NORTHERN
FEBRUARY 2017

GRDC GROWNOTES™

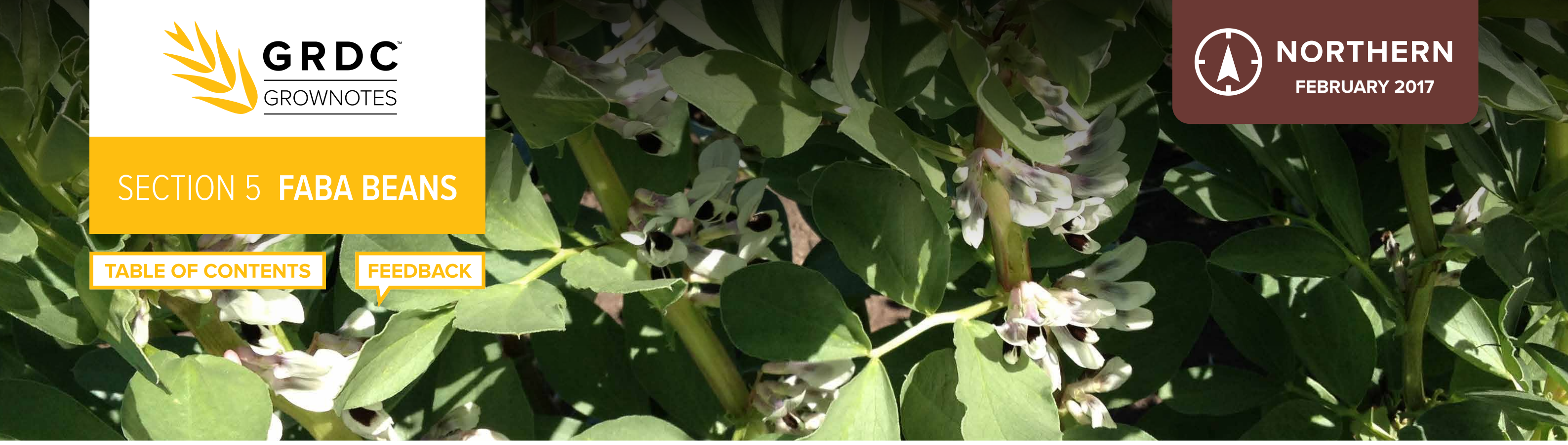
GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

FABA BEAN

SECTION 5

NUTRITION AND FERTILISER

DECLINING SOIL FERTILITY | CROP REMOVAL RATES | SOIL TESTING | NUTRITION | FERTILISER | ARBUSCULAR MYCORRHIZAE FUNGI | NUTRITION EFFECTS ON FOLLOWING CROP | REFERENCES



Nutrition and fertiliser

A balance of soil nutrients is essential for profitable yields. Fertiliser is commonly needed to add the essential nutrients phosphorus (P), potassium (K), sulfur and zinc. Lack of other micronutrients may also limit production in some situations.

Knowing the nutrient demand of crops is essential in determining nutrient requirements. Soil testing and nutrient audits assist in matching nutrient supply to crop demand. [1]

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.

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 (O_2). 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

1 P Matthews, D McCaffery, L Jenkins (2013) Winter Crop Variety Sowing Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/aboutus/news/all/2013/2013-wcvsg

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.

to utilise. Eventually a component of these residues will become resistant to further decomposition (resistant fraction Figure 1).

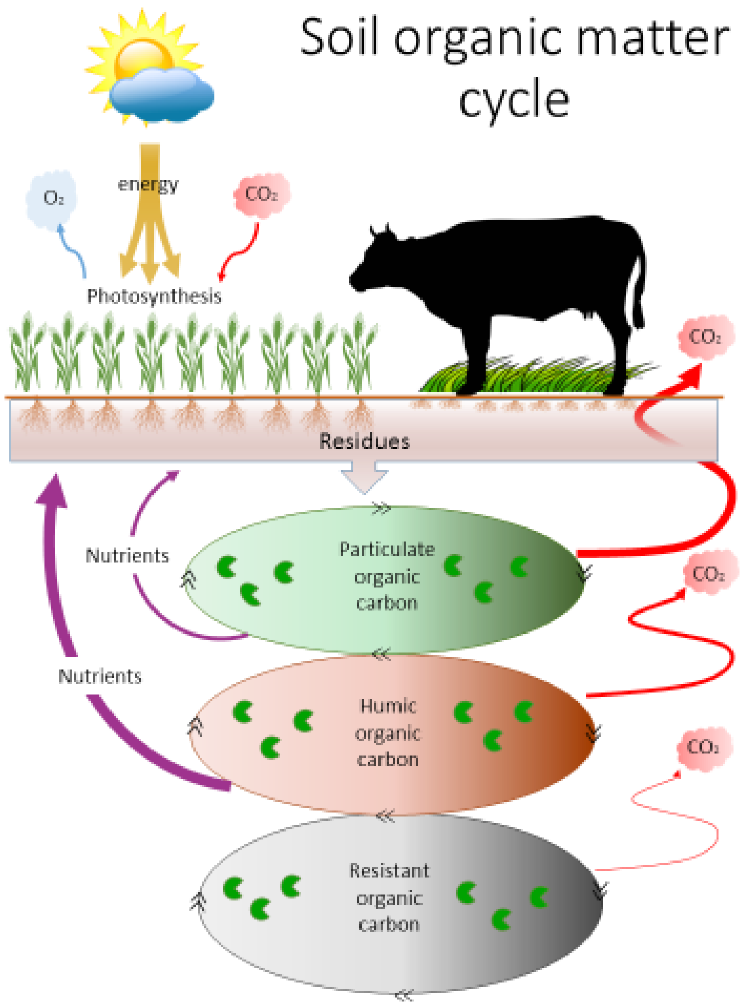


Figure 1: *Organic matter cycle*

Source: J Gentry, DAF

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 New South Wales 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 DAF (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

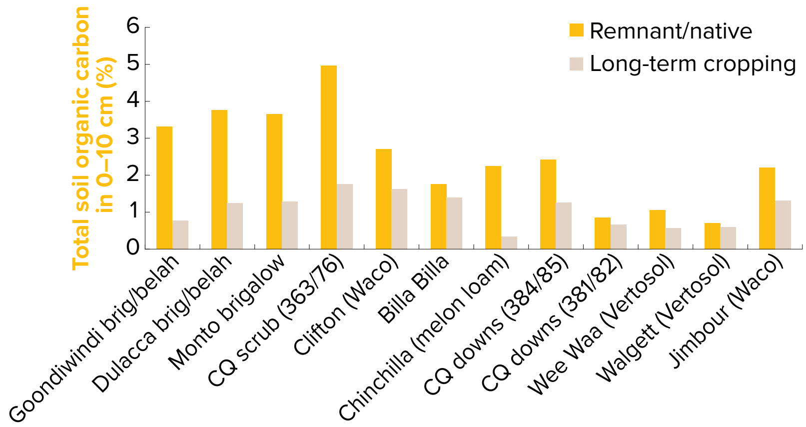


Figure 2: *The decline of soil organic carbon in long-term cropping systems 4*

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.

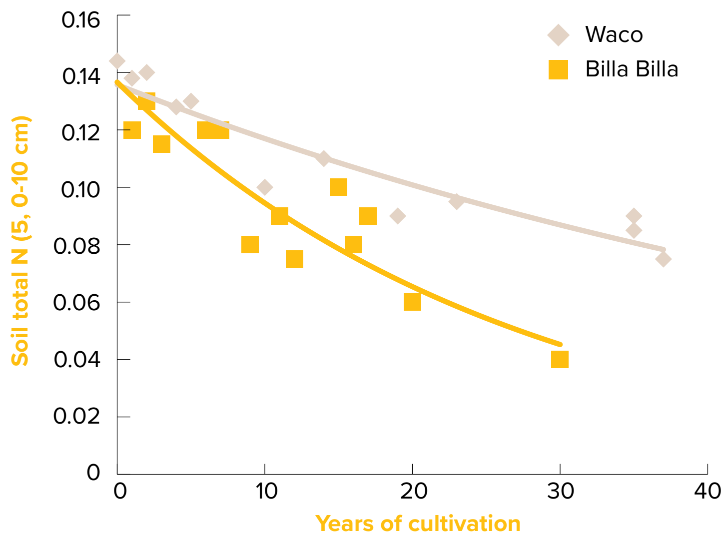


Figure 3: *Graph of decline in soil total N with years of cropping. The decline was greater for the Billa Billa soil (clay content 34%) than the Waco soil (clay content 74%)*

Source: based on Dalal & Mayer (1986a,b) [6]

4 DAF (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]

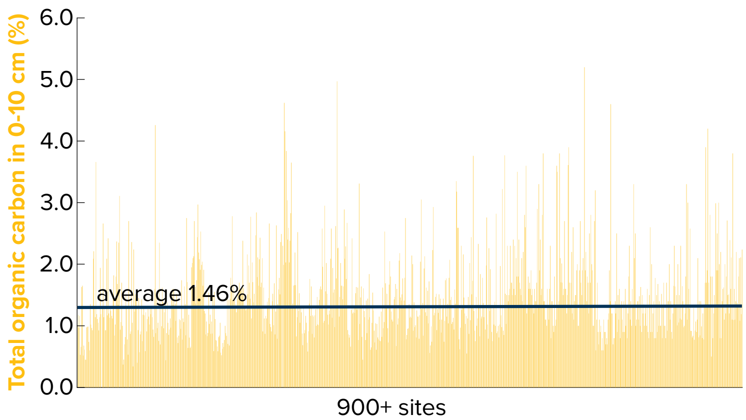


Figure 4: *Soil organic carbon levels on mixed farms within the GRDC Northern Region 9*

