other to develop a nutrient management plan for a high yielding canola crop.

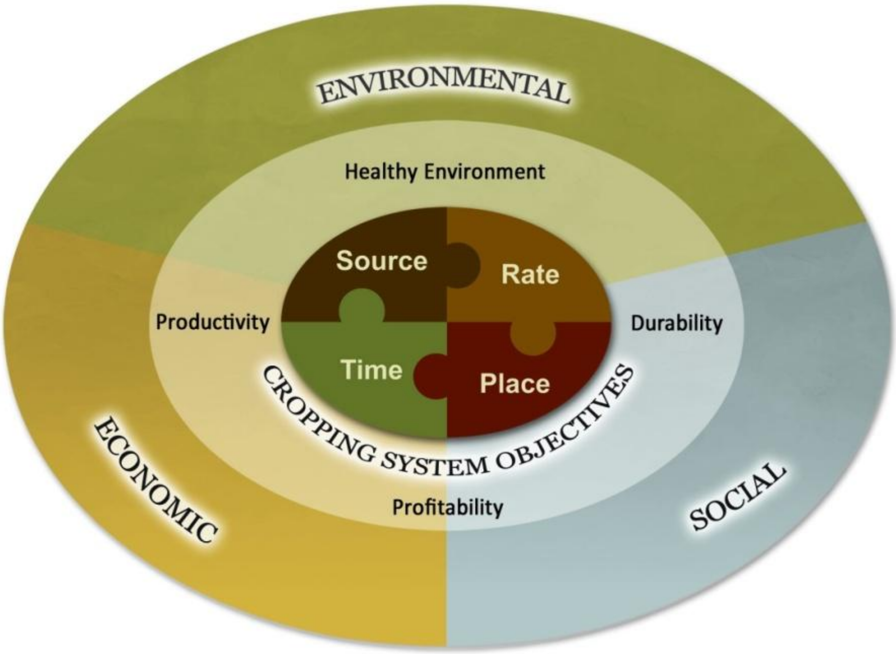


Figure 1: The 4R's approach to nutrient best management practice, to meet environmental, economic and social demands

In developing that plan, information will be collected from those tools above and then interpreted into an action plan, which should then be reviewed at the end of the crop year. In developing the plan, it is probably best to start with the nutrient most likely to be limiting, which in most of our cropping systems is nitrogen. Once a plan around that is made, the other macronutrients (P, K, S, Ca, Mg) should be balanced and then the likelihood of micronutrient shortages or toxicities assessed. This forms the basis of the plan.

1.1 Making a realistic yield estimate

In developing a balanced nutrition program for a canola crop, the demands of the crop and the ability of the soil to supply those resources should both be considered. Setting a realistic water limited potential will help assess the potential demand, and this can be done using simple water-use efficiency calculations, or by the use of more complex calculators such as Yield Prophet®. Table 2 gives an example of how to calculate a yield potential. Local knowledge and experience may be required to adjust potential yield to expected target yield. For example, if there are toxic levels of boron in the subsoil, the rooting depth of the crop may be reduced and the crop may not access water at depth in spring. This will mean a lower yield potential compared to a crop grown on a soil that did not have a subsoil limitation. Also, the rate of mineralization of N (and other nutrients) from organic matter is a function of rainfall and temperature, so the estimate in Table 2, supply estimate part B is a generalization used by many advisors, but will require local knowledge of seasonal rainfall patterns and soil texture to refine that aspect of the supply estimate.

1. Demand Estimate	2. Supply Estimate
A. Stored soil water at sowing Measured = 100 mm B. Estimated seasonal rainfall = 300 mm C. Water Use Efficiency WUE = 10-12 kg/ha/mm D. Non-productive Water Use (e.g. evaporation and drainage) SE = 120-170* mm E. Yield Potential WUE * (A + B –SE) = 10 x (400-120) = 2800 kg/ha = 2.8 t/ha F. N Demand = Yield x N content / Use Efficiency = 2.8 x 40 / 0.50 = **224 kg N**	A. Soil Mineral N at sowing Measured = 50 kg N/ha B. In crop mineralisation = Organic C% x Seasonal Rainfall / 6 = 1 x 300 / 6 = 50 kg N/ha C. N Supply = A + B = 50 + 50 = 100 kg N/ha ***Additional N required to support a 2.8 t/ha canola crop*** ***= 224 –100 = 114 kg N/ha***

* Use lower water use efficiency with higher non-productive water use and visa-versa.

Table 2: An example of a balance sheet approach to estimating crop N demand and soil supply, and therefore additional nutrient to be added to meet yield potential.

It is also important to ensure all the elements of good agronomic practice are in place. Even though canola can tolerate soil pH (calcium chloride) of 4.5 to 8.5, at higher pH zinc deficiency can be a problem. At lower soil pH, aluminium and manganese can be present at toxic levels and canola is particularly susceptible to damage from these micronutrients. Liming is the most effective treatment for these problems, and should target raising soil pH_{Ca} to above 5.0, which may require 1.0 to 2.5 t/ha of lime. The actual rate of lime required would depend on soil type, cation exchange capacity, initial pH, and the depth to which the acidity needs to be ameliorated. Lime should be incorporated to 10 cm two to three months before sowing if the paddock is to be cultivated. In zero-till farming systems, lime will need to be applied 12-18 months before rotating into canola. Liming can reduce the availability of boron, and the larger the amount of lime applied, the greater the chance of seeing a boron deficiency. Canola is particularly sensitive to boron deficiency. On the other hand, liming will increase the availability of molybdenum but reduce the potential for manganese and aluminium toxicity.

While a balance sheet approach is most appropriate for nutrients like N and S, because of the reactive nature of phosphorus, potassium and some of the micronutrients, soil tests to determine if sufficient nutrients are available is are recommended. Doing a balance sheet for phosphorus and potassium is difficult without a well calibrated soil test, because nutrient exchange between soil nutrient pools with low, medium or high availability can differ due to fertiliser history and soil properties such as pH, texture and organic matter content. A well calibrated soil test gives an estimate of the potential to get a response to added nutrients. However, in general soil tests for P such as Colwell, or for K such as ammonium acetate extractable (exchangeable) do provide reliable indicators of yield response.

