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GRDC™ GROWNOTES™

GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

PEANUTS

SECTION 5

NUTRITION AND FERTILISER

DECLINING SOIL FERTILITY | NUTRITIONAL REQUIREMENTS | SOIL FERTILITY | CROP REMOVAL RATES | SOIL TESTING | NUTRIENT AVAILABILITY AND SOIL PH | CALCIUM | NITROGEN | PHOSPHORUS | SULFUR | POTASSIUM | BORON | COPPER | IRON | MAGNESIUM | MANGANESE | MOLYBDENUM | ZINC | CADMIUM MANAGEMENT

Nutrition and fertiliser

5.1 Declining soil fertility

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

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

5.1.1 Soil organic matter

Soil organic matter (SOM) is a critical component of healthy soils and sustainable agricultural production. Growers understand that crops grown in healthy soils perform better and are easier to manage. Soil organic matter is *'all of the organic materials found in soils irrespective of its origin or state of decomposition'* [2] that is anything in or on the soil of biological origin, alive or dead. It is composed mainly of carbon (C; approximately 60%) as well as a variety of nutrients (including N, P 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 C is released from the system along with any nutrients that are not utilised by the microorganisms. These nutrients are then available for plants to utilise. Eventually a component of these residues will become resistant to further decomposition (resistant fraction Figure 1).

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

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

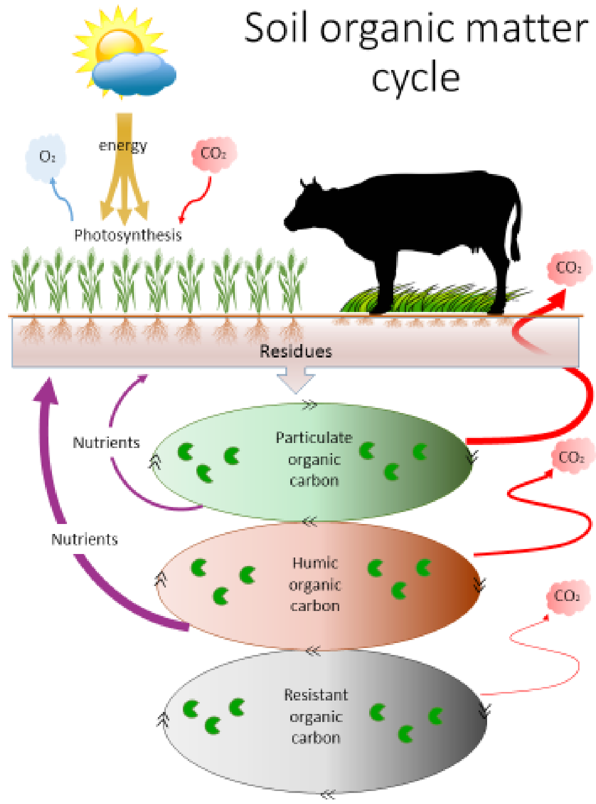

Figure 1: *Organic matter cycle.*

Source: J Gentry, QDAF

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

Australian soils are generally low in SOM. Initial SOM levels are limited by dry matter production (and so climate) for each land type/location. SOM levels have declined under traditional cropping practices. On-farm measures (sampled 2012–15) from over 500 sites in Queensland and northern NSW confirm that SOM, 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 C levels are so high (Figure 2). [3]

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

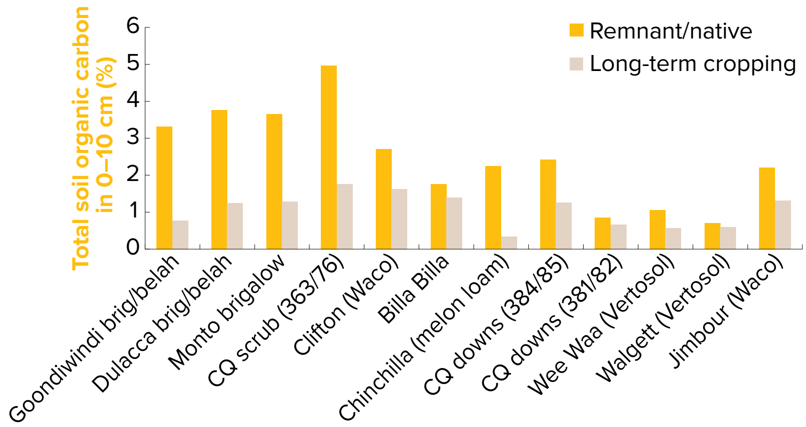

Figure 2: *The decline of soil organic carbon in long-term cropping systems.* [4]

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

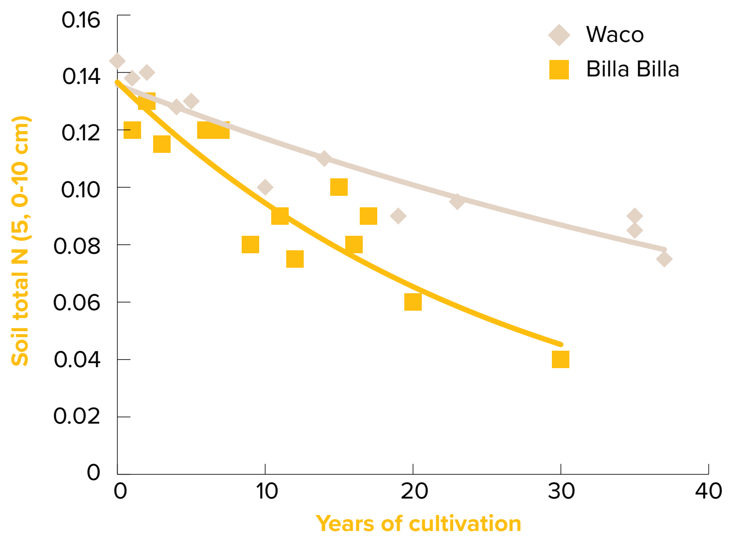

Figure 3: *Graph of decline in soil total N with years of cropping. The decline was greater for the Billa Billa soil (clay content 34%) than the Waco soil (clay content 74%).* [6]

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

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

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

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

5.1.2 Current situation

Soil organic carbon levels are simply a snapshot of the current balance between inputs (e.g. plant residues and other organic inputs) and losses (e.g. erosion, decomposition) constantly happening in each soil and farming system. The decline over time is overwhelmingly driven by the extent of fallowing in our farming systems. Most fallow rain in the northern region (as much as 75–80% in a summer fallow) is lost as runoff or evaporation. This wasted rain does not grow dry matter to replenish the organic matter reserves in the soil. However, increasing moisture in the fallowed soil continues to support microbial decomposition. This helps accumulate available N for the next crop, but reduces SOC. The SOM and C 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 SOC 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 C 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 C levels can be significantly different due to soil type (Figure 5). [8]

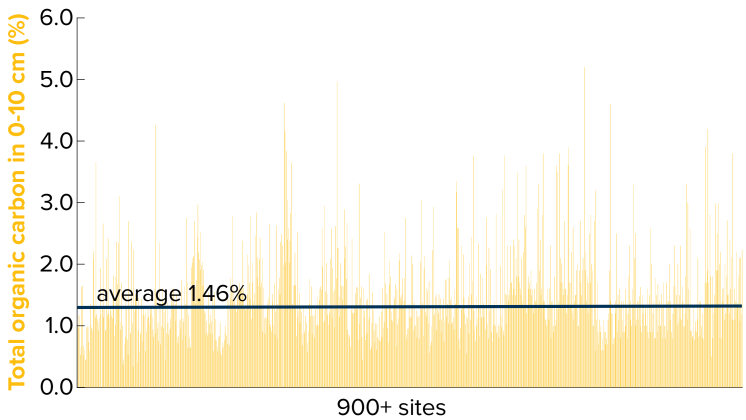

Figure 4: *Soil organic C levels on mixed farms within the GRDC Northern Region.* [9]