7 DAF (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 DAF (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 DAF (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

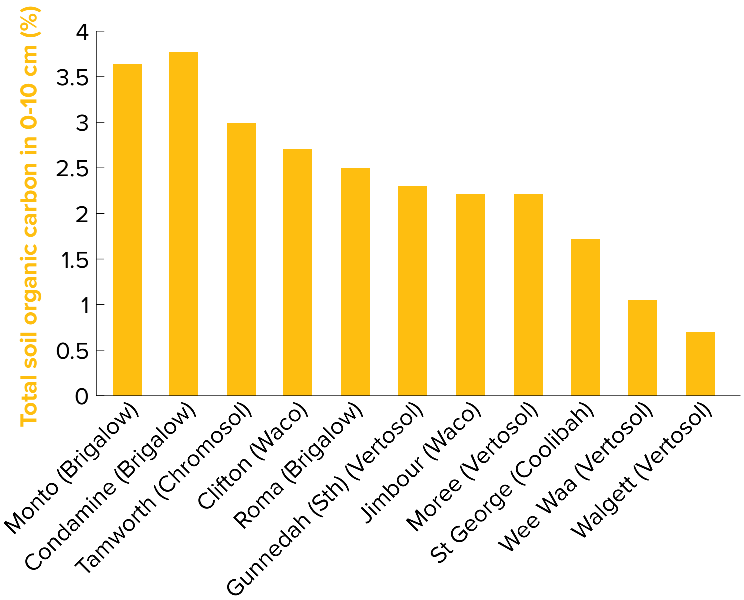


Figure 5: *Impact of land-type on total soil carbon levels (0–10 cm) across northern region 10*

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 DAF (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	Soil total N		Organic C	
		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	-

Source: Hossain et al. 1996a.

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 (DAF) 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 DAF (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

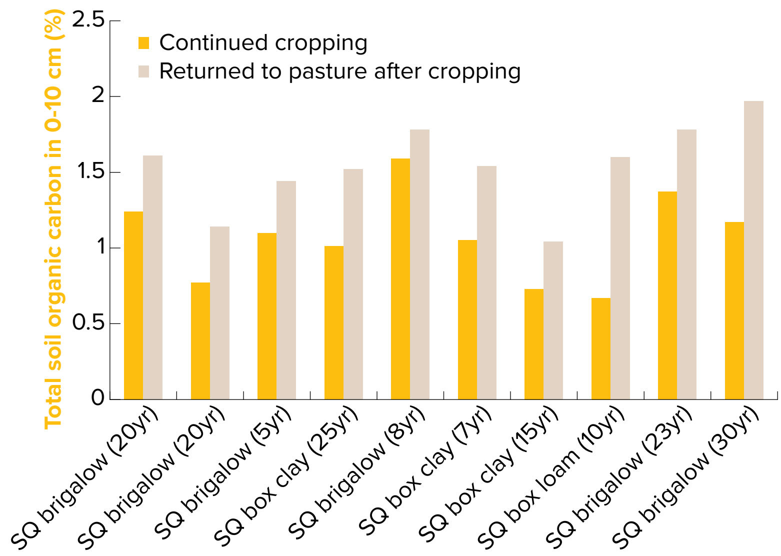


Figure 6: *Total organic carbon comparisons for croplands resown to pasture 15*

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 Crop removal rates

Balancing inputs

A balance-sheet approach to fertiliser inputs is a good starting point for considering the amount of fertiliser to apply to your faba bean crop. Other factors such as soil type, paddock history, soil test and tissue analysis results, as well as your own experience, affect the choice of fertiliser to be used.

The nutrients removed by 1 t of grain by the various pulses is shown in Table 1. Actual values may vary by 30% or sometimes more, due to the differences in soil fertility,

15 DAF (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

varieties and seasons. For example, the P per tonne removed by faba bean grain can vary from a low 2.8 kg on low fertility soils to 5.4 kg on high fertility soils.

From the Table 2, it can be seen that a 3 t/ha crop of faba beans will remove (on average) 12 kg/ha of P. This, then, is the minimum amount of P that needs to be replaced. Larger quantities may be needed to build up soil fertility or overcome soil fixation of P.

Table 2: *Nutrient removed by 1 t of grain.*

	N	P	K	S	Ca	Mg	Cu	Zn	Mn
Grain			**(kg)**				**(g)**		
Pulses									
Chickpea (Desi)	33	3.2	9	2.0	1.6	1.4	7	34	34
Chickpea (Kabuli)	36	3.4	9	2.0	1.0	1.2	8	33	22
Faba bean	41	4.0	10	1.5	1.3	1.2	10	28	30
Lentil	40	3.9	8	1.8	0.7	0.9	7	28	14
Lupin (sweet)	53	3.0	8	2.3	2.2	1.6	5	35	18
Lupin (white)	60	3.6	10	2.4	2.0	1.4	5	30	60
Field pea	38	3.4	9	1.8	0.9	1.3	5	35	14
Cereals									
Wheat	23	3.0	4	1.5	0.4	1.2	5	20	40
Barley	20	2.7	5	1.5	0.3	1.1	3	14	11
Oats	17	3.0	5	1.6	0.5	1.1	3	17	40

Source: Grain Legume Handbook.

Soil types vary in their nutrient reserves. For example, most black and red soils have sufficient reserves of K to grow many crops. However, the light, white sandy soils which, on soil test, have <50 µg/g (bicarbonate test) of K will respond to applications of K fertiliser. On some of the more highly sodic soils, K levels need to be higher to counteract the amount of sodium in the soil profile. Other soils may have substantial nutrient reserves that vary in availability during the growing season or are unavailable because of the soil's pH. This is often the case with micronutrients. Foliar sprays can be used in these cases to correct micronutrient deficiencies.

Nutrient budgeting

Even a simple nutrient budget, such as shown in Table 3, requires careful interpretation.

Table 3: *An example nutrient budget.*

Year	Crop	Yield (t/ha)	Nutrients removed (kg/ha)			
			N	P	K	S
2006	Faba bean	2.2	90	8.8	22	3.3
2007	Wheat	3.8	87	11.4	15	5.7
2008	Barley	4.2	84	11.3	21	6.3
2009	Chickpea	1.8	59	5.8	16	3.6
Total			**320**	**37.3**	**74**	**18.9**
	Fertiliser	**Rate (t/ha)**	**Nutrients applied (kg/ha)**			
			N	**P**	**K**	**S**
2006	0 : 20 : 0 (NPK)	50	0	10	0	1
2007	18 : 20 : 0 (NPK)	70	12.6	14	0	1
2008	18 : 20 : 0 (NPK)	70	12.6	14	0	1
	Urea	60	27.6	0	0	0
2009	0 : 16 : 0 : 20 (NPKS)	80	0	12.8	0	16
		Total	**52.8**	**50.8**	**0**	**19**
Balance			**–267.2**	**+13.5**	**–74**	**0**

Source: GRDC Grain Legume Handbook.

Nitrogen: The deficit of 267 kg needs to be countered by any N_2 fixation that occurred. This may have been 50 kg/ha per legume crop. It still shows that the N status of the soil is declining and should be increased by using more N in the cereal phase. Nitrogen fixation and application for faba beans is detailed below (see 5.5 Fertiliser).

Phosphorus: The credit of 13 kg will be used in the soil in building P levels, hence increasing soil fertility. No account was made for soil fixation of P.

Potassium: Because most Australian soils have ample K, drawing down the levels without replacing K is legitimate. However, some Australian cropping soils (usually white sandy soils) are showing responses to K, and applications should be considered to replace the K used by the crop.

Sulfur (S): The S inputs and removals are in balance.

Other nutrients such as zinc (Zn) and copper (Cu) can be included in a nutrient-balancing exercise. This is a useful tool for assessing the nutrient requirements of a cropping rotation; however, it needs to be considered in conjunction with other nutrient management tools such as soil and tissue testing, soil type, soil fixation and potential yields.

There are many fertilisers available to use on pulses. For the best advice, check with your local fertiliser reseller or agronomist.

5.3 Soil testing

It is a common belief that a soil or plant tissue test will show how much nutrient is required by the plant, but this is not so. A soil test will show only that, at a certain soil concentration, the plant will or will not respond to that nutrient. These tests are specific for both the soil type and the plant being grown.

MORE INFORMATION

http://www.grdc.com.au/Research-and-Development/Major-Initiatives/More-Profit-from-Crop-Nutrition

http://www.publish.csiro.au/pid/5352.htm

MORE INFORMATION

http://grdc.com.au/Resources/Factsheets/2013/11/Better-fertiliser-decisions-for-crop-nutrition

www.grdc.com.au/GRDC-FS-SoilTestingN

https://grdc.com.au/uploads/documents/Managing-N-for-Northern-Grains-Cropping.pdf

Experience suggests that the only worthwhile soil tests will be for P, K, organic matter, soil pH and soil salt levels. [17]

In northern cropping soils, nutrient deficiencies other than N are a relatively recent development. Consequently, less research has been conducted into nutrients in these soils and for the many crop types grown in northern cropping systems than in other regions. Most research has been done in wheat and barley.

For instance, research has highlighted that N applications can be wasted, even on cropping soils that have low N availability, if the levels of other nutrients such as K, P and S are not adequate. The importance of subsoil layers for nutrients such as P and K is not yet reflected in the limited soil test-crop response data available.

Researchers are currently using rough rules of thumb to help interpret P and K soil tests in terms of likely fertiliser responsiveness on northern region Vertosols. These values will be refined as more nutrient information becomes available during the second phase of the Grains Research and Development Corporation (GRDC) 'More Profit from Crop Nutrition' (MPCN) program.