Soil tests for micronutrients are less reliable than tests for the macronutrients, and the diagnosis of potential micronutrient responses may require a combination of soil type, test strips and plant tissue tests. In some areas, multiple nutrients can be lacking, and so unless all the deficient nutrients are added, test strips may not be a reliable indicator of response. In summer rainfall areas, the subsoil can lack P, S, K and micronutrients, so unless a test strip addresses all of limitations, the crop not achieve its water limited yield potential.

Close observation will also assist in the correct diagnosis of a shortage of a particular nutrient. Deficiencies of different nutrients result in a range of symptoms, and these can be useful when they appear, although sometimes the deficiency symptoms may only appear when the shortage is severe. Figure 2 gives a summary of the location of particular nutrient deficiency symptoms, and the tissues affected depend on the transport mechanisms of the different nutrients. For example, symptoms of N deficiency occur in the older leaves because it is remobilised to the younger leaves.

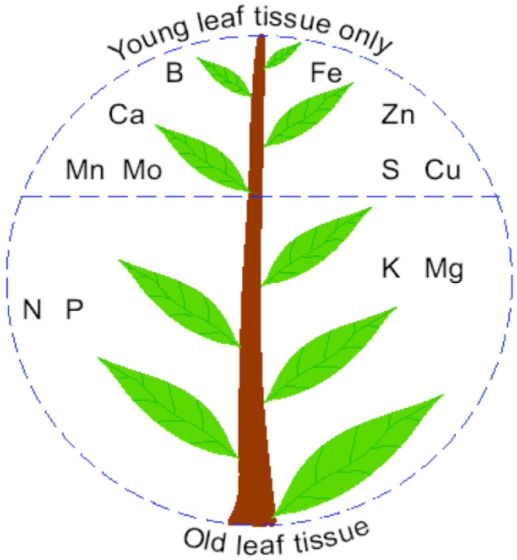


Figure 2: **Generalised diagram of the location of symptoms as a guide to diagnosis**

2. NITROGEN

Nitrogen management is a key part of achieving water limited canola yields. As a general rule, if canola follows a long legume based pasture phase, soil mineral N levels will be high and extra N may not be needed. Within more intensive continuous cropping systems, large applications may be required and symptoms of deficiency can be seen in the lower leaves (Image 1). A nutrient budget is a useful place to start with developing a N strategy. The overall N rate can be assessed based on the yield potential, estimated soil nutrient supply and the expected nutrient use efficiency. Yield potential can be set based on previous experience or using the water use efficiency guide used in the example given in Table 2.

Source: IPNI

Image 1: Typical symptoms of N deficiency in canola showing yellowing of the lower leaves

There are regionally developed decision support tools that can assist in selecting the right rate for N. For example, the SYN – Select your nitrogen (DAFWA) tool can help calculate N requirements for different rotations and seasonal conditions.

2.1 Selecting the right N rate

Nitrogen supply can be estimated from the measured soil mineral N content within the crop rooting depth plus the expected amount of in-crop mineralisation, which is where mineral N is released as soil organic matter breaks down. Growers will also need to make an estimate of nutrient use efficiency, as a canola crop will require 2 to 2.5 times the amount of N removed in the grain. Nitrogen use efficiency can be expressed in several ways, but for this case it is the amount removed divided by the amount supplied from soil and fertilizer.

Experience can help assess these variables, and the balance sheet approach helps select the right rate for N. Table 2 gives an example of the way in which N demand can be estimated from the potential yield, and how to calculate potential N demand. In that example, the demand is 114 kg N more than the expected supply, so that to ensure the crop is not N limited, that amount of N would need to be supplied.

2.2 Selecting the right N time

Nitrogen is needed all the way through crop growth, with the largest demand when the crop is growing fastest during stem elongation. The objective of efficient N management is to match the rate of supply with the rate of demand, so that peak N supply corresponds to the peak growth phase. Ensuring adequate N is available early in the growth of the crop, and then top-dressing additional N as the season unfolds help match supply and demand. If the soil has 40-50 kg N in the top 60 cm, this should be adequate to get the crop through to the start of stem elongation although high vigour types such as hybrids may require additional N early in their growth. It is important to "read" the crop during this stage, taking particular note of paling of the older leaves, which is a sign the crop is limited by nitrogen.

There appears to be little or no yield penalty from split N fertiliser applications to canola (Table 3). With the first N application at or near seeding, the second N application can be made as late as at the flower buds visible stage. Split N applications to canola are useful if N fertiliser rates need to be varied according to seasonal conditions on difficult soil types.

One reason that N can be withheld until stem elongation is because the crop has a good capacity to recover if the stress is only mild. In the example in Table 3, the most important aspect was the total amount of N applied rather than the time at which it was applied. Crops supplied with luxury amounts of N early in growth can grow too tall and so risk lodging. Other important benefits from delaying N are the spreading of financial risk to later in the season. Using paddock test strips can also be a good way to assess if there will be a response to any extra N. Later applications can be made at the flower buds visible stage if the crop shows signs of N deficiency. Providing early N stress is not severe, applying N as late as the appearance of the first flowers can assist with crop yield (Table 3).

	Timing						
Rate	All predrilled	All at stem elongation	All at first flowers	Split early	Split late	Nil N	LSD (5%)
9 kg N	1.60	1.37	1.67	1.55	1.32	1.36	0.33
50 kg N	1.80	2.11	1.63	2.03	1.69		
90 kg N	2.11	2.30	1.92	2.10	2.16		

Source: Pritchard and Norton, 2012, Tactical Use of N in canola, Final project report, http://anz.ipni.net/article/ANZ-3150)

Table 3: The effect of split N applications on the yield (t/ha) of canola on a moderate fertility site in the Wimmera. Early applications were at stem elongation and late applications were at the appearance of the first flowers.

Particular care needs to be taken with canola and fertiliser placement at sowing as the seedlings can be damaged by both salt and ammonia as they develop. Damage is worst on dry coarse textured soils with wide rows and little disturbance of the soil as was seen in 2011 and 2012 with drying soils at sowing. Table 4 gives some guidance for seed row use of N with different row widths, soil textures and machinery.

