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INTERPRETING SOIL TEST INFORMATION

C – Carbon
Ca – Calcium
K – Potassium
Mg – Magnesium
N – Nitrogen
P – Phosphorous
S - Sulphur

Most Australian soils are deficient in one or more nutrients in their natural state, especially the nutrients Phosphorus (P), Sulphur (S), Nitrogen (N), and often one or more trace elements.

Soil fertility

Soil fertility is a reflection of the overall nutrient content of the soil, including the balance of these nutrients, soil pH and soil organic matter content. Soil testing is carried out in order to estimate the fertility status of the soil in which crops and pastures are grown. Soil samples are collected according to protocols that have been developed over a long period of time. The way in which the samples are taken, and the nutrient analyses required depend on what questions that you are trying to answer (see factsheet on soil testing).

Soil organic matter

The material commonly referred to as organic matter includes plant and animal residues undergoing decomposition as well as intermediary and end products. It is constantly changing its composition. The level of organic matter is generally estimated from soil organic carbon (% OC x 1.72) and is dependent on the balance between incoming residues and the breakdown of organic matter. Soil organic matter tends to reflect the overall fertility status of the soil.

Most Australian soils tend to be low in organic matter (<5%) because of our hot and dry climate and the highly weathered nature of our infertile soils limiting plant growth, and therefore residue inputs. Farming systems that limit the growing time of plants (eg. crop fallows) also limit residue inputs. Many soils in the Maranoa-Balonne and Border Rivers Regions contain less than 2% organic matter, even in non-cropped situations. Cultivation also causes losses in soil organic matter, which may fall to less than 1% under cropping. Organic matter supplies most of the nitrogen and sulphur and some of the phosphorus taken up by plants.

The slow release pattern of nitrogen and sulphur mineralisation offers a definite advantage over soluble fertilisers. It also supplies most of the Cation exchange capacity (nutrient holding capacity) of highly weathered loams and sands. Organic matter also contributes to soil aggregation and thus improves soil physical and structural properties, improving water infiltration, soil water holding capacity, and reducing susceptibility to erosion.

Soil testing for cropping

Most broadacre crops that are grown in the Maranoa and Border Rivers Regions are sown annually and their hay or grains are harvested and the products removed from the paddock and the farm. Nutrients are exported in the products, with some nutrients exported in greater quantities than others.

Hay crops export significantly higher levels of nutrients than grain. For example, grain sorghum removes about 2kg P and 15kg N per tonne of grain, while wheat removes about 3kg P and 21 kg N per tonne of grain produced (Bell and Moody, 2003). Therefore a wheat crop producing 2.5 tonnes of grain per hectare will remove about 7.5kg P and 52kg N per hectare from the paddock.

Over a period of 20-30 years of cropping the amount of nutrients removed can be substantial so it is recommended that nutrient levels be monitored. Combinations of nutrient budgeting, soil and tissue testing need to be undertaken in order to monitor changes in nutrient levels over time. Soil testing for nitrogen generally needs to be done every 2-3 years, while tests for phosphorus, potash, salt and trace elements are generally only required every 5 to 7 years.

Soil testing for pastures

In most sown pasture systems we look for reasonable production levels that are sustainable over the longer term.

Native pasture species are well adapted to grow and persist on these nutrient deficient soils, although their production levels and nutrient content may be low. However, such low soil nutrient levels are often inadequate for the growth and persistence of introduced pastures such as Bambatsi panic and buffel grass.

Furthermore, the nutrient contents of native pastures growing on these nutrient deficient soils may be inadequate to support satisfactory levels of animal production. Some years ago, research in southern Qld demonstrated that pastures growing on soils that had Colwell P levels of less than 10ppm (= 10 mg/kg) contained inadequate P for beef production, irrespective of pasture productivity. In other words, the animals would directly suffer from P deficiency unless they were given P supplements, or the pasture was fertilised.

Exotic pasture species like buffel grass, green, Gatton and Bambatsi panics, along with a number of pasture legumes, were introduced to Australia because of their ability to achieve and maintain a higher nutritive value than the native species. A fertility-building programme was part of a package that enabled these species to grow on Australia's infertile soils.