5.3.1 Types of soil test

It is important to understand how faba beans will respond to different soil types and the background levels of nutrients required for the coming season requirements.

Appropriate soil tests for measuring soil extractable or plant-available nutrients in the northern cropping region are:

- bicarbonate-extractable P (Colwell-P), to assess easily available soil P
- acid-extractable P (BSES-P), to assess slower release soil P reserves and the build-up of fertiliser residues (not required annually)
- exchangeable K
- KCl-40 extractable S or monocalcium phosphate (MCP)-S
- 2 M KCl extractable mineral N, to provide measurement of nitrate-N and ammonium-N

The more consideration we give to all of the activities that contribute to the nutrient-management process (Figure 7), the better the outcome we will get from soil and plant testing. Testing may not provide a useful contribution if one or more of these activities is not done well. [18]

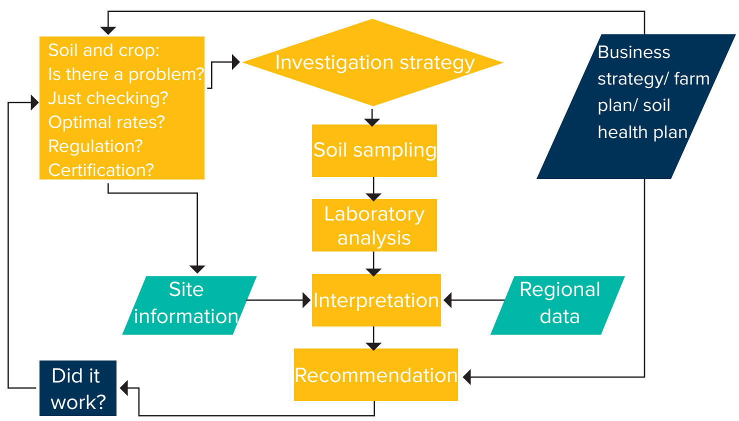


Figure 7: *Nutrient management flow chart.*

17 GRDC (1998) Nutrition. Grain Legume Handbook. GRDC, http://www.grdc.com.au/uploads/documents/4%20Nutrition.pdf

18 Northern Faba Bean—Best Management Practices Training Course 2014. Pulse Australia.

5.4 Nutrition

Too little or too much of a nutrient, or incorrect proportions of nutrients, can cause nutritional problems. If the condition is extreme, plants will show visible symptoms that can sometimes be identified. Visual diagnostic symptoms are readily obtained and provide an immediate evaluation of nutrient status. Visual symptoms do not develop until a major effect on yield, growth or development has occurred; therefore, damage can be done before there is visual evidence.

Healthy plants are more able to ward off disease, pests and environmental stresses, leading to higher yields and better grain quality. A plant tissue analysis can be important in detecting non-visible or subclinical symptoms, and in fine-tuning nutrient requirements. This is particularly helpful where growers are aiming to capitalise on available moisture.

Tissue tests also help to identify the cause of plant symptoms that are expressed by plants but not readily attributable. Technology is enabling quicker analysis and reporting of results to enable foliar- or soil-applied remedies to be used in a timely manner for a quick crop response.

Identifying nutrient deficiencies

Many nutrient deficiencies may look similar:

- Know what a healthy plant looks like in order to recognise symptoms of distress.
- Determine what the affected areas of the crop look like. For example, are they discoloured (yellow, red, brown etc.), dead (necrotic), wilted or stunted.
- Identify the pattern of symptoms in the field (patches, scattered plants, crop perimeters).
- Assess affected areas in relation to soil type (pH, colour, texture) or elevation.
- Look at individual plants for more detailed symptoms such as stunting, wilting and where the symptoms are appearing (whole plant, new leaves, old leaves, edge of leaf, veins, etc.).

If more than one problem is present, typical visual symptoms may not occur. For example, water stress, disease or insect damage can mask a nutrient deficiency. If two nutrients are simultaneously deficient, symptoms may differ from those when one nutrient alone is deficient. Micronutrients are often used by plants to process other nutrients, or work together with other nutrients, so a deficiency of one may look like a deficiency of another. For instance, molybdenum (Mo) is required by pulses to complete the N_2-fixation process.

MORE INFORMATION

http://www.publish.csiro.au/sr/SR9820265

Nutrient types

Plant nutrients are categorised as either macronutrients or micronutrients (also called trace elements or trace amounts).

Macronutrients are those elements that are needed in relatively large amounts. They include N, P and K, which are the primary macronutrients, with calcium (Ca), magnesium (Mg) and S considered secondary. Higher expected yields of crops for grain or forage will place greater demand on the availability of major nutrients such as P, K and S. Nitrogen, P and at times sulfur are the main nutrients commonly lacking in Australian soils. Others can be lacking under certain conditions. Each pulse type is different, has different requirements for nutrients, and may display different symptoms.

A balance sheet approach to fertiliser inputs is often a good starting point when determining the amount and type (analysis) of fertiliser to apply. A soil test, paddock history, soil type, and personal or local experience can all help. Tissue analysis can be helpful in identifying any deficiencies once the crop is growing, and can assist in fine-tuning nutrient requirement even when deficiency symptoms are not visible.

Micronutrients are those elements that plants need in small amounts, such as iron (Fe), boron (B), manganese (Mn), Zn, copper (Cu), chlorine (Cl) and Mo.

Both macro- and micronutrients are taken up by roots and they require certain soil conditions for uptake to occur:

- Soil must be sufficiently moist to allow roots to take up and transport the nutrients. Plants that are moisture-stressed from too little or too much (saturation) moisture can often exhibit deficiencies even though a soil test may show these nutrients to be adequate.
- Soil pH affects the availability of most nutrients and must be within a particular range for nutrients to be released from soil particles. On acid soils, aluminium (Al) and Mn levels can increase and may restrict plant growth, usually by restricting the rhizobia and thus the plant's ability to nodulate.
- Soil temperature must be within a certain range for nutrient uptake to occur. Cold conditions can induce deficiencies such as of Zn or P.

The optimum range of temperature, pH and moisture can vary for different pulse species. Thus, nutrients may be physically present in the soil, but not available to those particular plants. Knowledge of a soil's nutrient status (soil test) pH, texture, history and moisture status can be useful for predicting which nutrients may become deficient. Tissue tests can help to confirm the contents of individual nutrients in the plant. [19]

5.4.1 Balancing inputs

If the nutrients (P, N, Zn, etc.) that are removed in grain from the paddock are not replaced (via fertiliser), then crop yields and soil fertility will decline.

This means that fertiliser inputs must be matched to expected yields and soil type. The higher the expected yield and therefore nutrient removal, the higher the fertiliser input, particularly for the major nutrients (i.e. P, K and S).

For example, P removed by faba bean grain can vary from a low 2.8 kg/t on low-fertility soils to 5.4 kg/t on high-fertility soils.

5.4.2 Nutrient budgeting

Nutrient budgeting is a simple way to calculate the balance between nutrient removal (via grain) and nutrient input (via fertiliser).

For an accurate guide to nutrient removal, use analysis of grain grown on your farm. The best picture emerges when several years of a rotation are budgeted.

Because P is the basis of soil fertility and hence crop yields, all fertiliser programs are built on the amount of P needed. Table 4 shows examples of P rates required, and the rates of various fertilisers needed to achieve this.

There is a recent trend to use 'starter' fertilisers such as mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP) on pulses. Some growers are concerned that use of N on their pulse crop will affect nodulation; this will not occur with the low rates of N supplied by MAP or DAP. In fact, early plant vigour is often enhanced on low-fertility soils, and yield increases have been gained. [20]

19 Northern Faba Bean—Best Management Practices Training Course 2014. Pulse Australia.

20 Northern Faba Bean—Best Management Practices Training Course 2014, Pulse Australia.

Table 4: *Fertiliser application rate ready-reckoner (all rates are kg/ha) for some phosphate fertilisers used on pulses.*

P rate	Superphosphate						Legume Special 6 : 16 : 0 : 10 (NPKS)			MAP 10 : 22 : 0 (NPS)		DAP 18 : 20 : 0 (NPS)		Grain Legume Super 0 : 15 : 0 : 7 (NPKS)	
	Single 8.6% P		Gold Phos 10 18% P		Triple 20% P										
	Fert.	S	Fert.	S	Fert.	S	Fert.	N	S	Fert.	N	Fert.	N	Fert.	S
10	116	13	50	5	45	0.7	62	4	6	46	5	50	9	69	5
12	140	15	67	7	60	0.9	75	4	8	55	6	60	11	83	6
14	163	18	78	8	70	1.1	87	5	9	64	6	70	13	97	7
16	186	20	89	9	80	1.2	99	6	10	73	7	80	14	110	8
18	209	23	100	10	90	1.4	112	6	11	82	8	90	16	124	9
20	223	25	111	11	100	1.5	124	7	12	91	9	100	18	138	10
22	256	28	122	12	110	1.7	137	8	14	100	10	110	20	152	11
24	279	31	133	13	120	1.8	149	8	15	110	11	120	22	166	12

5.4.3 Detecting nutrient deficiencies

Soil tests are specific for both the soil type and the plant being grown (Table 5). The most useful soil tests are for P, K, organic matter, soil pH and salt levels. A test for S has now been developed. The pulse crops can have different requirements for K; hence, they have different soil test K critical levels.

