The nitrogen book

Principles of soil nitrogen fertility management in central Queensland farming systems

Includes easy-to-use electronic nitrogen fertiliser calculator

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Preface

Declining fertility of arable soils remains a problem of national and international significance. In eastern Australia's northern grain belt, soil erosion and nutrient removal are the main factors causing soil fertility decline.

In most cropping regions of northern Australia (Central Queensland, Darling Downs, Western Downs and northern NSW) soil fertility rundown has occurred and needs to be corrected in order to obtain satisfactory yields in good seasons because in most areas the period of continuous grain cropping has exceeded after 40-50 years. Hence the frequency response to applied nitrogen is likely to be quite high, drought years not withstanding.

This manual details:

- identifying causes of variability
- methods to obtain a 'target' yield
- discussion of soil sampling
- alternative strategies to improve soil fertility.

In this manual, outputs from crop simulation models are used quite extensively. The reader is encouraged to obtain the program *WhopperCropper* for their own use. *WhopperCropper* is an easy way to visualise the full range of yield (and gross margin) outcomes that are possible. This allows the user to choose a strategy to match a targeted seasonal outcome in keeping with the grower's knowledge of paddock performance over a range seasons and attitude to managing financial risk.

A web-based version is in preparation; search for CropARM or contact 13 25 23 or visit **www.daf.qld.gov.au**

The grower may choose to manage for the lower end of the yield range, minimising costs but also limiting the potential for high yields. Alternatively the grower may apply fertiliser rates targeting a seasonal outcome with high returns in good seasons but with higher financial risk in poorer seasons.

Nitrogen management strategies and aids to guide the use of nitrogen fertilisers, designed to cope with declining soil fertility in southern Queensland and northern New South Wales, are described in this manual. The role of other nutrients is mentioned briefly but will be more extensively described in a subsequent publication.

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Executive summary

Declining soil fertility through soil erosion and/or product removal has created the need for nitrogen addition. Vertosol soils have proved resilient to decline for lengthy periods but inevitably actions to improve or maintain soil physical, chemical and biological integrity will be required. Because of geological history, soil depth, length of farming, some soils are more vulnerable than others and need more immediate remedial activity. In some instances, return to pasture may be the most appropriate strategy.

Sustainable soil management currently focuses on the important issues of retention of surface residues, minimising wheeled traffic and managing soil nitrogen and other nutrients. Agronomic practices impact soil biota largely by the quantity and quality of crop residues returned to soil. Large amounts of residue increases the size of the potential carbon energy source for soil biota, since plant residues contain about 40% carbon. Periodic pasture leys and reduced tillage practices can benefit soil biota. Any short-term detrimental effect on biota from the increased use of herbicides, insecticides or fungicides appears to be out-weighed by wider ecological and crop production benefits. There is a large body of evidence demonstrating that many commercial fertilisers and animal manures increase rather than decrease soil biota and their activities in soil.

At the time of land clearing, fertility of most arable soils of central Queensland was adequate to meet needs for continuous cropping regardless of levels of seasonal crop production. However, as has been found for similar soils in most cropping regions of northern Australia (Darling Downs, Western Downs and northern NSW), response to applied nitrogen occurs with increasing frequency after 40-50 years of continuous grain cropping. Theperiod of cropping for many central Queensland soils is now of a comparable duration, so similar practices and strategies to supplement nutrients can be used as adopted by other northern regions. However, several characteristics of central Queensland cropping systems distinguish them from systems of other northern regions:

- higher occurrence of shallow soils
- higher rainfall variability
- slower rundown of nutrients because of generally lower yielding crops.

The overall effect of this is that yield expectations are generally lower and hence growers are more likely to be risk averse.

However, in many situations soil fertility rundown has occurred and needs to be corrected in order to obtain satisfactory yields in good seasons. This manual details methods of:

- identifying causes of variability
- methods to obtain a 'target' yield
- discussion of soil sampling
- alternative strategies to improve soil fertility.

Stored soil water and rainfall directly determine crop grain yield and crop grain yield determines the demand for nitrogen. This region has highly variable rainfall and hence yields and nitrogen demand will vary widely. There are two actions that can be taken to improve the management of risk involving nitrogen fertiliser application.

1. measure or estimate soil water and soil nitrogen levels close to planting
2. use the *WhopperCropper* program to view the full range of potential yield outcomes. Scenarios are easily created for inputs (including nitrogen fertiliser). Having access to the full range of potential outcomes is superior to a calculation involving a single 'district average' because the user can readily evaluate how their attitude to risk is matched by the effect of different input on potential yield and gross margin outcomes.

Deep soil testing is the best method available for determination of soil nitrate-nitrogen but is still prone to inaccuracy. Carefully consider the number of cores that are used to get the representative sample.

After determining the soil nitrate level, the nitrogen fertiliser rate required can be calculated by the difference between the expected crop nitrogen demand and the soil nitrogen supply. Remember there may be an extra contribution from the soil in the time between soil sampling and planting.

WhopperCropper can also be used directly to view the potential yield ranges from different soil nitrogen levels and several potential nitrogen fertiliser rates.

After the soil nitrogen fertiliser rate is determined, source the cheapest or most convenient form of nitrogen that can be applied with the available equipment. Decide on application timing based on equipment available and work load requirements. The timing of the nitrogen application appears less important than satisfying the crop nitrogen demand. Observe the recommendations of the maximum quantity of fertiliser that can be placed with the seed or place nitrogen fertiliser at an appropriate distance from the seed row.

The cheapest form of nitrogen fertiliser should be sourced that is also appropriate to use with available equipment and for the timing of the application. Application at or prior to sowing is the most effective means of ensuring that the crop is able to readily access applied nitrogen. Nitrogen applied after sowing, when the soil surface is dry, may remain unavailable for crop uptake until the surface soil moisture has been re-wetted. When nitrogen fertiliser is applied at sowing, only a moderate rate should be applied with or in close proximity to the seed; recommendations of maximum quantity of nitrogen fertiliser that can be placed with the seed are provided. Where pre-sowing nitrogen application cannot be achieved, post-sowing application results in increased financial risks which are probably greater than revealed by outputs of *WhopperCropper*.

Pulse crops may contribute much less nitrogen (usually <30 kgN/ha) than a ley, particularly if grain removal is large by comparison to the vegetative material produced by the pulse crop. Leys or pulse crops may provide rotational benefits, like disease suppression, in addition to the variable accretion of nitrogen in soil.

The quantity of nitrogen added will vary in proportion to the quantity of vegetative material returned to the soil, in the case of a ley, or inversely in proportion to the amount of nitrogen removed in grain, in the case of a pulse. Seasonal conditions, primarily rainfall during pasture production and yield of pulsegrain, will exert greatest impact upon the nitrogen contribution following a ley or pulse. Lablab and butterfly pea are the most successful ley pastures in central Queensland, and could add up to 100 kgN/ha. Whilst nitrogen supply following a ley may be adequate to support the following cereal crop, water used by the ley should be adequately recharged by rainfall for a successful rotation back to cropping. Pulse crops may contribute much less nitrogen (usually <30 kgN/ha) than a ley, particularly if grain removal is large by comparison to the vegetative material produced by the pulse crop. Leys or pulse crops may provide rotational benefits, like disease suppression, in addition to the variable accretion of nitrogen in soil.

1. Introduction

This manual covers important aspects of soil types, soil biology, organic carbon and management of factors pertinent to Central Queensland cropping industries. The nitrogen cycle and the flows between pools are described in detail. Losses and potential losses are detailed with the aim of maximising production whilst reducing fertility rundown.

High rainfall variability is well recognised in this region. In terms of managing risk it is important to understand how this rainfall variability affects crop yield and hence nitrogen demand. In this manual, outputs from simulation models, via the *WhopperCropper* program, are used extensively to generate seasonal production for wheat and sorghum crops including financial returns using weather data available from locations across the region over the past 100 years.

Whilst far from perfect, soil testing has been recognised as the primary means to determine plant-available nitrogen supply. Calculation of crop demand and soil supply of nitrogen and supplementary fertiliser requirements can be automated using the electronic calculator supplied with this manual.

Management options for timing, placement and safe application of nitrogen fertiliser are outlined. Also discussed is the integration of pastures with a legume component into cropping systems to offset soil nitrogen decline with continuous cropping.

Risk management with nitrogen fertilisers

To manage nitrogen nutrition and financial risk, two features of central Queensland cropping need to be recognised;

a) soil types differ in their original nitrogen status and in their capacities to supply plant-available nitrogen

b) seasonal rainfall variation has a major impact upon financial risk associated with fertiliser application.

A successful strategy to manage nitrogen nutrition and financial risk must embrace these aspects of cropping as well as providing a platform from which advice can be modified/fine tuned as new research findings come to hand. For this reason the current state of knowledge about use of nitrogen fertilisers and ley pastures in the region has been captured.

2. Understanding and managing soil biology

Key messages

- An enormous diversity of microbes exists in the soil, most in massive numbers.
- Because the majority of soil biota relies on carbon as their energy substrate, concentration of bio-available organic carbon in soil is associated with most changes in soil biota.
- Agronomic practices impact soil biota largely by the quantity and quality of crop residues returned to soil.
- The quantity of plant residues returned impacts the magnitude of potential energy source for soil biota.
- Nitrogen flows in the soil are complex and involve continuous movement of nitrogen between pools including biota.

Soil organic matter

Schwenke (2004) defined soil organic matter (SOM) as everything of biological origin whether living or dead. Both humus and organic carbon are components of the soil organic matter (Table 1). The above-ground portion of living plants is excluded. Humus is the most stable part of soil organic matter and is slow to break down.

Soil organic matter influences the biological, physical and chemical properties of soils which in turn provide ecological benefits. These include:

- Nitrogen storage, supply and cycling
- Food for microbes
- Cation exchange capacity
- Water-holding capacity infiltration and soil porosity
- Aiding soil aggregation
- Phosphorus storage
- pH buffering
- Chelation of micronutrients
- Pesticide degradation (substrate for microbes and chelation)
- Carbon sequestration
- Weed suppression (soil cover and allelopathy)
- Nematode and other disease organism suppression.

However, there can be downsides that include:

- allelopathic (growth inhibiting) chemicals
- hydrophobic (water repelling) substances
- nutrient tie up during decomposition of plant residues, particularly nitrogen and sulphur.

Soil organic carbon is an indicator of soil nitrogen fertility as well as an indicator of soils ability to support microbial populations.

Table 1. Components of soil organic matter (SOM)

Component	Percentage	Comment
Active SOM (living)	2 to 12%	see Table 2
Active SOM (non-living)	8 to 24%	Stubble, dead roots, manure, bones, sugars, amino acids, organic acids
Stable SOM (humus)	70 to 90%	Sugars, amino acids, proteins, fats, lignin, other humic substances, charcoal

Table 2. Types and functions of soil microbes

Type of microorganism	Function in soil
Organisms that add nutrients to soil	
Nitrogen-fixing micro-organisms Symbiotic N2-fixing bacteria e.g. *Rhizobium* and *Bradyrhizobium* species	Fix atmospheric nitrogen in symbiosis with legume plants
Non-symbiotic N2-fixing bacteria e.g. *Azospirillum, Azotobacter species*	Fix atmospheric nitrogen in bulk soil, near crop residues and in rhizosphere
Organisms that transfer nutrients into plant available forms or facilitate their uptake by plants	
Nitrifying microorganisms e.g. *Nitrosomonas and Nitrobacter* species	Convert ammonia nitrogen into plant available nitrate form
Sulfur-oxidizing micro-organisms e.g. *Thiobacillus thioxidans*, most heterotrophic bacteria and fungi	Convert elemental sulfur and organic sulfur into plant-available sulfates and'solubilise phosphates' (unlikely to occur in alkaline soils of CQ)
Mycorrhizae e.g. *Vesicular Arbuscular Mycorrhizae* (VAM) (except for crops such as canola)	Facilitate the uptake of phosphorus and zinc by most agricultural crops
Phophorus-solubilising micro-organisms e.g. *Penicillium* species	Solubilise plant-unavailable inorganic and organic phosphorus into available forms
Organisms whose action results in the loss of nutrients from soil	
Denitrifying micro-organisms e.g. *Thiobacillus denitrificans*	Convert nitrate nitrogen into nitrogen and nitrous oxide gas
Sulfur-reducing bacteria e.g. *Desulfovibrio* species	Reduce sulfate sulfur into hydrogen sulfide gas
Organisms involved in the decomposition of crop residues	
Cellulolytic bacteria and fungi e.g. *Cellulomonas* species	Decompose cellulose and like compounds in crop residues
Organisms that promote above-ground and/or below-ground plant growth	
Plant growth promoting rhizobacteria e.g. *Pseudomonas* species, *Bacillus* species *Streptomyces* species	Promote above-ground and/or below-ground plant growth through hormone production or other mechanisms
Organisms involved causing plant diseases	
Rhizoctonia solani, Pythium ultimum, Fusarium species, *Verticillium* species, Ggt) *Bipolaris sorokiniana;* *Fusarium graminearum;* *Pyrenophora tritici-repentis*	Rhizoctonia barepatch, take-all, damping-off diseases. Common root rot Crown rot Yellow spot
Organisms involved in the control of plant diseases	
Bacteria: *Pseudomonas fluorescens, Bacillus subtilis* Fungi: *Trichoderma koningi, Fusarium oxysporum* Actinomyces: *Streptomyces rimosus*	Control soil-borne plant diseases

Source: Gupta and Roget 2004

Soil micro-organisms

Soil organisms (biota) are involved in transformation processes that are essential for crop production, soil quality and environmental health. There is a two way relationship between the soil biota and agricultural production; soil biota plays a key role in a number of nutrient transformation processes and crop residues supply carbon and nutrients to the soil biota. Soil biota also provide the following benefits:

- increased carbon and nitrogen transformations
- direct benefit to plants (nitrogen-fixing rhizobia)
- aiding soil stability (fungi filaments bind aggregates)
- competing with plant pathogens (disease suppression)
- providing short-term immobilisation of inorganic fertilisers.

Soil organisms can be grouped according to their size, morphological characteristics, function and food preference (Gupta and Roget 2004). Soil biota are also combined into groups based on their role in specific soil functions (Table 2). For example nitrifying micro-organisms are those that convert ammonia nitrogen into nitrate nitrogen, making it available to plants. Soil organisms range in size from microscopic (bacteria) to centimetres (earthworms).

The four major groups of soil biota, based on size are:

- microflora (bacteria, fungi, algae and actinomycetes)
- microfauna (protozoa, nematodes)
- mesofauna (collembola, mites)
- macrofauna (earthworms, beetles, termites).

In addition, soil fauna are also classified into various groups based on their principal food source, e.g. bacterial-feeding, fungal-feeding, plant parasitic or predatory fauna.

Micro-organism populations are generally enormous. The population will vary dependent on temperature, moisture and food supply. Only in extremely dry situations will most of the micro-organisms desiccate and die. Examples of population numbers are:

- bacteria: millions or trillions/gram of soil (400 to 5000 kg/ha)
- actinomycetes: (similar to bacteria) millions/gram of soil (400 to 5000 kg/ha)
- fungi: 1000 to 20 000 kg/ha
- algae: 1 to 10 billion/gram soil (10 to 500 kg/ha).

(from Brady and Weil 1996)

Specific bacteria associate with the particular conditions present in the soil e.g. wet or dry, with or without oxygen. Exchangeable calcium is important for their survival, as is soil pH.

Reduced tillage supports a fungal based system, whilst conventional tillage favours a bacterial-dominant system (Gupta and Roget 2004).

Carbon and nutrient cycling and nutrient availability

Gupta and Roget (2004) report the following summary of the contribution of microbial biomass:

"Organic matter in soil is the most important fraction that supports microbial populations, especially the biologically available portion of soil organic matter."

Microbial biomass, the living component of soil organic matter, constitutes 2 to 7% of the organic carbon in soils. Microbial biomass acts as the engine for organic matter turnover and nutrient release. The size of microbial biomass carbon in the surface soil may range from 250 mg C/kg in a sandy soil to 1100 mg C/kg in a clay soil rich in organic matter. Microbial biomass carbon may only represent a small portion of soil organic matter (2 to 7%), but it is dynamic and living and thus is more sensitive to management practices than total soil organic matter.

Microbial biomass is a storehouse of plant-essential nutrients. For example, nitrogen levels in microbial biomass range from 15 to 150 kg N/ha. Microbial biomass also holds 5 to 15 kg/ha of sulphur and 10 to 45 kg/ha phosphorus. Nutrients held in microbial biomass are not prone to leaching, are tied up only temporarily, and are released for plant uptake as a result of predation by microfauna and the death of microbes during soil drying. It is the interactions between micro-organisms and organic matter in the soil that largely determine the fertility and overall quality of the soil. Therefore it is extremely important to use farm management practices that maintain organic matter levels, especially biologically available organic matter, in our soils'.

Effect of pastures

Plants are the major source of available carbon for biological activity, so soil biodiversity and biological activity depend on the quality and quantity of carbon inputs from plants, through root exudation and above and below-ground plant residues, and plant-induced changes in soil physical and chemical properties.

Pastures composed of mixtures of plant types (legumes, grasses) are considered to have a greater potential to influence diverse biological processes. This is due to the mixture of exudates and quantity and quality of residues. However, the quantity of carbon in grazed systems is affected by grazing management.

Effect of agronomic practices on soil biota

Because soil biota are dominated by heterotrophic organisms (those which rely on carbonaceous materials as an energy substrate), the concentration of organic carbon in soil, will in turn, affect the soil biota (Bunemann and McNeil 2004).

Australian soils are inherently low in biologically available carbon, so carbon inputs have a major influence on soil biological activity (Gupta and Roget 2004).

Agronomic practices impact soil biota largely by the quantity and quality of crop residues returned to soil. The quantity of plant residues returned directly affects the magnitude of the potential carbon energy source for soil biota, since all plant residues contain about 40% carbon. Residues of different chemical composition tend to favour different soil biota; for example, bacteria are favoured by inputs with high nitrogen concentration such as legume residues whereas cereal residues tend to increase populations of fungi. Crop residues decompose at varying rates so nitrogen availability will vary. There may even be large differences in nitrogen availability across various residues of the same species; woody or lignin containing residues are much less bio-available than herbaceous residues.

Several agronomic practices of northern farming systems are likely to impact soil biota and their activities in soil and some are discussed below:

- the occurrence of tillage and/or stubble retention
- the use of chemicals such as herbicides, insecticides and fungicides
- the application of fertilisers or manures.

Effect of tillage and stubble

Bell *et al.* (2004) found that overall microbial activity was less in soil continuously cropped (with a fallow between crops) than in soil with periodic leys. Reduced tillage results in less soil erosion, less exposure of soil organic matter to oxidation, and no dilution with subsoil material (Dalal and Chan 2001). However, reduced or no-till systems can also concentrate stubble and its contained nutrients within the uppermost layer of surface soil; only in the top 2.5 cm layer was there an increase in soil carbon detected during 8 years of no-till wheat with 75 kg N/ha applied annually on a Vertisol at Warra (Dalal *et al.* 1998). Also, it is likely that long fallows and/or bare areas in widely-spaced sorghum rows would result in reduced soil carbon inputs. Whether microbial populations are impacted by tillage and/or stubble retention will depend upon the quantity and quality of residues returned and weather conditions during its decomposition.

Effect of pesticides

Van Zwieten (2004) provides evidence that soil biota are affected by some but not all pesticides, ranging from negligible to large negative impacts but also with some positive impacts.

Immediate impacts can include short term stimulation of enzymatic activity, and bacterial numbers through to elimination of earthworm populations. It must be remembered that while pesticide effects may be evident in short-term laboratory tests, they may have little if any lasting effects in the field. Any short-term detrimental effect to soil biota may be out-weighed by wider ecological and crop production benefits. Specific examples of the effect of herbicides, insecticides and fungicides include the following (as cited by van Zwieten 2002):

- **Glyphosate:** bacterial numbers were reduced, fungi and actinomycetes were increased, overall increase in microbial activity of 9 to 19% (Araujo 2003); short term effects but no lasting changes to microbial community (Busse *et al.* 2001).
- **Glyphosate and paraquat:** activation of urease, suppression of phosphatase, enzymes that might impact upon action of micro-organisms, particularly soil bacteria (Sannino and Gianfreda 2001).
- **Atrazine:** urease activation, suppression of invertase (Sannino and Gianfreda 2001).
- **Atrazine and metolachlor:** altered community structure of bacteria and actinomycetes (Seghers *et al.* 2003).
- **Chlorpyifos:** reduced bacterial numbers and slightly increased fungal numbers (Pandey and Singh 2004).
- **Copper:** reduced microbial biomass and OM breakdown; earthworms avoid soil with concentrations as low as 34 mg/kg (van Zwieten *et al.* 2004).

Effect of fertilisers

Effects of fertiliser additions on soil biota have been reported by Bunemann and McNeil (2004). They present a large body of evidence demonstrating that applications of many commercial fertilisers and animal manures increase rather than decrease soil biota and their activities in soil. Most effects of fertiliser addition on soil biota are immediate but may last up to 3 months or longer after the addition. The greater influence of organic versus inorganic fertilisers was emphasised in a study of soil respiration, acid phosphatase and dehydrogenase activity in maize. Three months after application of 200 kg N/ha as ammonium nitrate, the above components were greater than in the non-fertilised control. However, all these changes were more pronounced when the same amount of nitrogen was added as dairy manure or composted sewage sludge (Marinari *et al.* 2000).

Long-term application of phosphorus fertiliser often has little if any effect on soil biota. However, mineral nitrogen fertilisation has been reported to have a negative effect on soil biota in acid soils of South Australia and elsewhere. These negative effects are due to increased soil acidity created by addition of fertilisers such as ammonium sulphate and urea. However, addition of these fertilisers is unlikely to affect pH of central Queensland's well buffered neutral to alkaline vertosol soils and therefore should have little impact on soil biota.

A reduction in specific organisms such as arbuscular mycorrhizal (AM) fungi by phosphorus fertilisation appears to be fairly well established. In a comparison of Australian pastures under conventional and biodynamic management, a negative relationship existed between available phosphorus and colonisation rates of clover roots with AM fungi (Ryan *et al.* 2000), but AM colonisation rates of ryegrass were not affected by phosphorus addition (Ryan and Ash 1999). These findings agree with the variable effect of nitrogen, phosphorus, potassium (NPK) fertilisation on percent root colonisation by AM in different grassland species observed by Rillig *et al.* (1998). Research suggests that mycorrhizal symbioses are affected primarily by indirect effects of fertilisers through changes in plant growth and metabolism rather than by any direct effects on AM fungi.

Managing soil organic matter

Maintaining or increasing the amount of soil organic matter comes down to well recognised current best management practices:

- reduce soil erosion (results in less physical removal of nutrients)
- maintain stubble cover (Dalal and Chan 2001, Bell *et al.* 2004)
- avoid long fallows where possible (Bell *et al.* 2004) (maintains microbial population)
- grow healthy crops (adds biomass). May require use of inorganic fertilisers and pesticides
- apply well composted manure if available
- retain crop residues (no removal by burning or baling).

Can soil organic matter be increased?

The soil contains a massive reserve of organic matter. One hectare of soil to a depth of 10 cm weighs at least 1000 tonnes (assuming a soil bulk density of 1 g/cm^3). If soil organic carbon (OC) is 1%, SOM is 1.7% or 17 t/ha in the top 10 cm. To increase OC to 2% (SOM = 3.5% or 35 t/ha) would require an additional 18 t/ha of OM. This could NOT be in the form of fresh manure because 80 to 90% of the product is lost over time (Schwenke 2004) although manures can be considered as valuable nutrient sources (especially for P and K).

A more successful way to increase soil organic matter is to incorporate a pasture phase into the cropping system. At *Warra* in south Queensland soil organic matter was increased by 20% (650 kg C/ha/year) after a 4-year pasture phase although this effect was likely to be short-lived because of the greater proportion of active materials added.

Building soil organic matter should be an aim in broadacre agriculture for soils that have very depleted soil organic carbon levels (less than 0.8% organic carbon). Growers with soils with this level or more may employ strategies to at least maintain moderate soil organic carbon levels assuming no physical constraints are limiting production. A pasture ley phase may suit some mixed farmers to build nutrient reserves. Pulse crops may 'save' some nitrogen depletion when conditions and prices favour their incorporation in the rotation.

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3. Gains and losses of soil nitrogen

Key messages

- Soils that had brigalow trees as the native vegetation usually had high levels of nitrogen fertility (organic carbon of 1.4 to 2%) before being used for farming.
- Open downs soils had a lower nitrogen fertility (organic carbon levels of 1 to 1.2%) because of the predominantly grass vegetation.
- The rate of decline of nitrogen fertility is initially a little faster in scrub soils but the open downs soil will require nitrogen addition sooner than brigalow/softwood scrub soils.
- The onset of nitrogen fertiliser response could be in the range 10 to 20 years for open downs soil compared to 40 to 50 years for scrub soil (sooner if rainfall favours high grain yields).
- Soils will mineralise 50 to 100 kg N/ha per year.
- Organic carbon can be used as arough indicator of soil fertility and is a reasonably inexpensive test.
- Flow rates of nitrogen between pools vary from very slow (immobilisation or mineralisation) to very fast (denitrification), are all affected by weather conditions, and are difficult to measure independently.
- Vertosol soils are chemically well buffered and appear comparatively resilient to negative impacts of nitrogen loss due cultivation, crop removal and soil erosion.
- Nitrogen fertiliser application or nitrogen accretion by legumes can slow the decline of soil nitrogen.