Nutrients exported in crop products during cropping operations also lead to declines in soil fertility unless sufficient fertiliser is applied to replace the losses. In order to achieve satisfactory production and persistence of introduced pasture species in old cropping country it is therefore often necessary to re-build soil fertility levels. Legumes have the ability to "fix" atmospheric N and grow on low fertility soils, provided other nutrients, especially P and S, are adequate.

Legumes therefore have the ability to improve soil N levels so that grasses grow better. This is why it is recommended that pasture legumes be included in pasture mixes when sowing new pastures.

Key nutrients

Most of the soils in the Maranoa-Balonne and Border Rivers regions are alkaline in nature. The nutrients most likely to be deficient in these soils are P, N and S, and sometimes Zinc. Salt levels can also be important if they are high.

Critical nutrient levels

The critical levels of the various nutrients required for plant growth varies with crop or plant species, as well as their potential yields. For example, the critical level of phosphorus for growing wheat varies from 20mg/kg in the Maranoa to 35mg/kg on the Darling Downs because of the higher yield potential on the Downs. Pasture grasses tend have a lower fertility demand than most crops. On the other hand, pasture legumes tend to be more sensitive to soil P and S levels than the grasses.

Different grasses also differ in their fertility demands. For example, buffel grass, green and Bambatsi panics have a moderate to high soil fertility requirement, Rhodes grass has a moderate fertility requirement, while Bisset creeping bluegrass and Premier digit grass have a moderate to low fertility requirement.

As previously mentioned, most native species are well adapted to growing on low fertility soils, but they do respond to increased fertility. There are also variations between native grasses in their N requirements.

Therefore, if species such as buffel grass are sown into a low fertility soil, then some fertility building will be required, either by the application of fertiliser, the sowing of legumes, or both. Without such fertility building, production will be poor and the buffel may become run down in only two to three years, or even die out. Maintenance fertiliser inputs may also be required over the longer-term in order to maintain adequate fertility levels for these introduced grasses. However, if we are able to match the pasture species to the soil type according to their fertility requirements, then the system is likely to be more sustainable over the longer term, albeit at a lower level of production.

When sowing mixtures of different grasses and legumes we need to consider the nutritional requirements of each of the species in the mix, with the type of fertiliser and the rate at which it is applied needing to address the nutrient requirements of the most nutrient sensitive species. For example, introduced grasses will often cope with marginal levels of P and S, levels at which legumes either grow poorly or fail to persist. The amount of N fixed by legumes is directly proportional to their growth, so if low levels of P or S limit legume growth, then nitrogen fixation will also be limited and the legumes may be ineffective in building or maintaining soil fertility. Table 1 lists some critical nutrient levels for a range of crop and pasture species.

Table 1. Some critical nutrient levels for crops and pastures grown in the Maranoa – Balonne and Border Rivers Regions.#

Crop or Pasture	Colwell P (mg/kg)	Sulphate Sulphur (mg/kg) (profile*)	Zinc (mg/kg)
Wheat	20	5	0.5
Grain sorghum	30	8	0.8
Green Panic, Buffel grass, Bambatsi panic	15-20	10	0.5
Rhodes grass, Bisset Creeping Bluegrass	15	8-10	0.5
Animal production	10		
Medics and Lucerne	20-25	8	0.9
Burgundy Bean, Siratro	15-20	5	0.8
Caatinga stylo, Desmanthus, Wynn Cassia	10-15	3	0.8

*# The figures in the above table are based on research, or in the case of newer legumes like Caatinga stylo and Desmanthus, on best estimates at this point in time. *Sulphate Sulphur – a profile average should be used to assess S requirements.*

When a soil test report is received from the laboratory the test results should be compared with the ‘critical nutrient levels’ in Table 1. If the soil test results are greater than those in the table, then no action is required. However, if the test results are less than those in table 1, fertiliser application might be considered. The fertiliser rates required are judged according to how close the test results are to the figures in table 1. For example, in the Maranoa-Balonne and Border Rivers regions we would recommend applying 5 kg P/ha if the test result is within 3-5 units of the value in table 1, 7 kg P/ha if the value is between 5-7 units lower and 10 kg P/ha if the deficit is greater than this. Then we look at other nutrients.

The choice of fertiliser will depend on what other nutrients are required. The cheapest form of P is usually MAP or DAP. Both these fertilisers contain P levels of 20–22%, but contain insufficient S to be of any benefit. A fertiliser such as superphosphate (9% P; 11% S; 20% Ca) may be required if both P and S are lacking. Consult your local agribusiness supply companies when making fertiliser choices.