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

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

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

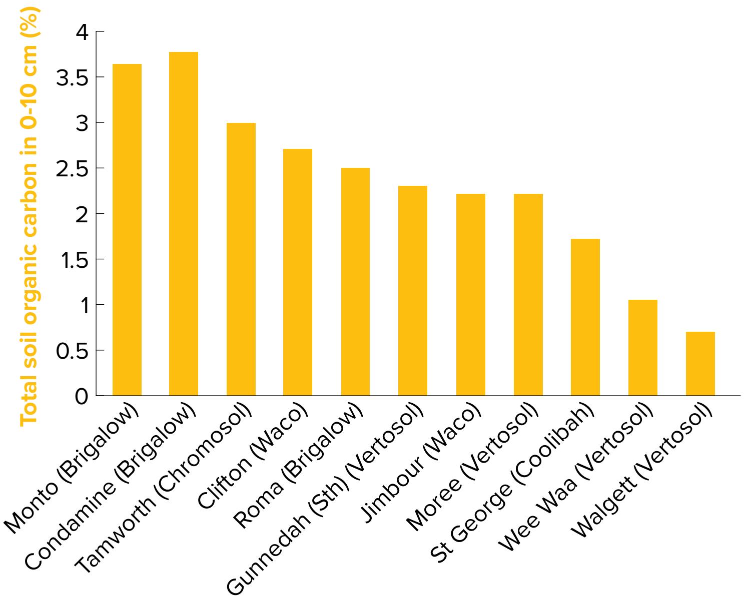

Figure 5: *Impact of land-type on total soil C levels (0–10 cm) across the northern region.* [10]

5.1.3 Options for reversing the decline in soil organic matter

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

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

Research in the past has shown the most direct, effective means of increasing SOM levels is through the use of pastures, however these pasture have to be productive. A grass only pasture will run out of N especially in older paddocks, which is normally the reason why these paddocks are retired from cropping. As a result, a source of N 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 C and N, 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 SOC and N (Table 1).

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

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

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

Clearly, time and good sources of both C and N 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 N 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	-

Further research was initiated in 2012 to identify cropping practices that have the potential to increase or maintain SOC and SOM levels at the highest levels possible in a productive cropping system. Paired sampling has shown that returning cropping country to pasture will increase soil C levels (Figure 6). However, there were large variations in C level increases detected, indicating not all soil types or pastures preform the same. Soil type influences the speed by which C levels change, i.e. a sandy soil will lose and store C 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 N and P) will maximise increases in soil C over time. Current research in Queensland being undertaken by the Department of Agriculture, Fisheries and Forestry (QDAF) is indicating that the most promising practice to date to rebuild soil C stocks, in the shortest time frame, is the establishment of a highly productive pasture rotation with annual applications of N 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://www.researchgate.net/publication/293958450_Managing_Legume_and_Fertiliser_N_for_Northern_Grains_Cropping

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

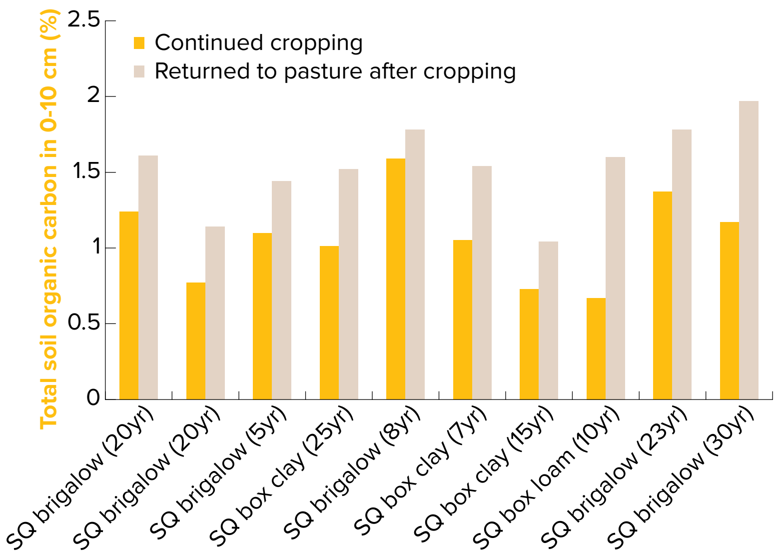

Figure 6: *Total organic carbon comparisons for croplands resown to pasture.* [15]

Impact of fertiliser N inputs on soil

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

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

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

5.2 Nutritional requirements

Peanuts differ from other crop in some of their nutritional needs. Most of the pod's Ca and boron (B) is taken directly from the soil rather than via the roots. Calcium is often applied to the crop before flowering. Peanut roots depend on arbuscular mycorrhizal (AM) fungi (previously known as vesicular arbuscular mycorrhizal, or VAM) and are very effective at utilising residual phosphorus (P) from previous crops in the rotation. [17]

VIDEOS

Crop nutrition

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

16 D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, https://www.researchgate.net/publication/293958450_Managing_Legume_and_Fertiliser_N_for_Northern_Grains_Cropping

17 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

Peanuts have special nutritional needs because the fruit grows under the ground. The fertility of the soil where pegs and pods develop is important because the pod absorbs most of its required Ca and B through the shell, rather than through the roots, and then through the peg. This influences the method and timing of some fertiliser applications, which may differ considerably from those of other crops.

Soils naturally contain beneficial fungi that help the crop to access nutrients such as P and zinc (Zn). The combination of the fungus and crop root is known as arbuscular mycorrhiza(e) (AM). Many different species of fungi can have this association with the roots of crops. Many that are associated with crops also form structures called vesicles in the roots.

The severe reduction or lack of AM shows up as long-fallow disorder—the failure of crops to thrive despite adequate moisture. Ongoing drought in the 1990s and beyond has highlighted long-fallow disorder where AM fungi have died out through lack of host plant roots during periods of long fallow. As cropping programs restart after dry years, a yield drop is likely from reduced AM levels, making it difficult for the crop to access nutrients.

Long-fallow disorder is usually typified by poor crop growth. Plants seem to remain in their seedling stages for weeks and development is very slow.

Benefits of good AM levels are:

- improved uptake of P and Zn
- improved crop growth
- greater drought tolerance
- improved soil structure
- greater disease tolerance.

In general, the benefits of AM are greater at lower levels of soil P because AM increase a plant's ability to access this nutrient. [18]

Peanuts have an exceptional ability to extract some nutrients from the soil, particularly P and Zn. This is why peanuts have a reputation for being able to respond better to fertiliser left after previous crops than to fertiliser directly applied to the peanut crop. AM fungi are one reason for this phenomenon. These fungi occur naturally in most soils and readily infect peanut root systems.

The AM fungi assist the plant's roots to extract P and Zn from the soil. So dependent are peanuts on AM fungi for uptake of P that if the fungi are not present, the crop needs soil P levels up to 10 times higher than normally required.

In the South Burnett, Queensland, peanuts are commonly fertilised with P by over-fertilising the previous maize crop. Some growers also apply P before or at planting. Similarly, on the Atherton Tableland, peanuts are often grown on the residual fertiliser following a potato crop.

Different fertiliser programs are needed on other soil types. Iron (Fe) deficiency is a particular problem on heavier clay soils with pH >8.0, because peanut roots are not very efficient at accumulating Fe.

Copper (Cu), magnesium (Mg) and Zn responses have also been recorded on lighter sands in coastal and inland areas, and Zn deficiency can also be a problem on soils with pH >7.5.