Cropping soils of central Queensland

Soils need to be able to store at least 120 mm of plant available water within their rooting depth for reliable dryland cropping. Rooting depth is the depth of soil to an impervious barrier such as rock or to a zone in the subsoil with a high concentration of soluble salts (greater than 0.8 dS/m) and/or sodic conditions (greater than 15% exchangeable sodium percentage). These zones may be referred to as the salt bulge or sodic bulge. Crops are unable to use the majority of water present in layers of soils with these conditions.

There are three main groups of soils that can store at least 120 mm of available water in their rooting depth: The distribution of these soils is shown in Map 1.

1. Cracking clay soils; either derived from basalt with a rooting depth of at least 60 cm, or derived from other parent materials with a rooting depth of at least 80 cm;
2. Non-sodic duplex soils with a rooting depth of at least 100–120 cm.
3. Non-cracking clay soils with a rooting depth of at least 80–100 cm.

Cracking clay soils

Cracking clay soils are the most important and widespread soils used for dryland cropping in central Queensland. They occur on a variety of landscapes and parent materials, and are suitable for cultivation provided they are deep enough, do not have well developed melonholes (gilgai) and are not prone to flooding. The shrinking and swelling nature of cracking clay soils also assists with recovery from compaction.

The predominant types of cracking clay soils and vegetation associations are:

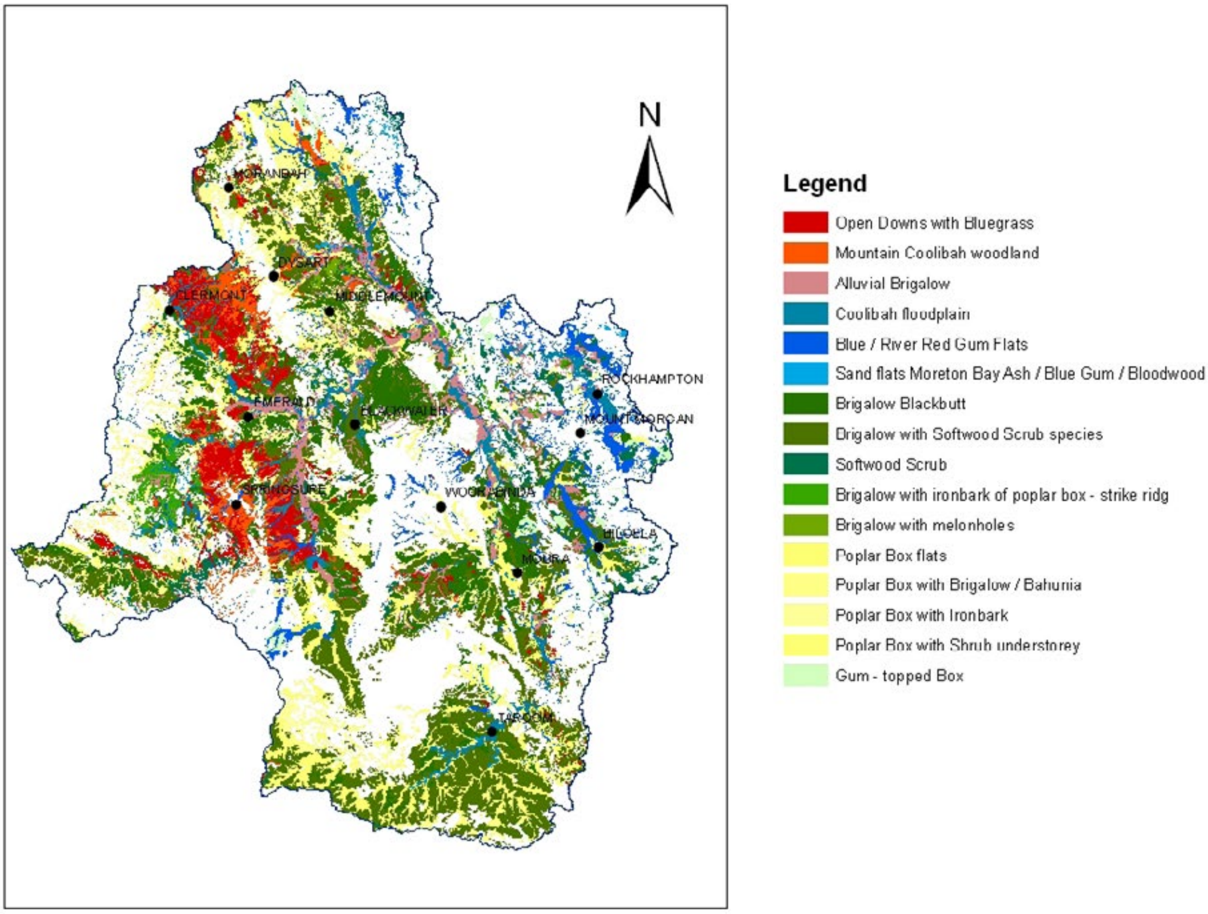
a) Soils developed on basalt: open downs, mountain coolibah, brigalow or gidgee scrub; with black, brown and red cracking clay;

b) Soils developed on other parent materials: brigalow and/or softwood scrub; with black, brown or grey cracking clays;

c) Soils developed on alluvium along river and creek flats: coolibah or blue gums; with black cracking clays.

(a) Cracking clay soils developed on basalt

When compared with other clay soils, the clay soils developed on basalt have a high clay content (usually greater than 70%) and may have a high water-holding capacity if the rooting depth is high. However, some of these soils are shallow, with a rooting depth as low as 50 cm. These soils support two main vegetation types, open grasslands and brigalow and/or gidgee scrub.



Map 1. Distribution of major dryland cropping soils for the Fitzroy Basin in Central Queensland

Source: Department of Primary Industries and Fisheries 2007. Land Types of Queensland – Fitzroy. Prepared by the Grazing Land Management workshop team, Department of Primary Industries and Fisheries, Brisbane. PR07-3212

Open downs soils

The open downs soils cover large areas of land from Rolleston through to north of Clermont. They are strongly cracking and have coarse self-mulching topsoils. Their features include a moderate to high water holding capacity; some being limited by the depth of the soil. They have moderate fertility with low to medium nitrogen and phosphorous contents.

There are minor areas of open downs soil that occur on parent materials other than basalt, such as shales. As they have similar properties, they are included with the basalt-derived open downs soils. The main difference is that shale soils may contain significant soluble salt at depth.

Brigalow and/or gidgee scrub soils

The brigalow and gidgee scrub clay soils developed on basalt have a fine selfmulching topsoil with a high organic matter content. They generally have a deeper rooting depth and higher water holding capacity than the open downs soils, but are less extensive. They have high fertility with medium to high content of nitrogen and phosphorous.

(b) Brigalow and/or softwood scrub cracking clay soils developed on unconsolidated clay sediments

The more extensive areas with brigalow, gidgee and softwood scrub vegetation are developed on unconsolidated clay sediments (or old alluvial and colluvial deposits) and a range of sedimentary rocks such as sandstone and shale. These soils occur throughout all areas of central Queensland. These soils have a rooting depth defined by the depth to a sodic and/ or salt bulge, usually around 80–100 cm; have high clay contents of 50–60%, and a high water holding capacity. They were originally fertile soils with medium concentrations of nitrogen and medium to high phosphorous. They generally have fine self-mulching topsoils.

Grey, brown and dark cracking clays with strongly developed melonholes occur over large areas of the unconsolidated sediments. These soils are generally not suitable for cropping because they have a shallow rooting depth due to high concentrations of soluble salts and exchangeable sodium in the upper Open downs 30–50 cm of the subsoil. The melonholes hold water for prolonged periods and also restrict machinery operations.

Open downs

Flooded coolibah

Brigalow/softwood scrub

Alluvial brigalow

Source: Department of Primary Industries and Fisheries (2008). Land Types of Queensland – Darling Downs. Version 1.0. Prepared by the Grazing Land Management workshop teams, Department of Primary Industries and Fisheries, Brisbane

(c) Coolibah or blue gum alluvial cracking clay soils

The coolibah or blue gum black cracking clay soils are found on the floodplains of the major river systems and their tributaries in the region. Usually these soils have a high clay content (50– 65%), high water holding capacity (sufficient for dryland cropping) and variable rooting depth according to the location of the salt bulge. They also have a high to very high phosphorous content with low nitrogen levels and variable surface conditions (from fine self-mulching to hardsetting surfaces). The areas of clay soil 16 with brigalow, which also occur on these floodplains, (i.e. flooded brigalow lands) generally have higher nitrogen levels and a similar phosphorus range. Most river flats are prone to flooding which prevents or restricts cropping.

Brigalow with blackbutt (eucalypt) landform

Source: Department of Primary Industries and Fisheries (2008). Land Types of Queensland – Darling Downs. Version 1.0. Prepared by the Grazing Land Management workshop teams, Department of Primary Industries and Fisheries, Brisbane

Non-sodic duplex soils

Duplex soils (or texture contrast soils) are those with a light textured topsoil (i.e. sand to clay loam) overlying a clay subsoil. Duplex soils suitable for rainfed cropping are very limited in area within central Queensland. These soils occur mainly to the west of Moura and on some river floodplains and creek flats. Vegetation varies from brigalow-Dawson's gum (blackbutt) scrub to eucalypt woodlands. These soils have a sandy loam to clay loam surface overlying well structured red, brown or black subsoil which is nonsodic in the upper subsoil. They have a moderate water holding capacity requiring a rooting depth of 100–120 cm to store sufficient water for dryland cropping. Nutritionally, they have low to medium nitrogen and medium to high phosphorus contents in the brigalow and alluvial soils in this group. They have low nitrogen and phosphorus concentrations in eucalypt woodlands with duplex soils along with hard-setting, poorly structured surface soils that are difficult to work. Thin surfaced (less than 10 cm thick) duplex soils often develop into a cracking clay soil after a period of cultivation, as the topsoil becomes mixed with the subsoil.

Non-cracking clay soils

These soils occupy a small area when compared with the cracking clay soils and are only of minor importance for cropping. Non-cracking clays generally occur in association with cracking clay soils, but lack distinctive cracking at the surface. They consist of well-structured red to brown soils with brigalow or softwood scrub vegetation and deep black, well-structured alluvial soils with blue gum vegetation. Surface condition ranges from self-mulching to hard-setting topsoils. They have well drained profiles with low soluble salt contents and a deep rooting depth (with clay contents around 45–55%, a rooting depth of at least 80–100 cm is needed to store sufficient moisture for dryland crops). They have low to medium nitrogen and medium to high phosphorus contents, depending on which landscape they occur in.

Fertility status of central Queensland soils

Grain-growers and advisers frequently describe soils and their fertility by association with the original vegetation. Below are listed, in approximately descending order of original nitrogen fertility, five major soil/vegetation associations:

- Brigalow/softwood scrub soils
- Mixed brigalow soils
- Open downs soils
- Alluvial soils and
- Eucalypt woodlands, generally considered unsuitable for cropping.

The original vegetation type distinguishes the brigalow scrub soils, with generally higher initial fertility, from the bluegrass open downs soils with generally lower initial fertility status.

The difference in soil fertility reflects the ability of brigalow softwood scrub to maintain a higher total soil nitrogen level than the grass vegetation of open downs soil. This difference in original total nitrogen status significantly affects the length of time after the commencement of cropping before supplementary nitrogen will be required to continue to crop profitably with cereal crops. Hence, it is likely that most brigalow scrub soils will continue to support satisfactory cereal production long after plant available nitrogen supplies from open downs soils have been exhausted (see Figure 2).

As has been found for soils of similar initial fertility to softwood scrub soils in most cropping regions of northern Australia (Darling Downs, Western Downs and northern NSW), response to applied nitrogen occurs with increasing frequency after 40-50 years of continuous grain cropping. Responses to nitrogen fertiliser application on open downs soils have been observed for many years.

Soil fertility decline

There is worldwide recognition that the fertility of arable soils is in decline.

Within Australia, evidence of declining soil fertility, crop production, and grain quality has been reported by Dalal and Mayer (1986), Spackman and Garside (1995) and Cornish et al (1998). Wheat yield in 39 shires was related to low nitrogen fertility and in some cases phosphorus deficiency.

Furthermore, improved soil fertility is linked to increased water use efficiency, an essential requirement of Australia's grain production systems that cannot be overemphasised (Cornish et al 1998).

Growers in central Queensland are also well aware of the issues of fertility rundown as evidenced by responses to a 2002 survey of participants of the central Queensland Sustainable Farming Systems Project (Cox and Spackman, 2002). The survey indicated:

- 65 per cent of growers use nitrogen fertiliser
- nitrogen fertiliser use increased 60 percent over the previous five years
- average rate of nitrogen applied to wheat and sorghum increased by 10kg/ha over the previous five years
- 70 per cent of growers expected to be using nitrogen fertiliser within five years.

Evidence of fertility decline in soils of central Queensland is similarly compelling; declining levels of crop production (Spackman and Garside, 1995) and declining soil properties (Millar and Armstrong, 1999; Cox et al 2003) have been reported.

A decline in soil organic carbon and total soil nitrogen of approximately 25 per cent was reported after cropping a brigalow scrub soil for only 21 years (Figure 1). The dilemma for central Queensland growers is how to continue profitable cropping regardless of soil fertility decline.

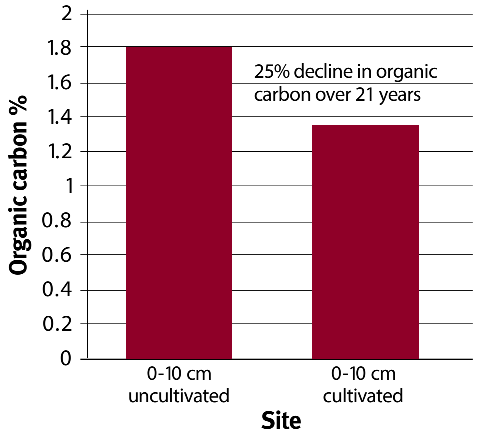


Figure 1. Comparison of soil organic carbon levels from brigalow scrub soils at Dysart cultivated for 21 years or not cultivated

Source: CQSFS project trial report

Soil nitrogen fertility decline will generally occur with continuous cereal cropping (Figure 2a and b). The two major soil types also differ in the initial soil fertility and the initial rate of nitrogen fertility decline (Figure 2a). The addition of a legume (pulse) crop may slow the process but is unlikely to eliminate it. Agronomic practices such as no-till and controlled traffic that reduce soil erosion may slow fertility decline but the introduction of a grass / legume phase is the only way toreverse the soil fertility decline.

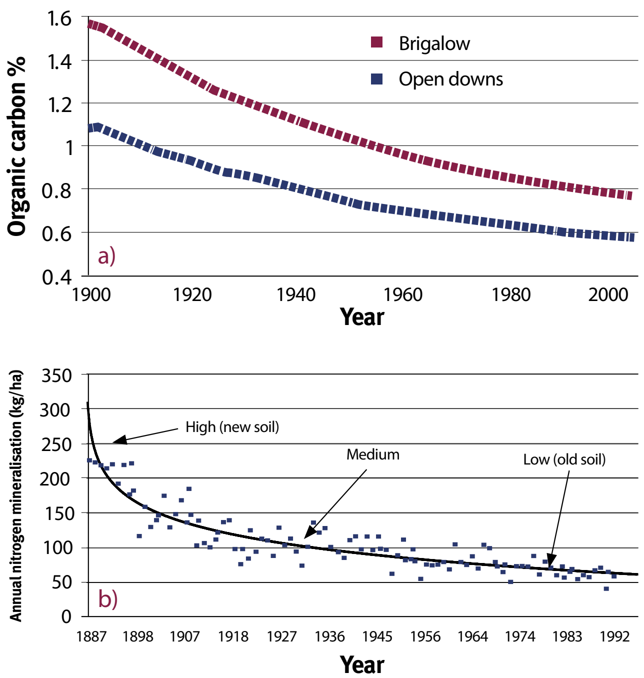


Figure 2. Simulated changes in soil a) organic carbon and b) annual mineralisation, potential simulated with a continuous cereal based opportunity cropping system and with no nitrogen fertiliser applied

Source: APSIM crop model

Useful indicators of soil nitrogen fertility

Soil organic matter content

Most central Queensland soils contained large quantities of organic matter at the commencement of cropping. This quantity has declined over the duration of cropping, particularly in the topsoil from which crops derive most nutrients and much of the crop's water supply. Because of the high clay content of most central Queensland soils (50 to 70 per cent), the organic matter decline is less than would be for other soil types located in a tropical region. Decline in soil organic matter of brigalow or softwood scrub soils appears initially faster than for open downs soils, due possibly to the lower clay content which is known to offer some protection from decomposition of soil organic matter.

Most arable central Queensland soils contain 170 t/ha or more of organic matter to a depth of 1 m, of which 58 per cent is organic carbon. Soil organic matter is most frequently measured by the quantity of soil organic carbon present. Up to 50 per cent of the organic matter resides in the upper 30 cm of soil.

Soil organic carbon

Soil organic carbon (OC) is the laboratory test that measures the quantity of soil organic matter (SOM). Hence organic carbon can be used as an indicator of soil fertility status. Because OC % can be measured using a relatively inexpensive oxidation procedure it is commonly used as a surrogate measure of soil nitrogen status.

SOM contains approximately 58% carbon (C) thus its concentration in soil can be estimated from OC content as follows: SOM = OC * 1 / 0.58 = OC * 1.72

Total nitrogen content

Total nitrogen content of soil in the top 10 cm can be measured directly using a standard laboratory process but is also frequently estimated from soil organic carbon assuming an approximate ratio of C:N of 10:1. Soils of southern Queensland may vary from less than 0.1 to more than 0.2% total nitrogen. The lower values are generally from open grassland soils, whilst the higher values are usually indicative of brigalow/softwood scrub soils.

Total nitrogen identifies the soil's potential to supply plant-available nitrogen. More than 90% of the soil's total nitrogen may be initially unavailable to the crop because it exists in organic forms. Total nitrogen therefore is a measure of the soil's capacity to supply plant-available nitrogen over the long term.

Plant-available nitrogen (mineral-nitrogen)

Plant-available nitrogen is best determined by soil tests that measure the forms of soil nitrogen referred to as mineral nitrogen. Mineral nitrogen is principally nitrate-nitrogen because in the northern region, transformation of organic-nitrogen to nitrate-nitrogen through an intermediate ammonium-nitrogen, phase is very rapid.

Ammonium nitrogen is a very temporary phase and detected in field moist soil at only very low concentrations (<1 mg/kg). Disregard any ammonium soil test value conducted on air-dried (40°C) soil because the value of ammonium-nitrogen will usually be artificially high. This occurs because air-drying promotes transformation of organic-nitrogen to the ammonium nitrogen form. Ammonium-nitrogen tests, if required, must be conducted quickly on field-moist soil.

Because the level of ammonium-nitrogen present in unfertilised field-moist top-soil is usually very low (<1 kg N/ha) it is generally disregarded in calculating plant-available nitrogen supply in a nitrogen budgeting calculations.

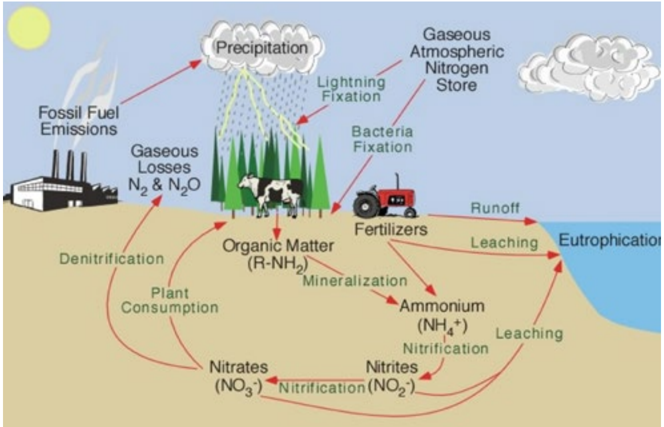


Figure 3. The complete nitrogen cycle

The nitrogen cycle

The full nitrogen cycle is shown in Figure 3. The flows are continuous and rapidly change in size. Of particular interest to farming systems is the flow from organic matter to mineral-nitrogen because of the large quantity of nitrogen involved.

Nitrogen transformations

The process of mineralisation involves:

- The decomposition of soil organic matter by microbes to release inorganic (mineral) forms of nitrogen (initially ammonium) and water (Figure 4). Soil nitrate is the inorganic form of nitrogen that is available for plant uptake whilst organic nitrogen is not.
- A reverse process from mineral nitrogen to organic nitrogen can occur (called immobilization)
- The enzymatic oxidation from ammonium to nitrite is undertaken by the nitrosomonas bacteria whilst the conversion from nitrite to nitrate occurs via the nitrobacter bacteria
- In central Queensland soils approximately 50 to 100 kg N is mineralised annually

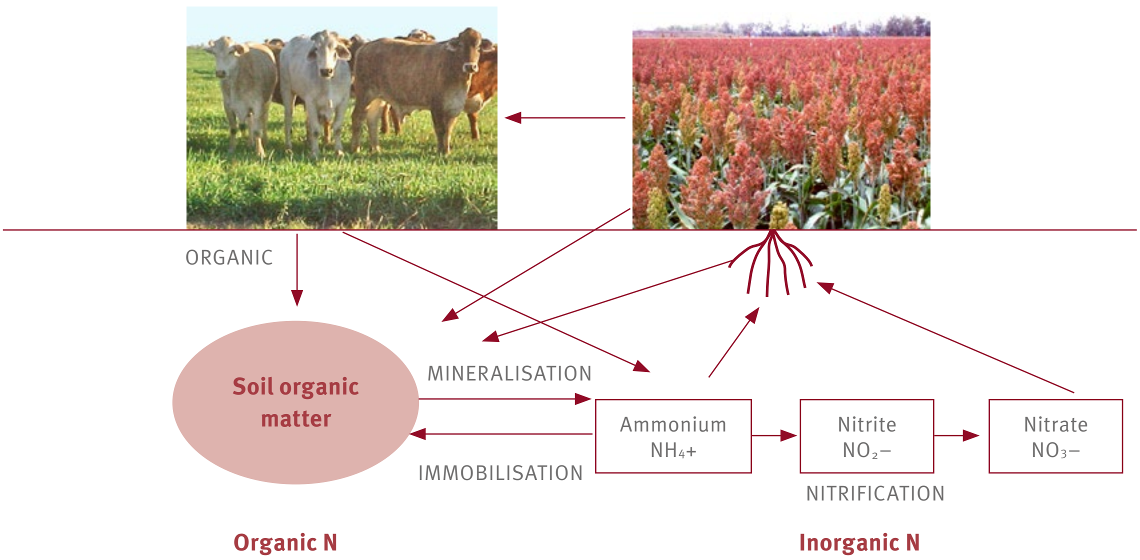


Figure 4. Major nitrogen transformations in the soil-plant system

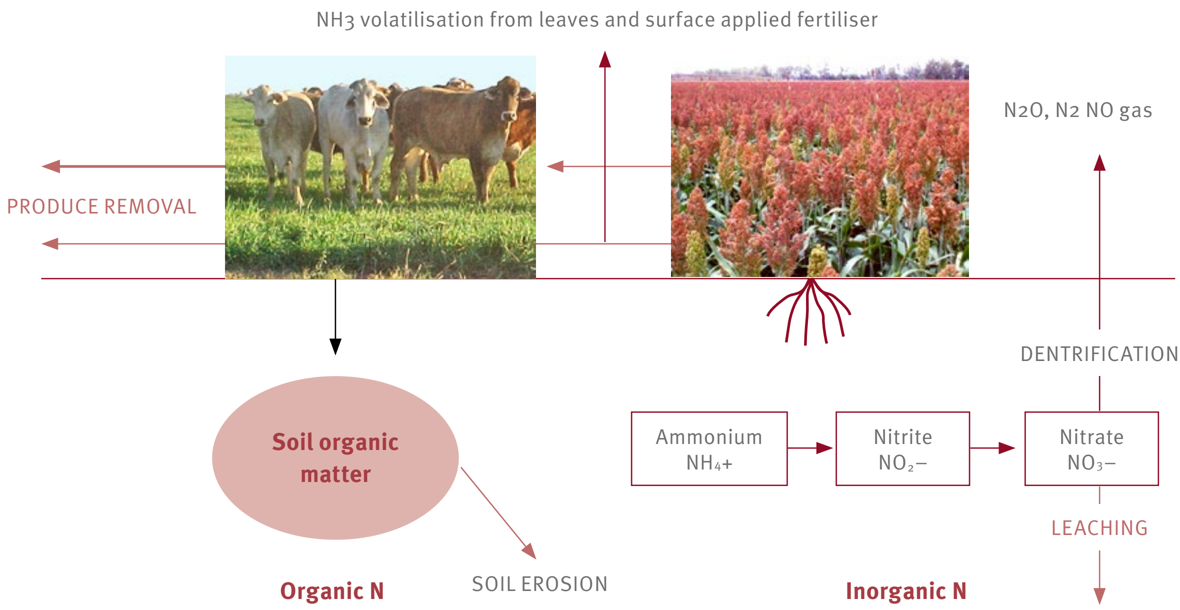


Figure 5. Major outputs/losses of nitrogen in the soil-plant system

- The mineralisation rate is greatest under warm (25 to 35°C), moist (neither dry nor water-logged) conditions with sufficient aeration
- After a phase when nitrogen rundown is initially rapid, the amount of inorganic nitrogen released is approximately proportional to OC% (SOM) content
- i.e. soil with 2% OC will mineralise twice as much nitrogen annually as a soil with 1% OC.