Sulphur and Nitrogen

Both Sulphur and Nitrogen are mobile nutrients that move down through the soil profile in water, so a soil test that only covers the top 10 cm is of little value. This is where deeper tests are required, with emphasis on the top 30-60 cm. For sulphate sulphur (S) we normally make a decision based on the weighted mean level of S averaged across different depths. The average is based on 10 cm depth intervals and is calculated by multiplying the sulphate sulphur concentration (mg/kg) by the number of 10 cm depth intervals making up a sample. This is done for each of the depth intervals. These values are added together and divided by the total number of depth intervals to give a mean for the paddock.

For example, if the Sulphate Sulphur concentration in the 0-10 cm layer is 3.4 and in the 10-30 cm layer is 14.0, we multiply 3.4 by 1 and 14.0 by 2.

Add these together and divide by 3 (we have 3 x 10 cm depth Intervals), to give an average of about 10.5mg/kg. This figure is adequate for all species listed in table 1. However, if we had only considered the surface 10cm, the value of 3.4 would have been considered inadequate for most of the species listed.

Soil nitrogen

Most of the soil nitrogen (97% or more) is bound up in soil organic matter. The remainder exists mainly as ammonium (NH_4^+), nitrate, or urea. Nitrate nitrogen is only a small fraction of the total N in soils, yet it is the only form of nitrogen that is taken up by plants. Nitrogen levels generally affect growth and production of crops and pastures much more than other nutrients, although they are all inter-related. The Total N content of a soil can be estimated using the Kjeldahl digestion method (acid extraction), but it is the “Nitrate Nitrogen” component that is normally estimated and most useful for most agronomic purposes. Most references to “soil fertility” are generally referring to the total soil nitrogen content (organic matter) of the soil, which tends to reflect overall soil fertility, including the levels of key nutrients.

Nitrate N is produced (mineralised) from soil organic matter by microorganisms. Therefore, if soil organic matter levels are low, then soil nitrate N levels are also likely to be low. The soil microorganisms require both heat and moisture to function, so mineralisation rates will be lower in winter and very slow or non-existent when soils are dry. Soil microorganisms also require adequate dietary nutrients in order to multiply and function (Table 2). It is often said that microorganisms have similar dietary requirements to our domestic cattle and sheep. Nitrate N is taken up quickly by growing plants and is also used by the soil microorganisms, so there is little nitrate N to be found in soils where plants are growing. In contrast, both nitrate N and soil water accumulate in crop fallows that are kept weed free. Testing for nitrate N just before planting a crop provides an indication of the amount of nitrate N that the crop will have for growth and production.

Research has provided good estimates of the amount of N required for producing specific yields and grain protein levels, so fertiliser N can be applied to meet any predicted shortfall in N requirements for achieving yield and protein targets. It takes time for mineralisation to occur, so testing for nitrate N soon after harvesting the previous crop, or testing in situations where plants are actively growing (eg. Pastures), will have little meaning unless double cropping is intended.

Calculating crop nitrogen requirements

Where crops are to be grown it is important to know how much nitrate N is in the soil close to planting and to compare this with projected crop requirements.

Soil nitrate N is generally calculated in terms of kg N per hectare by multiplying the nitrate N concentration of the soil sample (mg/kg) by the soil bulk density, and then multiplying this by the number of 10 cm depth intervals that the sample represents (10cm = 1; 10-30 = 2; 30-60 = 3; etc). The amounts of N from the various depth intervals (kg N/ha) are then added together to give a profile total. In making these calculations we normally assume that the bulk density of the top 10cm of a non-cultivated soil is about 1.2-1.3 gm/cc, that of the 10-30 layer to be 1.3-1.4gm/cc and that of deeper layers to be about 1.4gm/cc.

If the surface soil has been cultivated the bulk density estimate should be reduced to about 0.9-1.0gm/cc. Therefore if we have a soil with concentrations of 8.7mg/kg in the 0-10cm layer, 4.5mg/kg in the 10-30cm layer and 0.5mg/kg in the 30-60cm layer, then we can calculate the soil to have 24.2kg N per hectare in the top 60cm of soil {(8.7 x 1 x 1.2)+(4.5 x 2 x 1.3)+(0.5 x 3 x 1.4)}. This 24.2kg N per hectare is quite low, being insufficient N to produce 1 tonne of wheat per hectare (5 bags/acre) with a grain protein of only 8%.