Other factors can cause symptoms similar to those of nutrient deficiencies. For example, night temperatures <9°C cause leaf yellowing and a slight interveinal chlorosis (Photo 1), and Verticillium wilt shows as a pale-green colour around the leaf margins.

18 QDAF (2010) Nutrition—VAM and long fallow disorder. Department of Agriculture, Fisheries and Forestry Queensland, 14 Sept. 2010, http://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam

Photo 1: *Yellowing between veins is typical of cool temperatures, <9°C.*

Table 1 presents the essential nutrients for peanuts and the concentrations found in the youngest fully expanded leaves. Use these values as a guide only. Nutrient levels vary depending on the part of plant that is sampled. Levels also change as the plant matures and nutrients are relocated into the pods as the kernels develop. A soil test for Ca provides the only reliable guide for pod development. [19]

19 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

Table 2: *Classification of nutrient status of peanut crops by analysis of the youngest fully expanded leaves.*

Nutrient	Severely deficient	Deficient	Marginally adequate	Adequate	High
N (% DM)	<3.2	3.2–3.7	3.8–4.1	4.2–4.5	>4.5
P (% DM)	<0.19	0.19–0.23	0.24–0.26	0.27–0.40	>0.40
K (% DM)	<0.7	0.7–1.3	1.4–1.7	1.8–2.5	>2.6
S (% DM)	<0.15	0.16–0.20	0.21–0.25	0.26–0.30	>0.3
B (mg/kg DM)	<13	13–23	24–30	30–50	>50
Mo (mg/kg DM)	<0.02	0.02–0.05	0.05–0.13	0.13–1.0	>1.0
Cu (mg/kg DM)	<1.3	1.3–1.7	1.8–2.1	2.2–5.0	>5.0
Mg (% DM)	<0.2	0.2–0.25	0.25–0.3	0.30–0.80	–
Ca (% DM)	–	<1.0	1.0–1.2	1.4–2.0	–
Mn (mg/kg DM)	–	<10	–	50–350	600–800
Zn (mg/kg DM)	<12	15–18	18–20	20–50	>200
Fe (mg/kg DM)	<25	25–35	35–50	50–300	–

Note: these values apply only before the crop starts to fill pods. Sources: Bell et al. 1990; Reuter and Robinson 1986; Reuter and Robinson 1997

5.3 Soil fertility

Soil fertility is very important for peanuts. During the growing of the peanut pod, Ca and B are absorbed through the shell rather than through the plant's roots. This has implications for the method and timing of fertiliser applications.

Peanuts tolerate a wide range of soil acidity levels; however, the ideal pH is 6.0–7.0. Soils that are more acidic (pH <6.0) should be limed. Ensure your soil test is properly interpreted by a qualified agronomist. [20]

Potassium (K), P, Ca and sulfur (S) are the nutrients most commonly applied to peanuts, but growers should also check Mg levels, which are becoming depleted in some Australian soils.

Micronutrients must not be ignored—deficiency can sometimes lead to major yield losses. Zinc (Zn), B and molybdenum (Mo) are commonly applied. Copper (Cu) is often deficient on very sandy soils. Some soils also have manganese (Mn) deficiency.

Foliar applications of micronutrients are common; however, soil applications are also suitable for some nutrients. [21] Your agronomist can provide advice.

MORE INFORMATION

The what where and why of soil testing in the northern region

5.4 Crop removal rates

Nutrient management needs to take into account the removal from the farm of nutrients contained in crop products such as grain and hay (Table 2). Peanuts have a high K content compared with most grain crops (although only half the K concentration of soybean seed), and when hay is taken from the paddock, even more K is removed.

20 PCA. Soil preparation. Peanut Company of Australia.

21 PCA. Peanuts and fertilisers. Peanut Company of Australia.

Table 3: *Mineral content of peanut kernel, shell and hay.*

Mineral element content (%)				Nutrients removed (kg/t)	
	Kernel	Shell	Hay	Hay	Nut-in-shell
N	4.6	1.3	1.5	15	40
P	0.4	0.03	0.15	1.5	3
K	1.0	0.9	2	20	8
S	0.2	n.a.	0.2	2	2+
Ca	0.07	0.2	0.8	8	1.3
Mg	0.2	0.1	0.3	3	2
Fe	0. 001	0.15	n.a.	n.a.	0.5
Cu	0.001	0.001	0.0005	0.005	0.01
Zn	0.006	0.002	0.001	0.01	0.05
Mn	0.002	0.004	n.a.	n.a.	0.02
B	0.03	0.001	0.003	0.03	0.2

Source: This table has been compiled from a range of sources; there is a great deal of variation between samples and sources and these values provide a general guide only; n.a., not available

MORE INFORMATION

PCA/QDPIF. Crop nutrition.

C Guppy *et al.* Interpreting soil tests in the light of P, K and S research.

M Bell, C Guppy. Interpreting soil test results for the northern region.

Table 2 provides values indicating the quantity of each element removed at harvest. This is a guide to what must be replaced to maintain soil fertility. For example, each tonne of hay will contain about 20 kg K, requiring 40 kg of muriate of potash (or equivalent) to replace it. [22]

5.5 Soil testing

Soil testing is essential. As well as tests to the traditional depth of 0–1 cm, deeper tests should be considered to check nutrient levels at depth. Many soils have reasonable levels of nutrients in the topsoil but nutrients are very low deeper in the profile. Consider 10–20 and 20–30 cm tests.

It is recommended that growers obtain a complete nutrient analysis or soil test prior to planting peanuts. Peanuts are regarded as good scavengers for nutrients, but if any nutrients are lacking in the soil, including micronutrients, then yield potential may be limited. Your soil test should be analysed through an ASPAC-accredited laboratory and properly interpreted by a qualified agronomist.

Once you have analysed soil test results you can plan a fertiliser program based on available nutrients and, most importantly, your budget or expected yield. If the hay is to be baled after harvest, you will need a different fertiliser program.

Replacements rates will need to be adjusted based on removal of both peanuts and hay.

5.6 Nutrient availability and soil pH

All pH levels presented here refer to the soil acidity testing method using 1 part soil : 5 parts water (pH_{H2O}). Soil acidity, or pH, affects the plant's ability to take up nutrients from the soil. If the pH is not within the range required for optimal plant growth, the plant is not able to make the best use of the nutrients in the soil, even if the correct amounts are present in the soil. It is important to correct soil pH so that the investment in nutrient applications is not wasted.

Peanuts tolerate a wide range of soil acidity levels. The ideal soil pH range is 5.5 (slightly acidic) to 7.0 (neutral). If the soil is more acidic (i.e. pH <5.5), nodulation and N_2 fixation can be reduced and trace element imbalances can occur, potentially causing

22 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

aluminium (Al) and Mn toxicity. If the soil is more alkaline (i.e. pH >7.0), deficiencies in Zn, and possibly Fe, can develop.

A soil test will show whether the pH needs adjusting with products such as agricultural lime. The amount of lime needed to correct low pH depends on the buffering capacity of the soil and the extent to which it is necessary to raise pH. The buffering capacity of a soil is its ability to 'absorb' Ca without causing a change in soil pH.

Clay soils and soils with higher organic matter, such as the red volcanic soils around Kingaroy, Queensland, generally have a higher buffering capacity than sandy soils. Although more lime may be needed to correct the pH in highly buffered soils, these soils are able to 'hold' the pH at the new level for longer than poorly buffered soils.

When you have your soils analysed, ask for a 'lime requirement' figure, which represents the lime required to reach, say, pH 6.5. This is based on well-researched data that take into account the buffering of the soil and the amount the pH is to be raised. The calculation used gives the amount of lime required to treat a 10-cm layer of soil only, so if the lime is mixed into the top 20 cm of soil, the recommended rate must be doubled to treat the extra soil.