Losses of nitrogen

Nitrogen removal in crop produce, and that lost by soil erosion and denitrification can account for the largest amounts of nitrogen loss (Figure 5 and Table 3). The quantity nitrogen leached through the profile is usually quite small (Radford *et al.* 2008).

The quantity removed in crops will depend upon the rainfall which is a significant driver of crop yield. Knowledge of the inherent soil nitrogen fertility will determine if nitrogen application is urgently required or can be postponed. On soils that are depleted in nitrogen, it may be advisable to supply nitrogen at a rate equal to potential removal rates.

With the exception of high intensity rainfall events, soil erosion has been significantly reduced by adoption of reduced tillage and controlled traffic systems, retention of stubble and contour banks.

Denitrification can be a significant loss under conditions where all three criteria of influence occur coincidently; presence of carbon residues, waterlogged soil and presence of quantities of nitrate from soil or fertiliser sources (Table 4).

Other losses from the soil are negligible compared to the losses from crop removal, erosion and denitrification.

Processes that result in depletion of soil nitrogen include (Figure 5 and Table 3):

- Removal in produce (grain, fibre, meat and wool), erosion of topsoil, gaseous losses as ammonia (NH_3) and oxides of nitrogen (chiefly N_2O, N_2)
- Gaseous loss of nitrogen as ammonia may occur from surface applied ammonium-forming nitrogen fertilisers (urea, ammonium nitrate, anhydrous ammonia). Ammonia may also be lost from cereal crops during the grain filling stage when nitrogen is being translocated from vegetative parts to grain.
- Nitrous oxide (N_2O), dinitrogen (N_2), and other nitrogen oxides may be emitted from soil to the atmosphere when soil is waterlogged, resulting in a denitrification process mediated by soil-borne organisms.

Denitrification

The loss of plant available nitrogen from topsoil usually occurs only occasionally from heavy clay soils in central Queensland. Nitrate–nitrogen may be lost when heavy clay soil is waterlogged for periods of 24 hours or longer, at high soil temperatures and when nitrate-nitrogen and plant residues are both present. Obviously this combination of factors does not occur frequently, so loss of plant available nitrogen should be a low risk to growers. The factors that must be present to result in a high risk of denitrification loss are shown in Table 4. Because of the requirement for easily decomposable organic matter, denitrification mainly occurs in the surface soil.

It can be seen from the Table 4 that when nitrogen fertiliser is applied during summer closely following harvest of a previous cereal crop, and when all 3 risk-factors coincide, only then will this loss be of greatest concern to growers. At other times, at least one risk-factor is likely to be absent or of little influence.

Even then, application of nitrogen may be so essential to supplying the needs of a double cropped cereal, the grower may be prepared to take the risk and apply nitrogen fertiliser.

Table 3. Sources, frequency and magnitude of nitrogen loss from the soil

N loss or process	Source	Frequency	Magnitude	Comment
Removal of produce	Grain / silage /hay	Regular	Gross	
Displacement of soil	Soil erosion by water	Episodic	Gross	
Leaching of solute	Soil nitrate and fertiliser	Episodic	Variable – unknown below rooting	Dominated by soil permeability
Gaseous N loss Denitrification	Topsoil nitrate soil or fertiliser	Episodic	Variable >10%	Dominated by soil drainage
Ammonia emissions from soil	Ammoniacal fertilisers	Regular	Variable <25% applied	Application method and weather
Ammonia emissions from plants	Plant N content	Regular	<1-15 kg/ha/yr	High N% / senescence -net loss

Source: Dr W Strong (pers. comm.)

The need to apply nitrogen to double crop a cereal has not been a common occurrence, so rarely will the grower have to balance the risk of losing some nitrogen (up to 40%) to increase the plant-available nitrogen requirements for the next cereal.

Alternatively, growers may choose to apply nitrogen during late summer or early autumn for the forthcoming winter crop to spread the work load or to obtain discounted fertiliser prices. The risk factors in doing so should be taken into account.

It is sometimes stated that there is an advantage in applying nitrogen fertiliser early as it will allow applied nitrogen to move with rainfall to deeper soil layers and hence lengthen the window of availability to a dryland crop. This concept is flawed for two reasons. Firstly, rainfall events necessary to move applied nitrogen deeper into heavy clay soil can also create loss of applied nitrogen as described above. Secondly, more than 200 mm of rain is generally required to displace applied nitrogen to depth greater than 20 cm in clay soils.

Quantifying potential losses from nitrogen applied in late summer

The highest likelihood of nitrogen loss occurs from nitrogen fertilised soil between November and March when a high level of crop residues is present and when the likelihood of waterlogging is high.

On the Darling Downs (Strong and Cooper 1992) reported that anhydrous ammonia was completely converted to nitrate-nitrogen in 11 days after application. The nitrogen was applied in February and only 8 mm of rain received after application.

Losses as high as 71% have been reported with waterlogging created by irrigation but in dryland systems, substantial loss (30 to 60%) of applied nitrogen has been measured during summer fallow (Avalakki *et al.* 1995).

Nitrogen application during drought periods

In periods of unpredictable rainfall it might be economical to withhold the application of nitrogen to crops with high risk of crop failure, principally those with low soil water at planting and/or moderate soil nitrate levels. Applying nitrogen to crops at lower risk or in more favourable seasons (high soil water at planting and low soil nitrate) may yield a more economical result. Expect some carryover benefit of applied nitrogen to crops following failed fertilised crops but inevitably losses of up to approximately 15% can occur.

Simulated crop outputs are useful to demonstrate the range of potential yield outcomes. The concept of the 'expected' yield relies on the correct 'guess' regarding the rainfall of the forthcoming season. Thus there is no guarantee that using crop simulations will result in less financial loss unless the grower chooses the 'correct' grain yield expectation. Low expected yields generally discourage nitrogen fertiliser application. Thus, using low input levels should reduce financial loss where actual yield outcomes are moderate to low, but may sacrifice potential profit when infrequent high yields occur.

Nitrate leaching

At 13 sites in southern Queensland drainage under cropping averaged 8 mm/year (Tolmie *et al.* 2003). The annual rate of deep drainage under native vegetation was lower, averaging 0.3 mm/year on grey vertosols and 1 mm/year on black vertosols. In a similar study in central Queensland, nitrate-N had been leached below crop rooting depth at only three of seven sites. Thus it appeared that although water appears to be moving through soil profiles there is little chance that significant nitrogen will be lost via this process.

It was also reported that drainage for farming systems currently practiced in southern Queensland (less tillage, more summer/opportunity crops) was about half that of farming systems involving high level of tillage, less stubble retention and a wheat-dominant cropping system (Silburn *et al.* 2008).

Gains of nitrogen

Several processes result in soil nitrogen accumulation:

- dominant potential sources of nitrogen input into central Queensland cropping soils are nitrogen fertilisers and legumes (Figure 6 and Table 5)
- a small quantity (<10 kg/ha/year) may derive from lightning strikes
- a small (unknown) quantity may derive from processes of stubble decomposition and asymbiotic nitrogen fixation, processes mediated by soil-borne organisms.

Other contributing sources are complex and very difficult to measure. They contribute only a small amount of nitrogen to the system and operate in a continual state of flux with the quantities contributed being small compared to the gross amounts that are required by crops or lost by erosion or denitrification.

Soil contains from 2% to 12% of its organic matter as living microbes; equivalent to 20 to 120kg/ha. Populations of the native biota will flourish under conditions of adequate water and energy (carbon) supplies. Management that facilitates these conditions will promote microbial populations even without additional amendments.

Note: Soil nitrate is NOT a soil fertility measure. Soil nitrate levels constantly change in the soil, due to losses and gains that occur throughout a fallow and whilst soil nitrate does estimate supply of plant-available nitrogen for the forthcoming crop, it is not a measure of the inherent soil nitrogen fertility.

Table 4. Risk factors that may promote denitrification N losses from soil, waterlogging, nitrate and crop residues that may occur during summer and winter seasons

	Summer		Winter	
Factor	Nil N	+N fert	Nil N	+N fert
Waterlogging	High	High	Low	Low
Nitrate supply	Low	High	Low/med	High
Residues	High	High	Low/med	Low/med
Overall losses	Low	Potentially high loss	Low	Low

Source: Strong et al (1996)

Soil fertility decline

There is worldwide recognition that the fertility of arable soils is in decline.

Within Australia, evidence of declining soil fertility, crop production, and grain quality has been reported by Dalal and Mayer (1986a). Soil fertility declines with increasing time in cultivation. Using anaerobic mineralisable N as an indicator, Dalal and Mayer (1990) proposed that crops would respond to applied nitrogen fertiliser after 5 to 15 years of commencing grain cropping.

Growers in central Queensland appear well aware of the issues of fertility rundown and nitrogen fertiliser requirement. Lawrence *et al.* (2000) stated all attendees at a nitrogen fertiliser management workshop reported using nitrogen fertiliser at an average rate of 37 kgN/ha. Admittedly these were farmers motivated to attend such a workshop but in most areas of central Queensland some form of nitrogen application is considered necessary in most years.

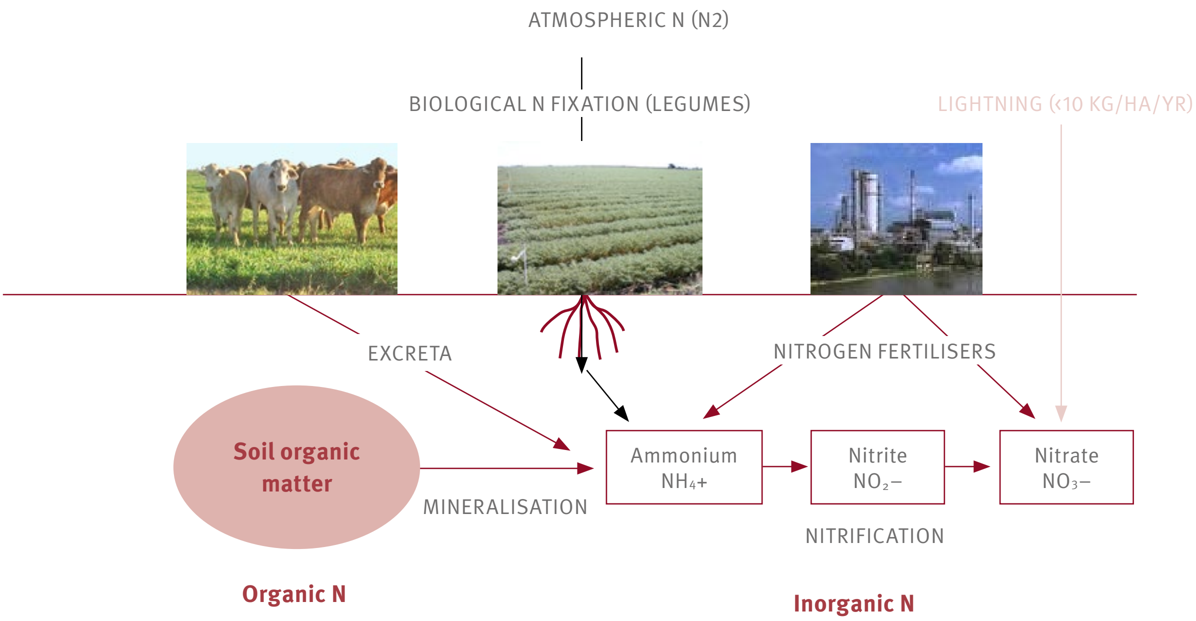


Figure 6. Major inputs of nitrogen into the soil nitrogen mineral-nitrogen pool

Paddock conditions likely to induce denitrification

The dilemma for central Queensland growers is how to continue profitable cropping regardless of soil fertility decline.

Cornish *et al.* (1998) and Spackman and Garside (1995) have reported that wheat yield in 39 shires was related to low nitrogen fertility and in some cases phosphorus deficiency. Furthermore, improved soil fertility is linked to increased water use efficiency, an essential requirement of Australia's grain production systems (Cornish *et al.* 1998).

Restoring soil organic matter

Soil nitrogen fertility decline will generally occur with continuous cereal cropping. The introduction of a grass/legume phase is the only way to significantly reverse the soil fertility decline. Addition of a legume (pulse) crop may slow the process but is unlikely to eliminate it. Agronomic practices such as no-till and controlled traffic that reduce soil erosion have been shown to increase soil organic matter only when nitrogen fertiliser was applied and stubble was retained. (Wang *et al.* 2004).

Dalal (1995) reported that an increase of 650 kgC/ha/year was recorded in a vertosol by a grass+legume pasture for four years. The organic C increase was attributed to input from the grass root biomass (10 t/ha/year compared the continuous wheat of 2 t/ha/year). Nitrogen fixed by the legume plays an important part in this increase because of the increase biomass production of the grass and the 'locking up' of nitrogen in the grass, thus reducing potential losses from denitrification.

Conversely, short (two year) phases of lucerne-wheat or medic-wheat had a negligible effect on soil organic carbon.

Fate of applied nitrogen

The quantity of in-crop rainfall affects the removal, loss and apportionment of nitrogen fertiliser applied to a cereal crop in farming systems of northern Australia

Results from a trial quantifying the recovery of nitrogen fertiliser labelled with N15 and its loss from the system when applied to wheat at sowing at *Warra*, in southern Queensland are shown in Figure 7.

- In a dry year (1990) grain removal was only slightly lower but loss to the atmosphere was very low and the amount recovered in soil higher.
- In a wet year (1988) loss was much higher and the amount recovered in soil was reduced. In all seasons, fertiliser recovered in soil was mainly in organic forms.
- Total loss of the nitrogen fertiliser was 5 to 25% depending upon the seasonal rainfall.

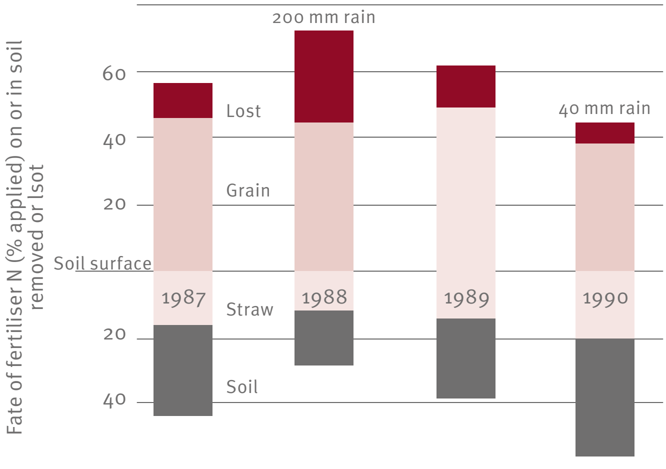


Figure 7. Fate of 75 kgN/ha nitrogen fertiliser (urea) labelled with 15N applied to wheat at sowing over 4 seasons at Warra, in southern Queensland. Recovery in grain, straw, soil and that lost or not recovered are shown for each season; rainfall was for June to October

Source: Dr W Strong (pers. comm.)

Carryover of fertiliser nitrogen after failed crops

If conditions remain dry following a failed crop, it is likely that a significant amount of applied nitrogen fertiliser will be available for the next crop. Armstrong and Halpin (1993) reported that following wheat crop sown in June and killed immediately after emergence, that 75% and 87% of the original nitrogen fertiliser was recovered in the soil in September. Rainfall during the growing season totalled only 29 mm. Similarly, sorghum in 1993 took up as much 15N-labelled fertiliser applied 12 months previously as it did for freshly applied fertiliser (Armstrong *et al.* 1996).

Interaction between nitrogen and other elements

In this section, the effect of phosphorus, zinc, and potassium are described briefly in relation to effective nitrogen management. The general principle is that other nutrients must be in a non-limiting supply in order for the full response from nitrogen fertiliser to be realised. Nitrogen fertiliser is usually the most expensive input and the response is rate-related i.e. up to a point the more that is applied the greater the yield (water not limiting).

Table 5. Potential sources, frequency and magnitude of nitrogen gains in the soil

N gain or process	Source	Frequency	Magnitude	Comment
Fertiliser	Inorganic/organic	Regular	Gross	Residual in soil OM
Symbiotic N fixation	Legume plants	Regular	Gross	Growth dependent
Associative N fixation	Particular plant sp.	Regular	Slow rate	Indirect measurement
Other non-symbiotic fixation	Microbial available carbon (straw)	Irregular	Variable <1-20 kg/ha/yr	Dependent on C inputs
Electrical discharge	Lightning	Irregular	5-10 kg/ha/yr	Tropical storms
Plant ammonia absorption	Atmospheric ammonia	Irregular	usually <ammonia emissions	Net emissions usually greater

Source: Dr W Strong (pers. comm.)

- Is important that the supply of other elements is non-limiting to enable a crop to respond to applied nitrogen fertiliser.
- The critical soil potassium level is 0.4 meq/100g. Most Queensland vertosol soils currently contain higher levels of potassium and so N response should not be negatively impacted.
- The critical soil sulphur level is approximately 5 mg/kg. Soil surface levels are sometimes less than this but crops may access large sulphur reservoirs deeper in the soil. Low sulphur levels are likely to negatively impact crop N response only when cereals are double cropped.
- The zinc critical level is usually reported as 0.8 mg/kg for soils with pH greater than 7. Grain yield responses to zinc are highly variable and not always reflected by soil zinc test. Plant tissue analysis is accepted as a more reliable indicator of zinc adequacy for the plant. After a long period of continuous cropping, a strategy to apply modest application of zinc may avoid negative impact on crop response to applied N; where applied P is required, zinc can be efficiently co-applied.

Classifying soils according to original vegetation does not usually help to identify most other soil nutrients and characteristics that may impact on long-term crop and pasture performance. Soil testing for the elements in question is necessary to identify inadequate plant-available supplies of most nutrients or other soil dysfunctions in central Queensland.

Phosphorus soil testing

In many central Queensland soils phosphorus levels may be in the low to moderate range. Moderate success using soil tests to recommend phosphorus application is evident for south Queensland.

In central Queensland, results from 27 fertiliser experiments conducted in 1970s indicated less reliability for phosphorus soil tests.

Key features:

- Of those soils for which bicarbonate extractable phosphorus test was below 20 mg/kg, only 60 per cent responded to applied phosphorus.
- The BSES acid extractable phosphorus tests helped identify only a few extra phosphorus responsive soils compared to the bicarbonate test alone
  - 65 per cent of soils with bicarbonate test below 20 mg/kg and BSES acid test below 50 mg/kg were responsive to applied phosphorus.

The lesser success in central Queensland in the use of soil tests to distinguish phosphorus responsive soils is presumably related to lower overall cropping frequency and lower grain yields.

Frequency of response of yield to phosphorus fertiliser

After 20 to 30 years of cropping, soil testing of most central Queensland soils is recommended because of the inevitable depletion of soil phosphorus reserves.

However, both the bicarbonate extractable phosphorus test and/or the BSES acid extractable phosphorus tests may not necessarily identify soils that may demonstrate a yield response to applied phosphorus fertiliser. This is because crop responses at moderate to high nutrient supplies sometimes occur and vice versa. This occurs because of the highly variable rainfall.

Thus in a similar way to nitrogen soil tests, phosphorus soil tests of nutrient supply are at best indicative of response frequency to applied nutrient rather than a categorical indication of a yield response. The challenge for the grower is to establish when the response frequency or supply of nutrient from soil is adequate to sustain the expected level of crop production. Hence it is also important therefore to monitor phosphorus requirements of crops from time to time with on-farm experiments or seek crop computer simulation outputs of yield response frequency.

Sampling deeper soil layers for phosphorus

There is some evidence of relocation of phosphorus from sub-soil to the surface especially under zero-till practices. The surface soil test (0-10 cm) remains standard industry practice. However it is advisable to test the sub-surface level of phosphorus every 8 to 10 years to monitor changes in that region. The main outcome of an indication of low soil levels would be support for fertiliser application to crops at rates in line with the expectation of the response frequency.

When sowing chickpeas into the 10 to 15 cm soil layer it would be advisable to sample from this layer and apply phosphorus fertiliser if required.

Potassium

Potassium supply is potentially limiting in central Queensland. Potassium is removed in substantial quantity by most cereal crops and may be in moderate to low supply.

The key points are:

- 0.4 meq/100g level, which is reported as being the critical level for wheat crops. Legume crops have critical levels as low as 0.25. Currently many current soil tests are returning levels in excess of this amount so potassium applications may not be warranted
- High clay content of most central Queensland soils would suggest that potassium supply should not be quickly exhausted by continuous grain cropping.
- However, where cropping for silage production or where hay is removed, available potassium levels should be monitored at intervals of 3 to 5 years.

Sulphur

Sulphur is usually released in soil and used by crops in the same way as nitrogen.

The key points are:

- Only about one tenth as much sulphur is required by crops as nitrogen
- In spite of this difference in quantitative requirement, it is anticipated that response to applied sulphur might occur when cereal response to applied nitrogen is frequent; in such soils sulphur may be required, particularly when switching to a leguminous crop
- In many central Queensland soils, the existence of gypsum ($CaSO_4$) in subsoil layers will mean that a ready supply of sulphur will be available for crops even when sulphur supply from its release into topsoil is low. A surface soil test is of very limited value for assessing sulphur sufficiency.

Zinc

Zinc is used in small amounts by all crops but soil zinc supplies may also require supplementation in central Queensland soils. Important points regarding zinc nutrition are:

- Low chemical availability of zinc in soils with high pH, e.g. vertisols
- Reduced colonisation of mycorrhiza-dependent plants after protracted fallow periods due to drought may combine to reduce plant-available zinc levels
- Crops not dependent on mycorrhiza are recommended to be sown after long fallow or failed crops
- Zinc-coated phosphate fertilisers provide a practical means of applying zinc to mycorrhiza-dependent crops like maize.

Soil testing procedures

It is vital that rigorous sampling procedures are adhered to and soil samples are handled appropriately. Soil testing companies supply such protocols. Another useful reference is 'Soil Matters' – monitoring soil water and nutrients in dryland farming (Dalgliesh and Foale 1998).

Some important issues are:

- Take sufficient samples for the paddock area in a randomised sampling pattern but avoiding atypical areas such as old fencelines, close to trees etc.
- Ensure that sampling equipment is clean
- Avoid contamination of the sample with other materials e.g. do not use galvanised buckets
- Avoid touching soil samples in hot weather (use a trowel)
- Sample to the correct depth
- Be aware that paddock history may be atypical e.g. after prolonged drought
- Collect the required quantity prescribed for laboratory testing that is bulked from the multiple cores from the paddock
- Be wary not to mix soil between the different depth increments
- Store samples in cool place (e.g. esky with ice) until they reach the lab
- Refrigerate samples if they cannot be sent immediately, air dry or dry at up to 40°C in an oven
- Record the position and time of collection on a map or with a GPS
- Despatch samples early in the week to avoid transit delays during weekends.

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Simulated onset of crop responses to applied nitrogen

The lag-time before nutrients like nitrogen and phosphorus need to be applied will depend on the frequency and quantity of rainfall during cropping;

- High frequency of above average rainfall may increase soil fertility decline because of increased nutrient removal by crops, leading to a short lag-time
- High frequency of below average seasonal rainfall may slow the decline, creating a longer lag-time. Thus, predicting the lag-time for a particular paddock before nitrogen needs to be applied is very difficult. A reliable estimate of the lag-time will also depend on accurately predicting initial soil properties like soil total nitrogen or its surrogate, organic carbon (OC).

Crop simulation modelling using historical rainfall may improve estimations of lagtime and can predict fallow mineralisation.

Because of the initially high fertility status of most brigalow scrub soils, yield and economic responses to applied nitrogen are unlikely at commencement of cropping. A comparison of nil fertiliser and nitrogen applied at a rate to optimise crop production was simulated using the APSIM crop model (Figure 8).

According to model outputs, significant response to applied nitrogen occurred after 40 to 50 years cropping when the organic carbon level would have declined to approximately 1.0 per cent (Figure 8).

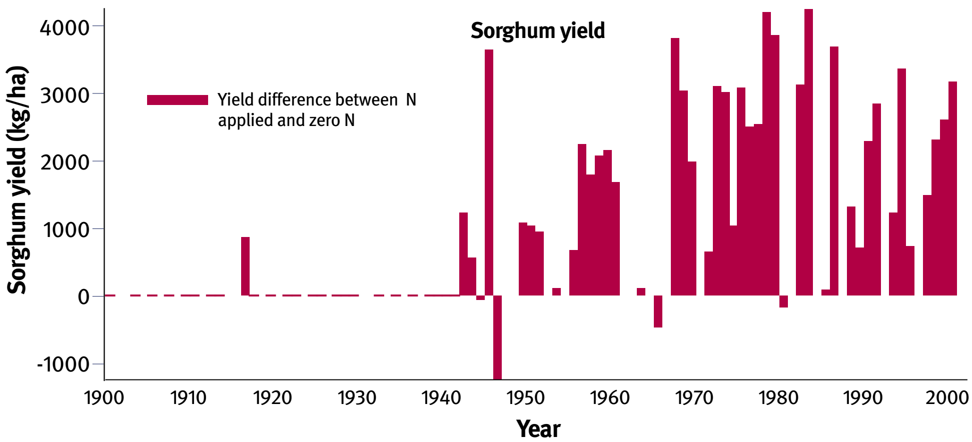


Figure 8. Difference in yield response of monoculture sorghum to nitrogen applied at the rate adequate to optimise grain yield over the period 1900 to 2003 compared to a zero nitrogen application. Notice approximately 40 years lag-time before consistent response to nitrogen fertiliser is obtained

Case study

– measuring soil nitrogen fertility rundown, Dysart, central Queensland

Where is the soil on the rundown curve?