We would need at least 60kg N/ha to produce 1.5 tonnes of wheat per hectare with a grain protein of 11.5%. In sustainable farming systems we therefore look for at least 100-120kg nitrate N in the soil profile at planting time, or sufficient N to produce about 2.5 tonnes of wheat per hectare with a grain protein of around 12%, when sufficient moisture is available.

Nitrogen run-down in grass pastures

Nitrogen run-down is common in all grass pastures, but is most noticeable and the effects are greatest in those grasses that have the highest nitrogen or fertility requirements. Nitrogen run-down in grass pastures can be attributed directly to changes in N availability (Myers and Robbins, 1991). There is no measurable net loss of soil total N associated with this run-down; rather it is a reduction in the rate at which nitrate N is released from organic forms by soil microorganisms.

The rate at which soil microorganisms are able to digest organic components and produce nitrate N depends on the C:N ratio of the organic substrate, as well as the temperature and moisture contents of the soil. Research in the US suggests that the release of nitrate N declines as the C:N ratio of the substrate rises above 24:1 (See Table 2). Tropical C_4 grasses have the ability to recycle and dilute the protein levels within the plant in order to make more N available for plant growth. This reduces the N (and protein) content within the plant and therefore increases the C:N ratio. These tropical grasses therefore return large amounts of low quality litter (high C:N ratio) to the soil (Myers and Robbins, 1991). In high fertility soils, such as the brigalow soils following initial clearing of the scrubs, there was a big surplus of nitrate N, so grass production levels were high and the C:N ratios were moderate.

Each year the N content of the grass (protein) declines a bit more so that the C:N ratios of the litter entering the soil rise, until they reach levels of 80-100, or more.

Table 2. Carbon to Nitrogen ratios of crop residues and other organic materials
Source: USDA Natural Resources Conservation Service

Residue Material	C:N Ratio
Legumes	11:1
Young Lucerne hay	13:1
Beef manure	17:1
Ideal Microbial Diet	24:1
Mature Lucerne hay	25:1
Pea straw	29:1
Oat straw	70:1
Wheat straw	80:1

As the C:N ratio of the organic matter increases, microbial action declines and so the amount of nitrate N released (mineralised) becomes marginal and inadequate for growth of the high fertility demanding grasses. Their production declines and the C:N ratio of their litter becomes even higher, setting up a downward spiralling cycle of production. An external source of N needs to be supplied in order to rectify the situation. This can either come from fertiliser application (eg. Urea) or via legumes.

The C:N ratio of legume material ranges from about 11-25:1, depending on species and maturity. When this is added to the organic pool it is more easily broken down by the microbes because of its lower C:N ratio and so more nitrate N is released.

Other major nutrients (Ca, Mg, K)

Deficiencies of these nutrients for most crop and pasture species are less common, especially on clay and loamy soils. Tropical grasses require concentrations of at least 1.00 cmol(+) Ca/kg, 0.4 cmol(+) Mg/kg and 0.2-0.3 cmol(+) K/kg. Tropical legumes like Siratro and stylos require at least 0.15-0.2 cmol(+) K/kg, but Ca and Mg deficiencies are rare. Wheat, barley and oats require at least 2.0 cmol(+) Ca/kg, 1.6 cmol(+) Mg/kg and 0.4 cmol(+) K/kg. Lucerne, a temperate legume, has a higher requirement for these nutrients at 5.0 cmol(+) Ca/kg, 0.8 cmol(+) Mg/kg and 0.31 cmol(+) K/kg.

Trace elements

Zinc is the trace element most likely to be deficient in alkaline soils throughout the region. On alkaline soils with a pH > 7.0, most crops and pastures require at least 0.8mg Zn kg soil. However, winter cereal crops (wheat, oats, barley) tend to be slightly more tolerant of low zinc levels down to about 0.5-0.6mg Zn/kg soil. Summer crops, including grain sorghum, sunflowers, maize and cotton are more sensitive to zinc deficiency, so a fertiliser containing zinc (MAP + Zinc, or Starter Z) should be used when levels fall below 0.8mg/kg. Pasture species, including Lucerne and white clover, as well as the grasses have a similar requirement to the crops when soil pH > 7.0, but a level of only 0.5mg Zn/ kg is required when soil pH < 7.0.