Table 5: *Adequate levels (µg/g) for various soil test results.*

Nutrient	Test used		
Phosphorus			
	Colwell	Olsen	
Sand	20–30	10–15	
Loam	25–35	12–17	
Clay	35–45	17–23	
Potassium			
	Bicarb.-extractable	Skene	Exchangeable K
Sand	50	50 100	Not applicable
Other soils	100	–	0.25 cmol(+)/kg
Sandy loam	–	–	–
Faba bean	100–120	–	–
Field pea	70–80	–	–
Lupin	30–40	–	–
Canola	40	–	–
Cereals	30	–	–
Sulfur			
	KCl		
Low	5		
Adequate	8		

Source: Grain Legume Handbook.

Plant tissue testing can also be used to diagnose a deficiency or monitor the general health of the pulse crop. Plant tissue testing is most useful for monitoring crop health, because the yield potential can be markedly reduced by the time noticeable symptoms appear in a crop.

Several companies perform plant tissue analysis and derive accurate analytical concentrations; however, it can be difficult to interpret the results and determine a course of action. As with soil tests, different plants have different critical concentrations for a nutrient, and in some cases varieties can vary in their critical concentrations.

Table 6 lists the plant analysis criteria for faba beans. These should be used as a guide only, and plant tissue tests should be used for the purpose for which they have been developed. Most tests diagnose the nutrient status of the plants only at the time they are sampled, and cannot reliably indicate the effect of a particular deficiency on grain yield.

Table 6: *Critical nutrient levels for faba beans at flowering.*

Nutrient	Plant part	Critical range
Nitrogen (%)	YOL	4.0
Phosphorus (%)	YOL	0.4
Potassium (%)	YML	1.0
Calcium (%)	YML	0.6
Magnesium (%)	YML	0.2
Sulfur (%)	Whole shoot	0.2
Boron (mg/kg)	YOL	10
Copper (mg/ka)	YML	3.0–4.0
Manganese (mg/kg)	YML	<40
Zinc (mg/kg)	YOL	20–25

YOL, Youngest open leaf blade; YML, youngest mature leaf. Any nutrient level below the critical range will be deficient; any level above will be adequate

5.4.4 Diagnosing nutrient disorders

Table 7 summarises the symptoms of nutrient deficiencies in faba bean leaves of various ages.

Table 7: *Key to nutrient deficiencies in faba beans.*

Symptom	Old to middle leaves						Middle to new leaves					New leaves to terminal shoots					
Deficiency:	**N**	**P**	**S**	**K**	**Mg**	**Zn**	**N**	**Mg**	**Mn**	**Zn**	**B**	**Mn**	**Fe**	**Zn**	**Cu**	**Ca**	**B**
Chlorosis (yellowing)																	
Complete	x		x									x[#]	x				x[#]
Mottled	x	x	x		x					x	x						
Interveinal					x						x						
On margins			x		x												
Necrosis (tissue death)																	
Complete		x				x											
Distinct areas (including spotting)				x		x		x	x		x	x		x			
Margins													x			x	
Tips				x		x			x			x		x	x		
Pigmentation within necrotic (yellow) or chlorotic (dead) areas																	
Purple	x	x	x	x		x		x	x	x		x				x	
Dark green		x									x						
Brown		x	x						x		x	x	x	x			
Red					x						x			x			
Malformation of leaflets																	
Rolling in of margin				x				x					x			x	x
Wilting		x													x		
Twisting									x			x			x		x
Malformation of leaves																	
Cupping	x						x								x		
Umbrella formation								x			x						
Malformation of stems and roots																	
Internode shortening											x			x			x
Petiole collapse																x	
Root distortion											x		x			x	x

#, Mild

Source: Symptoms of nutrient disorders: faba beans and field peas. (Snowball and Robson 1991).

5.4.5 Nutrient toxicity

Soil pH has an effect on the availability of most nutrients. Occasionally, some nutrients are so available that they inhibit plant growth. For example on some acid soils, Al and Mn levels may restrict plant growth, usually by inhibiting the rhizobia and so the plants ability to nodulate (Table 8, Figure 8).

Table 8: *Pulse reactions to nutrient toxicities.*

	Boron	Aluminium	Manganese
Chickpeas	Sensitive	Very sensitive	Very sensitive
Faba beans	Tolerant	Sensitive	Sensitive
Lentils	Very sensitive	Very sensitive	Very sensitive
Lupins	Very sensitive	Tolerant	Tolerant
Field peas	Sensitive	Sensitive	Sensitive

Lentils and lupins are not usually grown on alkaline–high boron soils

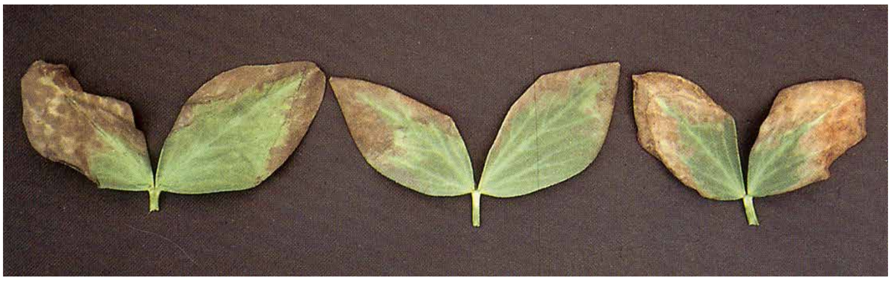


Figure 8: *Similarity of visual toxicity symptoms of manganese (left), boron (centre) and phosphorus (right) in old and middle leaves of faba bean.*

Photo: A. Robson

5.4.6 Boron toxicity

Boron toxicity occurs on many of the alkaline soils of the southern cropping areas. The most characteristic symptom of boron toxicity in pulses is chlorosis (yellowing), and if severe, some necrosis (death) of leaf tips or margins (Figure 9). Older leaves are usually more affected. There appears to be little difference in reaction between current varieties of faba beans.

Shallow (0–10 cm) and deep (10–90 cm) soil tests can be a good guide to the suitability of some soils for growing faba beans and to the toxicities that may affect plant growth and rooting depth.

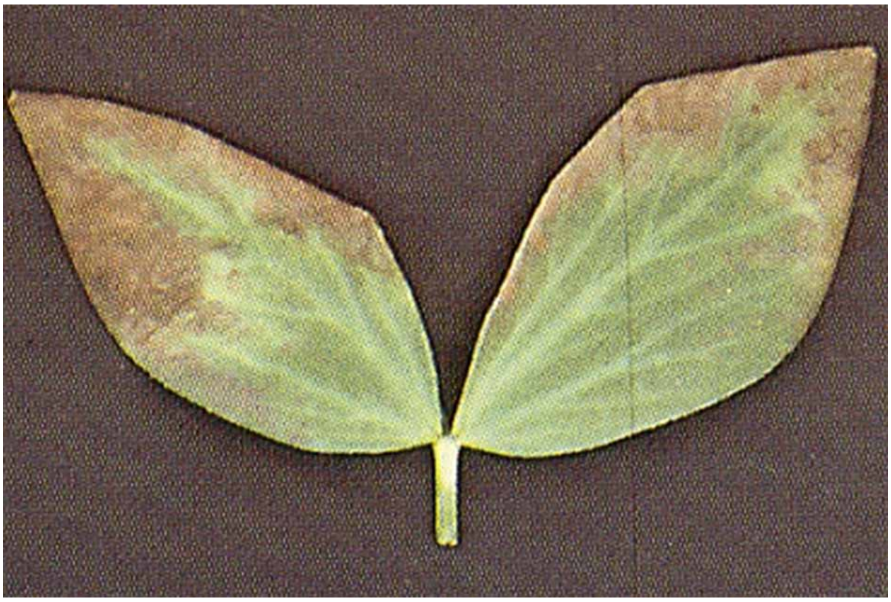


Figure 9: *Boron toxicity in old and middle faba bean leaves.*

Photo: A Robson

5.4.7 Manganese toxicity

Manganese toxicity can occur in well-nodulated faba beans grown on soils of low pH.

Symptoms

Symptoms appear on new leaves first and can then develop in middle-age and older leaves, the opposite to other toxicities such as Mn or P. Small purple spots appear from the margins on young leaves, and in slightly older leaves take on a reddish colouration (Figure 10).

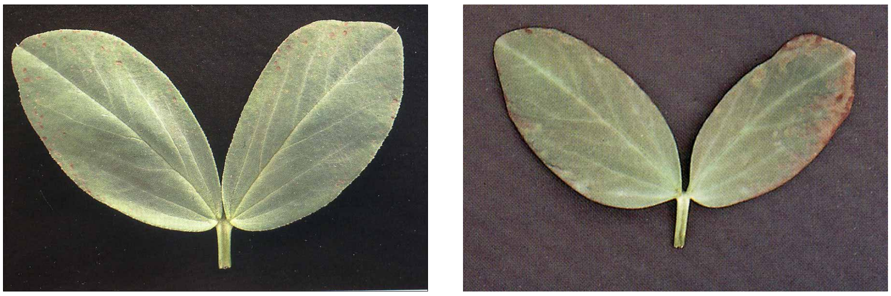


Figure 10: *Manganese toxicity in young leaves (left) and in middle-age leaves (right) of faba bean.*

Photos: A. Robson

5.4.8 Aluminium toxicity

Aluminium toxicity can develop in faba beans that are well nodulated but grown on soils of low pH.

Visual symptoms

There are no visual symptoms of Al toxicity in faba beans other than delayed germination and plants appearing miniature and dark green. Roots are extremely stunted, with many laterals appearing dead. Symptoms may be confused with P deficiency. [21]

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5.5 Fertiliser

5.5.1 Overview

Faba beans have a high P requirement. Phosphorus should be applied at rates of at least 12 and up to 22 kg/ha for this crop. On black soils of pH >8, Zn deficiencies can be caused by these high P rates. Zinc can be applied either with the fertiliser at sowing or as a foliar spray.