There is an important distinction between correcting pH and correcting Ca deficiency. Once the pH is correct, Ca applications may still be needed to feed the crop (Photo 2). Calcium nutrition is particularly important for growers on sandy soils. [23]

Photo 2: *Lime or gypsum banded over the row will provide Ca to the plant.*

MORE INFORMATION

Incitec Pivot Fertiliser. Nutrient advantage.

23 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

5.7 Calcium

Because of their underground fruiting habit, peanuts have a relatively high requirement for Ca. Calcium is not very mobile within the plant, and the peanut pod takes up its own Ca directly from the soil. Consequently, available Ca must be present in the podding zone (the top 2–10 cm of soil). Growers should check that applications of Ca post-plant are available to the crop.

Adequate Ca is essential for ensuring high-quality kernels. Insufficient Ca may lead to smaller kernels and kernels with hollow hearts (not completely filled). Low Ca will also reduce the germination of seed peanuts. In larger seeded peanuts (Virginia types), low Ca can lead to kernel abortion, causing empty pods or 'pops' [24] as well as splits and poor germination. [25]

To provide an adequate supply of Ca in the podding zone, natural gypsum (calcium sulfate) is usually applied at early flowering over the peanut row. Gypsum is a relatively soluble source of Ca that is easily absorbed by the pods. Gypsum contains 23% Ca and is applied at rates of 600–1,000 kg/ha. [26]

Gypsum may be used as a Ca fertiliser, but it may not be the product of choice. Lime should be used on acid soils that are low in Ca. Not only does lime supply Ca, it also corrects acidity (raises the soil pH). However, it is ineffective in neutral and alkaline soils.

Typically, gypsum is applied during the fallow period. The rate at which gypsum is applied as a Ca fertiliser where the pH does not need amending is 1–2.5 t/ha. This can remain effective for several years. [27]

Dolomite contains Ca and Mg. It can correct soil acidity and supply some Ca. However, you should find out the ratio of Ca to Mg in the soil before using dolomite. The Ca level should be at least double that of Mg. Otherwise, the Mg can interfere with the pod's uptake of Ca.

Alternatively, fine lime can be applied 4–6 weeks prior to planting (if soil pH is <6.0) and lightly incorporated. Lime is less soluble than gypsum. It is usually applied at rates of 2.5–5 t/ha and contains 35–40% Ca. [28]

Note that peanuts need much higher Ca levels in the surface soil (top 5–10 cm) than other crops. It is a major factor in kernel development and quality.

Deficiency symptoms are likely where soil surface Ca levels are low, large kernel varieties are being grown, and the soil surface is dry. Sandy soils generally have low Ca levels.

A severe lack of Ca in the podding zone will cause pops (full size pods with no kernels inside) or pods with only one kernel (Photo 3). A mild deficiency may cause the embryo to turn dark, reducing germination and vigour.

Low soil moisture can limit the uptake of Ca because soil Ca can only move through the soil when it is dissolved in water; therefore, pops are always worse in a dry season. It is common to have paddocks where no pops are recorded in wet seasons and quite a few in drier seasons.

Foliar symptoms of Ca deficiency include yellowing, multiple branching (rosetting), death of the growing point and petiole collapse. Such symptoms are rare in field conditions.

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24 G Wright, L Wieck, P Harden (2015) Peanut production guide, August 2015. Peanut Company of Australia, http://www.pca.com.au/wp-content/uploads/2016/11/PWH-Peanut-Production-Guide-2015.pdf

25 PCA. Peanuts and fertilisers. Peanut Company of Australia.

26 G Wright, L Wieck, P Harden (2015) Peanut production guide, August 2015. Peanut Company of Australia, http://www.pca.com.au/wp-content/uploads/2016/11/PWH-Peanut-Production-Guide-2015.pdf

27 Incitec Pivot. Gypsum. Fertfacts. Incitec Pivot Ltd, http://www.incitecpivotfertilisers.com.au/en/Soil%20,-a-,%20Plant%20Tests/~/media/Gypsum%20Fact%20Sheet.ashx

28 G Wright, L Wieck, P Harden (2015) Peanut production guide, August 2015. Peanut Company of Australia, http://www.pca.com.au/wp-content/uploads/2016/11/PWH-Peanut-Production-Guide-2015.pdf

Photo 3: *Pops (shells without a kernel or a shrivelled kernel) of Virginia or Runner types are typical of low soil Ca. A mild deficiency may cause the embryo to turn dark.*

Calcium deficiency in the podding zone can be overcome with applications of gypsum or lime. Liming will generally correct Ca deficiency for several years. However, in some very sandy soils, the ability to hold a large amount of Ca in the shallow pod-zone is limited and some Ca may be leached from the zone within a season. Annual applications of a Ca source may then be required. Choose pH-neutral and more soluble sources of Ca, such as gypsum, rather than lime in this situation.

Where soil pH is acceptable but Ca is low, gypsum applied in bands over the row (i.e. into the pegging zone) is more economical and more effective over the relatively short period of pod-filling.

A rate of 400–600 kg/ha applied in bands 30–40 cm wide is usually adequate, although soils with very low Ca or high Mg may need a higher rate.

Choose Spanish and Runner types for soils with a low ability to hold positively charged nutrients such as Ca (i.e. soils with a cation exchange capacity, or CEC, of <4 cmol/kg or meq/100 g). In these situations (e.g. on sandy soils), the soil cannot hold enough Ca to adequately fill pods in the larger Virginia types, which are less efficient at accumulating Ca. In these soils, the 'exchangeable' Ca needs to be ~70% of the total CEC, i.e. the desired cation balance is Ca 70%, Mg 15%, K 5%, and others, including sodium (Na) 10%.

In red and brown forest soils of the inland Burnett, the CEC and Ca levels are usually adequate, but extra Ca is sometimes applied because the topsoil is dry, reducing the efficiency of Ca uptake. Normal liming practices (to maintain pH) usually meet this requirement.

Only 10–14% of the Ca taken up by the crop ends up in the pods; most is in the foliage (66%) and roots. The shells and kernels extract their Ca directly from the soil in the podding zone, whereas Ca absorbed by the roots is carried to the stems and leaves but not down the peg to the pod.

Larger kernel varieties of peanuts need higher soil levels of Ca. Small-seeded Spanish types are much less susceptible to low soil Ca than Runner types, which in turn are less susceptible than Virginia types.

For large-seeded varieties, the need for Ca also depends on the level of soil K. Pops can result from low Ca in the podding zone and/or inhibited Ca uptake because of high levels of other nutrients, particularly K.

Apply Ca if a soil test shows any of the following:

- Ca <70% of the CEC and CEC <6 cmol/kg
- Ca >70% of the CEC and CEC 6–10 cmol/kg, but soils likely to be quite dry during pod-filling

- CEC <4 cmol/kg, regardless of the proportion of CEC as Ca.

Low Ca can affect the germination of seed, as well as the peanut's ability to resist pathogens such as *Aspergillus flavus* (the cause of aflatoxin), *Rhizoctonia* and some fungi causing pod rots.

Analysis of peanut foliage will not show whether sufficient Ca is available for kernel development. A soil test in the pod-zone will give a better indication.

Seed peanuts from crops grown under marginal to low Ca have poor germination. The level of Ca in the kernel needs to be ≥420 mg/kg for satisfactory germination. As a precaution, apply extra Ca to all seed crops.

Gypsum is more soluble than lime and is preferable for over-the-row applications, particularly if timing is close to flowering. Gypsum also corrects deficiency of S and should be used on alkaline soils (pH >7) instead of lime.