The rates in Table 4 are based on N fertiliser placed in the seed row and this applies to any N source. From this, in a moist and medium textured soil, with 30 cm row spacing and narrow openers for example, the approximate "safe" rates for N would be 5 kg N/ha or about 10 kg urea/ha, or 25 kg DAP/ha or 50 kg MAP/ha. The same basic principles also apply to fluids, with the safe rate for UAN in the above example as 15 litres of UAN/ha. To check on safe rates contact your supplier, or see http://anz.ipni.net/article/ANZ-3076.

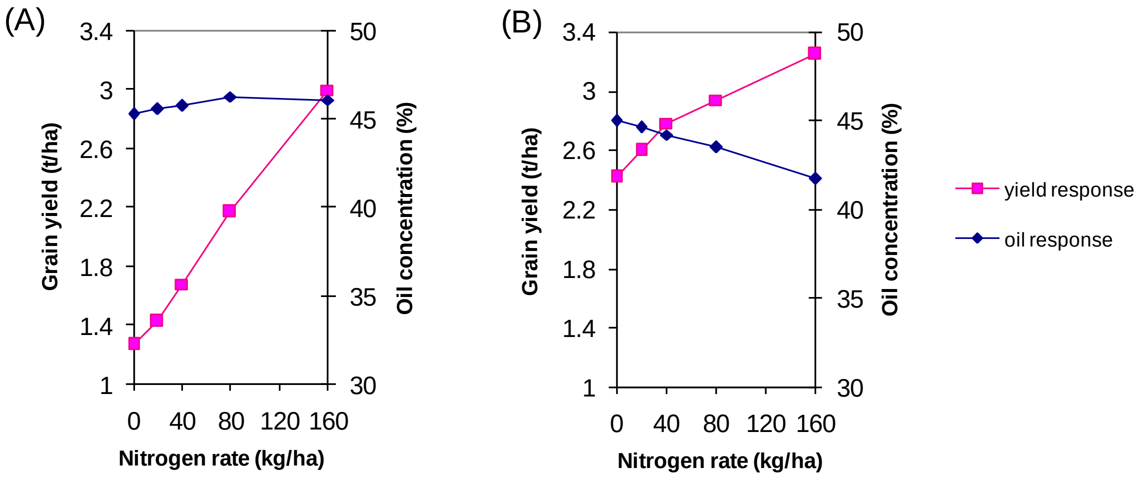
Opener and row spacing	Inverted T or similar narrow point/opener (25 mm spread)			Share or sweep with a lot of mixing (75 mm spread)		
Soil Texture	Row spacing			Row spacing		
	15	22.5	30	15	22.5	30
Light (sandy loam)	10	5	0	30	20	15
Medium (loam/clay loam)	15	10	5	40	30	20
Heavy (clay)	20	15	15	50	40	30

Sources: IPNI: http://anz.ipni.net/article/ANZ-3074, Pritchard, 2012, Ground Cover, Jan/Feb, 2012 (http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-96-January-February-2012/Plan-now-to-prevent-fertiliser-burn). Incitec Pivot Fertilisers, FertFact Guidelines for suggested maximum rates of fertilizer applied with seed In winter crops.

Table 4: For canola – typical safe N rates (kg N/ha) for in-furrow application for two tyne types at three row spacings (cm) on three soil types. This assumes a moist seedbed.

Alternative strategies are to pre-drill the N but this tends to be less efficient than splitting (Table 3), or to use equipment that can separate the seed and fertiliser bands at seeding. Equipment with twin chutes that give 2 to 3 cm distance between the bands, preferably below and to the side of the seed row, will enable higher rates of N to be used at seeding.

Plant tests based on critical nitrate-N and total N concentrations at various canola growth stages are available commercially to assist growers in monitoring the N status of their crops. The nitrate-N concentration in the petiole of the youngest mature leaf (YML) and the total N concentration in the whole shoot are used to assess the likelihood of a response to additional N fertiliser. The nitrate-N concentration is generally considered to be a more sensitive indicator than total N of the N status of the crop up until stem elongation. However, critical nitrate-N and, to a lesser extent, total N concentrations decline during crop development, so the value obtained for the crop needs to be compared to the critical concentration for the growth stage at the time of sampling. Critical tissue test values also vary with plant density and crop variety. Slower growing cultivars tend to have higher values than faster growing types, so it may become difficult to calibrate robust plant N tests.



Source: Hocking P, RM Norton, A Good 1999. "Canola nutrition.", In Canola in Australia – the first thirty years. (Eds. PA Salisbury, TD Potter, G McDonald, AG Green). (Organising Committee for the Tenth International Rapeseed Congress, Canberra). p. 15-22.

Figure 3: The effect of nitrogen fertiliser on seed yield and oil concentration at (A) Wellington and (B) Parkes in central New South Wales. In (A) N fertiliser increased yield but had no effect on oil concentration, whereas in (B) the N increased yield but decreased oil concentration at the higher rates.

Moderate rates of N fertiliser usually have little effect on seed oil concentration (Figure 3A), although high rates may increase seed protein and therefore reduce the oil concentration (Figure 3B). Even though oil content may decline, the increased seed yields due to N fertiliser more than compensate for any decrease in oil concentration. Seed fatty acid profile and glucosinolate contents of modern cultivars is largely unaffected by nutrition.

2.3 Selecting the right source

Growers generally apply the N fertiliser as urea plus a portion of the N in compound fertilisers such as MAP or DAP used principally as a P source at sowing. Granulated ammonium sulfate can also be used to supply both N and S, either at sowing or top-dressed. The fluid N source UAN can be applied in-furrow at seeding using specialized equipment, or sprayed on during growth. When applied to a canola canopy under good conditions, rates of up to 100 litres UAN/ha can be used. Leaf damage can be expected depending on rates used, environmental conditions, other products applied concurrently and the type of application equipment used. Application can be through flat fan or streaming nozzles, or using dribble bars. Flat fans usually cause more foliar damage than streaming nozzles or dribble bars.