Soil fertility decline is primarily affected by duration of cropping, quantity of nutrients removed in grain or other produce as well as nutrient removal due to soil erosion.

The modelled decline in soil organic carbon for a site at Dysart demonstrates the effect that duration of cropping has on nutrient decline. Soil samples were taken from a number of paddocks cropped for different duration to establish the trend line in Figure 9. These observed data are shown as (■), there is a moderate amount of scatter in the data. The modelled data (●) mimic the observed data quite well.

The trend in organic carbon shows a gradual decline of approximately 25 percent over the 21 years of cropping.

Projecting duration of cropping to 100 years, without fertiliser addition, nutrient rundown continues, as indicated in Figure 10. After 60 years of continuous cropping soil organic carbon would decline to a level of less than 1.0 per cent, similar to that found in many central Queensland open downs soils which have been cropped continuously for a similar period.

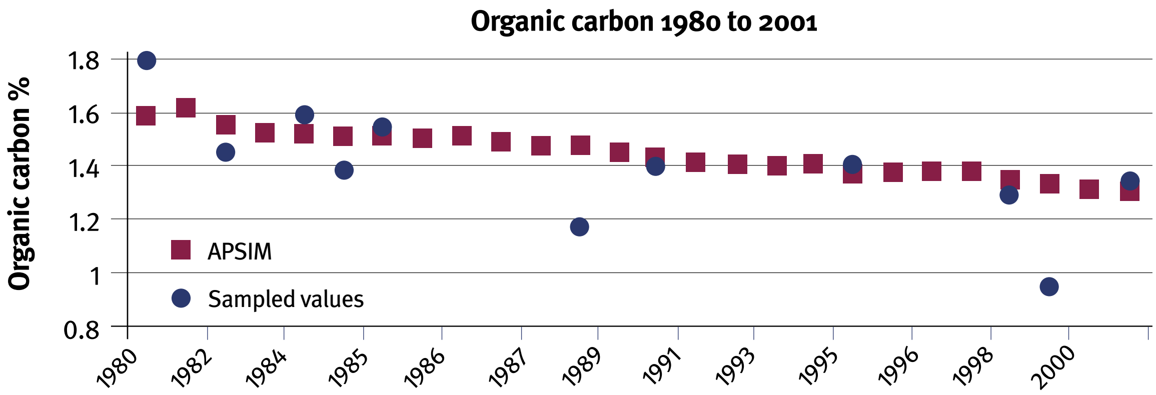


Figure 9. Fertility decline curve for a Brigalow scrub soil at Dysart

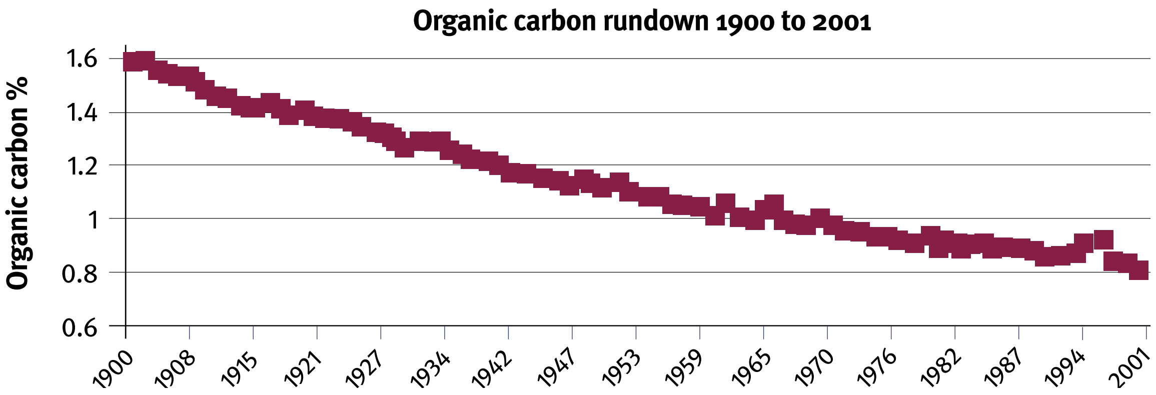


Figure 10. Simulated fertility decline for Brigalow scrub soil at Dysart

4. Determining crop demand for nitrogen

Key messages

- Total crop water supply (rainfall plus stored soil water) determines grain yield. Grain yield determines the crop demand for nitrogen.
- Measure or estimate stored soil water at planting.
- Take soil water at planting into account when estimating target yield either ‘informally’ or with the *WhopperCropper* program.
- Use *WhopperCropper* to estimate yield ranges and select the midpoint of the season type of choice.
- Calculate crop nitrogen demand from a grain yield target and an optimal grain protein value; use the value for grain protein that will optimise grain yield with the available water supply (for wheat that grain protein value is 11.5%).
- Use the spreadsheet-based Nitrogen Fertiliser Calculator (Smart N Decisions) included with this manual.

Factors that affect crop grain yield

The main determinant of grain yield is water supply, namely:

- Stored soil water
- Rainfall received during crop growth.

Highly variable rainfall will result in highly variable quantities of stored soil water and in-crop rainfall. There are two important aspects for managing this variability:

- Measure or estimate stored soil water
- Use the probability concepts described in this manual to work with potentially variable yield outcomes
- The computer program, *WhopperCropper* directly provides the effect of soil water at planting and in-crop rainfall on yield.

Indicator of rainfall variability

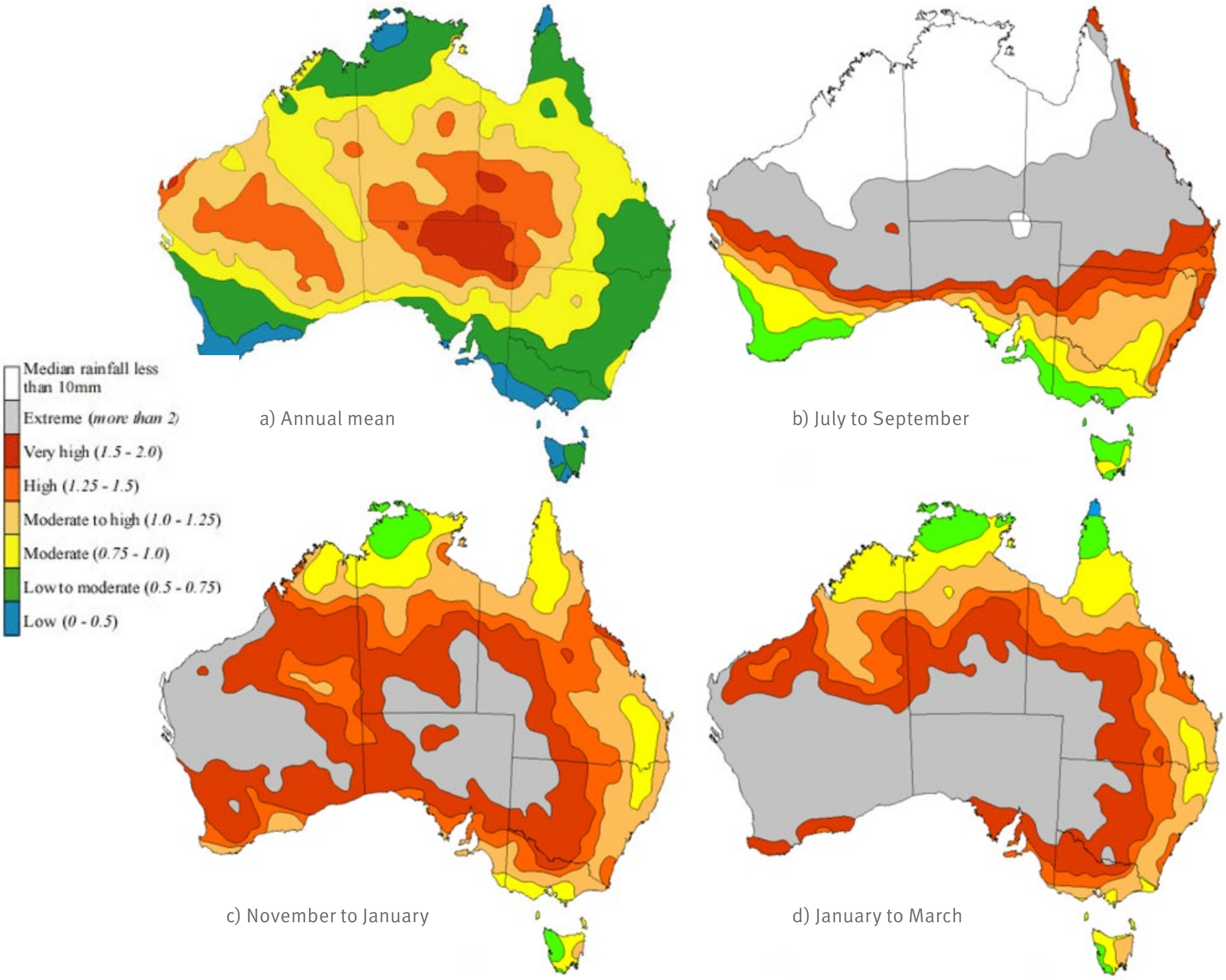
For central Queensland, the rainfall variability is rated from moderately to extremely variable (Table 6 and Map 2).

- ANNUAL rainfall is rated as *moderately variable* (Map 2a)
- WINTER rainfall is *extremely variable* (Map 2b)
- SUMMER-growing periods have *high variability* in rainfall (Map 2c and d).

Table 6. Summary of rainfall variability ratings for central Queensland

Season	Rating scale #	Variability rating
Map a) – Annual mean	0.75 to 1.0	low to moderate
Map b) – July to September	› 2.0	moderate to very high
Map c) – November to January	1.0 to 1.25	moderate
Map d) – January to March	1.25 to 1.5	moderate to high

Variability = (90p-10p)/ 50p where 90p, 50p and 10p are annual 90th, 50th and 10th rainfall percentiles respectively



Map 2. Regions of similar rainfall variability for periods, a) annual, b) July to September, c) November to January and d) January to March

Source: Bureau of Meteorology http://www.bom.gov.au/climate/averages/variability

Factors affecting soil 'plant available water capacity' (PAWC)

The quantity of plant-available water that a soil can store depends upon its physical and chemical make-up.

a) Physical factors include:

- depth to bedrock materials
- texture (higher clay percentage stores more water)
- organic carbon percentage (hold water to a monor extent)
- structure (macro and micro pores hold water in clay soils but sandy soils allow considerable drainage)
- physical barriers such as compaction (reduced water entry)
- surface crusting (reduced water entry).

b) Chemical factors can also affect the 'effective' water-holding capacity by reducing root exploration or water uptake. The factors are:

- Salinity (presence of dissolved salts reduces water uptake, but not when gypsum is the cause of high electrical conductivity)
- sodicity (excess sodium ions – poor water infiltration, increased runoff).

Shallow soils in central Queensland store less water and have lower yield expectancy

Open downs soils in central Queensland may have a shallow effective crop rooting depth because of a layer of decomposing gravel as shallow as 50 cm. The gravel layer stores little water and so winter and summer cereals do not extract much water below the start of the gravel.

Brigalow scrub soils can be saline at depth which can restrict water extraction by crops, particularly if the dominant anion is chloride. In particular, chickpea and mungbean yields are likely to be reduced where high subsoil chloride levels exist. Because of the prevalence of subsoil gypsum (calcium sulphate) in central Queensland soils, which does not restrict water uptake by crops, high subsoil electrical conductivity (EC) levels do not always indicate unfavourable subsoil conditions. EC is effectively a measure of the 'saltiness' of the soil although not all of the ions that contribute to the EC level have detrimental effects (Table 7).

High sodicity is an excess of sodium ions relative to calcium, magnesium and potassium. It can lead to soil 'dispersion' resulting in crusting, cloddy seedbed, poor infiltration and waterlogging. Sodicity is high if exchangeable sodium percentage is greater than 6.

Stored soil water as a factor affecting grain yield

The quantity of **stored soil water** has a significant effect on crop production, and will be the prime reason to adjust target yield. Thus the grower should have some knowledge of the expected stored water status of the paddock at planting.

Stored soil water at planting has considerable effect on crop yields and hence on crop nitrogen demand. This is especially apparent for *winter* crops. Thus it is important to:

- Maximise the storage of rainfall over the previous fallow
- Estimate or measure the stored soil water especially prior to winter crops by using either:
  - A push-probe to measure the depth of wet soil
  - Using the *HowWet* computer program
  - The '20% rule'
  - Use *WhopperCropper* to indicate
  - The effect of stored water on grain yield
  - The effect of plant-available water-holding capacity (PAWC) has on potential yield.

Maximising the storage of rainfall in the previous fallow

Summer fallow efficiency (percentage of rainfall that is stored) is most commonly in the range of 18 to 22%. Very short fallows can have a fallow efficiency as high as 50%. The remainder is lost to evaporation, runoff or deep drainage. The key to maximising infiltration is to maintain a minimum of 30% soil stubble cover. Many growers have recognised this need and implemented zero or minimum tillage practices. This is even more effective when combined with fully matched two-centimetre accuracy controlled traffic farming systems.

Fallow efficiency decreases as fallow length increases so many growers have adopted 'opportunity cropping'; crops are sown when stored soil water is adequate to sustain a dryland crop. This reduces loss of soil water to evaporation and dramatically reduces runoff and erosion when high intensity rainfall occurs when the soil profile is approaching fully recharged. Individual crop yields may be slightly reduced because of lower stored water reserves grain production is often higher in the longer term because of increased cropping frequency. Research is on-going to model optimum crop frequency for Queensland farming systems.

Critical components of stored soil water

Not all of the water in the soil is available for use by a crop. The crop can only reduce water content to the level of 'crop lower limit' (CLL) or 'wilting point'. The maximum amount of water a soil can hold is the 'drained upper limit' (DUL). The difference between these two values is the 'plant available water capacity (PAWC). As soil water is recharged, the quantity of water stored is the 'plant available water (PAW) (Figure 11).

As plant roots grow, soil water will be extracted progressively from soil until the soil reaches the CLL (approximately 50% of the total water in clay soil may be extracted by plants). This 'drying-front' progresses downwards as the roots grow into the soil.

The surface soil can dry to less than the crop lower limit due to the evaporation effects of sun and wind. If this occurs, this deficit will need to be overcome before water is available for crop use. During rainfall, after the cracks in the soil are closed, water recharge occurs from the top down.

Methods to estimate the amount of soil water at planting

All the methods have inaccuracies, but all should enable estimation of soil water especially to the broad categories required for *WhopperCropper* (one-third, two thirds and full profile).

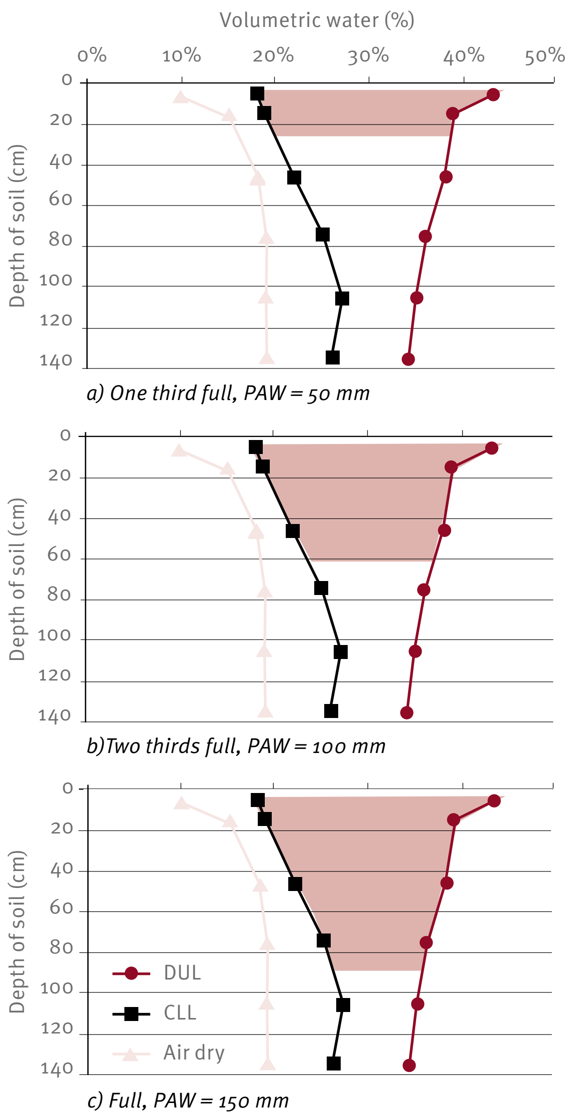


Figure 11. Representation of critical components of soil water. Likely location of plant-available water in a typical vertosol of 150 mm water-holding capacity (PAWC) when a) one third recharged (=50 mm plant-available water PAW), b) two thirds recharged (=100 mm PAW) and c) fully recharged (= 150 mm PAW)

Depth of wet soil

The amount of water held in the soil can be roughly determined by the depth of wet soil using a ‘push probe’. From experimental results, the two major soils in central Queensland hold similar quantity of water/cm of wet soil. The main difference between the soils is depth of the soil profiles. However, the effective depth of a brigalow scrub soil may be reduced by high electrical conductivity (EC) levels or high chloride (Cl-) levels.

Thus, estimating the depth to which soil is recharged provides an estimate of the total amount of plant-available water (Figure 12).

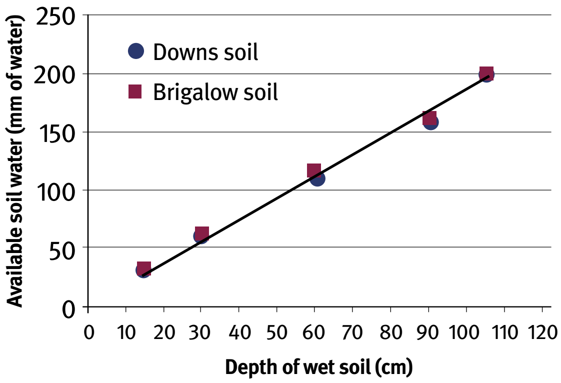


Figure 12. Relationship of depth of wet soil (cm) to quantity (mm) of plant-available water for ‘brigalow scrub soil’ and ‘open downs’ soils

Source: CQSFS Project trial data

Thus 50 cm of wet soil would equate to approximately 100 mm of available water for both ‘brigalow scrub soil’ and ‘open downs’ soil.

Remember that the surface 30 cm of soil is prone to rapid evaporation so this should be taken into account when estimating the potentially available soil water.

Use the HowWet software program

HowWet allows the user to enter actual rainfall data for a paddock of interest. Using selectable factors such as:

- soil type
- stubble cover
- paddock slope
- fallow start and end date.

The program estimates the proportion and total amount of the rainfall that should be stored in the soil (Figure 13).

Figure 8 illustrates simulated accumulation of soil water between 1 October 2005 and 15 April 2006 at Dalby, south Queensland. It shows that favourable early fallow rainfall (October and November 2005) quickly recharged the soil profile. Rainfall in January and February 2006 probably moved water to deeper soil layers, adding to that portion of water storage that is protected from subsequent evaporation. Efficiency with which water can be stored early in the fallow can be quite high (up to 40 to 50%) because of structural cracks in dry soil and the short time over which evaporation can occur. The downward slope of the line indicates loss of soil water through evaporation. The red columns illustrate water runoff.

HowWet also provides a table of outputs (e.g. Figure 14). Some example details are:

- 441 mm (75%) of the 588 mm of rain received during this period evaporated
- The gain in soil water was 120 mm from a total rainfall of 588 mm (about 20% of fallow rainfall stored)
- The overall fallow efficiency of 20% is fairly typical for fallow periods at this time of year in south Queensland
- The estimate for soil water stored at the end of the fallow, 137 mm (83% of a fully wet profile) could be described as an ‘excellent’ prospect for subsequent cropping in spite of the high overall quantity of rainfall that was evaporated.
- 31% of rainfall occurred in events of less than 15 mm that quickly evaporated (high percentage of small rainfall events to reduce efficiency with which rainfall is stored).

Table 7. Soils and typical plant available water contents in Queensland

Soil type	Rooting depth (m)	Available soil water (mm/m)	Typical PAWC
Heavy alluvial, flooded brigalow or yellowwood	1.25	170	212
Friable alluvial	1.25	185	230
Shallow open downs	0.75	180	135
Deep open downs	1.0	160	160
Light alluvial	1.2	185	222
Heavy mixed alluvial	1.1	180	198
Deep/heavy brigalow or brigalow-belah clay	1.2	160	192
Scrub walloon soils	1.05	180	189
Brigalow/softwood scrub	1.0	160	160
Light Callide alluvial	1.2	150	180
Shallow/light brigalow or box clay	0.9	160	144
Black upland soils	1.05	180	189
Light box clay	0.85	160	119
Softwood brigalow	0.85	140	119
Brigalow/Dawson gum brigalow duplex	0.95	150	143
Forest walloon soils	1.0	120	120
Red brown/red earths	1.05	125	131
Red upland basalt	1.0	100	100

Source: from Wheatman v4

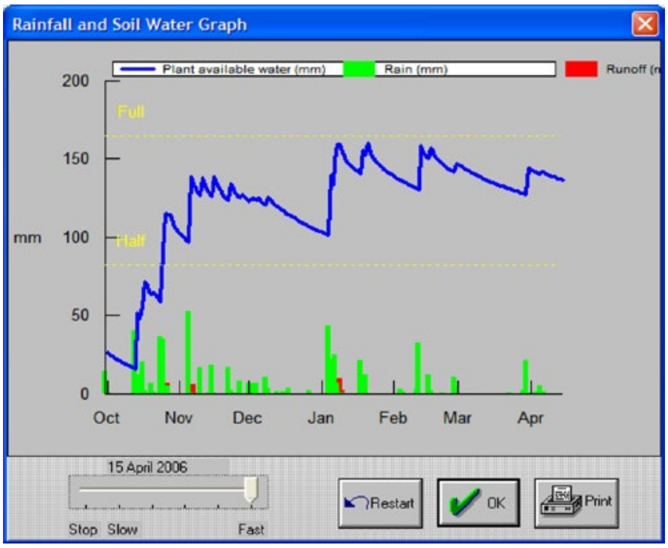


Figure 13. Graphical representation of soil water accumulation at Dalby from rainfall events during the fallow period, 1 October 2005 to 15 April 2006, as simulated by HowWet

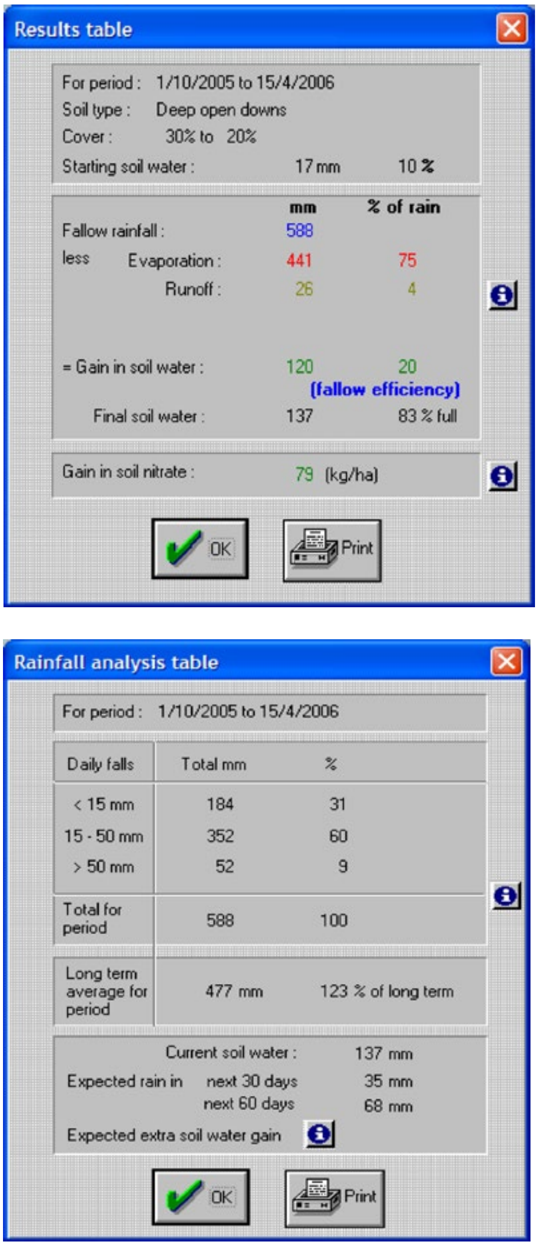


Figure 14. Soil water storage simulated for the summer fallow, 1 October 2005 to 15 April 2006, using *HowWet*

The '20% rule'

Most grain growers have access to rainfall records, so when all other methods to estimate fallow water storage are unavailable, a rough rule of thumb could be derived from fallow rainfall using a figure of 20% of the rainfall being stored (Figure 15).