A drawback of the relatively high solubility of gypsum is that very heavy rain may leach it from the pegging zone in sandy soils. When using gypsum on these soils, time application as close as practical to flowering.

Because lime is less soluble, it is best applied at least 1 month before planting to ensure that the Ca has become available. Calcium is needed in the pod-zone, so do not incorporate the lime deep into the soil. Lime applied to soils with a pH >6.5 may cause Zn or Mg deficiency. [29]

5.8 Nitrogen

MORE INFORMATION

[The want and waste of the nitrogen economy]

High levels of N are needed for high-yielding peanut crops. However, like other legumes, peanuts fix N_2 from the air via symbiotic bacteria (rhizobia) living in nodules formed on the peanut plant roots (Photo 4).

Nitrogen is required for growth and is taken up throughout the season. It is sourced from the soil or from N fixation. Growers must inoculate peanut seed with efficient strains of rhizobia prior to planting to ensure optimum N fixation. When the suitable rhizobia become established in fields, farmers may not need to add N fertilisers to peanut crops. [30]

Photo 4: *Many nodules, like those on these roots, are needed to fix sufficient N. Inoculating the soil with rhizobia at planting is essential.*

29 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

30 PCA. Peanuts and fertilisers. Peanut Company of Australia.

Poor nodulation, waterlogging or a lack of other nutrients essential for N fixation, such as P and Mo, can cause N deficiency. Generally, plants recover quickly from temporary waterlogging. A shallow cultivation will allow the soil to aerate and will hasten recovery from waterlogging.

Symptoms of N deficiency include stunting of the plant and yellowing of the leaves, frequently with a reddish discoloration of stems (Photo 5).

Photo 5: *Pale plants and leaves are typical of low N levels, often associated with poor nodulation or wet soils.*

Rates of N up to 50 kg/ha may be useful where waterlogging has killed rhizobia or where nodulation is slow or has failed. Greatest benefit will come from applying N when the crop is podding; however, 20–30 kg/ha of early (starter) N may be warranted in situations where soil N is very low prior to nodules becoming established and functional (after about 1 month). This can happen when a sugarcane trash blanket is incorporated before planting the peanut crop.

To avoid these problems, inoculate seed carefully, do not plant in areas prone to waterlogging, and provide the nutrients essential for successful nodulation.

Excessive soil N, from either natural fertility or fertiliser, can delay nodulation, can cause excessive vegetative growth, and lead to fewer flowers producing mature fruit.

Nitrogen fixation can provide up to 70% of the total N uptake of the plant, often ≥200 kg N/ha. The remainder is obtained from the soil. High-yielding crops will fix more N than low-yielding ones.

Check the plant roots for signs of nodulation. Slice through the nodule and note the colour inside. Reddish colour indicates that N is being fixed; green, the nodule is mature but not fixing N; white, the nodule is immature; and brown, old nodules.

Nitrogen fixation of 100 kg/ha under dryland conditions has been recorded at Kingaroy, and 200 kg/ha under irrigation at Bundaberg.

Total N uptake from soil reserves and symbiotic fixation under high-density, irrigated conditions may reach 300–350 kg/ha (excluding N in the roots) and under dryland conditions 100–200 kg/ha. Commonly, an additional 30–40% of the N is stored in the roots and pods (i.e. 100–120 kg N/ha under irrigation and 40–80 kg N/ha in dryland situations). About 25% of the total crop N remains in the roots after harvest and 30–50% is removed in the harvested pods, with the remaining 25–45% left as stubble or removed as hay.

Peanut crops generally do not add N to the total soil N store, although they will contribute soluble N to the next crop. Peanut residues typically contain 2% N by weight and, if left in the paddock, release N quite quickly to a following crop.

It is possible to gain up to 100 kg N/ha in the soil store from the peanut crop, but only if a crop of large, healthy plants does not yield as well as expected. With the new, high-yielding varieties, the net N balance after the peanut crop is more likely to be negative, because the peanut crop has put more N into the pods than what remains in the plant residues. [31]

5.8.1 Nitrogen loss

Key points

- Nitrogen is a mobile nutrient and can be lost downwards (leaching), sidewards (erosion) and upwards (gas emissions).
- To reduce losses, avoid unnecessarily high N rates.
- Delay or split N fertiliser application so that peak N availability coincides with peak crop demand.
- Using legumes in crop rotations will also reduce N losses.

N fertiliser is one of the most significant input costs for northern grain growers, so understandably growers want to minimise applied N losses through better management to maximise return on investment.

N for crop production can come from SOM, crop residues (especially legumes), manure and fertiliser. The amount of plant-available N (mineral N) released from microbial breakdown of SOM, crop residues and manure depends on the amount of organic matter in the soil, the amount of crop residue remaining and its N concentration, and the amount and type of manure applied and how it is applied. However, as the N release process is undertaken by microbes, temperature and moisture availability can also influence the rate of release.

In the north, growers either measure this 'mineralised' N in the soil profile towards the end of a fallow period using soil testing or estimate it from SOM levels, fallow rainfall and rotation histories.

They then derive a fertiliser N requirement based on the difference between this soil mineral N and the likely crop demand based on expected yields. N fertilisers such as urea are then applied either directly into the soil (banding), or broadcast onto the soil surface and then incorporated.

In contrast to the soil organic N reserves, fertiliser N is either immediately available for plant use (in ammonium or nitrate forms) or soon available after conversion in soil (for example, from urea to ammonium and nitrate).

Any loss of N will reduce the pool of N that a crop can use to produce biomass and grain yield. [32]

How nitrogen is lost

Essentially, cropping systems are 'leaky' and N (especially when in the nitrate form) can be lost via downward, sideward or upward movement.

Downward movement via leaching (the drainage of water through the soil profile) is a greater problem in lighter textured soils than the medium–heavy clay soils dominating the northern grains zone, but previous research has demonstrated some losses can occur this way.

31 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

32 GRDC (2017) Lost N and what you can do. Ground Cover Issue 123, July–August 2016, https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-123-julyaugust-2016/lost-N-and-what-you-can-do

Sideways movement can occur rapidly through erosion of organic matter-rich topsoil during intense rain events, or more slowly through lateral movement of nitrate in soil water.

The main upwards N loss pathways consist of gaseous losses through ammonia volatilisation or denitrification of nitrate (a biological process occurring within the soil profile wherever there is sufficient available nitrate, labile C substrate and low oxygen conditions, such as in slowly draining soils).

Understanding N-loss pathways and how they are influenced by seasonal conditions and management strategies is a critical first step in optimising the efficiency and profitability of applied N use. [33]

Case study: One management strategy to reduce nitrogen losses

A trial at Kingaroy in southern Queensland explored the impact of crop rotation (grain or grain-legume pre-histories) on fertiliser N requirements and N use efficiency during a subsequent sorghum crop in 2014–15. The pre-histories were sorghum/peanuts/soybeans in the 2013–14 summer, all harvested for grain.

In the second summer crop year when sorghum was planted, the fertiliser N rate required to achieve a sorghum grain yield of 6.3 t/ha was reduced by 50% after the peanut rotation and the need removed entirely after soybeans. Specifically, sorghum following sorghum needed 120 kilograms of N/ha, sorghum following peanuts needed 60 kg of N/ha and sorghum following soybeans required no N fertiliser at all.

Fertiliser N losses were negligible at the optimum N rate in the peanut or sorghum histories on this friable soil, with each history recovering 65 to 70% of the applied N in crop biomass in these high-yielding crops.