Faba beans appear more susceptible to K deficiency than other pulses such as peas and, especially, lupins.

Fertiliser recommendations for faba beans, as with most pulses, tend to generic, with an over-reliance on the recommendation of MAP-based starter fertilisers across nearly all situations. This is often based more on convenience and availability, rather than meeting the specific nutrient requirements of the crop.

Fertiliser recommendations need to be more prescriptive, and should take into account:

- soil type
- rotation (fallow length and impact on arbuscular mycorrhizae fungi (AMF) levels)
- yield potential of the crop
- plant configuration (row spacing, type of opener and risk of'seed burn')
- soil analysis results
- effectiveness of inoculation techniques

Molybdenum and cobalt (Co) are required for effective nodulation and should be applied as needed.

Soil P levels influence the rate of nodule growth. The higher the P level the greater the nodule growth.

MAP or DAP fertilisers can be used because fertilisers containing N in small amounts (5–15 kg N/ha) are not harmful to nodulation and can be beneficial by extending the early root growth to establish a stronger plant.

Excessive applied N will restrict nodulation and reduce N_2 fixation. High background levels of soil N can have similar effects or delay nodulation until N levels are depleted.

Inoculated seed and acidic fertilisers should not be sown down the same tube. The acidity of some fertilisers will kill large numbers or rhizobia. Neutralised and alkaline fertilisers can be used.

Acid fertilisers include:

- superphosphates (single, double, triple)
- fertilisers with Cu and/or Zn included
- MAP (also known as 11 : 23 : 0 and Starter 12)

Neutral fertilisers include:

- Super Lime

Alkaline fertilisers include:

- DAP (also known as 18 : 20 : 0)
- starter NP
- lime

5.5.2 Pulses and fertiliser toxicity

All pulses can be affected by fertiliser toxicity. Lupins are especially susceptible to higher rates of P fertiliser, which are toxic to lupin establishment and nodulation if drilled in direct contact with the seed at sowing.

Drilling 10 kg/ha of P with the seed at 18-cm row spacing through 10-cm points rarely causes problems. However, changes in sowing techniques to narrow sowing points or disc-seeders with minimal soil disturbance, and wider row spacing, have increased rates of fertiliser (all of which concentrate the fertiliser near the seed in the seeding furrow) and increase the risk of toxicity.

The effects are also increased in highly acidic soils, sandy soils and where moisture conditions at sowing are marginal. Drilling concentrated fertilisers to reduce the product rate per hectare does not reduce the risk.

The use of starter N (e.g. DAP) banded with the seed when sowing pulse crops may reduce establishment and nodulation if higher rates are used. On sandy soils, up to 10 kg/ha of N at 18-cm row spacing can be safely used. On clay soils, do not exceed 20 kg/ha of N at 18-cm row spacing.

Deep banding of fertiliser is often preferred for lupins, or else broadcasting and incorporating, drilling pre-seeding or splitting fertiliser applications so that a lower rate or no P is in contact with the seed.

5.5.3 Nitrogen

Fertilisation with N is unnecessary for faba beans, because the crop can meet its N needs through biological N_2 fixation in nodules formed on the roots, unless a nodulation failure has occurred.

On the other hand, soil nitrate inhibits legume nodulation and N_2 fixation. At low nitrate levels of <50 kg N/ha in the top 1.2 m of soil, the legume's reliance on N_2 fixation is generally high. As soil nitrate levels increase, legume nodulation and N_2 fixation become increasingly suppressed. However, the suppression effect is much less pronounced on faba beans than chickpeas.

Deficiency symptoms

First sign of N deficiency in faba beans is a general paleness of the whole plant, even before a reduction in plant growth. There may be a cupping of the middle to new leaves. With time, a mottled chlorosis of old leaves slowly develops with little sign of necrosis (Figures 11 and 12).

Check for nodulation and for whether nodules are fixing N_2 (nodule colour), to confirm suspected N deficiency from visual plant symptoms.

Figure 11: *Nitrogen deficiency—plants show signs of stunting, yellowing and poor growth relative to well-nodulated plants.*

Photo: W. Hawthorne, Pulse Australia

Figure 12: *When plants show signs of stunting, yellowing and poor growth, check nodulation and nodule colour to confirm nodulation failure and nitrogen deficiency.*

Photo: W. Hawthorne, Pulse Australia

Some situations where N fertiliser may warrant consideration include:

- The grower is unwilling to adopt recommended inoculation procedures.
- Late or low fertility situations, where rapid early growth is critical in achieving adequate height and sufficient biomass to support a reasonable grain yield (Table 9).

Table 9: *Nitrogen balance.*

Total plant dry matter (t/ha)	Total shoot dry matter yield (t/ha)	Grain yield (t/ha) 40% HI	Total crop nitrogen requirement (2.3% N) kg/ha	Nitrogen removal in grain (kg/ha)
1.75	1.25	0.5	40	17
3.50	2.50	1.0	80	33
5.25	3.75	1.5	120	50
7.00	5.00	2.0	160	66
8.75	6.25	2.5	200	83
10.50	7.50	3.0	240	100

HI, Grain harvest index—grain yield as a percentage of total shoot dry matter production (averages ~40%

Faba bean grain contains about 40 kg N/t.

5.5.4 Phosphorus

Deficiency symptoms

Symptoms of P deficiency take time to develop because of initial seed reserves of P. When symptoms start to appear, large differences in growth are apparent and smaller leaves compared with P-adequate plants. Visual symptoms appear first on the oldest pair of leaves as a mildly mottled chlorosis over much of the leaf. These symptoms could be confused with N or S deficiency, but middle and new leaves remain a healthy green, so the whole plant does not appear pale.

As symptoms on old leaves develop, round purple spots may appear within areas of dark green in an otherwise mildly chlorotic leaf (Figure 13).

Note that faba beans are deemed very responsive to P fertiliser, but Zn status must be adequate to achieve a P response. [22]

Figure 13: *Symptoms of phosphorus deficiency in old leaves of faba bean. Note the spotting within darker green areas of an otherwise mildly chlorotic leaf.*

Photo: A. Robson

22 Northern Faba Bean—Best Management Practices Training Course 2014. Pulse Australia.

5.5.5 Potassium

Deficiency symptoms

Older leaflets show symptoms first, and initially growth is stunted compared with other parts of the paddock, eg in old stubble rows. Older leaves show a slight curling and then a distinct greying of leaf margins, eventually dying (Figures 14–19).

Figure 14: *Potassium deficiency in faba beans. Note the necrosis of leaf margins and purple blotching.*

Photo: Grain Legume Handbook

Figure 15: *Potassium deficiency in faba bean (left and middle, alongside a plant with adequate K taken from the same paddock but from within old cereal stubble rows from the harvester.*

Photo: W. Hawthorne, Pulse Australia

Figure 16: *Potassium deficiency in Faba bean leaflet.*

Photo: A. Robson

Figure 17: *Potassium deficiency in faba beans. Note loss of lower leaves and general poorer height and vigour compared with K-adequate plants from the same paddock shown in Figures 18 and 19.*

Photo: W. Hawthorne, Pulse Australia

Figure 18: *Faba beans with adequate potassium taken from the same paddock as Figures 17 and 19, but from within old header rows of canola stubble.*

Photo: W. Hawthorne, Pulse Australia

Figure 19: *Potassium deficiency in faba beans shows up as poorer strips between old header rows from canola stubble (centre right of shovel and far left). Healthy strips are where canola stubble was left by the harvester (centre left of shovel and far right). See Figures 17 and 18.*

Photo: W. Hawthorne, Pulse Australia.

Responses to K are unlikely on most black earths and grey clays; K fertilisers may be warranted on red earths (Ferrosols) but should be based on soil analysis.

Fertiliser responses are likely where soil test levels using the ammonium acetate test fall below:

- 0.25 cmol(+)/kg of exchangeable K on black earths and grey clays
- 0.40 cmol(+)/kg of exchangeable K on red earths and sandy soils

Applying 20–40 kg K/ha banded 5 cm to the side of, and below, the seed line is recommended where soil test levels are critically low.

Alternatively, blends such as Crop King 55 (NPK, 13 : 13 : 13) may be considered at rates of 80–120 kg/ha where K levels are marginal.

5.5.6 Sulfur

Deficiency symptoms

Youngest leaves turn yellow, and plants are slender and small (Figure 20).

Certain soil types are prone to S deficiency, e.g. some basaltic, black earths. On these soils with marginal S levels, deficiency is most likely to occur in double-crop situations where available S has become depleted to very low levels, for example when double-cropping faba beans after high-yielding sorghum or cotton crops.

Soil sampling to a depth of 60 cm is the recommended procedure to test for S. A soil analysis of available sulfate-S below 5 mg/kg (MCP test) indicates a likely response. Below 3 mg/kg is considered critically low.

Application of 5–10 kg S/ha will normally correct an S deficiency. Where soil P levels are adequate, a low rate of gypsum is the most cost-effective, long-term method of correcting S deficiency. Granulated sulfate of ammonia is another effective option where low rates of N are also required.

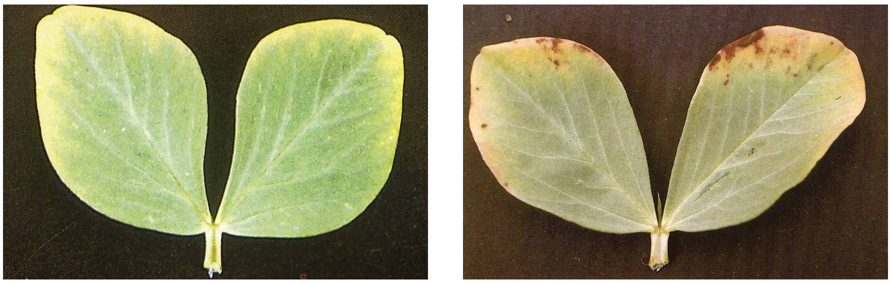

Figure 20: *Sulfur deficiency in faba beans shows up as chlorosis of leaf edges (left photo) and can progress to necrosis within those chlorotic areas (right photo).*

Photos: A. Robson

5.5.7 Zinc

Note that faba beans are deemed very responsive to Zn fertiliser, but P status must be adequate to achieve a Zn response.