The '20% rule assumes that the single fallow efficiency value of 20% accounts for the average losses through runoff and evaporation that occurs following fallow rainfall. It is a reasonable first approximation of the amount of rain that may be accumulated over a seasonal fallow (e.g. from winter crop harvest to the next winter crop planting). A weakness in this approach is that fallow efficiency usually varies with the length of the fallow and patterns of rainfall. Typically, actual values are higher at the start of a fallow (around 40%) when the soil is dry and cumulative evaporation is low. As the fallow period is extended cumulative evaporation (and sometimes runoff) can increase. Thus in a double crop situation the fallow efficiency value can be very high. Average fallow efficiency values of between 18 and 25% (average 23%) are typical for southern Queensland for a full summer fallow (winter crop to winter crop).

Note: In a test of the same set of fallow data (Figure 15) it was found that improved accuracy was gained if values of 18% were used for western Queensland and 23% for south eastern regions. When this was done, accuracy of the result was similar to *HowWet*

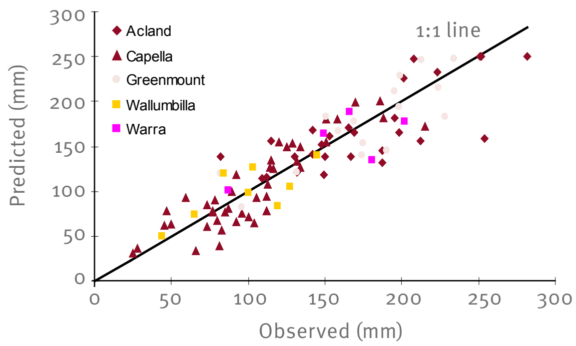
Using *WhopperCropper* to indicate the effect of soil water-holding capacity and soil water at planting

Because of rainfall variability, a field nutrition experiment over one or two years will not be a good indicator of the possible yield outcomes. For this reason, crop simulation modelling is used to demonstrate the full range of potential yields. This enables the user to act upon their 'attitude to risk' when choosing input levels.

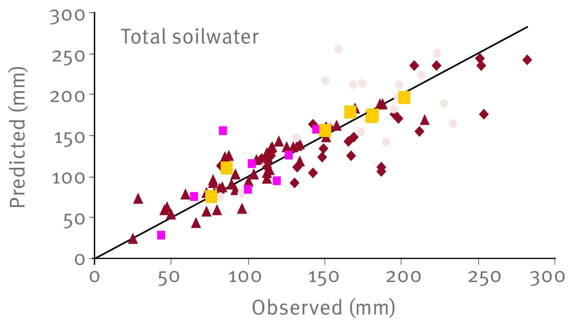
When the soil water at planting has been calculated by one of the methods previously described, the potential yield ranges can be generated by the *WhopperCropper* program.

Because the data is generated from 100 years of rainfall data, the graphs are 'probabilistic' in nature. This has the advantage of providing a realistic range of potential yields to 'target' rather than a single yield as used in previous nitrogen budgeting techniques.

Figure 16 indicates the large effect of soil water at planting on wheat yield at Emerald. The median yield (heavy dark line) increases from 700 kg/ha to almost 2900 kg/ha as the soil water at planting was increased from one third full to completely full (in every year of the simulation). Because the soil water is reset to the indicated value **every** year, the output indicates the broad insights rather than a yield for any particular year.



a) Modified ‘20%’ rule. (Note: 18% fallow efficiency used for central and western Queensland and 23% fallow efficiency for south Queensland) $R^2 = 0.75$



b) *HowWet* $R^2 = 0.74$

Figure 15. Observed vs predicted plant available water in the root zone at the end of fallows

Source D Freebairn (pers comm.)

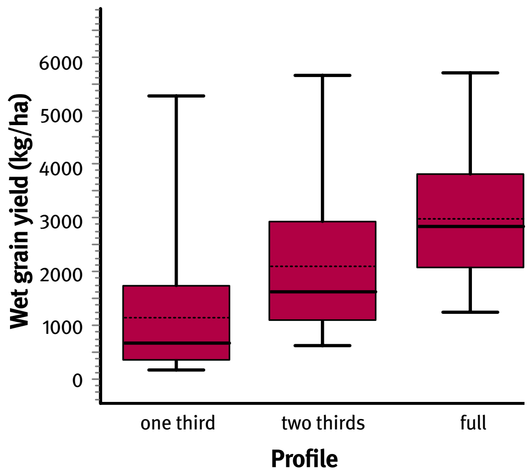


Figure 16. Seasonal distribution of wheat yields at Emerald with stored water at planting equal to 1/3, 2/3 or full at planting. Soil N assumed to be 100 kgN/ha + 50 kg/ha fertiliser N applied at planting. Planting date of 30 April, 1million plants/ha, medium maturity variety, soil PAWC=150 mm

In contrast, the effect of soil water at planting is slightly less evident on sorghum yield because of the more dominant summer rainfall (Figure 17). However the riskiness of the yield outcome is significantly increased if planting was conducted with one-third full profile every year as indicated by to absolute range of yields from 0 kg/ha to 4500 kg/ha depending upon the seasonal rainfall.

Probability concepts

Whilst it is widely recognised that yield variability occurs, understanding and working with yield ranges may assist input planning and risk management compared with using a ‘commonly-accepted’ farm, district or state average.

Probability is derived from the concept that a ‘theory’ (hypothesis) is tested more than once to ensure the result has not occurred simply by chance and/or is an ‘unusual’ result. In terms of crop yields, we know that many factors can affect yield in a particular year. Some of the factors are controllable e.g. nitrogen fertiliser rate but many are not e.g. rainfall and the timing of that rainfall. Some factors also interact e.g. yield response to nitrogen fertiliser rate with rainfall. Several factors can interact in ways that increase or decrease yield.

Generating ‘target yield’ ranges

In order to calculate crop nitrogen demand, a **target yield** range for the forthcoming season must be determined. This can be achieved from:

- Farmer experience (paddock history)
- Crop simulation models (as used in *WhopperCropper*).

Farmer experience

Farmer experience and knowledge of paddock performance over many seasons can indicate an achievable level of crop production. Farmer field trials can also test principles but it must be remembered that they only represent a small percentage of the possible outcomes. Crop models are developed from accurately conducted research trials and then tested in other trials.

WhopperCropper

The APSIM Crop simulation model (the building block for *WhopperCropper*) can be used to demonstrate the distribution of yields achieved over the full length of rainfall records from a site.

How to read this *WhopperCropper* boxplot

The black line in the ‘red box’ is the median yield (50% of all years have this ‘yield’ or less). The dashed line within the ‘red box’ is the mean yield. The upper edge of the ‘red box’ is 75% probability. This is read as ‘in 75% of years, yields will be less than this value’. The lower edge is the 25% probability value i.e. ‘in 25% of years, yields will be less than this value’. The upper and lower short horizontal lines represent 100% and 0% probabilities respectively.

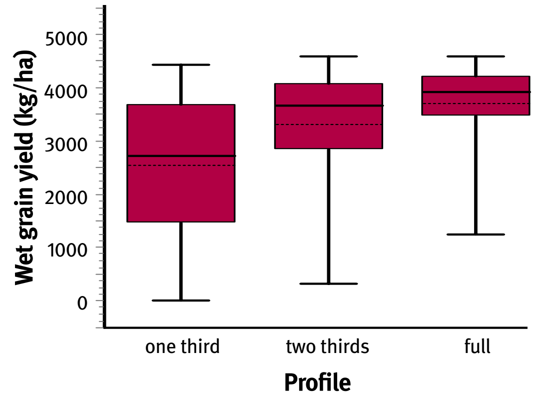


Figure 17. Seasonal distribution of sorghum yields at Emerald with stored water at planting equal to 1/3, 2/3 or full at planting. Soil N assumed to be 100 kgN/ha + 50 kg/ha fertiliser N applied at planting. Planting date of 15 December, 40 000 plants/ha, medium maturity variety, soil PAWC=150 mm, solid 1 m rows

After they are generated, the simulated outcomes provide a yield distribution from which a target yield might be selected. Selecting a target yield from the full possible range is a more informed decision because of the inherent seasonal variability but also because it embraces the grower's attitude to risk.

WhopperCropper is an easy-to-use package that enables scenarios to be created to generate yield ranges with appropriate practical setup parameters. The full range of input parameters in *WhopperCropper* are:

- Crop type – common summer and winter
- Soil water-holding capacity – up to five levels
- Soil water at planting – one third, two thirds and full
- Planting date – up to five dates
- Maturity length – three categories
- Plant population – usually three levels
- Row configuration – skip in sorghum and cotton
- Effect of soil nitrogen content – usually three levels
- Nitrogen fertiliser rate (planting and in-crop) usually six nitrogen rates – usually six nitrogen rates.

Simulating long-term yield ranges

The first step in generating yield probability graphs is to generate annual crop yields from a desired scenario or scenarios. This graph type is an output from *WhopperCropper* (Figure 18).

To generate a *probability distribution*, the simulated yield data is arranged from lowest to highest and then subdivided into (for example four) categories of equal number of seasons representing low, low-moderate, moderate-high and high yields.

Each of these categories is represented for simulated wheat yields and are shown as a box plot in Figure 19. When expressed in terms of probabilities the yield ranges are as indicated.

The sections of the boxplot are effectively subdividing the yield range into sub-groups (Figure 20).

These are read as (for example):

- In '75% of years, yields will be less than 2939 kg/ha'
- The lower edge is the 25% probability value i.e. 'in 25% of years, yields will be less than 1074 kg/ha'
- The upper and lower short horizontal lines represent 100% and 0% probabilities respectively (5665 and 608 kg/ha respectively).

These outputs provide reference for the grower to judge the likelihood of the expected yield target, as well as enabling adjustment of the expected yield target for potentially different water supplies to the crop.

This approach allows yield and financial risks to be made quite evident.

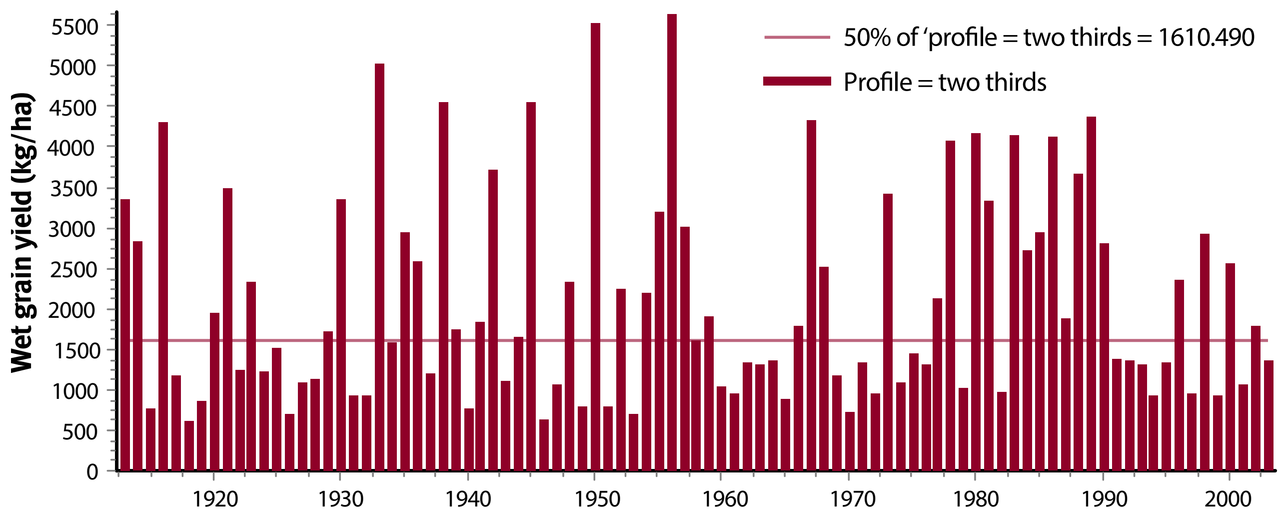


Figure 18. Wheat grain yields (600 kg/ha to 5500 kg/ha) were simulated for the period 1915 to 2004 at Emerald, each with monoculture cropping with two-thirds of a full profile stored soil water

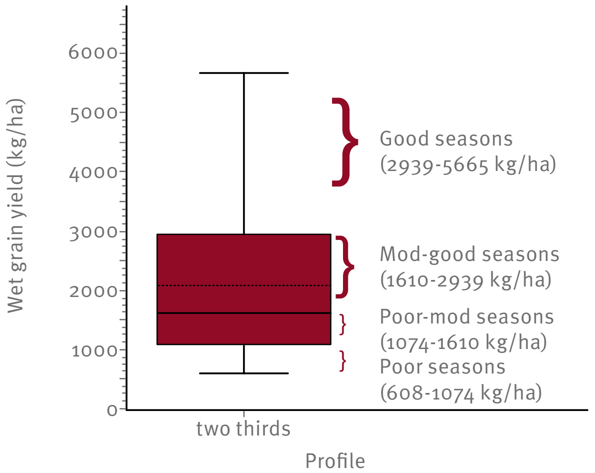


Figure 19. Diagram of how 'boxplot' yield results relate to four season type ranges

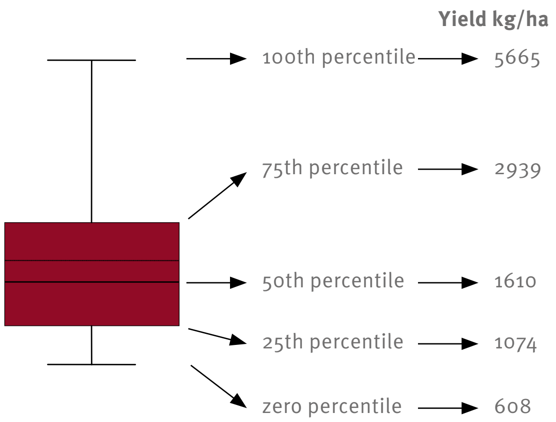


Figure 20. Diagram of how individual yield results are grouped as a boxplot with the lowest and highest yields being represented as 0 to 100th percentile of the range respectively

Choosing a single target yield

The components for calculating crop nitrogen demand are simply:

- target crop yield
- grain protein content.

The basis for the nitrogen demand calculation is that a single target yield be selected. Selecting a high target yield might expose a grower to unspecified financial risk because of a high frequency of poor to moderate crop yields. Provision of the likely yield range for long-term seasonal outcomes enables the target to be selected with full knowledge of the associated risk or likelihood of achieving that yield. Selecting from the full potential range of yield outcomes is a more informed way to select a target yield because of the high inherent seasonal variability in regions of northern Australia.

Nitrogen fertiliser needs to be managed in the context of districts rainfall variability. Maximising profits in the good seasons whilst reducing losses in the more frequent moderate to poor seasons is the key to optimising profits in this environment. A suggested process is a follows:

- Use *WhopperCropper* to provide the long-term range of yields that occur for a district
- Use the default *WhopperCropper* 'boxplot' to demonstrate the four categories of equal number of seasons that may occur (low, low-moderate, moderate-high and high yields)
- Select a target yield from a category knowing the likelihood with which that yield might be achieved; 25% high to very high yields, 25% moderate-high yield, 25% low-moderate yields and >25% zero to low yields
- Calculate nitrogen demand for the target yield using the formulae below.

Selection of target yield knowing that yield can vary considerably enables a grower to incorporate their 'attitude to risk' in the decision. Anticipation of the forthcoming season or a 'desired-bet' attitude can be reflected in the choice of target.

The mid-point of the yield range for each category could be a reasonable choice for the single 'target yield' value. Naturally the final choice of target yield may be influenced by financial constraints but knowledge of the likely long-term outcomes will enable the grower to avoid unnecessary financial risks.

These outputs provide reference for the grower to judge the likelihood of the expected yield target, as well as enabling adjustment of the yield target for expected water supply for the crop and for an acceptable financial risk.

This is probably the most informed approach of all to evaluate fertiliser needs because financial risk is made evident in model outputs.

Calculating crop nitrogen demand from target yield

To estimate nitrogen demand for the target grain yield, a final grain protein is assumed that reflects a crop in which the nitrogen supply has not restricted grain yield. Yields of cereal crops will not have been limited by nitrogen supply when grain protein concentrations are more than:

- 11.5% for wheat
- 9.5% for sorghum
- 10.5% for barley.

Source: Dr W Strong

These proteins refer to grain moisture levels of 12%, 13% and 0% respectively.

These are considered the optimum grain protein levels to target and indicate the adequacy of the nitrogen supply for the seasonal outcome. Crops with resultant grain proteins below these critical contents may have been adversely affected by inadequate nitrogen supply. Crops with proteins above these concentrations can usually access an adequate supply of nitrogen to respond to the water available, including water stored at planting and rainfall during crop growth. At these grain protein levels there is confidence that the nitrogen supply was adequate for the optimum economic production.

Equation to calculate nitrogen demand

Crop nitrogen demand can be readily estimated by calculating grain nitrogen (kg/ha) and converting this to crop demand using a simple multiplier that has been derived from many field trials with wheat and sorghum.

The multiplier to obtain total amount of nitrogen that is required for wheat and sorghum (grain + vegetative matter) at the optimum grain protein is 1.7.

Note: Constants in the equations below describe the fraction of nitrogen in wheat protein (10/5.7), conversion of grain yield t/ha to kg/ha (*1000), nitrogen concentration as a percentage (1/100) and the multiplier to convert grain nitrogen to crop nitrogen demand (1.7). Calculations for sorghum nitrogen demand are identical to those for wheat except the fraction of nitrogen in sorghum protein is (10/6.25).

The 1.7 conversion factor, and the given grain protein percentages, are those considered to give the most economic use of nitrogen.

Hence nitrogen demand for a **wheat** crop, with a target yield of 2.5 t/ha can be calculated as follows;

Equation 1.
Nitrogen demand (kg/ha)
= (Grain yield (t/ha) * Grain protein percent * 10/5.7) *1.7
= (2.5 * 11.5 * 10/5.7) * 1.7
= 85.7 kg/ha

Similarly, nitrogen demand for a **sorghum** crop, with a target yield of 2.5 t/ha can be calculated as follows;

Equation 2.
Nitrogen demand (kg/ha)
= (Grain yield (t/ha) * Grain protein% * 10/6.25) *1.7
= (2.5 * 9.5 * 10/6.25) * 1.7
= 64.6 kg/ha

Table 8. Crop nitrogen demands (kg/ha) estimated using the above formula for a range of expected wheat and sorghum yields (t/ha) and targeting 11.5 and 9.5% protein respectively

Target grain yield	Wheat N demand	Sorghum N demand
1.0	34	26
1.5	51	39
2.0	69	52
2.5	86	65
3.0	103	78
3.5	120	90
4.0	137	103
4.5	154	110
5.0	171	129
6.0	206	142
7.0	240	155
8.0	274	181

Note: remember that these values represent the total crop demand not the fertiliser applicatio required. The soil nitrogen supply needs to be subtracted from this value to obtain the fertiliser required (see Chapter 5 and 6).

Table 9. Efficiency with which plant-available nitrogen in soil is transferred to grain of wheat, barley or sorghum. The shaded area represents the most economic target level

Protein (%)	Wheat	Barley	Sorghum
9	1.35	1.32	1.58
10	1.49	1.43	1.94
11	1.64	1.56	2.50
12	1.81	1.74	

Source: Dr W Strong (pers. comm.)

Table of crop nitrogen demand as determined by grain yield

Estimated crop nitrogen demand for wheat and sorghum at various yield expectations have been calculated using equations 1 and 2 and are shown in Table 8. It can be used to directly determine nitrogen demand at 9.5% and 11.5% protein for wheat and sorghum respectively.

Table 8 was generated using the same nitrogen transfer efficiency factors of 1.7 which corresponds to grain protein levels of 11.5 and 9.5 for wheat and sorghum respectively. If a different grain protein is to be targeted a different transfer factor should be used (Table 9). Notice that for each crop the 'efficiency factor' varies with final grain protein content. Shaded areas denote grain nitrogen factors at protein ranges of most economical production.

If different grain protein targets are required, substitute values from Table 9 into equations 1 or 2.

Using the SOI phase system to modify the target yield

To this point we have considered that simulated outputs be categorised only by yield, with equal number of seasonal outcomes assigned to each yield category. However, if a reliable seasonal forecasting tool was available, different yield distributions may be apparent for different seasonal forecasts. The SOI phase may provide some skill to forecast the coming season. Figure 21 shows the shift in wheat yield distribution for contrasting phases of SOI at Dalby, south Queensland.

Note the modelled planting date was 30 May with an April/May SOI phase used. This was because at earlier planting dates, the SOI phase has no skill to modify yield probabilities. The 'locking-in' of the SOI phase is often after the desired winter crop planting date and thus of no value to a winter-planting decision. However, late winter/early spring rain can also be impacted by SOI which may influence a spring or summer crop planting and nitrogen fertiliser decisions.

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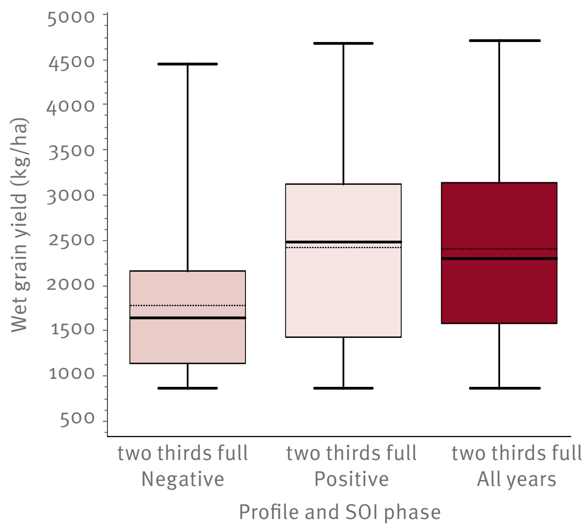


Figure 21. Yield ranges for wheat at Emerald 15 June planting for Positive and Negative SOI phases and stored water two-thirds full. The positive and negative SOI distributions are significantly different at the 5% level using the Kruskal-Wallis test

Source: *WhopperCropper*

Case study

Effect of sorghum row spacing on yield

Results from modelling and field experiments have indicated that skip row configurations can result in increased yields compared with solid plant configurations at yield levels below about 2.6 t/ha (Routley *et al.* 2003). This is presumed to be a result of conservation of soil water in the centre of the skip area for use by the plant in the grain filling stage. At higher potential yield levels, a yield reduction can occur with skip row configurations (Figure 22). Hence the choice of row configuration for a particular paddock situation will depend on available soil moisture at planting, likely in crop rainfall and the producer's attitude to risk.

Additional factors that should be taken into account are:

- Possible reduced rainfall infiltration because of low stubble cover in the inter-row space;
- Weed control difficulties because of lack of crop competition in the inter-row space.

A wide row sorghum configuration demonstrating low cover in the inter–row area which may impact on rainfall infiltration in this zone

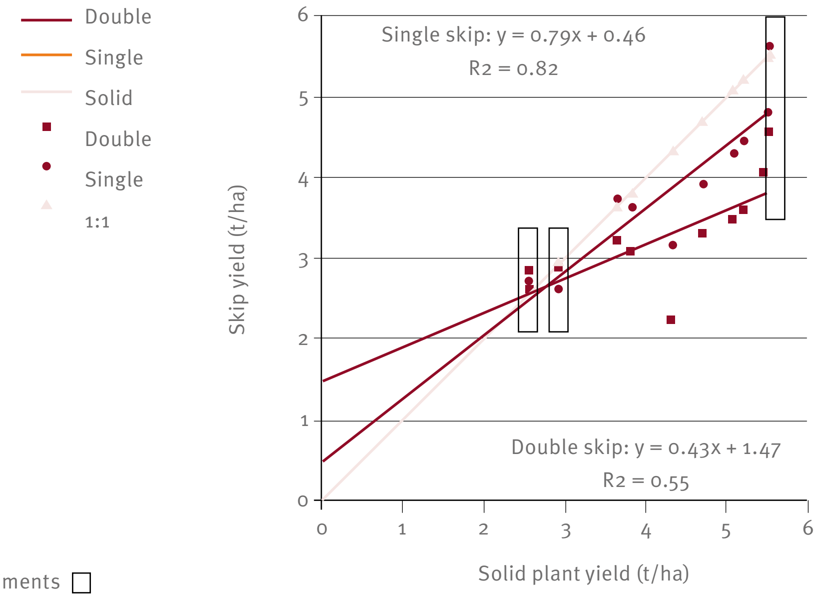


Figure 22. Relationship between solid plant yield and skip yield (Source Routley et al 2003, adapted from Butler et al 2001)

References

Butler G, Cawthray S, Castor M,Yeates S and Christian T. 2001. Improving the reliability of sorghum production in the farming system. In: Proceedings 10th Australian Agronomy Conference, 2001. Australian Society of Agronomy.

Routley R, Broad I, McLean G, Whish J. and Hammer G. (2003). The effect of row configuration on yield reliability in grain sorghum: 1. Yield, water use efficiency and soil water extraction. In: Proceedings of the 11th Australian Agronomy Conference, 2003, Australian Society of Agronomy.