Fertiliser is a major input cost for northern growers and will continue to be so as the region's soil organic matter and associated mineralisable N reserves continue to decline. This will continue to be the case unless legume frequency in crop rotations increases substantially. [34]

5.9 Phosphorus

MORE INFORMATION

Phosphorus and potassium nutrition

Peanuts also require relatively large amounts of P but the presence of arbuscular mycorrhizal (AM) fungi on their roots makes them very efficient at absorbing any reserves in the soil.

QDAF experiments at Kingaroy, showed that very high levels of P were needed when no AM fungi were present. Soils that had been sterilised required ~240 kg P/ha to achieve full growth potential, but when the AM fungi were not destroyed, the rate was just 30 kg P/ha.

Peanut growers have traditionally used high rates of P on alternate crops (e.g. maize) during crop rotation. Peanuts respond better to fertiliser left over from the previous crop than to fertiliser directly applied to the latest crop. [35]

Peanut plants require moderate amounts of P. When AM fungi are present in the soil, peanut plants become very efficient at extracting soil P. Phosphorus is required for general plant growth and plays an important role in root development and crop maturation.

Deficiency symptoms show when soil P levels are <20 mg/kg of soil (Colwell or bicarbonate P tests) or where AM fungi are not present. Many Australian soils are naturally low in P, but many cropped soils have a considerable P bank because of residual phosphate fertilisers applied over the years.

33 GRDC (2017) Lost nitrogen and what you can do. Ground Cover Issue 123, July–August 2016, https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-123-julyaugust-2016/lost-nitrogen-and-what-you-can-do

34 GRDC (2017) Lost nitrogen and what you can do. Ground Cover Issue 123, July–August 2016, https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-123-julyaugust-2016/lost-nitrogen-and-what-you-can-do

35 PCA. Peanuts and fertilisers. Peanut Company of Australia.

The first sign of P deficiency is a light flecking, gradually becoming more yellow until parts of the leaf die (Photo 6). Severely P-deficient plants are stunted, with small leaflets, often bluish green in colour and later developing pale spots between the veins before turning yellow and falling off. The stems may be purplish. Severe deficiency symptoms may only appear when growth has already been depressed by 70–80%.

Photo 6: *Top: light flecking gradually becoming more yellow until parts of the leaf die indicates P deficiency. Bottom: leaves folded together can also indicate a lack of P.*

Peanut growers traditionally applied high rates of P on other crops in the rotation, rather than directly applying P to the peanut crops.

Direct applications of P are necessary when soil levels are <20 mg/kg of soil (bicarbonate P). For irrigated crops and crops on the red soils of the Atherton Tableland, P rates of 30 kg/ha, and occasionally higher, may be needed. This contrasts with rates of ~10 kg P/ha for dryland crops on many red soils in southern Queensland. In the South Burnett, where soil test levels are <10 mg/kg, apply 10 kg P/ha broadcast before planting and a further 10 kg P/ha at planting.

The total P taken up by a peanut crop may range from 5 kg/ha to >30 kg/ha. AM fungi help peanut plants to exploit residual P from earlier fertiliser applications and soil P reserves that are unavailable to many other crops. Peanuts extract some P from relatively deep in the soil, but most is extracted from the top 40 cm.

Activity of AM fungal is reduced at high soil P concentrations; therefore, banded applications of fertiliser do not achieve the best uptake of P (unlike for most other crops). The maximum rate of uptake of P starts at flowering. About 65% of the P taken up by the plant is translocated to the pods and removed from the peanut field at harvest. [36]

MORE INFORMATION

The what where and why of soil testing in the northern region

36 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

5.10 Sulfur

Peanuts require S, along with N, to form proteins. Soil reserves of S decline where soils are cropped for many years without applications of S-containing fertilisers.

Sulfur deficiency in peanuts is difficult to diagnose from foliar symptoms. The symptoms can include pale yellowing of young leaves, while older leaves remain darker green (Photo 7). This is similar to the appearance of other nutrient disorders, such as the early stages of N and Fe deficiency, and to some non-nutrient disorders.

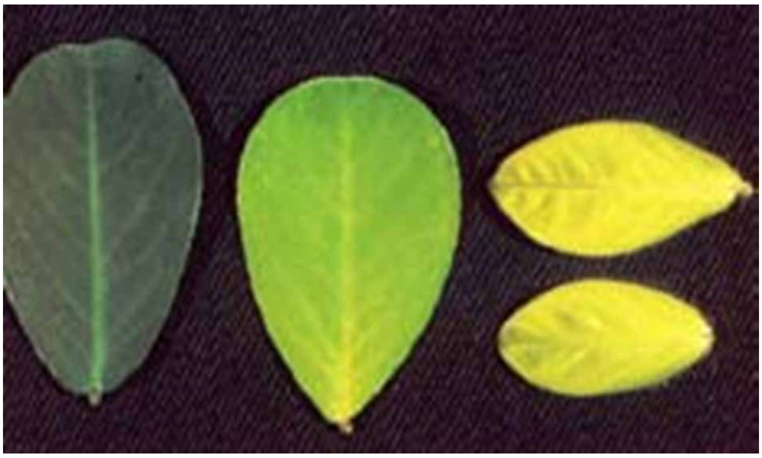

Photo 7: *Pale yellow leaves on the top of the plant are typical of S deficiency. Sulfur deficiency is unlikely where gypsum is used to supply Ca.*

Applications of 10–20 kg S/ha are generally adequate unless a very high yield potential exists. Total S taken up by peanut crops can be up to 60 kg/ha, with very high-yielding crops expected to require more.

Sources of S include some N (sulfate of ammonia) and K (sulfate of potash) fertilisers, as well as superphosphates.

High-analysis P fertilisers such as triple superphosphate (20% P) contain less S than single superphosphate (1% S *v.* 11% S), which means that S inputs may become necessary as the use of single superphosphate declines. If gypsum is used (see *Calcium* above) no other source of S should be needed.

Use of superphosphate (with ~11% S content) on light-textured soils has often masked S deficiency. The form of soil S taken up by plants (sulfate-S) is soluble and can be leached down the soil profile. Therefore, soil tests that take account of the S in deeper soil layers will better guide fertiliser requirements. [37]

5.11 Potassium

Peanuts require large amounts of K to grow the crop canopy, although only 20–30% of the total crop K is removed in the harvested product.

Deficiencies are most likely in sandy soils and are also common in long-term cropping areas on the red and brown forest soils in the South Burnett. Deficiencies are more likely on soils with a history of hay-making.

Soil K content is often highest in the topsoil layers, because most of the plant's K is stored in the crop residues and K does not leach easily through the profile (except in light sands).

Under direct drill, the K accumulates in just the top 5–10 cm. This layer is often dry when the peanut crop needs to take up K for later growth, and despite a high soil-test value, the crop can still become K-deficient.

37 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

Potassium deficiency in peanuts causes tip and margin (and sometimes interveinal) yellowing, followed by early leaf drop and death of tissue (Photo 8). Symptoms first appear on older leaves. Stems may also show some dead spotting and are shorter and thinner than in adequately supplied plants.

Photo 8: *Potassium deficiency typically showing yellowing then browning of the tips and leaf edges.*

In deficient situations, an application of 50–100 kg K/ha may be needed and should be placed below the pod-zone.

Where soil levels are <0.15 cmol/kg, apply 50–100 kg K/ha for a few crops until soil levels increase. Annual applications of ~15 kg/ha will maintain satisfactory soil K levels. Peanuts remove ~10 kg K for each tonne of pods harvested.

Occasional sampling of the subsoil (30–40 cm deep) will help you to develop the best strategy for K fertiliser application.

Peanuts can extract K from the soil faster than they need it, especially in the seedling stage. As a result, the K concentration in the plant can be high in the early growth stages until flowering, when it starts to be redistributed from leaves to pods.