Deficiency symptoms

Plants are small; the areas between veins turn yellow, becoming yellower on the lowest leaves. Maturity can be delayed (see Figures 21–25).

Faba beans are considered to have a relatively high demand for Zn, but have evolved highly efficient mechanisms for extracting Zn from the soil (similar to the previous discussion on P).

Foliar application of Zn is relatively common, often fitting in with herbicide or early fungicide applications.

There is a lack of Australian and overseas research on Zn responses in faba bean. Zn fertiliser recommendations are conservatively based on a general recommendation used for all crops, based on DTPA analysis of soil samples 0–10 cm:

- <0.8 mg/kg on alkaline soils
- <0.3 mg/kg on acid soils

AMF can be extremely important to Zn nutrition in faba beans, and responses can be expected in situations where AMF levels have become depleted after long fallows (>8–10 months).

Pre-plant treatments

Severe Zn deficiency can be corrected for 5–8 years with a soil application of zinc sulfate monohydrate of 15–20 kg/ha, worked into the soil 3–4 months before sowing.

Zinc is not mobile in the soil and needs to be evenly distributed over the soil surface, and then thoroughly cultivated into the topsoil.

In the first year after application, the soil-applied zinc sulfate monohydrate may be not fully effective and a foliar Zn spray may also be required.

Seed treatments

Zinc seed treatments may be a cost-effective option where soil P levels are adequate but Zn levels are likely to be deficient.

Broadacre Zinc (Agrichem)

Contains 650 g Zn/L and is applied as 4 L product /t seed. Pre-mix with 1 L water prior to application.

To minimise damaging effects on the rhizobia, Broadacre Zinc treatment needs to be applied first and then allowed to dry before applying the inoculum.

Broadacre Zinc is compatible with either Thiraflo or P-Pickel T®, and the two products can be mixed to treat faba bean seed in the one operation, should it be required.

Teprosyn Zn (Phosyn)

Contains 600 g Zn/L and is applied as 4 L product/t seed (pre-mix with 2–3 L water to assist coverage).

Apply inoculum first and allow to dry before applying the Teprosyn.

Fertilisers applied at sowing

A range of phosphate-based fertilisers contain, or can be blended with, a Zn additive.

Foliar zinc sprays

A foliar spray of 1.0 kg zinc sulfate heptahydrate + 1.0 kg urea + 1200 mL of a non-ionic wetter (1000 g/L) in at least 100 L water/ha will correct a mild deficiency. One or two sprays will need to be applied within 6–8 weeks of emergence.

Hard water (high in carbonate) will produce insoluble sediment (zinc carbonate) when the zinc sulfate is dissolved, with the spray mix turning cloudy. Buffer back with L1-700 or Agri Buffa if only hard water is available. Zinc oxide products are highly alkaline with pH 9.5–10.5.

Figure 21: *Zinc deficiency in faba beans.*

Photo: Grain Legume Handbook

Figure 22: *Zinc-deficient faba beans (left) and those with adequate Zn applied as solid fertiliser at seeding or earlier foliar application (right).*

Photo: Grain Legume Handbook

Figure 23: *Zinc-deficient faba beans (far left and centre right) are paler and poorer grown than those with adequate Zn applied (centre left).*

Photo: Grain Legume Handbook

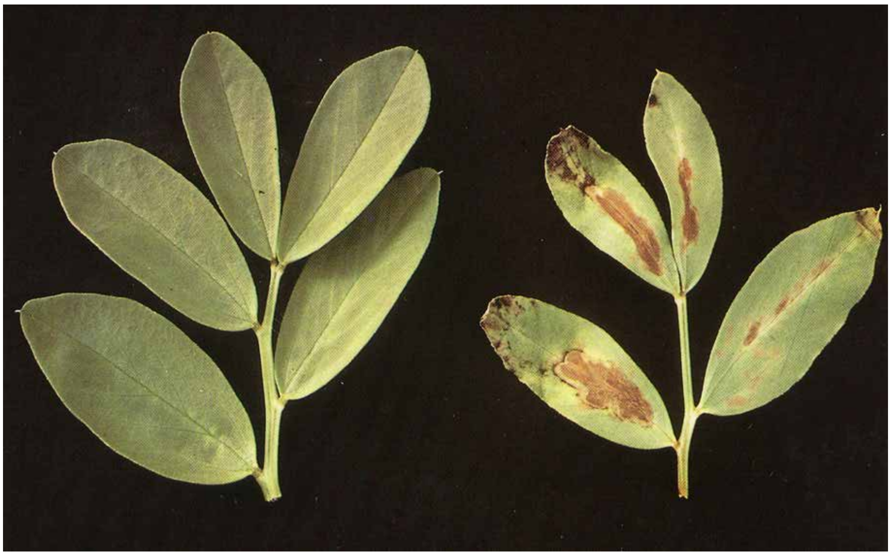

Figure 24: *Zinc-deficient middle leaves of faba bean (right).*

Photo: A. Robson

Figure 25: *Zinc-deficient leaves of faba bean—oldest to youngest (left to right).*

Photo: A. Robson

5.5.8 Iron

Iron deficiency can be confused with Mn and Mg deficiency. Iron is strongly immobile in plants.

Deficiency symptoms

Yellowing between leaf veins can progress to completely yellow plants (Figures 26 and 27). Contrast in colour between old and new leaves is much stronger with Fe deficiency than Mn deficiency.

Figure 26: *Iron deficiency showing in faba beans in wheel tracks.*

Photo: W. Hawthorne, Pulse Australia

Figure 27: *Bean varieties have different tolerances to Iron deficiency. Aquadulce (between the pegs) is more tolerant, but not immune compared to many other faba beans (e.g. left).*

Photo: Grain Legume Handbook

Occurrence and treatment

Iron deficiency is observed occasionally on alkaline, high pH soils. It is usually associated with a waterlogging event following irrigation or heavy rainfall, and is attributed to interference with Fe absorption and translocation to the foliage.

Symptoms include a general yellowing of young leaves, which can develop in severe cases to distortion, necrosis and shedding of terminal leaflets (pinnae).

A mixture of 1 kg/ha of iron sulfate + 2.5 kg/ha of crystalline sulfate of ammonia (not prilled) + 200 mL non-ionic wetter/100 L water has been successfully used to correct Fe deficiency.

The addition of sulfate of ammonia will improve absorption of Fe, with a significantly better overall response.

Cultivars exhibit marked differences in sensitivity to iron chlorosis, and major problems with Fe deficiency have largely been overcome through the efforts of the plant breeders. Whereas Tyson was highly sensitive to Fe deficiency, most current varieties are considered tolerant to all but extreme situations.

Iron deficiency symptoms tend to be transient, with the crop making a rapid recovery once the soil begins to dry out.

5.5.9 Manganese

Deficiency symptoms

Deficiency appears in new leaves, which first show mild chlorosis, followed by small dead spots or purple spotting at each side of the mid-rib and lateral veins. The leaves can turn yellow and die. See Image 4.22 to Image 4.25.

Some plants may have only a few brown spots on unopened new growth, where-as in other plants symptoms may extend to middle leaves and range from blackened tops of leaves and new growth to purple necrosis over much of the leaf (Figures 28–29).

Figure 28: *Manganese deficiency (right) in middle leaves of faba bean.*

Photo: A. Robson

MORE INFORMATION

For detailed descriptions and images of nutrient deficiencies 'Faba bean: The Ute Guide', available from the GRDC book shop on the GRDC website

Figure 29: *Manganese-deficient faba bean new leaves as they are opening (right).*

Photo: A. Robson

Figure 30: *Manganese-deficient faba bean new leaves and new growth.*

Photo: A. Robson

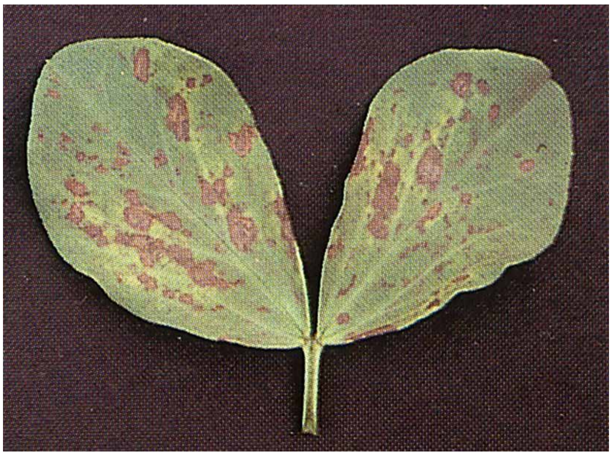

Figure 31: *Manganese-deficient faba bean middle leaf.*

Photo: A. Robson

Occurrence and treatment

Manganese deficiency is observed occasionally on alkaline, high pH soils. It is usually associated with a drier, fluffy soil conditions, for example rolled areas or wheel tracks in a paddock may appear healthy while the remainder shows Mn deficiency.

5.5.10 Copper

Copper has a role in cell wall constituents of plants.