5. The soil's capacity to supply nitrogen

Key messages

- Deep soil testing for nitrate-nitrogen is the best method available but still prone to inaccuracy.
- Refer to the soil sampling rate table to determine a sampling rate for accuracy:
  - For example to be correct 8 times in 10 with an accuracy of ± 10% would require 18 cores per 40 ha
  - Avoid obvious non-representative areas like old fence lines and different soil types.
- Soil organic carbon will generally reflect the period the paddock has been growing crops and can give an approximation of the potential to supply nitrogen:
  - Use organic carbon or the yield and protein of previous crops to gauge ability to supply nitrogen.

Calculation – Soil nitrogen supply (from soil test)

For each depth layer, plant-available soil nitrogen is calculated from the quantity of nitrate-nitrogen measured in that layer.

Available nitrogen = soil test value (mg/kg)
* soil bulk density (g/cm^3)
* number of 10 cm increments.

For example, depth layer 1(e.g. 0 to 60 cm)

e.g. Available nitrogen = 8
* 1.1 (average bulk density over the layer)
* 6 (six ten cm layers)
= 52.8 kgN/ha

Smart N decisions – a nitrogen fertiliser calculator

Supplied with this manual is an easy-to-use calculator into which the following data is entered;

- Soil sampling date
- Expected planting time
- Stored soil water
- Expected season type
- Soil test results.

The calculator estimates;

- Nitrogen mineralisation from soil sampling to planting
- Crop demand
- Soil supply
- Nitrogen fertiliser rate required.

By using the Seasonal Outlook and Desired Yield graph ('Expected Season Type'), in conjunction with the 'Seasonal Comparison' table (where gross margins are calculated), the optimum nitrogen fertiliser rates for each season type can be calculated (Figure 23).

In addition, an estimate of the losses incurred if the season turns out differently to that targeted or anticipated can be calculated.

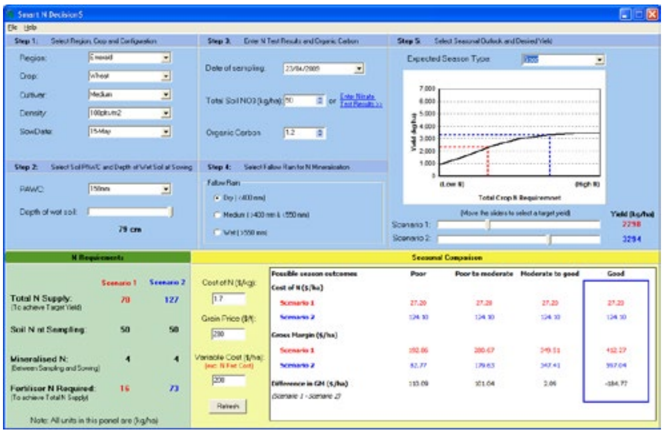


Figure 23. The single page on which the calculations are made

Direct measurement of plant-available nitrate-nitrogen in the soil

Direct measurement of the pool of nitrate-nitrogen to rooting depth, usually by soil layer and close to sowing, provides the most accurate measure of plant-available nitrogen supply in soil.

Applying nitrogen fertiliser without measuring soil nitrogen supply may lead to oversupply of nitrogen due to build up of plant-available soil nitrogen after extended fallow periods as a result of drought. Measurement of soil nitrogen supply may avoid unnecessary fertiliser application.

Table 10. Relationship between the number of soil cores taken on areas up to 40 ha, the accuracy of the results and the confidence that the mean value will fall within the level of accuracy

Confidence level #	Number of cores required	
	Med level of accuracy ± 20% of mean	
	Nitrate	Water
66%	3	2
80%	5	3
90%	8	5
	High level of accuracy ± 10% of mean	
	Nitrate	Water
66%	10	7
80%	18	12
90%	29	20

the confidence level indicates how often the result would be within the level of accuracy i.e. 80% = correct 8 in 10 times

Source: Soil Matters –monitoring soil water and nutrients in dryland farming, Eds. N Dalgliesh and M Foale, CSIRO, Australia (derived from Jones 1994)

Principles of soil sampling

Unfortunately, soil testing is time consuming and prone to error due to inherent variability in soil nitrate-N in most soils. This is especially so in brigalow scrub soils, in which the original vegetation may have been patchy, and due to a generally shorter duration of cropping.

This contrasts with more uniform open grassland soils that were originally predominantly grass vegetation and have been farmed for longer, resulting in mixing of the organic matter and depletion of soil nitrogen to uniformly low levels.

The only option is to take as many soil samples as is practically possible. Samples should be kept cool (4°C) and sent to the laboratory as soon as possible. Table 10 demonstrates the trade-off between accuracy and the number of samples that are bulked to make a test sample. These values were formulated for soils of south Queensland for areas up to 40 ha. Soils of higher variability such as in central Queensland may require higher sampling intensity than listed here. Sampling for soil water requires fewer cores because it is slightly less variable.

Sampling patterns

Typical soil sampling patterns for fallow paddocks are diagonal, circular or random positions (Dalgliesh and Foale 1998). None of these techniques make it easy to identify where the samples originally came from. GPS locating of sample sites may be useful if there is a need to return to the same spot for repeated sampling as may be required where soil properties such as organic carbon are to be monitored.

Depth of sampling

For nitrate sampling to determine plant-available nitrogen, coring to the depth of the wet soil is advisable in order not to over-estimate the potential supply. An estimation of the rooting depth of the crop is required when soil sampling is well ahead of planting. The supply of plant-available nitrogen for the next crop will most likely be derived from the depth of soil water recharge. Table 11 details the current accepted depths of sampling.

Table 11. Suggested sampling depths (cm) for chemical and water analysis for deep soils without sub-soil constraints

Crop	Rooting depth	Water, chloride, E.C and pH	Nitrogen [1]	Phosphorus, zinc, organic carbon
Sorghum, cotton	180	180	90	10
Wheat, chickpea [2]	150	150	90	10
Mungbean	120	120		10

1. Sample to full rooting depth if a nitrogen bulge is suspected

2. If 'deep' planting, sample to expected planting depth

Sample depth increments

The number of increments is a compromise between the cost of sampling and analysis and the benefits gained from knowing the position of water, nitrogen and other nutrients in the profile. Too few increments may miss a dry layer thus overestimating the effective amount of water available. Too few or too shallow sampling may also miss a nitrogen bulge that may be able to supply a crop in a good season or accurately identify the position and concentration of chemical subsoil constraints to root growth and water extraction in the profile. However, a judgement must be made as to whether nitrogen in deep soil layers would be available in the majority of seasons.

Limitations of soil nitrate-nitrogen testing

Soil nitrate-nitrogen tests should only be used as a guide to indicate potential nutrient supply. Predicting supplementary nutrient needs with any degree of accuracy relies on capability to predict **total crop requirements** at the time fertiliser is applied, usually before sowing.

Possible errors in using soil testing to predict crop nitrogen demand include:

- Variability of distribution of plant-available N creates difficulty in collecting representative soil samples
- Dry conditions in the previous fallow may underestimate soil potential to supply nitrogen for the subsequent crop
- In dry seasons, fertiliser nitrogen may be stranded in dry top soil
- In wet seasons, applied or native nitrogen in topsoil may be lost to the atmosphere.

Nevertheless, frequency of response to applied nutrient over a sequence of crops is still a useful parameter that can be derived from most soil tests in regions of unreliable cropping. As this is expensive and time consuming the easiest way is use simulation modelling tools such as *WhopperCropper*.

Using soil nitrate as an indicator of the potential of a soil to respond to nitrogen fertiliser

Season-to-season variation in crop production is usually related to variable water supplies (stored soil water and in-crop rainfall), and may create huge variation in crop nutrient demand. When used against a background of such extreme variation in season-to-season nutrient demand, soil tests can never be expected to separate responsive from non-responsive seasonal outcomes. If the soil inherently contains a considerable quantity of nitrogen, additional nitrogen fertiliser will only increase grain yield in years of highest rainfall. An example of this is shown for 11 wheat crops at *Warra* on the Western Downs where the frequency of response to applied nitrogen decreased with increasing soil test (plant available nitrogen) from 90% at a low total available soil nitrogen (50 kg/ha) to 36% at 150 kg/ha total plant available soil nitrogen (Figure 24).

The challenge for applying soil tests wisely to cropping in unreliable regions is to establish a soil test and frequency of response to fertiliser that is profitable while maintaining an appropriate level of soil nutrient for future crop production.

For nitrogen, where application costs per crop are high:

- applying nutrient only when there is high response frequency (low current nitrogen levels and high soil water availability) may be profitable but may not sustain cropping in the long term
- applying nutrient when the expected response frequency is low may be less profitable over the short term but may improve sustainability in the longer term
- when a soil test indicates a low soil level of nutrients like P and Zn, fertiliser application may be advisable even though the response frequency may be fairly low. This is because the application cost per crop is moderate but large yield gains can be obtained in some years. More importantly, non-limiting supply of the other nutrients will facilitate a more reliable yield response to applied nitrogen.

Soil organic carbon as an indicator of response to nitrogen fertiliser

Soil organic carbon is frequently used as a surrogate measure of soil fertility status because it is a proportional measure of the amount of organic matter in the soil (58% of soil organic matter is carbon). It is a relatively inexpensive laboratory test. However, this has limitations as indicated in both Tables 12 and 13. For soils of the Darling Downs with organic carbon content below 1.0%, response frequency did not exceed 70 percent (Table 12). At organic carbon levels greater than 1.0%, frequency of response was only 50% or less. Total N percent is also a measure of soil fertility but is a much more expensive test.

The management practices on the Darling Downs during the 1960s and 1970s when these trials were conducted, utilised a high proportion of long fallows (14 to 16 month) and mechanical tillage. High levels of nitrate-nitrogen in long fallows would have masked potential response to nitrogen fertiliser due to longer duration of soil nitrogen mineralisation. However, within shorter fallows, soil organic carbon can be a useful indicator of potential crop response frequency to applied nitrogen.

Organic carbon and total nitrogen levels are indicative or surrogates of the soil's capacity to supply nitrogen and are therefore useful to monitor trend in soil nitrogen supply or frequency of crop response within various crop rotations.

Soil nitrate level, on the other hand is a consequence of these soil properties (organic carbon and total nitrogen) as well as duration and conditions during the fallow when organic nitrogen is converted into the mineral form, principally nitrate-nitrogen. Hence level of nitrate-nitrogen in soil is dynamic and timing of its measurement is very important if it is used to indicate plant-available nitrogen supply.

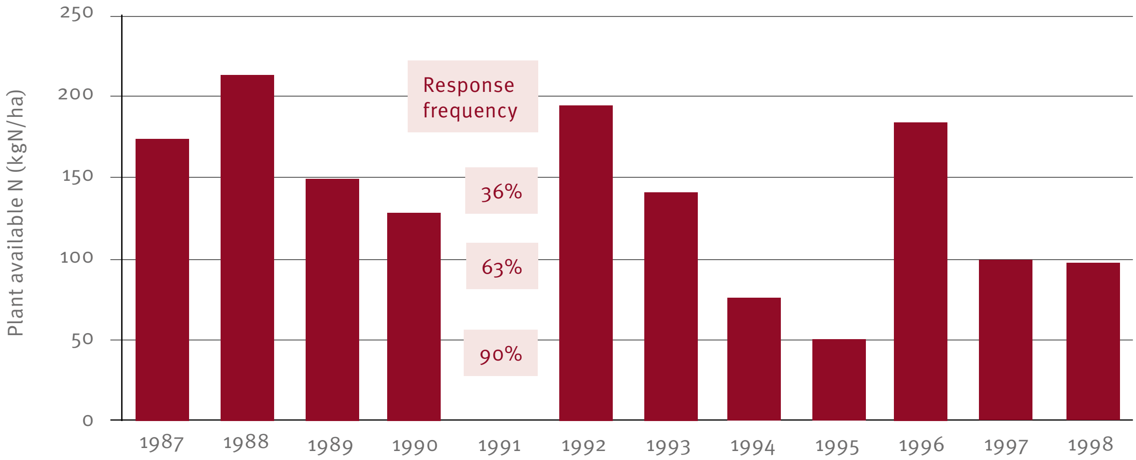


Figure 24. Demand for nitrogen (kg/ha) for 11 rain-fed wheat crops at Warra indicated by vertical bars. Horizontal lines indicate 3 soil test levels of available nitrogen, 50, 100 and 150 kg/ha. This sequence of wheat crops would have responded to fertiliser nitrogen with a frequency of 90%, 63%, and 36% respectively, where 50, 100 or 150 kg/ha of nitrate-nitrogen was measured at sowing. Notice the imprecise nature of predicting crop response from soil nitrate-nitrogen with such unreliable cropping

Table 12. Response frequency to applied nitrogen for Darling Downs soils cropped with wheat in 1965-1971, categorised by soil organic C level or total soil nitrogen level. Neither soil test totally separates responsive from non-responsive sites but each is useful to monitor trend in crop response frequency within various crop rotations

Organic carbon percent	<1.0	1.0-1.4	>1.4
Response frequency (per cent)	70	50	30
Total N percent	<0.1	>0.1	
Response frequency (per cent)	60	30	

Table 13. Simulated monthly release of plant-available nitrogen (kg/ha) for soils with a range of organic carbon levels at Emerald, the shaded area indicates mineralisation during a typical cropping period of either wheat or sorghum crops

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mineralisation
Wheat crop Emerald plant 1 Dec 50 kgN NO3/ha, 67% full of a 170 mm PAWC capacity soil													
OC 0.8	6.5	6.5	7.0	5.8	3.2	1.9	0.9	0.5	0.8	1.9	3.5	5.2	43.7
OC 0.9	7.6	7.5	8.1	6.5	3.8	2.3	1.1	0.6	1.0	2.2	4.2	6.3	51.4
OC 1.0	8.7	8.5	9.2	7.3	4.5	2.7	1.3	0.8	1.2	2.6	4.9	7.3	59.0
OC 1.1	9.4	9.2	9.8	7.8	4.9	2.9	1.4	0.8	1.3	2.8	5.3	7.9	63.4
OC 1.2	10.0	9.8	10.4	8.2	5.3	3.1	1.5	0.9	1.4	3.0	5.7	8.4	67.8
OC 1.3	10.7	10.3	10.9	8.6	5.7	3.3	1.7	0.9	1.5	3.2	6.1	9.0	72.1
OC 1.4	11.4	10.9	11.5	9.0	6.1	3.6	1.8	1.0	1.6	3.4	6.5	9.6	76.3
OC 1.5	12.0	11.5	12.0	9.4	6.4	3.8	1.9	1.1	1.7	3.6	6.9	10.1	80.4
OC 1.6	12.6	12.0	12.5	9.8	6.8	4.0	2.0	1.1	1.8	3.8	7.3	10.7	84.4
Sorghum crop Emerald plant 1 Dec 50 kgN NO3/ha, 67% full of 170 mm PAWC													
OC 0.8	5.0	3.3	2.9	2.3	2.1	1.9	1.9	2.2	2.9	4.3	6.1	6.3	41.2
OC 0.9	5.6	3.6	3.2	2.5	2.3	2.0	2.0	2.3	3.2	4.7	6.7	6.9	45.0
OC 1.0	6.1	4.0	3.5	2.8	2.5	2.2	2.2	2.5	3.4	5.0	7.2	7.6	48.9
OC 1.1	6.6	4.3	3.7	3.0	2.7	2.4	2.4	2.7	3.7	5.4	7.7	8.4	53.0
OC 1.2	7.1	4.6	4.0	3.3	3.0	2.6	2.6	2.9	4.0	5.8	8.1	9.2	57.1
OC 1.3	7.6	4.9	4.3	3.5	3.2	2.8	2.7	3.1	4.2	6.1	8.5	9.9	60.9
OC 1.4	8.1	5.2	4.5	3.8	3.5	3.0	2.9	3.3	4.5	6.5	9.0	10.5	64.8
OC 1.5	8.6	5.5	4.8	4.1	3.7	3.1	3.1	3.5	4.7	6.8	9.4	11.2	68.6
OC 1.6	9.1	5.8	5.1	4.3	3.9	3.3	3.3	3.7	5.0	7.1	9.7	11.8	72.3

Source: APSIM version 6.1, Keating et al (2003)

Table 14. Selectable inputs and parameter choices for *WhopperCropper* 'fallow'

Input factor	Options
Soil organic carbon levels	0.8, 0.9, 1.0, 1.1, 1.2, 1.4 (per cent)
Districts	Dalby, Goondiwindi etc.
Soil PAWC's	80, 120, 150, 190 mm
Date of start of fallow	15th of every month
Fallow length	2, 5, 7, 12 months
Soil water at start of fallow	0, 25% and 50% full
Soil nitrogen at start of fallow	0, 25, 100 kgN/ha

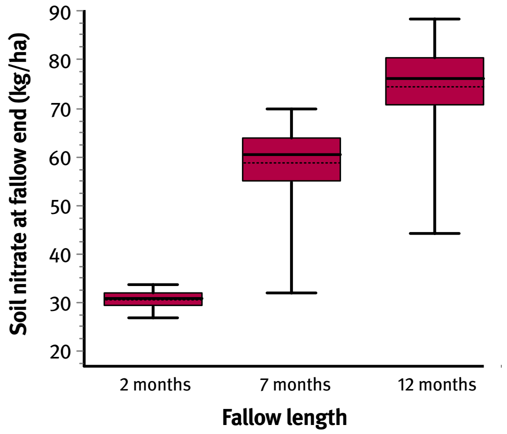


Figure 25. Range of simulated soil nitrates (kgN/ha) at end of 2, 7 or 12 month fallows commencing 15-October, Emerald, 150mm PAWC, 25 per cent full, 25kgN/ha at commencement of fallow. Simulations involved 100 years of weather data. The solid line is the median value, dashed line is the mean. Other points are 100 per cent, 75 per cent, 25 per cent and 0 per cent values respectively Source: *WhopperCropper*

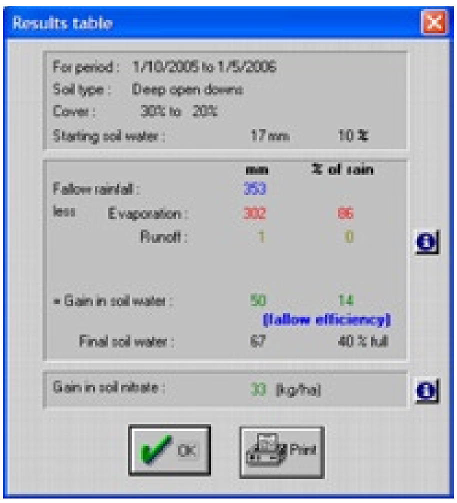


Figure 26 . Example of fallow nitrogen mineralisation estimate from HowWet The setup is partially described above and uses Emerald weather data, soil organic carbon of 0.9% (assumed 40 years of farming), 30% cover and 10% profile refill at fallow start, 20% cover at fallow end, slope = 1%

Simulation tools use for estimating nitrogen mineralisation during a fallow

The practicalities of soil testing require a time lag between sampling and planting to enable laboratory analysis. Hence, an estimate of the amount of nitrogen that might be mineralised between sampling and planting is required. Thus when soil sampling is much earlier than planting time, plant-available nitrogen determined by an early soil test can be adjusted to estimate the level at planting. An estimate of the additional nitrogen that is mineralised in that period can obtained from a number of simulation tools.

Using a 'look-up' table generated using the APSIM model

Estimated **monthly** nitrate-nitrogen releases for soils of differing organic carbon levels at Dalby, south Queensland derived from APSIM are shown in Table 13. These outputs were derived using the following set-up options:

- Soil organic carbon range 0.8 to 1.6%
- 170 mm soil PAWC
- Soil water approximately two thirds full every year
- 15 May sow date (wheat), 15 December sow date (sorghum)
- 50 kgN/ha in the soil at sowing.

WhopperCropper 'fallow'

Using the 'fallow' option (under the crops selection menu), *WhopperCropper* provides the capability to estimate the following outputs

- soil nitrogen mineralisation (and soil nitrate at end of fallow)
- storage of water (and stored soil water at end of fallow)
- runoff (total)
- drainage (total)
- evaporation (total)

using any combination of the selectable inputs shown in Table 14.

Example output - soil nitrate-nitrogen at the end of various fallow lengths

Soil nitrate available at the end of the fallow increases with fallow length and will vary widely in response to differing soil water and temperature conditions in the fallow (Figure 25).

HowWet

The *HowWet* program has a fallow mineralisation calculator (Figure 26). It is a simplified version of the nitrogen module from APSIM program used to create *WhopperCropper* ‘fallow’. However, it uses actual start and end dates of the fallow and actual rainfall records for the paddock in question, so can be a useful indicator of nitrate-nitrogen mineralisation.

Using yield and protein values of previous cereal crops to estimate soil nitrogen supply

Table of yield and protein results

Using the efficiency factors tabulated in Table 9 it is possible to estimate the minimum supply of plant-available nitrogen to recently grown cereal crops retrospectively using grain yield and protein values to estimate nitrogen (kg/ha) removed in grain. In this way, grain yield and protein for previous wheat or sorghum crops can be used to estimate a minimum supply of **soil nitrogen** for the next crop.

However, such estimates of likely nitrogen supply must be interpreted with care. Position of crop in the rotation could have considerable influence on estimating the future minimum nitrogen supply. The estimated future soil nitrogen supply might be over-estimated if:

- the preceding fallow was longer than 6 months
- the preceding crop was a grain legume.

However, even with these limitations, previous cereal crop production figures can be useful to obtain an approximate value for the soil’s capacity to release plant-available nitrogen. Minimum soil nitrogen supplies, calculated from previous sorghum and wheat crops are tabulated in Tables 15 and 16.

Note that Tables 15 and 16 show how much nitrogen was removed by various grain yield and protein combinations. The nitrogen amounts shown must be factored up by an appropriate efficiency factor to account for the total amount of nitrogen required to grow the crop: grain and stubble (refer to Tables 8 and 9).

Recording grain yield and grain protein outcomes of recent cereal crops is a valuable way to qualitatively evaluate the conditions of soil nitrogen supply and soil water that the crop experienced (Table 17).

Critical grain protein values have been used to identify probable onset of nitrogen deficiency or to monitor the adequacy of nitrogen supply for the cropping system. High frequency of crop production of grain proteins below the critical value is indicative of the need to either commence regular application of nitrogen fertiliser or increase the level of nitrogen applied to a particular rotation. Low cropping intensity or drought periods may prevent widespread use of this strategy.

Table 15. The minimum supply of nitrate-nitrogen that was available to a crop estimated retrospectively from grain yield (t/ha) and protein content (%) of a recent sorghum crop. These values are based on grain nitrogen only and thus must be factored up by an appropriate efficiency factor to account for the total amount of nitrogen required to grow the crop; grain and stubble

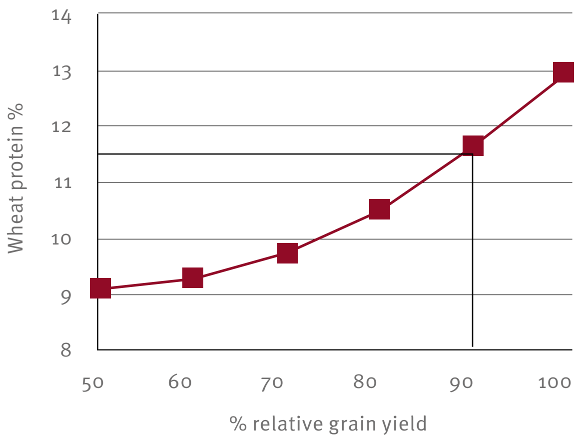
Grain yield	Sorghum protein					
	8	9	9.5	10	11	12
1.0	13	14	15	16	18	19
1.5	19	22	23	24	26	29
2.0	26	29	30	32	35	38
2.5	32	36	38	40	44	48
3.0	38	43	46	48	53	58
3.5	45	50	53	56	62	67
4.0	51	58	61	64	70	77
4.5	58	65	68	72	79	86
5.0	64	72	76	80	88	96
5.5	70	79	84	88	97	106
6.0	77	86	91	96	106	115

See Tables 8 and 9

Table 16. The minimum supply of nitrate-nitrogen that was available to a crop estimated retrospectively from grain yield (t/ha) and protein content (%) of a recent wheat crop. These values are based on grain nitrogen only thus must be factored up by an appropriate efficiency factor to account for the total amount of nitrogen required to grow the crop; grain and stubble

Grain yield	Wheat protein						
	9	10	11	11.5	12	13	14
1.0	16	18	19	20	21	23	25
1.5	24	26	29	30	32	34	37
2.0	32	35	39	40	42	46	49
2.5	39	44	48	50	53	57	61
3.0	47	53	58	61	63	68	74
3.5	55	61	68	71	74	80	86
4.0	63	70	77	81	84	91	98
4.5	71	79	87	91	95	103	111
5.0	79	88	96	101	105	114	123
5.5	87	96	106	111	116	125	135
6.0	95	105	116	121	126	137	147

See Tables 8 and 9



Source: Strong pers.comm.