High levels of K in the pod-zone will inhibit the Ca uptake of developing pods if the supply of Ca is limited. Although the shell will develop, only one kernel or even no kernels will form. High levels of K in the pod-zone can also lead to reduced shelf life of peanut kernels by causing an increased incidence of breakdown. Try to avoid large applications of K to the soil surface just before planting. If possible, apply K deeper than 5 cm.

Removing peanut hay will rapidly deplete soil K levels, because there is ~20 kg K in each tonne of peanut hay. [38]

5.12 Boron

Boron deficiency can have severe effects on peanut yields and quality. Boron, like Ca, must be taken up directly from the soil by the developing pod. Even though no foliar symptoms of deficiency occur, the developing pods may be deficient.

Boron is highly soluble and readily leached from sandy and sandy-loam soils. These light-textured soils and calcareous soils of high pH are most likely to be deficient in B. Some red soils of the Atherton Tableland are also deficient.

The kernel develops a 'hollow heart' and the embryo of the kernel may go dark (Photo 9). These effects reduce kernel weight and lower the likelihood of germination. Hollow heart is the classic symptom of B deficiency and it will show up long before leaf symptoms.

Peanut plants seem to tolerate low levels of B better than many other plants. Foliar symptoms of B deficiency include stubby, rosetted branches (similar to the symptoms of Ca deficiency), cracking of branches, discoloration of nodal areas, and leaves with a yellow–green mosaic appearance. Deficiencies also cause shell deformity and random shell cracking (other conditions also cause cracking).

Photo 9: *Kernels with 'hollow heart' are classic symptoms of low soil B. Hollow hearts will form well before deficiency symptoms on the foliage.*

Boron deficiency can be corrected with soil applications of B fertilisers, such a borax or regular liquid applications to the soil under a growing crop. Boron applied to the leaves can be taken into the plant but cannot be moved to the pod to supply the developing kernels.

Limit applications to 0.5 kg B/ha, which is ~5 kg/ha of borax applied to the soil or Solubor® sprayed at 2.5 kg/ha. Do not apply more B unless there has been leaching rain.

Soil tests using hot-water-extractable B can help determine the need for B, but are not very reliable.

Exercise caution when applying B because it is easy to change deficiency into toxicity, even using low rates of B fertiliser. Rates of only 4 kg B/ha have produced symptoms of B toxicity in peanuts. Boron toxicity looks like K deficiency, with

38 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

yellowing at the margins and between the veins and, eventually, browning of the margins. [39]

5.13 Copper

Low soil Cu is not common; it would mainly be expected on light sandy soils.

Copper deficiency has been seen on some of the coarse sandy soils of the Mareeba–Dimbulah Irrigation Area, and in some of the coastal sands near Bundaberg.

Plants are severely stunted and they can die if the deficiency is not corrected. Leaves show an interveinal chlorosis, with the tips and leaf margins dying. The leaves eventually wither and drop off. The pinched and 'burnt' leaf tips can be very distinctive (Photo 10).

Three or four applications of copper sulfate or copper oxychloride will usually correct the deficiency. Be sure that there is sufficient leaf area for foliar applications to be effective. Copper sulfate can be corrosive to brass boom-spray fittings.

Photo 10: *Top: leaf symptoms of low Cu levels—distorted leaf tips. Bottom: Cu deficiency in the field showing yellowing and browning leaf tips.*

With micronutrient applications, some phytotoxicity can occur; however, this damage does not affect the crop. [40] During flowering in weeks 4 and 5, apply foliar fertilisers (1% solution), especially Cu (on very sandy soils) and Zn. [41]

5.14 Iron

Lack of Fe is an important factor to consider when growing peanuts on alkaline soils. Peanut plants require Fe early in the crop growth to help establish functioning nodules to start N fixation.

39 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

40 G Wright, L Wieck, P Harden (2015) Peanut production guide, August 2015. Peanut Company of Australia, http://www.pca.com.au/wp-content/uploads/2016/11/PWH-Peanut-Production-Guide-2015.pdf

41 PCA. Peanut production season plan. Peanut Company of Australia, http://www.pca.com.au/wp-content/uploads/2016/11/checklist.pdf

Iron deficiency is most likely on calcareous soils or other soils of pH ≥8.0. Waterlogging or too much lime in some soils can induce Fe deficiency. Even temporary waterlogging from flood irrigation can be enough to induce deficiency if supplies of plant-available Fe are already marginal.

Iron deficiency has been seen on some of the heavy soils of the Burdekin and Mareeba irrigation areas, and on parts of the Darling Downs. It has also been confirmed on some heavy soils around Biloela, where the upper leaves turn a very light yellow after rain or irrigation. Iron deficiency is common on the alkaline soils in the Northern Territory.

Plants are usually stunted and pale, with leaves showing interveinal chlorosis (yellowing), eventually becoming very pale yellow and almost white (Photo 11).

Photo 11: *Top: Fe deficiency, showing the pale leaves with the veins staying green and eventually losing most of their colour. Bottom: Fe deficiency at Jandowae on a high pH soil.*

There is some debate over the best way to treat Fe deficiency. Foliar sprays with 3% Fe solution as ferrous ammonium sulfate are used in the USA. This generally corrects the deficiency for a few weeks; three sprays may be needed. Urea helps the uptake of Fe.

Chelated Fe (Fe-EDDHA) can be used in both soil and foliar applications, but ferrous (Fe^{2+}) sources are not useful as soil applications. In Israel, Fe is placed in a band at planting to supply both the plant and rhizobia.

Iron deficiency can prevent the formation of healthy rhizobial nodules. As a result, low Fe levels can cause N deficiency because the rhizobia are unable to supply N to the plant.

Some varieties are more tolerant to low levels of Fe. [42]

42 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

5.15 Magnesium

Peanuts are less susceptible to Mg deficiency than other crops. At levels of soil Mg where a response would be seen in maize and soybeans, peanuts do not show symptoms of deficiency or respond to Mg fertiliser. It appears that peanuts are more efficient at extracting Mg from soil, just as they have a greater ability to extract P, although the mechanisms are probably different.

Sandy soils are often Mg-deficient, for example, Innot Hot Springs in North Queensland, the tobacco soils of the Mareeba–Dimbulah Irrigation Area and some of the soils around Bundaberg. High levels of K can induce Mg deficiency.

Magnesium deficiency shows as yellowing (beginning at the margins and moving towards the midrib) followed by orange discoloration and finally necrosis (death) of older leaves. Veins often show a brown discoloration on the underside of the leaf (Photo 12). Younger leaves remain relatively normal in appearance. Magnesium deficiency symptoms are generally seen on leaves in the middle of the plant; both the oldest and youngest leaves can look normal.

Dolomite will supply both Mg and Ca but can raise the pH, so should be used with care on high-pH soils. Foliar fertilisers are available to treat Mg deficiency.