Deficiency symptoms

Copper deficiency does not appear until flowering; hence, there is little effect on vegetative growth. The first symptom of Cu deficiency is an apparent wilting and rolling of the leaflet ends of fully opened leaves. Such symptoms of wilting are seen in other plants with Cu deficiency. Wilting symptoms are followed by a partial un-opening of new leaflets, which in some cases appear puckered and kinked over towards the leaf ends. If the deficiency is severe, wilting of fully formed leaves develops into a 'withertip', as often seen in Cu-deficient wheat. Tips of each leaflet become pale green with a dried-up appearance, and then become twisted and necrotic (Figure 32 and 33).

Flowering is not delayed in faba bean as it is in field peas, and flowers appear quite normal, but few pods and seeds form.

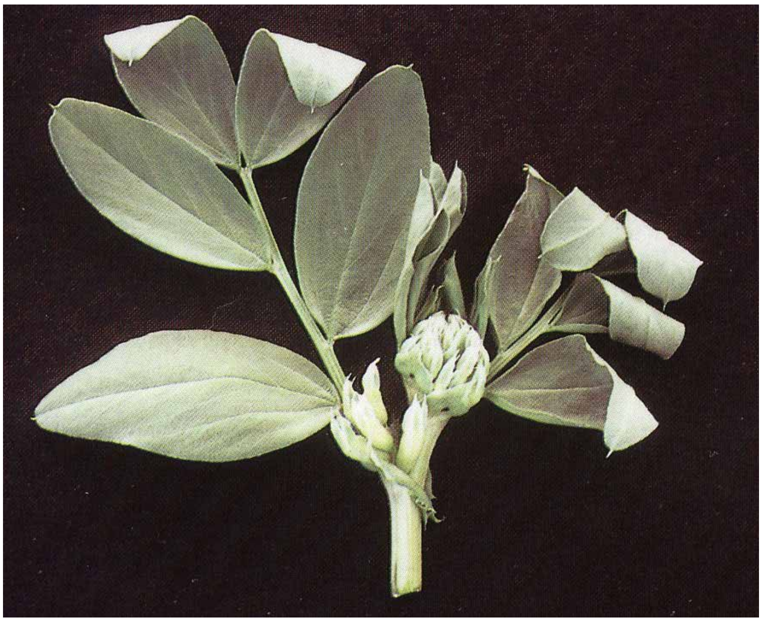

Figure 32: *Copper deficiency in faba bean new leaves showing 'withertip'.*

Photo: A. Robson

Figure 33: *Copper deficiency in faba bean new leaves (left) and fully opened leaves (right) showing 'withertip'.*

Photo: A. Robson

5.5.11 Molybdenum

Deficiency symptoms

Leaves are pale green and mottled between veins, with brown scorched areas developing rapidly between veins.

Molybdenum-deficient plants may contain high nitrate-N levels resulting from the inhibition of nitrate reduction to ammonia. The presence of high nitrate levels in a chlorotic, apparently N-deficient plant is thus evidence for Mo deficiency.

5.5.12 Boron deficiency

As with Ca, B has a dramatic effect on the root system of faba bean.

Deficiency symptoms

Roots become brown with lateral extremities showing shortening and thickening. The first leaf symptoms are a reduction in growth with a waxy look and a darkening of colour. This is followed by a folding back of these leaves in an umbrella fashion, leaving the leaflet folded over and twisted. Stem internode length is shortened. As the deficiency progresses, middle leaves develop a mottled chlorosis that forms between the veins (Figure 34).

Figure 34: *Boron-deficient leaves (youngest to older: right to left) of faba bean, with B-adequate leaf (left).*

Photo: A. Robson

As B becomes deficient, the vegetative growing point of the affected plant becomes stunted or deformed, or disappears. When this occurs, apical dominance of the growing point ceases to exert control over lateral shoot development. Thus, a proliferation of side shoots can occur resulting in a 'witches broom' condition. Deformed flowers are a common plant symptom of B deficiency. Many plants may respond by reduced flowering and improper pollination as well as thickened, curled, wilted and chlorotic new growth.

5.6 Arbuscular mycorrhizae fungi

The symbiotic relationships between some soil fungi and plant roots are known as arbuscular mycorrhizae (AMF; or vesicular-arbuscular mycorrhizae, VAM). These AMF can help plants to take up nutrients such as P and Zn from the soil and fertiliser. AMF colonise and build up on the faba bean root system. The fungi produce hyphae that colonise the root and then grow out into the soil (much further than root hairs). Phosphorus and Zn are taken up by the hyphae and transported back for use by the plant. AMF can build up to levels five times higher on chickpea root systems than on wheat.

Crops such as faba beans, chickpeas, safflower and linseed have a high AMF dependency and promote AMF build-up. Winter cereals and field peas are less AMF-dependent, but do allow AMF to build up. Canola, lupins and extended fallow do not host AMF, so AMF levels are reduced under these crops in rotation.

Faba beans are considered to have high crop requirement for P, and economic fertiliser responses to P are common. Therefore, AMF can be important in faba bean production and fertiliser responses.

Uptake of P can become far more inefficient in winter crops with:

- soils with critically low P levels (<6 mg P/kg) and no history of P fertiliser application; and.
- long-fallow situations with low AMF levels (≥10 months).

Products containing AMF are available as seed treatments, often in association with other seed enhancers, which in combination can give the most potent means to ensure a highly successful AMF spore inoculation. An example is Seed Enhancer™VAM from Ferti-Tech Australia Pty Ltd.

http://www.fertitech.com/site/DefaultSite/filesystem/documents/FTA%20Ferti%20Seed%20Enhancer%20VAM.pdf

High AMF situations

Where AMF levels are moderate–high (double-crop situations or short, 6-month fallows from wheat), consistent responses to applied phosphate fertiliser are more likely where soil bicarbonate-P levels fall below 6 mg/kg and are critically low.

Low AMF situations

Levels of AMF become depleted as fallow length is increased, or after crops such as canola or lupin, which do not host AMF growth (Table 10).

Where there are low levels of AMF (long fallows of >8–12 months), faba beans are expected to be very responsive to applied P and Zn. Faba beans will likely show a marked growth response to starter fertilisers, which likely translates into a positive yield response, depending on growth and onset of terminal drought stress in spring.

Table 10: *Effect of fallow length on arbuscular mycorrhizae (AMF) spore survival and maize yield with and without phosphorus + zinc.*

Fallow duration (months)	AMF spores (no./g soil)	Maize yield	
		–(P + Zn)	+(P + Zn)
21	14	2865	4937
11	26	3625	3632
6	44	5162	4704

Source: J. Thompson (1984).

5.7 Nutrition effects on following crop

5.7.1 Nitrogen

Northern grain growers sowed ~450,000 ha of chickpeas and 30,000 ha of faba beans in 2012, resulting in the fixation of ~35,000 t of N, worth A$55 million in fertiliser N equivalence. [23]

Agricultural legumes fix large quantities of N_2. Globally, the 185 million ha of crop legumes and >100 million ha of pasture and fodder legumes fix ~40 million t of N_2 annually (Herridge *et al.* 2008).

This represents a huge saving of fertiliser N that would otherwise need to be applied, and has positive economic and environmental consequences. Assuming 80% conversion of fertiliser N into plant N, the 40 million t of biologically fixed N_2 has a fertiliser-N equivalence of 50 million t, or about 50% of current global inputs of nitrogenous fertilisers. The nominal annual value of the fixed N_2 is about $63 billion (assuming cost of fertiliser N of $1.25/kg).

The situation for Australian agriculture is equally impressive. The 23 million ha of legume-based pastures are estimated to fix ~2.5 million t of N_2 annually, based on average production of 3.0 t/ha of legume biomass and rates of N_2 fixation of 110 kg N/ha (Table 11). Nitrogen fixation by the crop legumes is estimated at <0.2 million t annually. Using the assumptions above, the economic value of the N_2 fixed by legumes in our agricultural systems is >$4 billion annually.

23 GRDC (2013) Nitrogen fixation and N benefits of chickpeas and faba beans in northern farming systems. Northern Region. GRDC Nitrogen Fixation Fact Sheet, http://www.grdc.com.au/~/media/A16EDF6798064F419597DDFBC0B365E1.pdf

Table 11: *Estimates of the amounts of N_2 fixed annually by crop legumes in Australia.*

Legume	%Ndfa	Shoot DM[1] (t/ha)	Shoot N (kg/ha)	Root N_2 (kg/ha)	Total crop N (kg/ha)	Total N fixed[3] (kg/ha)
Soybeans	48	10.8	250	123	373	180
Lupins	75	5.0	125	51	176	130
Faba beans	65	4.3	122	50	172	110
Field peas	66	4.8	115	47	162	105
Peanuts	36	6.8	190	78	268	95
Chickpeas	41	5.0	85	85	170	70
Lentils	60	2.6	68	28	96	58
Mungbeans	31	3.5	77	32	109	34
Navy beans	20	4.2	105	43	148	30

%Ndfa, % of legume N derived from N_2 fixation

1 DM = dry matter
2 Root N = shoot N x 0.5 (soybeans), 1.0 (chickpeas) or 0.4 (remainder)
3 Total N fixed = %Ndfa x total crop N

Source: Primarily Unkovich et al. (2010). From D Herridge (2013) Managing Legume and Fertiliser N for Northern Grains Cropping (GRDC).

The major crop legumes in the northern grains region are chickpeas and faba beans. Local N_2 fixation data for the two legumes are consistent with the national data. In the NSW Department of Primary Industries (DPI) long-term farming systems experiments, faba beans fixed about 20% more N_2 than chickpeas (Table 12). Rates of N_2 fixation were less in on-farm surveys than in the experimental plots, but the differences between faba beans and chickpeas were consistent with faba beans fixing about 70% more N_2 than chickpeas.