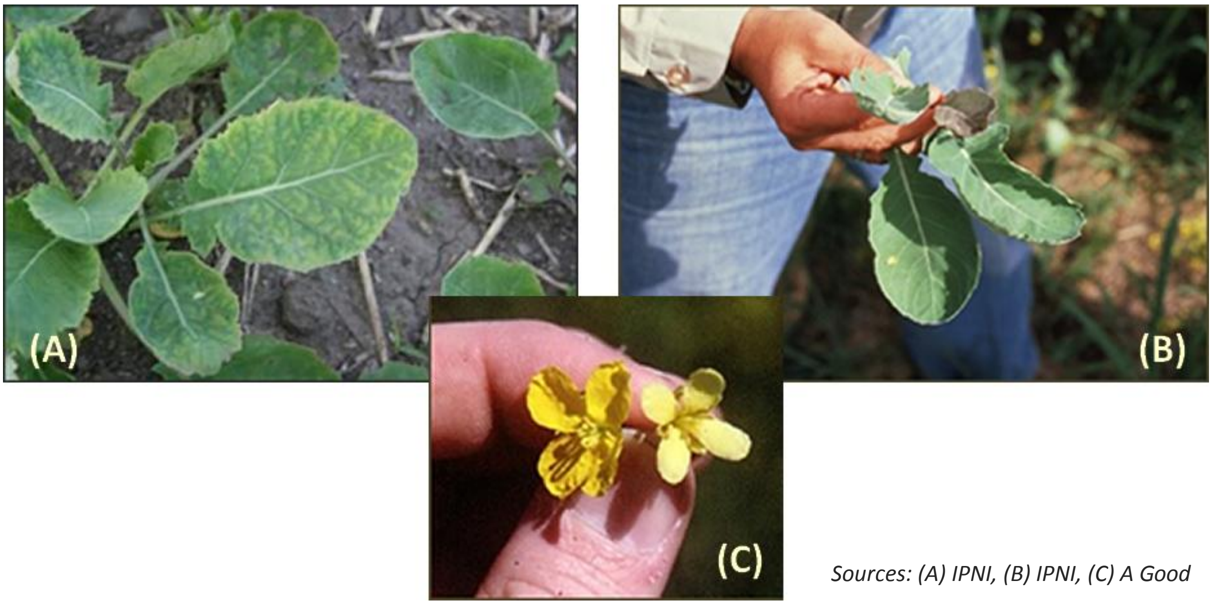
There appears to be little difference in yield response to the various fertiliser N sources so that landed price (including transport and application costs) is the dominant factor in determining the N source. However, it also seems that having other nutrients in the same granule can improve efficiency of nutrient use.

Enhanced efficiency N sources are becoming more common, and depending on the environmental conditions, their use can improve nitrogen use efficiency. Urease inhibitors slow the rate at which ammonia is produced from top-dressed urea particularly and preserve some N in the soil for plant use. Nitrification inhibitors reduce the rate at which nitrate is produced from ammonium, so reducing the potential for N losses through leaching or denitrification. Polymer coatings can reduce the rate of urea dissolution; so potentially better matching supply and demand. Under the appropriate conditions, where losses are avoided, using these products could provide similar yields to conventional products but at somewhat lower product application rates.

3. SULFUR

Sulfur deficiency has been seen in many canola production systems, mainly due to the reduced use of single superphosphate which contains 11% S as well as 9% P. Like nitrogen, sulfur in soil is present as the plant available form (sulfate), although the majority is present in organic matter. Sulfate, again like nitrate leaches down the profile with water movement. Deficiencies of sulfur are likely on soils with low organic matter, light texture and under high rainfall or flooding, and can occur even if a paddock has had a good superphosphate history. Irrigation water often contains significant amounts of sulfate so deficiencies are not common in that production system.

The right rate for sulfur will balance the soil supply with crop demand. Soil tests give a good estimate of soil supply on which to base fertiliser decisions. There are two topsoil mineral S tests, using either mono-calcium phosphate (MCP) or warm potassium chloride (KCl-40). Both give a good guide to the sufficiency of sulfur and current critical values for canola are 7-8 mg/kg, which is somewhat higher than the value for wheat, reflecting the higher demand by canola. Because sulfur is mobile, a deeper sample (0-10, 10-30, 10-60 cm) will give better information about the presence of deep sulfur that may meet the demand despite a low topsoil value.



Sources: (A) IPNI, (B) IPNI, (C) A Good

Image 2: Symptoms of sulfur deficiency in canola appear as yellowing (A) and cupping (B) of youngest leaves as well as paling of the flower colour (C).

Sulfur demand is quite closely linked to nitrogen demand, and removal of sulfur is about one seventh the removal of nitrogen. A budget approach similar to N can be used, taking into account soil mineral sulfate content and balancing that with an expected removal of S, which can be estimated as one seventh the amount of N. In the example in Table 2, the N removal of 112 kg suggests a S removal of 16 kg S. The supply from the soil plus fertiliser should at least balance that S removal.

3.1 The right sulfur source

The main P fertilisers used are either MAP or DAP, and the dominant N source is urea, and none of these contain adequate S to meet the demand by canola. As a result, supplementary S is often supplied as ammonium sulfate, although if applied even at moderate rates in the seed row this product has the potential to reduce emergence.

By-product or pit gypsum may also be used as a sulfur source but these sources have a lower solubility than sulfate S from ammonium sulfate. While gypsum is relatively cheap, it is important to ensure that a good quality product, with adequate sulfur and low salt content, is spread evenly, and that adequate rain occurs to dissolve and mobilise the sulfate. On acid soils, applying lime and gypsum gives a rapid dose of calcium and sulfur, as well as raising soil pH. On alkaline soils, there is no evidence that applying lime will have any effect.

Plants access sulfur as sulfate-S (SO42-) from the soil, and some fertilisers supply elemental sulfur, but this form is not water soluble and must be oxidised by soil bacteria to sulfate before it can be taken up by plant roots. The speed of this microbial process is governed by environmental factors such as soil temperature and moisture, as well as the particle size of the S.

Various approaches have been used to enhance the conversion of elemental S to plant-available sulphate. The speed of elemental S oxidation is directly related to the particle size, where smaller particles have a greater surface area for the soil bacteria to act on. Therefore, large particles of S may require months or years of biological action before oxidizing significant amounts of sulfate. Fine, dust-sized particles are oxidized quickly, but are not easy to apply. Very fine sulfur particles release S over weeks or months, and so products with blends of sulfate-S and elemental-S in a MAP matrix, can better match plant demand than products with only one of these sources.