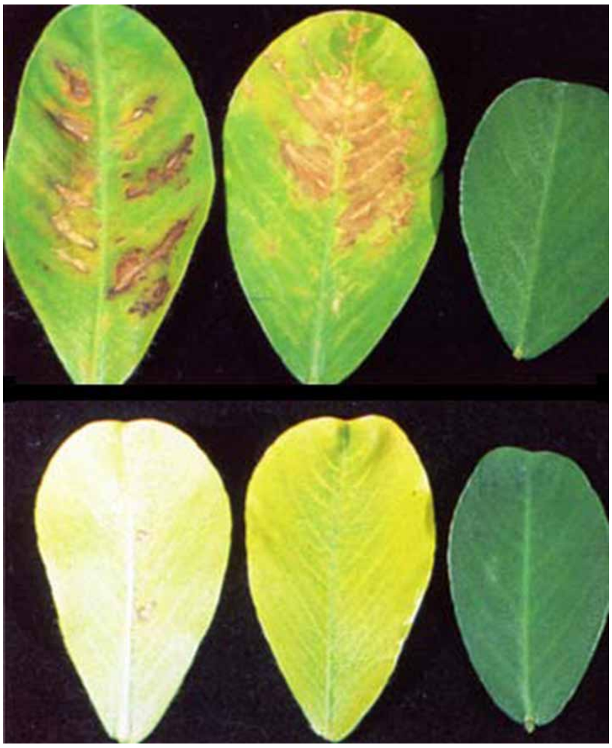

Photo 12: *Top: typical symptoms of Mg deficiency with browning patches on the leaf. Bottom: in the early stages, the veins on the top of the leaf are slightly lighter yellow than the rest of the leaf and the veins underneath the leaf are a darker colour.*

Uptake of Mg is closely related to dry matter accumulation. Thus, the concentration of Mg in the plant tissue remains relatively constant throughout the life of the crop.

High levels of soil Mg can reduce kernel quality. Magnesium can move from the foliage to the pod and can partially replace Ca under Ca-deficient conditions, reducing kernel quality. Adding Mg to the pod-zone can also reduce the uptake of Ca and therefore increase the incidence of pops and pod rots.

The soil test level for Mg is not well defined for peanuts. Crop responses have been obtained in other crops if exchangeable Mg is <0.2 cmol/kg. If a soil test is at or below this value, apply a test strip to determine whether there is a crop response to Mg. [43]

5.16 Manganese

Manganese deficiency or toxicity is unlikely, except in very high or very low pH soils, respectively. However, short periods of Mn toxicity can occur during periods of low oxygen availability (waterlogging, or wet soil with a lot of incorporated organic matter) in soils otherwise adequate for peanut production.

Deficiencies are most likely on alkaline soils, due to the insolubility of Mn at high pH, and on some very sandy soils.

Manganese toxicity may occur under wet conditions on very acid soils; however, in these soils, other limiting factors such as Ca deficiency or Al toxicity are also likely. Rhizobia are often more sensitive than the plant itself to Mn toxicity. As a result, short-term waterlogging or wet periods, combined with buried 'lumps' of organic matter such as cane trash, can result in death of rhizobia and short-term N deficiency. If this happens early in the season, the plants may re-nodulate, but if it occurs during podfill, re-nodulation may not occur and fertiliser N topdressings may be needed for the crop to mature.

With Mn deficiency, the older leaves turn yellow and the veins stay green (Photo 13). Younger leaves are green and distorted.

Photo 13: *Laboratory symptoms of Mn deficiency (field symptoms may be slightly different). Older leaves turn yellow with green veins, and young leaves are green and distorted.*

Lime will correct Mn toxicity by raising soil pH. Inter-row cultivation may help to restore soil oxygen levels quickly and reduce toxic levels of Mn after a very wet period. [44]

5.17 Molybdenum

Molybdenum is essential for protein synthesis and N fixation. Molybdenum deficiency is most likely where peanuts are grown on acidic soils (pH <5.5). Soil tests over time will show whether the soil is becoming more acidic and is more likely to respond to Mo.

If the level of Mo is too low for N fixation, symptoms of N deficiency will appear. The same symptoms will show if nodulation has failed or the rhizobia have died following waterlogging.

43 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

44 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

Molybdenum can be supplied by mixing with other fertiliser or as a foliar spray. Mo-superphosphate with 0.04% Mo or a foliar spray of sodium molybdate at 300 g/ha will supply 100 g/ha of Mo.

In most situations where Mo is low, it will need to be applied to each crop. In some cases, Mo deficiency can be corrected indirectly with lime or dolomite raising soil pH to ~6. Often the problem is one of unavailability at low pH, rather than actual low Mo.[45]

5.18 Zinc

Peanuts appear to tolerate lower levels of Zn than many other legumes because AM fungi help to extract this nutrient. However, growers in Israel suggest that peanuts can be more sensitive than maize or cotton to low levels of Zn.

Zinc deficiency can occur in soils with a pH >7 but is unlikely in acid soils, except for the very light sands and wallum areas in the coastal Burnett.

Zinc deficiency appears as interveinal yellowing with a browning around the midrib of the leaf (Photo 14).

Photo 14: *Top: leaf symptoms of zinc deficiency in the laboratory (note the browning around the midrib of the leaf). Bottom: field symptoms may be slightly different.*

Zinc deficiency can be corrected with foliar or soil Zn fertiliser applications.

Peanuts are very sensitive to Zn toxicity, which may build up after continual applications on other crops, such as irrigated maize. Symptoms of Zn toxicity include stunting 4 weeks after germination, leaf chlorosis, and flattened stems that develop

45 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

a characteristic vertical split at soil level. See *Cadmium management* below for more information on Zn toxicity.[46]

5.19 Cadmium management

Soils with a long history of superphosphate applications can have problems with cadmium (Cd) accumulation in the peanut kernel.

Cadmium is a heavy metal that accumulates in the human body and can cause health problems. It is therefore imperative that Cd in peanut kernels is minimised.

Cadmium in Australian soils has primarily been introduced as a contaminant of phosphatic fertilisers from marine deposits of phosphate rock from nearby sources (e.g. Nauru and Christmas Islands). The high use of phosphate (and other) fertilisers has added Cd to soils that now grow peanuts.

Not all Cd in a soil is available for uptake by plants. Cadmium uptake is greatest when the soil has low pH (i.e. acidic soils), low clay content (i.e. sands) and low organic matter levels. Marketing companies such as the Peanut Company of Australia (PCA) require soil tests before planting if Cd contamination is likely in a soil.

Growers can manage Cd uptake by the peanut plant, and subsequent movement of the Cd into the developing kernel.

Lime applications to keep soil pH ≥6 will reduce the amount of plant-available Cd, as will incorporation of organic matter (e.g. a cane trash blanket). However, both of these strategies require a few months of time and soil moisture to have a significant impact. Placement must occur wherever there is Cd in the soil profile (mostly the top 40 cm, or to the depth of previous cultivation or ploughings) to be effective. Remember that to lime the top 30 cm of the soil profile to a target pH (e.g. 6.5), lime must be applied at the required rate to treat each 10 cm layer.

Peanut varieties differ substantially in their ability to move Cd from the leaves down into the developing kernel. Low Cd-accumulating varieties should be grown on high-risk soils. Seek advice on the varieties best suited to your situation as new varieties become available.

The peanut plant also seems to move Zn preferentially, instead of Cd, to the kernel, so strategic applications of foliar Zn will help to reduce Cd in the kernels to acceptable levels. To do this, regular applications of up to 1 kg/ha of elemental Zn (4 kg/ha zinc hepta-hydrate) are required throughout the pod-filling phase. Be careful not to over-fertilise with Zn—toxicity can occur. Conduct soil tests and consult your local agronomist.

Zinc applications to the soil can reduce kernel Cd, but increased Cd uptake by the plant and Zn toxicity can occur; therefore, soil applications involve more risks than do foliar applications. The best solution is to build soil Zn levels slowly over time and conduct regular soil tests to avoid over-application.[47]

MORE INFORMATION

[QDPI/CSIRO. Managing cadmium in summer grain legumes for premium quality produce.]

[Cadmium. Nuts2u.]

[Incitec Pivot Fertilisers. Gypsum.]

46 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf

47 PCA/DPIF (2007) Crop nutrition. Peanut Company of Australia/Department of Primary Industries and Fisheries Queensland, http://www.pca.com.au/bmp/pdfs/3b_nutrition.pdf