Table 12: *Comparisons of N_2 fixation and yields of chickpeas and faba beans in crop-rotation experiments and on-farm surveys in northern New South Wales.*

	Soil sowing		Shoot		N_2 fixation	
Crop	Water (mm)	Nitrate (kg N/ha)	DM (t/ha)	N (kg/ha)	%Ndfa	Crop N fixed (kg/ha)
Long-term experiments[A]						
Faba beans	171	106	5.56	124	71	123
Chickpeas	171	95	5.21	98	53	105
On-farm surveys[B]						
Faba beans	163	54	4.57	121	60	100
Chickpeas	158	58	3.73	79	38	60

A Means of 18 site/years/tillage treatments; soil water and nitrate to depth of 1.2m (unpublished data of W. Felton, H. Marcellos, D. Herridge, G. Schwenke and M. Peoples)

B Means of 15 farmer crops; soil water and nitrate to depth of 0.9m (Schwenke et al. 1998)

Source: D Herridge (2013) Managing Legume and Fertiliser N for Northern Grains Cropping. GRDC.

Legume growth is the major driver of legume N_2 fixation (Figure 35). In the Australian environment, growth is mostly determined by the amount of water that the crop or pasture can access. Farmers cannot control the weather but they can optimise their management to capture and store the greatest amount of water in the soil, to keep soil nitrate levels as low as possible and to provide the legume with ideal, stress-free growing conditions.

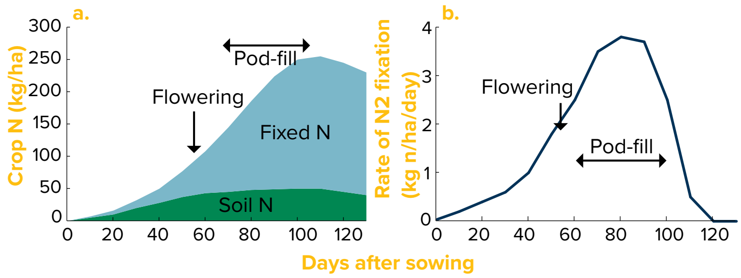

Figure 35: *Typical patterns of nitrogen accumulation and N_2 fixation by annual crop legumes. In (a), total crop N is shown to have two sources, soil N and fixed N, and the bulk of N accretion occurs after flowering. In (b), rates of N_2 fixation are shown to peak at 4 kg N/ha.day during mid-podfill, then decline as the crop matures.*

Source: D Herridge (2013) Managing Legume and Fertiliser N for Northern Grains Cropping. GRDC

Data from NSW DPI long-term rotation experiments in northern NSW show that no-till methods improve the productivity and N_2 fixation of chickpeas and faba beans. This is primarily due to increased soil-water retention and decreased soil nitrate accumulation during the summer (pre-crop) fallow.

In rotation experiments involving chickpeas, no-till soils had 35 mm more water available at sowing than cultivated soils and less nitrate-N by 15 kg N/ha (Table 13). The extra soil water resulted in about 16% more growth and the decreased nitrate-N increased the dependence of the chickpea crops on N_2 fixation (55% *v.* 44%). Total crop N_2 fixed was 43% higher (107 kg N/ha) in no-tilled chickpeas than in cultivated chickpeas (75 kg N/ha).

Similar results were achieved in trials with faba beans. No-tilled soils contained 38 mm more water than cultivated soils at the end of the summer fallows and less nitrate-N by 30 kg N/ha. Shoot dry matter, shoot N and crop N_2 fixed were 5%, 12% and 14%, respectively, higher in no-till crops.

Table 13: *Effects of tillage on soil water and nitrate-N at sowing, and chickpea and faba bean growth, grain yield and N_2 fixation.*

	Soil sowing (1.2m depth)		Shoot		N_2 fixation	
Tillage	**Water (mm)**	**Nitrate (kg N/ha)**	**DM (t/ha)**	**N (kg/ha)**	**% crop N from N_2 fixation**	**Crop N fixed (kg/ha) [B, D]**
Chickpeas[A]						
No tillage	144	71	5.4	95	55	107
Cultivated	109	86	4.7	82	44	75
Faba beans[B]						
No tillage	213	88	5.8	126	68	122
Cultivated	175	118	5.5	113	66	107

[A] means of 21 site/years of experiments
[B] Crop N calculated as shoot N x 2
[C] means of 9 site/years of experiments
[D] Crop N calculated as shoot N x 1.4

Source: Nitrogen Fixation Fact Sheet, GRDC 2013, http://www.grdc.com.au/~/media/A16EDF6798064F419597DDFBC0B365E1.pdf.

Benefits of nitrogen fixation

Crop legumes are usually grown in rotation with cereals, and the benefits to the system are measured in terms of increased soil total and plant-available (nitrate) N and grain N and yield of the subsequent cereal crop, all relative to a cereal–cereal sequence.

The N available to the cereal is a combination of the N mineralised as part of the decomposition of legume residues and soil humus and from applied fertiliser N. A fourth source of N is the mineral N not used by the legume during its growth, but spared. The residue N that is not released as mineral N remains in the soil as organic matter (Figure 36).

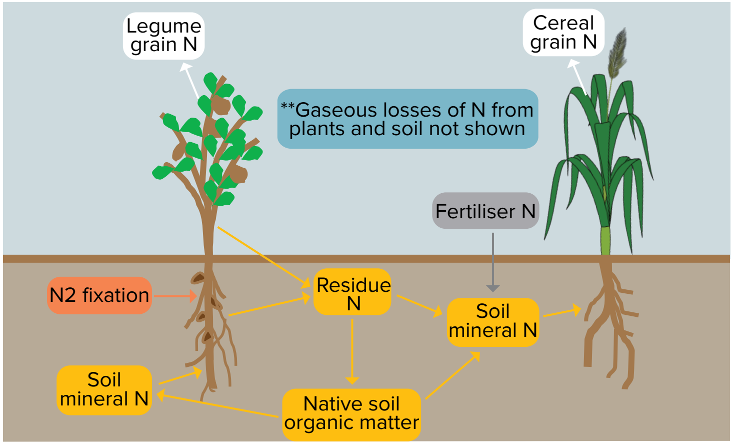

Figure 36: *Nitrogen cycling through a grain legume to the following cereal crop. Gaseous losses of N are not shown, nor are potential leaching losses. All of the flows of N are facilitated by the action of the soil biota.*

Source: D Herridge (2013) Managing Legume and Fertiliser N for Northern Grains Cropping. GRDC

Much research has now demonstrated that cereals grown after crop legumes commonly yield 0.5–1.5 t grain/ha more than cereals grown after cereals without fertiliser N. To generate equivalent yields in the cereal–cereal sequence, research has also shown that 40–100 kg fertiliser N/ha needs to be applied.

Results from more than a decade (60 sites × years) of chickpea–wheat rotation experiments conducted by NSW DPI researchers at North Star from 1989 to 1991 showed the clear financial and agronomic advantages that accrued from the legume. The research found:

Wheat following chickpeas outyielded wheat after wheat by an average of 0.7 t/ha in NSW trials and by 0.6 t/ha in Queensland trials. Wheat grain protein was increased by an average of 1 percentage point in NSW and 1.4 percentage points in Queensland.

Where water was not limiting, the yield benefit was >1.5 t/ha.

Nitrate supply was the major factor in the increased wheat yields. In NSW there was, on average, 35 kg more nitrate-N/ha in the top 1.2 m of soil after chickpeas than after wheat.

Chickpea yields were, on average, ~85% of unfertilised wheat and ~70% of N-fertilised wheat.

In the first year, chickpeas, unfertilised wheat (wheat 0N) and N-fertilised wheat (wheat 100 N) were grown in a soil with a moderate level of nitrate-N at sowing. The chickpeas fixed 135 kg N/ha and produced far more residue-N (133 kg N/ha) than either wheat crop (20–55 kg N/ha). The chickpea residues were also richer in N, with a C : N ratio of 25 : 1 compared with C : N ratios of 44 : 1 (wheat 100N) and 50 : 1 (wheat 0N) for the wheat residues.

The low C:N ratio of the chickpea residues meant that 16 kg mineral (ammonium and nitrate) N/ha was released into the soil during residue decomposition during the summer fallow. The wheat residues immobilised 21 to 22 kg mineral N/ha because additional N was needed by the break-down organisms for decomposition to occur. [24]

Table 14: *N and yield benefits of a chickpea-wheat rotation compared with unfertilised or N fertilised wheat-wheat. Values are the means of no-tillage and cultivated treatments at two sites in northern NSW.*

	Chickpeas - wheat 0N*	Wheat 0N - wheat 0N	Wheat 100N - wheat 0N**
Year 1 (chickpeas of wheat)	**Chickpeas**	**Wheat (0N)**	**Wheat (100N)**
Soil nitrate at sowing (kg N/ha, 1.2m depth)	67	67	67
Fertiliser N applied (kg N/ha)	0	0	100
Grain yield (t/ha)	2.3	2.3	3.2
Crop N fixed (kg/ha)	135	0	0
Residue N (kg/ha)	133	20	55
Residue C:N	25:1	50:1	44:1
Est. mineralisation or immobilisation (kg N/ha)	+16	-22	-21
Year 2 (wheat only)	**Wheat (0N)**	**Wheat (0N)**	**Wheat (0N)**
Sowing soil nitrate (kg N/ha, 1.2m depth)	102	53	74
Grain yield (t/ha)	2.8	1.7	1.8

* Wheat 0N = unfertilised wheat
** Wheat 100N = N fertilised wheat

Source: Nitrogen Fixation Fact Sheet, GRDC 2013, http://www.grdc.com.au/~/media/A16EDF6798064F419597DDFBC0B365E1.pdf.

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