3.2 The right time for sulfur

Sulfur deficiency symptoms can appear quite suddenly, particularly during stem elongation and when mineralization is low. Because sulfur is not mobile in the plant, symptoms appear in the youngest tissues and can show up as pale and cupped leaves, often with reddened leaf margins (Image 2). Canola can recover from mild nutrient stress, provided soil levels are not very low during early growth (Table 5), and a soluble sulfate source is applied before mid-stem elongation which is the period of peak nutrient demand. Reliable soil and tissue tests are available for evaluating the in-crop S status although sampling depth and subsequent S supply may result in topsoil or early season tissue tests indicating a low value but an incorrect potential response to further applied S. Critical tissue test values also vary with growth stage and the tissue selected for testing and like tissue N values can vary with plant density and cultivar.

S applied Kg/ha	Sowing	5-6 Leaf	Buds Visible	Stem Elongation	
10	1.73	1.62	1.56	1.41	LSD (p=0.05)
40	2.15	2.26	2.11	2.19	0.43

Source: Hocking PJ, A Pinkerton, A Good. 1996. Recovery of field grown canola from sulfur deficiency. Aust. J. Agric Res, 36:79-85.

Table 5: The effect of time and rate of top dressed sulfate-S on the yield of canola (t/ha).

Topdressing canola with ammonium sulfate (21%N, 24%S) has become a common strategy where both N and S deficiencies are being addressed. However, if the rate is targeted to meet the S demand, only a relatively small amount of N will be supplied, so that blends of urea and ammonium sulfate can be useful. There are also fluid N and S sources, such as ammonium, potassium, calcium or magnesium thiosulfates, which may have UAN added to increase the N supply, but due care needs to be used to avoid foliar damage with these products. In particular, the thiosulfate fluids should only be used as for soil application, where it converts to sulfate.

Because of the issues with applying both N and S in seed rows, there are other options to help address nutritional demands for canola by reviewing fertiliser strategies within the whole crop rotation. This is done by applying greater than needed rates of S in the seed-row fertiliser blend of less susceptible crops grown in the rotation. For example where canola is grown in a three-year rotation of canola-barley-wheat, higher rates of seed-row blends can be used in the cereals as they can tolerate higher rates of N contributed from the ammonium phosphate and ammonium sulfate components of the seed-row blend. An additional 5 kg S/ha can be safely applied during the two years of cereal crops and the total amount of required S (40 kg S/ha) over the three-year rotation is achieved by 10 kg S/ha in the canola year, 15 kg S/ha in the wheat year and 15 kg S/ha in the barley year. This is in comparison to trying to apply 20 kg S/ha in the canola plus only 10 kg S/ha in each year of the wheat and barley respectively. Where leaching losses are low, the S not used by the cereal crops remains in the soil and can be used by the canola crop.

4. PHOSPHORUS

For much of the cropping zone, phosphorus is a cornerstone of our current nutrient management, and the application of P fertiliser to crops, including canola, is routine. The application rate for canola varies from 10-15 kg P/ha in lower rainfall regions where yield expectations are about 1.0-1.5 t/ha, to 20-25 kg P/ha in higher rainfall regions where yields of 2.5-3.5 t/ha are expected.

Soils vary in their potential to fix P in forms that are only slowly available to the crop. This is measured as a Phosphorus Buffering Index (PBI), and soils with a high PBI (>300) will generally require higher rates of P each year because much of the phosphorus applied is tied up into forms that are not available to the crop. PBI only needs to be measured once for each soil type and that value can used be when considering P rates in subsequent years. Soils with a higher PBI will require more applied P to raise the Colwell P test value. High PBI values are generally associated with highly alkaline 'calcareous' soils such as in the Victorian Mallee and the Eyre Peninsula of South Australia, or on acid soils that have high levels of iron and aluminium.

Image 3: Symptoms of P deficiency in canola showing a reddened leaf margins on younger leaves.

Although the P requirement of canola is high compared to cereals, maximum yield responses on alkaline soils are sometimes attained at P rates similar to those for wheat. It appears that on these soils, canola roots secrete organic acids into the rhizosphere which dissolve some of the P 'fixed' in calcium phosphates, making it available for plant uptake.

Phosphorus deficiency in canola delays root development and maturity. This delay can push seed development into times when drought and heat stress are more likely. Poor P nutrition will also restrict the ability of the crop to respond to added nutrients such as N and S, and even mild deficiencies can reduce growth but without obvious symptoms. Under severe P deficiency, the older leaves will appear purple particularly on the tips and margins. Phosphorus fertiliser applied at commercial rates does not appear to have any effect on canola oil concentration.

4.1 The right time and place for P

Because P is relatively immobile in the soil, fertiliser P should be placed as close to the seed as possible, especially where soil P test levels are low. On soils that have high aluminium levels, P can be fixed quite quickly, and so banding the fertiliser can give an advantage by having less mixing with the bulk soil.

Crop demand for P peaks during crop establishment, early in the season, and most importantly, early P supply sets up the roots for later access to both water and nutrients. Later application with the currently available P sources is unlikely to produce economical responses.

Because of its poor mobility, top-dressing P after sowing rarely shows a crop response. In virtually all cases, the right time and place for P is at seeding, and near to the seed for maximum efficiency.

4.2 The right P source

The source of P that you choose should be specific to your soil and also your budget. The use of high analysis P sources such as triple superphosphate, MAP or DAP is now much more common than the use of superphosphate because of the higher nutrient density and so reduce costs of freight and handling. All these sources can be banded beside or below the seed at sowing to avoid chemical injury during germination. Although the straight P fertilisers are less prone to damage than the ammoniated phosphates, at high rates and under particular conditions they can still cause damage.

There has also been a lot of interest in using fluid P sources such as ammonium polyphosphate or phosphoric acid, and under certain conditions they do provide a benefit over MAP. This improvement is most common on alkaline calcareous soils with a high PBI. The presence of free lime is often a good indicator of where fluid P can be beneficial. A "fizz" test with a strong acid on the soil can help identify these soils.

Changing to fluid fertilisers requires a change in equipment to allow for their delivery to the seeding bar and into the soil along with the seed. These costs can be quite significant.