Figure 27. Wheat protein outcome and grain yield relative to yield with nitrogen unlimited

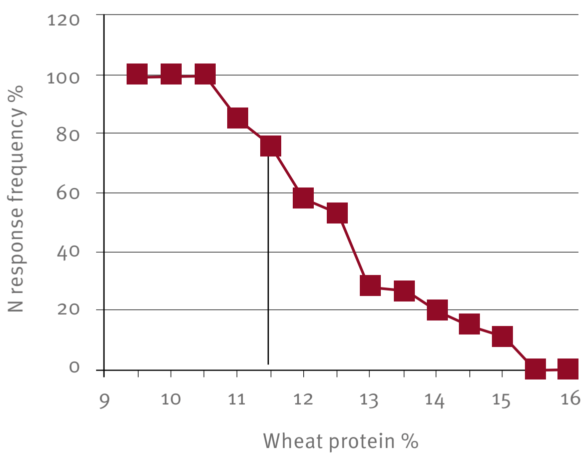


Figure 28. Frequency of response to nitrogen fertiliser for › 200 wheat crops categorised by protein content of unfertilised grain

Values of grain protein percentage alone can indicate nitrogen sufficiency

Results of numerous multi-rate nitrogen fertiliser experiments with cereals in Australia's northern region indicate robust relationships between the grain protein outcome and potential for cereal crops wheat, barley and sorghum, to respond to applied nitrogen.

Relative wheat yield (defined as crop yield relative to the yield with unlimited nitrogen supply) has a relationship with grain protein which is depicted in Figure 27. According to this relationship, wheat grain protein of 11.5% is produced at approximately 90% relative yield, which is normally accepted as reflecting the most economic grain yield in multi-rate fertiliser experiments.

Frequency of response to nitrogen fertiliser

As further evidence of a relationship between grain protein and low crop nitrogen supply, results of more than 200 dryland nitrogen fertiliser trials showed that wheat protein of 11.5% or less was produced on sites which have high frequency of response in grain yield to nitrogen fertiliser (Figure 28). This means that if a wheat grain protein of less than 11.5% was produced, grain yield would have been increased if additional nitrogen was available. Similarly, critical levels of grain protein to that indicated for wheat (11.5%) have been discovered for barley and sorghum using trial data available from multi-rate N fertiliser experiments. The critical grain proteins for barley (dry grain) and sorghum (moist grain) are 10.5 and 9.5% respectively.

Table 17. Using past grain yield and protein outcomes to reflect qualitatively on the water and nitrogen supplied to cereal crops of northern Australia

Qualitative yield and protein outcomes	Low protein	High protein
Low grain yield	Likely N deficiency	Low water supply or other limiting factor
High grain yield	Higher than average water supply	Rarely produced

References

Dalgliesh N P and Foale M A (1998). A guide to soil sampling. In: Soil Matters –monitoring soil water and nutrients in dryland farming, Eds. N Dalgliesh and M Foale, CSIRO, Australia.

Jones P N (1994). Sample size for on-farm soil sampling. CSIRO. Brisbane. IPP&P Biometrics Unit Report IPPP/BU/94/15.

Keating BA, Carberry PS, Hammer G L, Probert ME, Robertson M J, Holzworth D, Huth N I, Hargreaves JNG, Meinke H, Hochman Z, McLean G, Verburg K, Snow V, Dimes JP, Silburn M, Wang E, Brown SL, Bristow K, Asseng S, Chapman S, McCown RL, Freebairn DM and Smith CJ. (2003). An overview of APSIM, a model designed for farming systems *European Journal of Agronomy* **18** 267-288.

6. Determining nitrogen fertiliser requirement

Nitrogen fertiliser requirement = crop nitrogen demand – soil nitrogen supply

see Chapter 4 *see Chapter 5*

Crop demand

As described previously, **crop nitrogen demand** may be estimated from a target yield and a relevant grain protein.

Soil supply

As described previously, **soil nitrogen supply** may be estimated by field soil sampling or computer programs (*HowWet* or *WhopperCropper*).

Nitrogen fertiliser calculator

Also supplied with this manual is an easy-to-use computerised calculator (Figure 29). On a single page the relevant data are entered for:

- Soil sampling date
- Expected planting time
- Stored soil water
- Expected season type (e.g. poor, average etc)
- Soil test results.

The calculator estimates:

- Nitrogen mineralisation from soil sampling to planting
- Crop demand
- Soil supply
- Nitrogen fertiliser rate required.

Also included in the calculator is an estimate of the losses incurred if the season turns out differently to that targeted or anticipated.

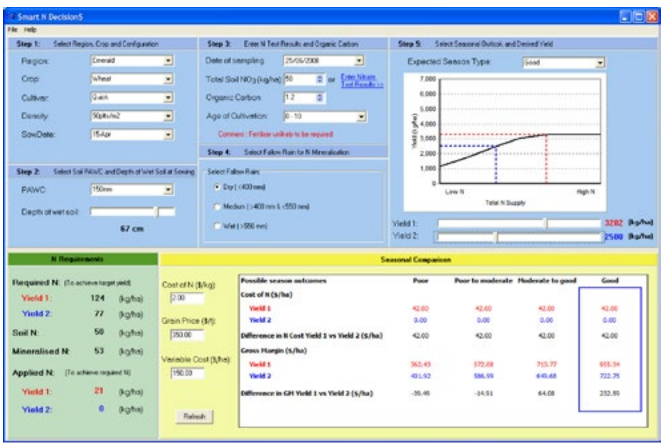


Figure 29. Nitrogen fertiliser rate calculator (included with this manual)

7. Alternative methods to calculate nitrogen fertiliser requirement

Key messages

- *WhopperCropper* is an easy-to-use program for calculating the effects of varying input levels (including nitrogen fertiliser) on potential yields using the full range of historical rainfall data.
- Having access to the full range of potential outcomes is superior to a calculation involving a single 'district average' because the user can readily evaluate how their attitude to risk is matched by the effect of different inputs on potential yield and gross margin outcomes.
- *WhopperCropper* is the best way to analyse the long-term financial aspects of varying input levels. A small amount of data entry is required.
- A total soil supply of at least 100 kgN/ha will satisfy the majority of yield outcomes likely in central Queensland.
- Grain nitrogen removal is 20 kgN/ha and 17 kgN/ha for each tonne of wheat and sorghum respectively. The total soil nitrogen requirement to grow a crop with adequate grain protein is typically 1.7 times this amount.

Simulating crop response to applied nitrogen with *WhopperCropper*

Crop responses simulated with *WhopperCropper* can be used to compare effects of nitrogen fertiliser application rate, stored water at planting, soil nitrogen supply, planting time, plant population and crop maturity, SOI phase and combinations of all of these factors. The program uses 100 years of weather data from selected sites and consists of a database of scenarios of all possible combinations of practical input levels that farmers must consider. For more information on *WhopperCropper* see http://www.apsru.gov.au/apsru/

The potential range of responses to applied nitrogen fertiliser is demonstrated in Figure 30. The analysis applies to wheat yield at Emerald with five levels of applied nitrogen, 0, 25, 50, 75 or 100 kg/ha where soil contains 50 kg/ha plantavailable nitrogen and the soil profile is fully wet (150 mm) every year. Other setup parameters: medium wheat maturity, 15 May planting, density of 100 pl/m2.

In the absence of fertiliser nitrogen, 75% of all yields would be expected to be less than 1600 kg/ha. With the addition of nitrogen, the range of potential yields increased with both 25 and 50 kgN/ha. Rates of N higher than 50 kg/ha increased median yield only slightly but made possible achieving optimal yield in the few years of high rainfall; these N rates were uneconomic in seasons of moderate to low rainfall (see Figure 31).

WhopperCropper also has the facility to enter costs and prices and hence GROSS MARGINS can be calculated. In Figure 31 it can be seen that the median gross margin declines with 100 kgN/ha. In addition, the proportion of 'lower-end' gross margins increase with the 100 kgN/ ha rate.

The '100N' rule

Crop simulation modelling using 100 years of weather data for central Queensland has demonstrates that total crop nitrogen demand by wheat or sorghum crops rarely exceeds 100 kg N/ ha. The outputs reveal that 100 kg N/ha satisfies the nitrogen demand of more than 90% of wheat crops 'grown' in the 100 years. There were few instances when a greater amount of nitrogen would have been more beneficial or economical. Thus, supplementing plantavailable nitrogen where 100 kg/ ha is already present would appear uneconomical for most dryland central Queensland farming systems.

Wheat

From simulation results, wheat crops at Emerald had a median nitrogen demand of 74 kg/ha (range 32 to 114 kg/ha) (Figure 32).

- Only 10% of crops have a nitrogen demand greater than 100 kg/ha. Note: the upper 'whisker' of the boxplot represents the 90% value of nitrogen demand. There are 10% of values greater than this amount.

Sorghum

From simulation results, sorghum crops at Emerald had a median nitrogen demand of 76 kg/ha (range from 47 to 101 kg/ha) (Figure 31).

For the inputs used in these simulations, the nitrogen demand of only one crop in 113 years exceeded 100 kgN/ ha. Thus, making available approximately 100 kg N/ha in the soil has been found to meet the majority of yield and protein combinations that arise in central Queensland's variable environment. Table 18 details some of potential yield and protein outcomes for wheat and sorghum.

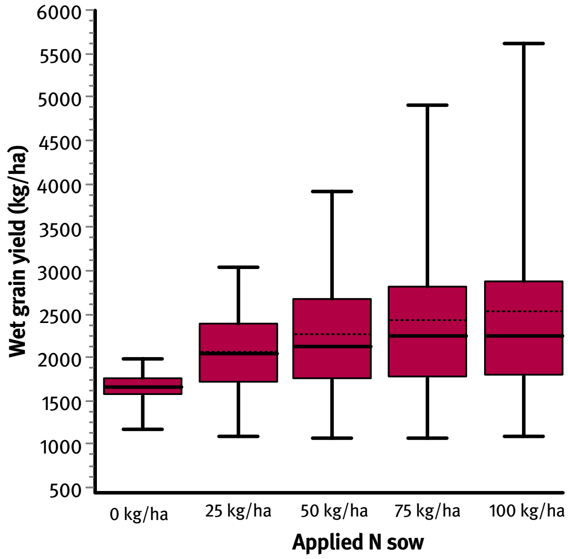


Figure 30. Wheat yield at Emerald with five levels of applied nitrogen, 0, 25, 50, 75 or 100 kg/ha where soil contains 50 kg/ ha plant-available nitrogen and profile is fully wet (150 mm). Other setup parameters: medium maturity, 15 May planting, density of 100 pl/m2

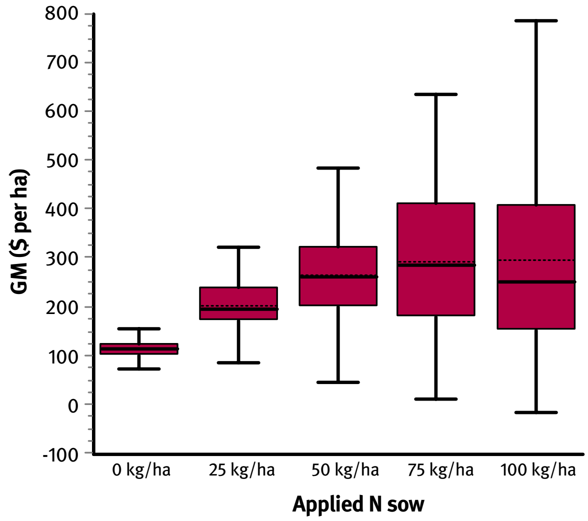


Figure 31. Gross margins for wheat at Emerald with five levels of applied nitrogen, 0, 25, 50, 75 or 100 kg/ha where soil contains 50 kg/ha plant-available nitrogen and profile is fully wet (150 mm). Other setup parameters: medium maturity, 15 May planting, density of 100 pl/m2

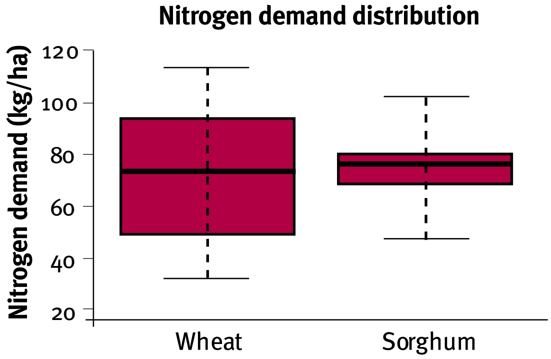


Figure 32. Range of nitrogen demands for wheat and sorghum crops simulated for Emerald using >100 years of weather records

Table 18. Yield and protein outcomes that are potentially obtainable with 100 kgN/ha

Wheat		Sorghum	
Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)
10.5	3.2	8.5	4.3
11.5	2.9	9.5	3.9
12.5	2.6	10.5	3.5

Nitrogen fertiliser rate based on grain removal rate

Table 19 indicates the typical nutrient removal rates per tonne of grain. Use this as a guide only because there can be considerable variation around these values because of different grain protein levels that may occur. Nutrient replacement rates below crop removal will increase soil fertility decline. Nutrient replacement while continuing to crop will slow fertility decline rather than arrest the decline.

Because of highly variable seasonal rainfall, application strategies that rely on nutrient removal rates of previous crops make nutrient applications a risky option in the short-term because:

- the supplied nitrogen fertiliser may not be ultimately required when rainfall is low and a low yield occurs
- the cost of supplementing the supply of the nutrient may not be economical in relation to market returns for the crops
- replacement of the nutrient may not match the original form or distribution, thus failing to simulate the original supply of plant available nutrient
- environmental sustainability may be affected by either over or under supply of nutrients in some situations.

Table 19 provides information to estimate nutrient removal by a crop or a sequence of crops. However, use the procedures described elsewhere in this manual and the electronic calculator as the preferred means to estimate crop nutrient needs.

References

Dalal, R. C. and Probert, M, E (1997). Soil nutrient depletion. In: Sustainable crop production in the tropics, an Australian perspective. Eds. A.L Clarke and P.B Wylie. Department of Primary Industries, Queensland.

Table 19. Quantitative removal (kg/t grain) of nutrients by grain crops common to central Queensland

Crop	Typical nutrient removal (kg/t of product)					
	N	P	K	S	Ca	Mg
Sorghum	19	3.7	4.8	2.8	0.5	1.4
Wheat	23	3.4	4.5	1.8	0.5	1.4
Maize-grain	24	3.3	5	3.8	0.2	0.9
Sunflower	26	4.1	8.0	4.0	2.0	2.2
Barley	20	2.7	5.0	2.0	0.4	1.2
Chickpea	42	2.0	5.3	-	1.6	0.6
Peanut-pods	52	5.1	7.1	-	0.6	2.0
Peanut –hay	13	0.5	-	-	-	-
Soybean	73	5.9	15.9	-	-	-

Source: Dalal, R. C. and Probert, M, E (1997)

8. Evaluating the financial risk of applying nitrogen fertiliser in south Queensland

Key messages

- Without addition of nitrogen, decline in soil nitrogen fertility is inevitable. This is already evident on open downs soils. At some point in time, nitrogen deficiency will reduce profitability.
- Accurately predicting crop nitrogen demand for an individual crop in central Queensland is not possible due to significant seasonal variability.
- Use the decision-support package *WhopperCropper* to display the range of seasonal yields with the aim of choosing an appropriate target yield. The aim is to reduce grower exposure to financial risk although there can be no guarantee that a result in a single year will be as desired.
- Use *WhopperCropper* to display the full range of potential gross margins using the selectable range of nitrogen fertiliser rates.
- Estimates of plant-available soil nitrogen and water are needed to minimise financial risks where soil nitrogen supply is likely to be very low or very high.

The role of field trials to diagnose nitrogen requirement

Since the 1960s when crop responses to nitrogen fertiliser were first identified in southern Queensland, numerous field trials were conducted to advance our capacity to predict nitrogen requirements of cereals (Littler *et al* 1969, Strong *et al* 1978, Dalal *et al* 1998, Strong *et al* 1996 a and b). Another aim of early field research was to develop a diagnostic technique to reliably predict future crop nutrient requirements. Soil testing was the primary diagnostic technique that held most promise at that time.

Soil tests for nitrogen, phosphorus and zinc were soon discovered to provide less skill for determining crop fertiliser requirements in southern and central Queensland farming systems than for more reliable rainfall environments (like the USA and UK). Other diagnostic approaches were therefore sought. In 1980s use of crop production information (grain yield and protein concentration) to estimate cereal crop nitrogen supply was promoted for use as a monitoring tool for grain growers to estimate when more frequent responses to applied nitrogen could be obtained. Results from previous multirate fertiliser experiments resulted in the use of grain protein as a nitrogen sufficiency indicator. Applications of these data is presented in this manual.

Evaluating the financial risk of applying nitrogen fertiliser to grain crops

Financial risk is important in a decision to apply nitrogen fertiliser in central Queensland, because of its variable and unreliable rainfall. Recognition of this variability, and its effect on seasonal crop production in dryland farming systems of northern Australia, led to development of crop simulation models. Many field trials were used to derive principles of crop nutrition that provided algorithms for the crop simulation models. Field trials were used, and continue to be used, to validate or justify simulation outputs. Simulation models such as Wheatman, APSIM and its derivative products (*WhopperCropper, Yield Prophet and HowWet*) have found applications in decision making for many grain growers in the region.

WhopperCropper is very relevant for nitrogen management decisions for cereal crops of northern Australia. Using *WhopperCropper*, the likelihood of unprofitable fertiliser use can be assessed as well as the frequency of profitable outcomes from any nitrogen management strategy. *WhopperCropper* provides yield outputs that are estimates over long-term cropping that are impossible to acquire by any other means. By adding costs and prices, the full range of potential gross margins can be generated. Hence the risk of negative gross margins can also be displayed.

Discussion on the effect of soil water, nitrogen fertiliser rate and SOI on cereal cropping gross margins in central Queensland farming systems follows, using *WhopperCropper* output for explanatory purposes.

The effect of soil water at planting on gross margin (with no nitrogen limitations)

As demonstrated previously (Figure 21 for wheat only) the soil water available at planting significantly affects the potential yield range. Figure 33 demonstrates the impact on wheat and sorghum yield at Emerald for soil with a total water-holding capacity equal to 150 mm (PAWC) with a full (150 mm), 2/3 full (100 mm) and 1/3 full (50 mm) profile of plant available water. The simulation assumes wheat variable costs (excluding N fertiliser) of $133/ha, sorghum variable costs (excluding N fertiliser) of $203/ha, and a nitrogen fertiliser cost of $1.30/ kgN (approx. $600/t urea).

Figure 33 shows that:

In wheat:

- Simulated median gross margin for wheat increases by approximately $200/ ha for each 50 mm increase in plantavailable water at planting
- More than 50% of the gross margins for wheat are negative when the soil water recharge is only 1/3 full at planting. Planting with an extra 50 mm of stored water (2/3 full = 100 mm) decreases the risk of negative returns from wheat to less than 25%. This demonstrates the crop reliance in central Queensland of water stored in the soil rather than the small quantity of in-crop rainfall that occurs during winter.
- Moderate to high returns are possible for wheat but only in the 'best' 25% of years

In sorghum:

- Filling the soil to 2/3 full significantly reduces the risk of negatives gross margins from 25% to less than 10%.
- A full profile increases the sorghum gross margin by only a small amount compared to the 2/3 full (with a potential soil erosion risk)
- Sorghum is less dependent on stored soil water because of the summer-dominant rainfall in central Queensland and increased chance of useful in-crop rain. Sorghum provides more reliable returns for each category of stored soil water than wheat, even though the maximum returns for wheat are greater than sorghum.

Note: the difference in stored water between these scenarios (50 mm) could approximate the quantity of extra water accumulated with good fallow management.

How to read this *WhopperCropper* boxplot

The black line in the 'red box' is the median yield (50 per cent of all years have this 'yield' or less). The dashed line within the 'red box' is the mean yield. The upper edge of the 'red box' is 75 per cent probability. This is read as 'in 75 per cent of years, yields will be less than this value'. The lower edge is the 25 per cent probability value i.e. 'in 25 per cent of years, yields will be less than this value'. The upper and lower short horizontal lines represent 100 per cent and 0 per cent probabilities respectively.

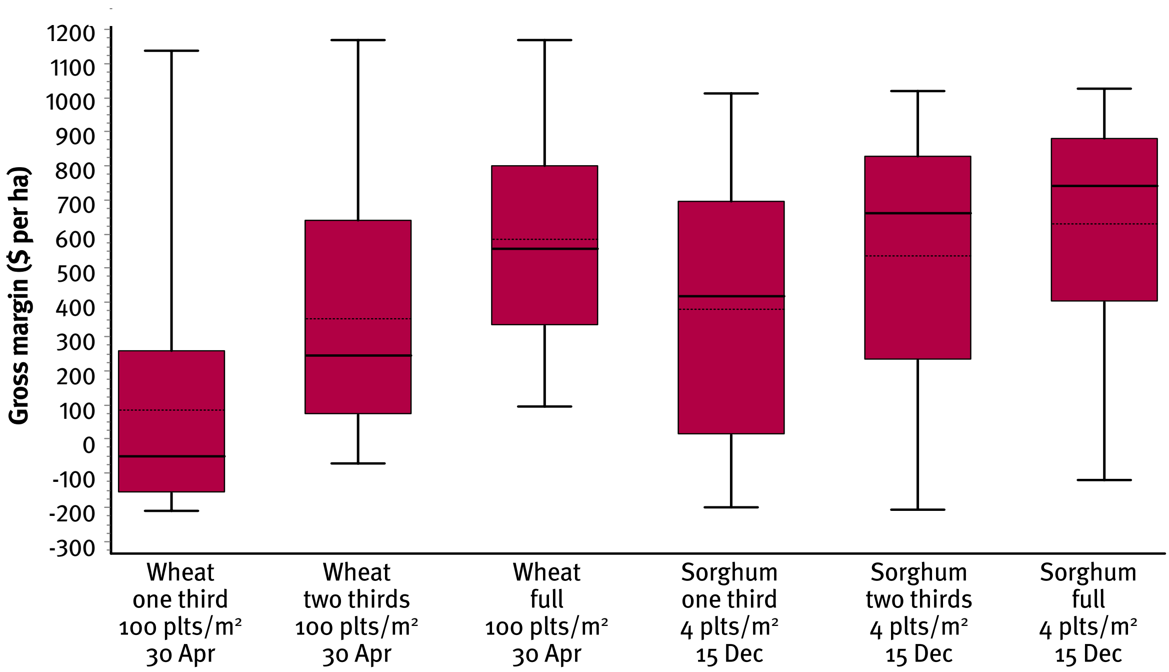


Figure 33. Effect of soil water at planting of wheat and sorghum yields at Emerald with stored water at planting equal to 1/3, 2/3 or full at planting. Soil nitrogen set to 150kgN/ha at planting. Planting dates as shown. Density: Wheat 100 pl/m2, sorghum 4 pls/m2, medium maturities, soil PAWC=150mm, sorghum solid 1m rows

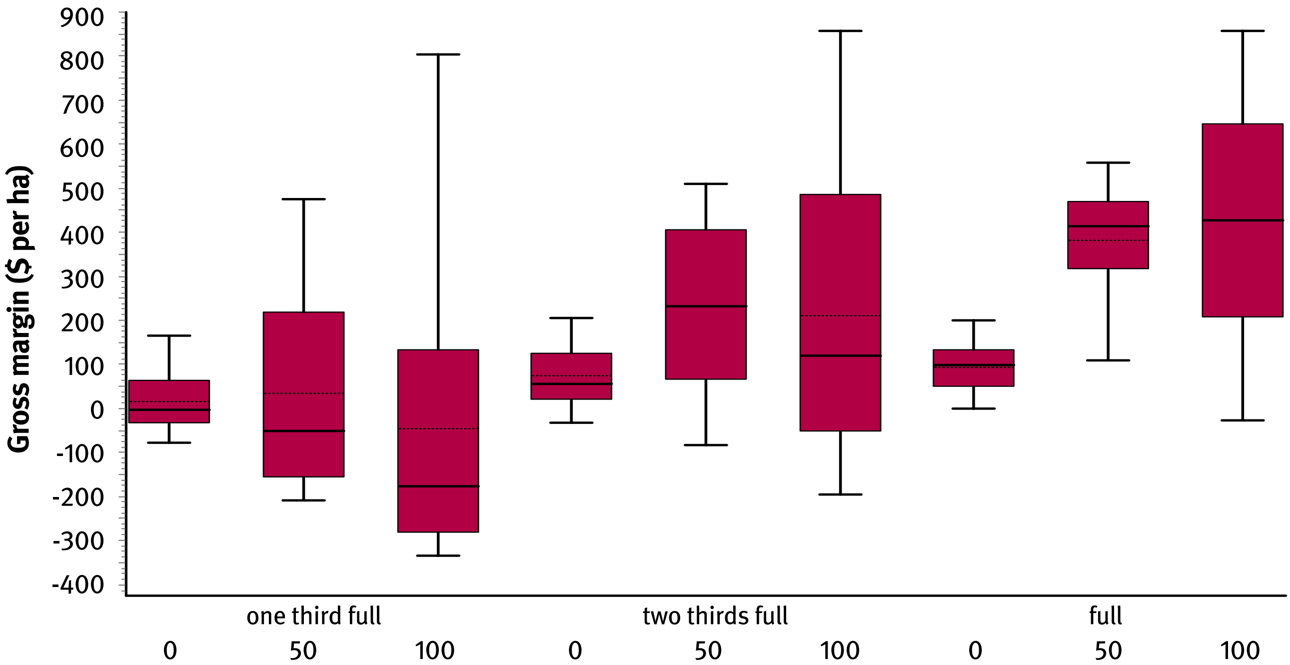


Figure 34. Effect of soil water at planting of wheat and sorghum yields at Emerald with stored water at planting equal to 1/3, 2/3 or full at planting. Soil nitrogen set to 150kgN/ha at planting. Planting dates as shown. Density: Wheat 100 pl/m2, sorghum 4 pls/m2, medium maturities, soil PAWC=150mm, sorghum solid 1m rows

The interaction of stored soil water and nitrogen fertiliser rate

Figure 34 demonstrates the impact on wheat and sorghum yield at Emerald of a soil with a total water-holding capacity equal to 150 mm (PAWC) with a full (150 mm), 2/3 full (100 mm) and 1/3 full (50 mm) profile of plant available water AND three rates of nitrogen fertiliser (0, 50,100 kgN/ha). Soil nitrogen level was set to a low value of 25 kgN/ha. The same wheat variable costs as above are assumed.