Salt

Most alkaline soils in the region have high salt levels somewhere in the soil profile. If the high salt levels are located deeper than about 1 metre, then they may have little effect on plant growth. However, if they are located shallower than this, especially in the top 60 cm, they can have a serious effect, or may even be toxic to plant growth.

The amount of salt in the soil is normally estimated by electrical conductivity and expressed as the “Saturated Extract Equivalent” (ECse). Sodium and chloride concentrations are also measured. Different plants have different sensitivity / tolerances to salt (Table 3). Some vegetable crops like peas and beans are extremely sensitive with 50% yield reductions with a soil ECse of only 3.6ds/m. Fortunately most of our crop and pasture species have higher tolerances to soil salt levels. Rhodes grass, barley and cotton have some of the highest tolerances to salt with 50% yield reductions at 15-18ds/m ECse. We do not have salt tolerance levels calculated for many of our pasture species, but field observations indicate that Bambatsi panic may have a tolerance similar to Rhodes grass. On the other hand, most legumes have relatively less tolerance to salt than grasses. High levels of salt in the root zone can be toxic to plant roots, or increase soil osmotic pressure making it more difficult for plants to extract soil water, even when the soil has reasonable moisture levels.

Table 3: The relative salt tolerance of some crop and pasture plants expressed in terms of soil salinity ECse at 90%, 75% and 50% yield.

Crop	Salinity Threshold* ECse at 100% yield (ds/m)	Salinity Threshold ECse at 90% yield (ds/m)	Salinity Threshold ECse at 75% yield (ds/m)	Salinity Threshold ECse at 50% yield (ds/m)
Beans	1.0	1.5	2.3	3.6
White clover	0.9	1.5	2.1	3.3
Lucerne	1.5	3.7	5.8	9.4
Barrel Medic	2.0	3.7	5.3	8.6
Vetch	3.0	3.8	5.1	7.2
Oats	5.5	6.5	7.5	13.0
Sunflower	5.5	5.9	7.2	9.0
Barley Forage	6.0	7.4	8.5	13.0
Barley (grain)	8.0	10.0	13.0	18.0
Wheat	6.0	7.4	8.5	13.0
Wheat (durum)	5.7	7.6	8.7	11.0
Sorghum	6.8	7.4	8.4	9.9
Cotton	7.7	9.6	12.6	15.0
Rhodes Grass cv. Pioneer	7.0	10.1	13.0	18.0
Siratro (Burgundy Bean)	3.0	6.0		12.0
Stylos	3.0	4.0		8.0

**Salinity Threshold ECse (ds/m) is the electrical conductivity of a soil saturation extract at which soil salinity begins to decrease crop yield*

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Sodium ions tend to affect soil structure and soil water movements within the soil rather than having direct chemical effect on plant growth. When the exchangeable sodium level (ESP) is above 5% soil structure starts to be affected. The soil structural units (crumbs) break down, soils crust, porosity is reduced and bulk density increases. Crusting reduces water infiltration and soil water movements and root growth can also be restricted. Soil organic matter and calcium tend to offset the effects of sodium so that soils with ample calcium and organic matter are usually well-structured and friable. Sodium is also a strong base and tends to increase soil pH. Soils with a pH over 8.5 generally contain very high sodium levels. At high levels, sodium can interfere with the uptake of potassium, calcium and magnesium. There are few practical solutions to high soil sodium levels.

Gypsum can be applied to treat sodium in the soil surface and reduce crusting, but this may not be economic.

Chloride ions are just as important, if not more important, than general salt levels. Plants like cotton, barley and Rhodes grass, which have higher salt tolerances (Table 2) do not have any greater tolerance to chloride than other plants that are less tolerant of salt.

The growth of most crop and pasture species is affected by soil chloride levels above 300 mg/kg and is highly affected by soil chloride levels above 600-700 mg/kg. In fact, soil chloride levels above 700 mg/kg may be toxic to some species. Chloride levels above 300 mg /kg reduce plant growth of most species in dry years.

Chloride ions can also directly interfere with, and restrict nitrogen uptake.

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Further Reading:

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