4.3 The right P rate

A number of soil tests are available to estimate P fertiliser responses, but most soil tests are based on the Colwell bicarbonate extraction procedure, along with a modification (the Phosphorus Buffering Index – PBI) which accounts for P losses as soil fixation. Periodic testing for Colwell P in the top 10 cm is a good way to estimate if there is sufficient P for the crop. Sampling for P should be done at about the same time of year and careful selection of sampling sites and depths will provide the best estimate of the sample to be submitted for testing.

Other soil tests, such as Olsen-P, Bray 1-P or Mehlich 3-P can useful, but by far the largest data set available for calibration is for the Colwell-P test, sometimes with an adjustment for PBI. On high PBI alkaline soils, the DGT-P test is giving some useful guidance, but at the moment the data sets for canola using this test are limited.

Based on the recent Better Fertiliser Decisions for Crops project, the critical range for 0-10 cm Colwell P for canola is 20-27 mg/kg, although the data used to define this limit is predominantly from Western Australia. This is lower than the critical range for wheat, indicating that canola is more efficient than wheat at accessing soil P reserves.

Using the Colwell soils test, or indeed any one assessment alone is not always the best way to determine the rate of P to apply to a crop. Rather, soil tests used over time in conjunction with nutrient application and product removal (balance method) may be a better strategy to judge crop P requirements. After initial testing, Colwell P can be used to estimate P levels for the next 4-5 years, however after this time it is best to retest the paddock.

5. POTASSIUM

Potassium, unlike other nutrients, does not form compounds in plants, but remains free to regulate many essential processes. These include enzyme activation, photosynthesis, water use efficiency, starch formation and protein synthesis. Adequate K nutrition also helps with increased disease resistance. Canola has a high K demand, although only modest amounts are removed in grain. The nutrient content of canola hay is four times the grain K content, and nutrient removal can be ten times higher if a canola crop is cut for hay compared to being harvested for grain.

Source: IPNI

Image 4: Symptoms of K deficiency in canola showing scorching of leaf margins in older leaves

The most common symptom of K deficiency is scorching or firing along the leaf margins, and this first appears in the older leaves of canola (Image 4). Deficient plants grow slowly and have poorly developed root systems, and even though the crop may not be tall, it will be liable to lodging.

Low soil K levels occur where there have been large off-takes of K, and particularly on light soils under high rainfall where K can be leached. There is little evidence of potassium deficiency in eastern Australian canola crops, although K deficiency has been reported in Western Australia. Most soils are well supplied with K, and deficiency of this nutrient in canola is only likely when it is grown on deep sandy acid soils in high rainfall regions, particularly if a heavy hay crop has been removed the previous season. As cropping moves into the high-rainfall zones, which generally have lower soil K levels than many of the lower rainfall areas, it would seem appropriate to consider K as part of a balanced nutrition program.

5.1 The right rate, time and place for K

Soil tests can provide guidance in both identifying areas where K responses are likely. The tests are either as ammonium acetate (exchangeable K, ex-K) or bicarbonate extractable K (Colwell K). Canola also has a higher demand for K than cereals, and typical values below which crops will respond to K are <30 mg/kg Colwell K, or <0.1 cmol(+)/kg for exchangeable K. The critical values are also affected by the cation exchange capacity (CEC) of the soil, with higher CEC soils (clays for example) showing higher critical values. This is because as the CEC of the soil increases, so does the K buffering capacity. Subsoils can also contain substantial K reserves, so sampling to the appropriate soil depth is also important.

In most situations, where soil test values are above critical levels, using a replacement strategy for K is appropriate. For the example given in Table 2, this would suggest an application of 8 kg K/t of grain removed is appropriate. Because the demand for K is relatively high early in crop growth and canola seems to have a limited capacity to recover from early K stress, the application of K ideally should be at or near seeding.

Muriate of potash (KCl, 50% K) is the most common K fertiliser used. It is soluble and easily handled, although can cause salt damage to sensitive crops if used at high rates in the drill row. For advice on safe in-row rates contact your fertiliser supplier, or see http://anz.ipni.net/article/ANZ-3076. Alternatively, muriate of potash could be safely applied within four weeks of sowing. Where other nutrients are required, alternative K sources are potassium sulfate, potassium nitrate, or potassium-magnesium sulfate (langbeinite), which supply additional sulfur, nitrogen and sulfur and magnesium respectively. Potassium nitrate is readily soluble and can be used in foliar applications if needed.

6. OTHER MACRONUTRIENTS

Most agricultural soils contain considerable amounts of Calcium (Ca). A good estimate is that each cmol(+) of exchangeable Ca is equivalent to 400 kg/ha to a depth of 15 cm. Many soils contain several tons of exchangeable Ca on cation exchange sites. Soil pH generally provides a good assessment of Ca levels in soils. Alkaline soils contain more Ca than acid soils, and even in soils where Ca is present as deposits of gypsum (calcium sulfate) or limestone (calcium carbonate), some of the Ca from these compounds will be available to the crop.

Although there is a widely held view that the base cation saturation ratios (BCSR) are important in defining soil health and nutrient status, the evidence shows that plant growth and yield is not impeded across a wide range of cation ratios. More important is the actual root zone concentration of these nutritionally important cations, however there are few reports of critical soil values in terms of either exchangeable calcium concentration or the calcium saturation percentage for temperate crops.

Calcium (Ca) deficiency occurs occasionally in Australian canola during early spring, particularly on acidic soils. The deficiency usually occurs when plants are waterlogged, and weather conditions are cold and cloudy, even though there may be adequate Ca in the soil. The main symptom of the disorder (called 'withertop' or 'tipple top') is the collapse of the inflorescence stalk tissue and subsequent withering of the flower head. However, the disorder is usually transient and its incidence patchy within a field, so it is considered to be of little economic significance. Liming to raise the pHCa to above 5.0 will also increase Ca availability and help reduce the incidence of 'withertop'.

There have been reports of low magnesium (Mg) levels in some canola crops particularly early in growth. However, it is generally considered that these are transient symptoms, which disappear once the root system reaches deeper into the subsoil where there is usually adequate Mg. If canola is likely to be grown on low Mg soils, then the use of dolomitic limestone prior to sowing is recommended. For a tactical response, there are some foliar Mg products, but check on local replicated field trials to make an assessment if this investment is really required.

Source D McCaffery, NSW DPI

Image 5: Calcium deficiency in canola showing as the collapse of the terminal growth tip

There is no evidence that adjusting the ratio of calcium to magnesium will have any effect on soil physical, biological or chemical fertility. It is important to have the soil levels above sufficiency rather than try to change their ratio to each other.

7. MICRONUTRIENTS

There is often a suggestion that once the supply of macronutrients is met, that the next level of yield will be through adding extra micronutrients. Yields will only increase if the correct diagnosis of a limiting micronutrient is made and addressed. Additional micronutrients applied tactically as foliar sprays may not be a large investment, but unless reliably diagnosed it will be money wasted.

At the other end of the spectrum is the occurrence of micronutrient toxicities. Where soil pHCa is less than 5.0, aluminium (Al) (Image 6) and manganese (Mn) toxicity can occur, and this can be rectified by liming to raise the soil pHCa above 5. 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 for ameliorating 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. Liming also reduces the potential for molybdenum (Mo) deficiency, although it can also increase the potential for boron (B) deficiency. 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.

Source: NSW DPI

Image 6: Symptoms of aluminium toxicity in a canola crop grown on an acid soil

There is also significant variation among canola genotypes for boron efficiency and manganese tolerance, although the responses of particular commercial lines are not known.

There are reports of deficiencies for B, Mn and Mo, and suggestions that copper (Cu), iron (Fe) and zinc (Zn) may also be issues in particular situations. Trace elements are often chemically similar to other elements and so there can be interactions among nutrients – where excess of one will induce a deficiency of another. Well documented examples are between phosphorus and zinc, and between sulfur and molybdenum. The literature is full of these types of interactions that may affect the response under certain conditions. Also some species, and even cultivars within species, can differ in their ability to access nutrients from soils.

Despite this considerable complexity, soil conditions can be a good guide to the potential for low availability of particular micronutrients. Soil pH is particularly important as it affects the plant availability of many nutrients. Waterlogging and drought, soil texture and organic matter content can also affect potential micronutrient availability. Table 6 gives a useful summary to check off particular nutrients under various soil and environmental conditions.

	Cu	Fe	Mn	Zn	B	Mo
pH > 7.0	---	---	--	---	**	++
pH < 5.5	++	+++	+++	+	--	--
water-logged soil	+	+	+	+		
drought	---	---	---	-	---	--
high organic C content	---	++	++	++	++	-
high P-content	-	---	-	---	-	+++
sand	---	---	--	---	--	-
compaction	+	++	+	+	+	+

Table 6: Soil factors affecting micronutrient availability. + indicates the factor increases plant availability, and – indicates a reduction in plant availability.

Soil tests for zinc, copper and boron are available but the caution with these tests (other than chemistry) is that often subsoil nutrient supplies can be more than topsoil, particularly with mobile nutrients (e.g. B). Copper and zinc are usually tested using the DTPA extractions method but the critical values for Cu vary for different species. Boron is tested from hot water or KCl extracts. There are no Australian data for soil test calibrations for Mo or Mn status. For all tests, often soil pH, organic C levels and clay contents may need to be included to make an assessment of the likelihood of deficiencies from a soil test.

The interpretation of soil tests is quite difficult because of low absolute values, sampling errors and analytical reliability. For example zinc critical soil test value is 0.75 mg/kg in alkaline soils, and while this can be accurately measured in the laboratory, the critical values are at the lower levels of confidence for predicting responses. In some cases, such as boron, the deficiency value is not very different to the toxicity value. As with all soil testing, it is important to use accredited laboratories that use ASPAC accredited methods for assessing nutrients – these tests are ones that have critical values established for Australian conditions.

Interpreting tissue concentrations requires a good understanding of the nature of the tissue content and yield relationship, and sometimes low tissue concentrations are a consequence of "yield dilution". Another major caution with tissue testing is about the timing of sampling of plant samples, as other reserves (e.g. deeper in the soil) may not yet be accessed and so false low tissue concentration can be indicated.

Micronutrients can be applied strategically as supplements to macronutrient fertilisers and/or tactically as in-crop treatments. Because of the potential for soil reactions reducing nutrient availability, it may be necessary to protect the micronutrients by the use of chelating agents such as EDTA. Different products have different efficiencies, and responses from well-designed field and glasshouse experiments should be considered when selecting an appropriate product. Depending on the particular micronutrient and soil conditions, there may be residual supply for several years following the use of micronutrient supplemented base fertilisers.

The use of foliar micronutrient is useful when root uptake is reduced and a rapid response is required, so that relatively low rates of micronutrients can be applied. The disadvantages of foliar application are that there is little residual activity and to avoid foliar damage only low concentrations can be used. Uptake is limited because only small quantities can be taken up through the stomata, leaf cuticles or parts of the epidermis, but if the nutrient (such as copper) is rapidly fixed in soils, it may an effective strategy. In general, the effectiveness of different micronutrient formulations is driven by solubility, with chlorides the most effective and oxides lease effective and sulfates intermediate. Chelated compounds when applied to foliage tend to be taken up slowly.

Even though the cost of some micronutrient applications is relatively low, it is important to monitor micronutrient responses within paddocks. Leave an area large enough to show up on a yield map as untreated and use this information to assess the effects of the use of this – or indeed any other – supplement to the nutritional program.

7.1 Boron deficiency

Description: Leaves become convex cupped with pale mottling, reddening and yellowing.

Impact: Reduced flower and pod numbers.

Contributing factors: Canola is susceptible to boron deficiency. Symptoms are more likely to occur during periods of moisture stress. Boron deficiency may become a problem as canola expands onto the acidic soils of the high rainfall tablelands of southern New South Wales, particularly where the soils are derived from granite, sandstone rocks and conglomerate parent material. These soils have low B levels, and the high rates of lime required to increase the pH of the soils to a level suitable for the crop could exacerbate B

Source: P Parker, NSW DPI

Image 7: Symptoms of boron deficiency in canola, showing pattern of abnormal shape of the leaf margins and necrotic patches in the leaf lamina of the younger leaves deficiency. Because B is mobile in the soil, low soil B (and therefore low tissue B levels in young plants) can result in high rainfall years.

Management: Canola has a high demand for B, maybe 10 times more than wheat, and B deficiency has been reported for canola grown on acidic soils in eastern Australia. The crops failed to set seed without supplementary B, whereas spraying with 0.6 kg B/ha at the start of stem elongation eliminated the deficiency. Even application of boron supplements is particularly important because there is a relatively narrow range between deficiency and toxicity.

7.2 Boron toxicity

Description: Reduced growth and stunting of growth, along with desiccation of the margins and tips of the leaves and patches of necrosis (dead tissue) in the lamina of the leaf (Image 7).

Impact: Boron toxicity restricts access of the roots to subsoil nutrients and water, which results in premature senescence and so yield loss.

Contributing factors: This occurs in some alkaline and sodic soils, where toxic levels of boron (>5 mg/kg hot water extractable) can occur at 30 cm or deeper in the soil.

Management: There is little that can be done about boron toxicity other than ensuring that other nutrients (such as N) are supplied at levels appropriate for the constrained root zone. The development of boron tolerant canola types is being investigated.

7.3 Copper deficiency

Description: Tissues begin to rot at the growing tips. Plant symptoms are often not present despite potential production losses although Image 8 shows some symptoms from a pot experiment.

Impact: Reduced pollen formation and pod set.

Contributing factors: Decline in soil available copper and soils with a low copper level. There are some reports of an induced Cu deficiency where relatively high N application rates are used and this suggests that micronutrient supply could be limiting under high yield potentials. In Canada, it is reported that canola is significantly more tolerant to Cu deficiency than wheat.

Source: R Holloway, SARDI

Image 8: Symptoms of copper deficiency in canola, showing pattern of paling of the younger leaves and necrotic patches in the leaf lamina

Management: Collect at least 100 youngest open leaves (YOLs) before flowering and analyse plant tissue for copper levels. If levels are deficient (less than 4 ppm) apply a foliar fertiliser. Actual rates depend on the formulation of the product, but are usually in the range of 250 g Cu/ha. Alternatively, applying 1.5 kg/ha of copper supplemented base fertilizer will give generally give several years of copper supply in the cropping system.

7.4 Manganese deficiency

Description: Whole plant becomes pale. A faint yellowing appears between the veins and is most prominent on the younger leaves. With severe deficiency the interveinal areas become yellow while the veins remain green (Image 9).

Source: M Mason DAFWA

Image 9: Symptoms of manganese deficiency in canola showing the paling of the younger leaves

Impact: Manganese deficiency in canola is likely on highly calcareous soils in South Australia and some deep sandy soils in Western Australia.

Contributing factors: High soil pH, especially where free lime is present. There are also differences in manganese efficiency among canola cultivars.

Management: Can be rectified by using manganese-fortified fertiliser or spraying manganese onto young plants. Foliar manganese can be more efficient than soil applied manganese as the latter can be complexed in iron or phosphate precipitates. Typical foliar rates would be 0.7 kg Mn/ha while rates for in-furrow application may be 20 kg Mn/ha, although the actual rate needed will vary with formulation and soil pH.

7.5 Manganese toxicity

Description: Cotyledons and leaf margins turn yellow, varying from pale to very intense yellowing of the leaves (Image 10).

Leaf margins die with reduced plant growth.

Impact: Reduced plant growth.

Source: D McCaffery, NSW DPI

Image 10: Symptoms of manganese toxicity in canola showing the paling of the younger leaves

Contributing factors: Highly acidic soils. More severe symptoms are seen where soils are warm and/or dry after sowing.

Management: Do not grow canola on soils below pHCa 4.5 where manganese toxicity is known to occur. Apply lime at the recommended rate to increase soil pH.

7.6 Molybdenum deficiency

Description: Molybdenum deficiency symptoms resemble N deficiency because Mo enables the plant to take up and metabolise N from the soil. Older and middle leaves become chlorotic first, and in some instances, leaf margins are rolled and growth and flower formation is restricted.

Impact: Reduced plant growth and poor nitrogen use efficiency.

Contributing factors: Highly acidic soils where the pHCa is less than 4.5.

Management: Strategically lime the soil to increase the pHCa above 5.0, and as a tactical intervention, use 0.05 to 0.10 kg Mo/ha as either sodium or ammonium molybdate to the soil or in-crop, or molybdate trioxide mixed with the starter fertiliser, added to lime or as a seed coating.

7.7 Zinc deficiency

Description: Plants are pale and stunted resulting in shortened internodes as the plants elongate. Plant symptoms are often not present despite potential production losses.

Impact: Zinc deficiency in canola will impair root growth and can severely depress seed yields.

Contributing factors: Decline in soil-available zinc and initial low zinc levels. Cold wet conditions. Some herbicides can exacerbate deficiencies in the crop.

Source: R Holloway, SARDI

Image 11: The symptoms of zinc deficiency in canola from a pot experiment

Management: Collect at least 100 youngest open leaves (YOLs) before flowering and analyse plant tissue for zinc levels. Where tissue levels are deficient or low (less than 20 ppm) apply foliar zinc at 0.25 kg Zn/ha. Chelated products can be more efficient that sulfate formulations, but this efficiency needs to be balanced against the relative cost of the products. Zinc at 2.0 kg/ha can be applied with at-sowing fertilisers, and the relative efficiency of different formulations varies with soil type.

8. INTEGRATED CANOLA NUTRIENT MANAGEMENT PLAN

1. Test the soil to find the potential restrictions, which will include soil pH, sodicity and maybe subsoil boron and salinity constraints.
2. Well before seeding, treat the soil with lime and/or gypsum to address those constraints where possible.
3. Soil test to assess levels of macronutrients, to root depth for N and S, and maybe for K. Topsoil test for P responsiveness.
4. Use soil type, soil test and paddock history to determine if there is a need for micronutrients, and then make the decision if this is to be addressed strategically with supplemented basal fertilizer, or tactically with in-crop foliar nutrients.
5. Build a fertilizer program by addressing the potential nutrient demand based on the target crop yield.
6. Start by getting P and K right at seeding, as there are no options for fixing P and some penalties for K in-crop.
7. Assess ongoing yield potential for N and S, and top-dress or not as the demand rises or falls.
8. Decide using appropriate tissue tests or the development of symptoms, and then ensure that untreated strips are left in the paddock if foliar or top-dressed nutrients are applied.
9. Consider grain analysis to check on N, S, P and micronutrient levels to assess off-takes.
10. Review the yield at the end of the season to assess if the crop was water or nutrient limited.