- **When the profile is only 1/3 full at planting**, gross margin is negative in 50% of years when there is no nitrogen fertiliser applied. This reflects the high risk of the low soil water at planting as well as nitrogen deficiency that negates most positive returns in better seasons. With 50 kgN/ha applied the average return is approximately zero. In the best 25% of seasons a moderate profit is indicated. Because of the high cost of the 100 kgN/ ha rate, the median return is negative and the average close to zero. High returns are evident only in the better seasons when in-crop rainfall interacts positively with the high nitrogen supply.
- **With the profile 2/3 full at planting**, a nil nitrogen rate severely limits yield potential. The 50 kgN/ha rate (75 kg/ ha total available N) produces mostly positive gross margin outcomes but nitrogen could still be limiting in good seasons. The 100 kgN/ha rate (125 kg/ha total available N) provides adequate nitrogen supply for the best 75% of seasons. However, losses in the poorest 25% of seasons are higher, due to the higher fertiliser cost thus reducing the median gross margin.
- **A full profile at planting** provides good insurance against negative returns, even with 100 kgN/ha applied. However there are a greater percent of lower gross margins than the 50 kgN/ha rate because of the high N fertiliser cost.

The decision to plant on a 2/3 full profile rather than wait for a full profile may be influenced by factors such as the time in the planting window (yields reduce with later plantings) and the need to guarantee cash flow.

The nitrogen rate selected can be influenced by financial factors and the grain price, the amount of stored soil water, and individual opinion on the outlook for coming season.

Figure 35. Map showing locations in Central Highlands where median rainfall during July to September decreases by more than 20 per cent or 30 per cent when SOI is consistently negative during May and June

Source: Rainman v4.3

Incorporating the SOI seasonal climate forecast into decisions to minimise the financial risk of applying nitrogen

The SOI phase system uses a two-month indicator period to change the rainfall probability for the next three months. Yield ranges may therefore be modified according to SOI phase. However the skill with which the SOI phase system may accurately forecast the yield range differs by location and by time of year.

The skill of using SOI phases in a desired location or time can be determined from the Rainman program. For example, Figure 35 indicates that for the 'consistently negative' SOI phase in May/June, there is a statistically significant reduction of 20 to 30 per cent in median July to September rainfall and this is consistent across most locations in the central Highlands.

Using *WhopperCropper* to produce a gross margin analysis of a three-way interaction of soil water at planting, nitrogen fertiliser rate and SOI phase

Figure 36 describes a three-way interaction of, soil water at planting (1/3 and 2/3 full), nitrogen fertiliser rate (0, 50 kgN/ha), AND SOI phase (positive and negative). The other setup factors are as for previous scenarios.

Figure 35 shows that knowledge of the soil water at planting and SOI phase might be used to reduce risks associated with the application of nitrogen fertiliser. Note that even in the most favourable situation demonstrated, the gross margin varies widely from a low of -$40/ha to a high of $220/ha.

For a negative phase of SOI (over April/ May) the following outcomes are indicated:

- the predicted gross margin range with 1/3 full (50 mm) stored water at planting would indicate no chance of positive crop return even without fertiliser
- applying 50 kgN/ha with a 1/3 full profile, worsens the gross margin outcome compared to a nil nitrogen application
- a nil nitrogen rate when the soil is 2/3 full reduces the losses compared to the 1/3 full scenario but has no chance of achieving positive returns in the better years
- however, with 50 kgN/ha applied, the predicted gross margin range with the 2/3 full (100 mm) stored water at planting indicates some chance (40%) of positive returns but 60% chance of negative returns. The median gross margin is -$20/ha and the average is zero.

In summary, when the SOI phase is negative, application of nitrogen fertiliser would present a high and perhaps unacceptable risk for many central Queensland wheat growers.

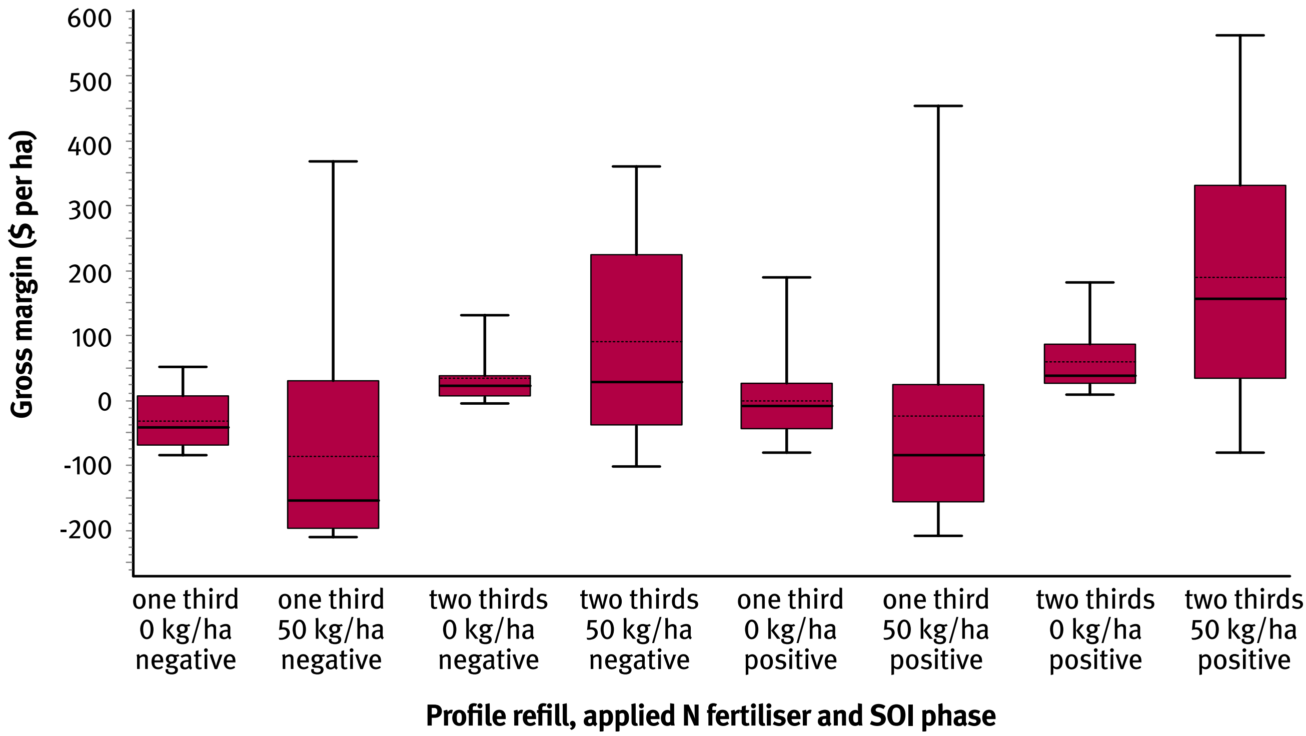


Figure 36. Using SOI phase (negative or positive) to reinforce decisions to apply or not apply nitrogen fertiliser to wheat with either low (1/3 full = 50 mm) or moderate (2/3 full = 100 mm) soil water at planting. Other setup factors as indicated above

However, with a positive SOI phase (over April/May):

- the predicted gross margin range for the 1/3 full profile (50 mm) with nil nitrogen applied at planting indicates very little difference to the negative SOI phase. Low soil water reserves will limit yield in low rainfall reasons and in the better seasons, the low soil nitrogen levels will limit grain yield response.
- With a 1/3 full soil profile, supplying 50 kgN/ha fertiliser (giving a total soil N supply of 75 kgN/ha), creates a wide ranges of possible outcomes that is slightly more profitable than for the negative SOI phase. Crop returns are higher in better seasons but the cost of the 50 kgN/ha of fertiliser reduces the gross margins in poor seasons. The median and average returns are still negative
- Applying 50 kgN/ha when the soil is 2/3 full provides the most favourable range of yields with 75% having a positive gross margin

In summary, nitrogen fertiliser is likely to be more profitable when the SOI is positive, particularly when starting soil water is reasonable. Although financial losses due to N fertiliser can potentially occur in any season, the risk of loss is lower when starting soil water is good and in a positive SOI season. Even higher gross margins would be expected with higher nitrogen fertiliser rates if the soil was fully wet at planting (150 mm) (data not shown), particularly in positive SOI years.

Additional risk analysis options

Using the spreadsheet 'Nitrogen Calculator'

On the accompanying CD is a nitrogen fertiliser rate calculator, the 'Smart N Decision Calculator'.

This automates the fertiliser calculation process described in previous chapters and also has a section that automates the process of analysing the yield and gross margin outcomes if the season turns out differently to the one targeted or anticipated.

The nitrogen fertiliser rate is calculated based on user-entered soil water at planting and targeted (or anticipated) season type. The spreadsheet calculates:

- A target yield
- Crop nitrogen demand.
- Soil nitrogen supply is calculated from soil sample test results.
- The difference between the demand and supply is the recommended nitrogen fertiliser rate.

There is also a 'risk analysis' worksheet. This calculates the yield across ALL seasons with the chosen nitrogen fertiliser rate. This is contrasted with the yield expectation in each season type with the fertiliser rate that would have been MORE APPROPRIATE for that season.

Using a 'set' nitrogen fertiliser rate as indicated by crop nitrogen removal

Experience of the full potential yield range combined with the knowledge that 20 kgN/t of grain is removed by each crop can give a starting point for a nitrogen fertiliser rate. For example, if the 'average' grain yield is 2 t/ha the average nitrogen removal will be 40 kgN/ha per crop. However, using this average value disregards the variability that occurs in soil water and nitrogen at planting due to soil type, seasonal and fallow length effects, and in-crop rainfall, and hence to potential yield ranges. Whilst the value will be 'roughly right' there will be cases of financial losses due to under- and overfertilising that may have been otherwise avoided.

'The 100 N rule'

Measuring the inherent soil nitrogen at planting and 'topping-up' to 100 kgN/ ha will better account for the range of potential yield outcomes.

This has the advantage that, depending on the soil nitrogen level, the nitrogen fertiliser requirement can be adjusted from year-to-year. Disadvantages with this method are that soil nitrogen sampling would be required each year, and the fertiliser rate may be unrealistically high when the soil nitrogen level is low especially if the stored soil water or seasonal expectation is poor.

Note: it may also be beneficial to adjust nitrogen fertiliser rates based on the amount of water in the soil present at planting. This can be done 'intuitively' (low soil water is likely to be lower yielding) or more formally using the *WhopperCropper* program.

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9. Applying nitrogen fertiliser in central Queensland

Key messages

- Calculate the elemental nitrogen rate required (previous chapters).
- Determine the cheapest or most convenient form of nitrogen that can be applied with the available equipment.
- Decide on application timing based on equipment available and work load requirements. The timing of the nitrogen application appears less important than satisfying the nitrogen demand.
- Observe the recommendations of the maximum quantity recommended with the seed or place urea at an appropriate distance from the seed row.

Calculating the cost of elements in nitrogen fertiliser products

Most producers will apply the cheapest source of fertiliser that is in a form suitable for their application equipment. When comparing the cost of fertilisers it is necessary to calculate the cost of the 'element' of interest.

When the tonnage price of the fertiliser is known, the actual cost of the elemental content can be calculated. The calculation is:

Elemental cost ($/kg) = (product cost ($/t) / 1000) / (percentage of element / 100)

e.g. cost of nitrogen in urea where urea cost = $550/t,
percentage nitrogen = 46%
nitrogen cost = (550 / 1000) / (46 / 100)
nitrogen cost = $1.20/kg

Phosphorus cost in MAP, percentage P = 22%
MAP cost = $780/t
P cost = (780 / 1000) / (22/ 100)
P cost = $3.55/kg

Table 20 indicates comparative prices, as at June 2015. Prices of the nitrogen fertilisers are usually linked to oil prices so updated prices should be obtained.

Readers are advised to check current fertiliser prices when making this calculation.

Common forms of nitrogen fertiliser

Urea

Urea is usually the cheapest form of solid nitrogen fertiliser. A bigger application boot is needed, so more soil disturbance can occur during application. However, while there is potential for soil moisture loss, damage to emerging seedlings is potentially less because of the larger quantity of soil into which the urea is mixed. Urea is most commonly applied prior to planting, or during planting if it can be placed away from the seed row. A three-bin cart is needed if applying both urea and starter fertiliser at planting time.

Anhydrous ammonia gas (NH_3)

This is usually the cheapest form of nitrogen fertiliser, and is widely used in irrigation and some dryland areas of south Queensland. The necessary plumbing is relatively cheap and easy to set up but it requires an extra trailing or mounted tank (see photo on the following page).

UAN (Urea ammonium nitrate)

This liquid product is currently more expensive ($/kgN) than urea, although can be competitive at times. It is extensively used in Western Australia and is especially useful for in-crop applications in sandy soils. Some farmers are trialing Queensland. It can be placed relatively close to seed. There is a need for a mounted or trailed liquid tank, the necessary plumbing, and on-farm storage.

Table 20. Approximate comparative nitrogen fertiliser prices as at June 2015

Product	%N	Cost ($/t, bulk)	$/kg N
Urea	46	550	1.20
Anhydrous ammonia	82	950	1.16
Ammonium nitrate	34	Now 'dangerous goods'	
Ammonium sulphate	20.2	480	2.38
Feedlot manure	approx 3		
MAP	10	780	3.55
MAP + Zinc Compound	10.5	800	3.64
DAP #	18	780	4.33

'starter' (P and Zn) fertilisers are not used as sole sources of nitrogen but the nitrogen content can be included in a nitrogen budget

Timing of nitrogen application

In northern Australia, the traditional time to apply nitrogen fertiliser to cereal crops is before planting, usually after soil water has been recharged during a fallow period. Without follow-up rain, nitrogen applied immediately before or during planting may remain trapped in topsoil as it dries. If dry conditions continue, the crop may not access the applied nitrogen until topsoil water has been recharged, but in such situations crop yield and demand for N is usually lower anyway. If soil water recharge occurs late during grain filling the crop may still access applied nitrogen and respond with increased grain protein.

Research shows that although in any one year there may be an advantage due to applying nitrogen fertiliser either during the fallow or at planting time, over a period of time there is likely to be little difference. An adequate N supply to meet crop demand it is more important than the timing of application.

If soil water recharge occurs too late to benefit the fertilised crop, a high proportion of applied nitrogen will be carried over for use by subsequent crops in the rotation. Similarly where nitrogen is applied before planting and a planting rain does not eventuate, significant carryover. In south Queensland the losses from the system were found to be 5 to 25% percent depending on the season (Strong pers. com.).

Nitrogen deficiency in the early stages can affect the number of grains that are formed in the embryonic head. Subsequent nitrogen demand is driven by the rapidly developing biomass prior to flowering. Under favourable early conditions, high nitrogen supply may promote high vegetative biomass which in turn can use large amounts of soil water. Restriction of nitrogen supply can theoretically reduce this early demand but is unlikely to work in practice unless soil nitrogen is very low. In addition, the restriction in potential yield (crop sink) may be a disadvantage if the season becomes favourable.

Pre-plant nitrogen application

Advantages

- More opportunity for nitrogen to move into the profile
- Gets the nitrogen application job out of the way
- Only option for many farmers and planter set-ups.

Disadvantages

- May cause excessive moisture loss during application, which on occasions can jeopardize planting opportunities
- Requires earlier nitrogen fertiliser decision (and soil testing)
- Fertiliser cost is incurred without a guarantee of when you will be able to plant the next crop
- Increased risk of nitrogen losses due to waterlogging in fallow.

Anhydrous fertiliser applicator

A strategy to apply nitrogen well before planting has been commonly used by growers in northern Australia, in an attempt to separate nitrogen application from planting for logistical reasons mentioned above. This method presents growers with the dilemma of deciding to apply nitrogen under the assumption that soil water will be recharged sufficiently after the application to support a rain-fed crop. Where nitrogen is applied early and a planting rain does not eventuate, significant carryover of applied nitrogen to subsequent crops can occur.

Nitrogen applied at planting

Advantages

- Ensures expenditure on nitrogen fertiliser only occurs when a planting opportunity arises
- More time to decide if nitrogen is needed relative to soil water recharge
- More easily done in summer than winter cereals (because of wider rows)
- No loss of moisture or planting opportunity
- Less risk of waterlogging losses.

Disadvantages

- Higher workload at planting time – increased labour needs and lower efficiency of planting operation
- Requires specialised planter setup; a three-bin seed cart if starter fertiliser is also required, otherwise a anhydrous or UAN cart is required
- Risk of nitrogen being stranded in dry soil therefore lower nitrogen availability to the crop (but lower crop demand if it stays dry).

Application of nitrogen in-crop

- Last resort if nitrogen not applied earlier
- Needs to be applied in first 35-40 days (by end of tillering in winter cereals). Follow-up rainfall is needed for benefit to accrue (this makes it a risky practice in Queensland)
- Side-dressing
  - requires row crop equipment, straight rows
  - rainfall soon after application less critical
- Top-dressing

- – Needs rain immediately after application to avoid losses (of urea, ammonium sulphate), and soon after application of other products (ammonium nitrate)
- Foliar application
  - – Only small amounts of nitrogen can be applied otherwise leaf burn may occur
  - – Relies on rain soon after application for best response
  - – Most of the nitrogen uptake occurs via the soil after being washed off the leaves.

In spite of the additional workload, nitrogen application at planting would appear worth pursuing to optimise its efficient use by the crop. The trend towards zero and reduced tillage, which usually extends the planting window, is another reason to delay nitrogen application until planting to avoid topsoil disturbance and soil moisture loss.

Nitrogen fertiliser placement

Placement and timing of nitrogen fertiliser will depend upon the type of available equipment and the need to match the nitrogen demand for the crop.

Pre-plant placement of nitrogen

- Generally band at less than 2 x seed row spacing. Not wider than 1m spacing
- Minimise soil disturbance (and moisture loss)
  - – Coulters/discs ideal
  - – Narrow tyne and point
  - – Only place deep enough to get coverage.

Placement of nitrogen at planting

Preferably nitrogen fertiliser should be placed at least 30 mm away from seed (unless applying very low rates or using wide points).

Maximum nitrogen fertiliser rate with seed.

Winter cereals	9 kgN/ha in 50 cm rows, 18 kgN/ha in 25 cm rows
Sorghum	4.5 kgN/ha in 1 m rows

Placement options include:

Winter cereals – place nitrogen in every second inter-row space. This will enable a substantial N rate (40-75 kg/ha) to be safely applied at sowing and ensures that each row has access to nitrogen. It also minimizes soil moisture loss, stubble handling and machinery setup issues although it does require extra applicators.

Summer cereals – ideally place 50 cm away from row.

How much fertiliser can be placed in the seed row?

The maximum application rate of fertiliser in the seed furrow is primarily influenced by the susceptibility of the crop species to ammonia and salt (osmotic) effects, the chemistry of the fertiliser, soil conditions and application equipment. Hence, the safe nitrogen rate with seed will be lower in dry conditions and using narrow tynes, points or discs on wide row spacings. Conversely, under cool conditions and in very wet soil higher rates with the seed may be possible. The rates in Table 21 would indicate safe application rates in most conditions in south Queensland.

The effects of nitrogen fertiliser on crop germination can be seen in the photo below.

Example: for a narrow point opener for wheat on 36 cm row spacing, the safe urea rate with the seed is approximately 27 kg/ha (Table 21).

Foliar applied nitrogen

Foliar applications are of limited use because of the small amount of nitrogen that can be safely applied. Leaf 'burn' can occur at high rates (see photo below). Urea can be used as a foliar spray. A 30% solution (30 kg in 100 L of water) applied at 110-120 L/ha applies an equivalent of 15 kg N/ha. Repeat every 2-3 weeks as needed. Some leaf burn may be expected, but this generally does not affect subsequent grain yield. If there is no prior experience with foliar application to the crop, it may be wise to conduct a test strip to test its sensitivity.

This can give a short term benefit to the crop for example immediately following waterlogged conditions when there are signs of root growth but cannot be relied on to supply the full crop requirement.

Minimising nitrogen fertiliser costs

Using a strategic process, such as that described in this manual will help to optimise nitrogen fertiliser use and avoid excessive, risky or unnecessary expenditure.

In particular, use of soil tests will more accurately identify when nitrogen fertiliser is necessary and provide a basis for calculating a nitrogen fertiliser rate.

If the required nitrogen rate is excessive and/or the fertiliser cost is prohibitive, consider planting a pulse crop on a proportion of the farm to reduce nitrogen fertiliser costs. The use of legumes in the crop rotation to help manage nitrogen fertility is discussed in the next chapter. In general, pulses would be expected to add 0-30 kgN/ha, and grazed lab lab enough nitrogen, for the next grain crop. Butterfly pea will be of benefit if soil water is replenished prior to the next cereal and the BFP residues have decomposed. Gearing up for bulk fertiliser will further reduce costs.

Evidence of leaf 'burn' from foliar applied nitrogen

Increasing length of fallow to accumulate more nitrate N is discouraged; savings in N fertiliser costs are likely to be offset by the more rapid decline in soil fertility as well as a decrease in cropping opportunities.

Applying spatial information to nutrient management

Two applications of precision agriculture are being explored in northern Australia to enable grain growers to maximise their returns:

- increasing capacity to monitor crop nitrogen requirements; and
- increasing capacity to distinguish areas within the crop of similar or contrasting grain protein for improved segregation of grain during harvest.

Grain yield and grain quality are rarely uniform over large areas of crop in south Queensland. Differences in soil type and soil depth are possible causes of variation in crop outcomes, although other soil and management factors also contribute to variation in crop performance. Production zones could be managed differently so as to optimise nutrient application where:

- similar variation in crop production occurs every cropping season
- components of 'precision agriculture', such as yield monitors and aerial imagery are available to gain knowledge of spatial variation.

Managing fertiliser input by zones would assist growers to produce grain of a target protein that attracts premium market returns. Even higher returns could eventuate if grain within the premium protein window could be identified prior to crop harvest, enabling better segregation of grain during harvest or blending at receipt to maximise the quantity of premium grain delivered.

Evidence of reduced emergence when too much fertiliser was applied close to the seed in oats planted in March and subject to high temperatures that caused rapid soil drying

Photo B Radford

In addition, monitoring nutrient management by zone is important for systems of continuous cropping because of the likelihood that fertiliser requirements may increase with continued cropping. Mapping grain yield and protein content of cereal crops (see Figure 37) should provide a guide to nitrogen requirements of subsequent cereal crops in the rotation.

Application of imagery captured from aerial or satellite platforms should increase grower capability to achieve these goals. At this point in time, protein monitors are not considered sufficiently accurate for widespread use.

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Table 21. Approximate recommended maximum rates of actual nitrogen and urea (kg/ha) when applied in the seed rows in winter and summer cereal crops in Queensland. Rates are for typical heavy clay soils with very good seedbed soil moisture in the Queensland region in wheat, triticale, barley, oats[1], sorghum and maize[1] crops

	Seeder opener type					
	Disc opener#		Narrow point#		Sweep#	
	Safe rates with seed					
Seed/fertiliser row spacing	N (kg/ha)	Urea (kg/ha)	N (kg/ha)	Urea (kg/ha)	N (kg/ha)	Urea (kg/ha)
10” (25 cm)	14	30	18	39	23	50
12” (30 cm)	13	28	15	33	20	43
14” (36 cm)	11	24	12.5	27	17	37
20” (50 cm)	7	15	9	20	12	25
40” (100 cm)	3.5	8	4.5	10	6	13

Note: These rates have been adapted from data supplied by Dr C Dowling and data from R Heller, Alberta Reduced Tillage Linkages Canada (www.reducedtillage.ca) that has been modified in accordance with knowledge and experience of Queensland conditions. In general, these recommendations account for a wet seedbed that may subsequently dry quickly after planting, thus increasing the risk of damage from applied nitrogen.

refers to the ‘relative’ width of disturbed soil into which the fertiliser is placed and is approximated at 25 mm, 50 mm and 75 mm respectively. The actual degree of mixing can vary widely because of variations of soil texture, implement speed, tyne movement etc. Checking dispersion of crop seed in the disturbed soil can give an idea of how closely the fertiliser may be placed with the seed. The greater the mixing, the greater the margin of safety.

[1] there is anecdotal evidence that these crops can tolerate approximately 10% more nitrogen with the seed than the table indicates.

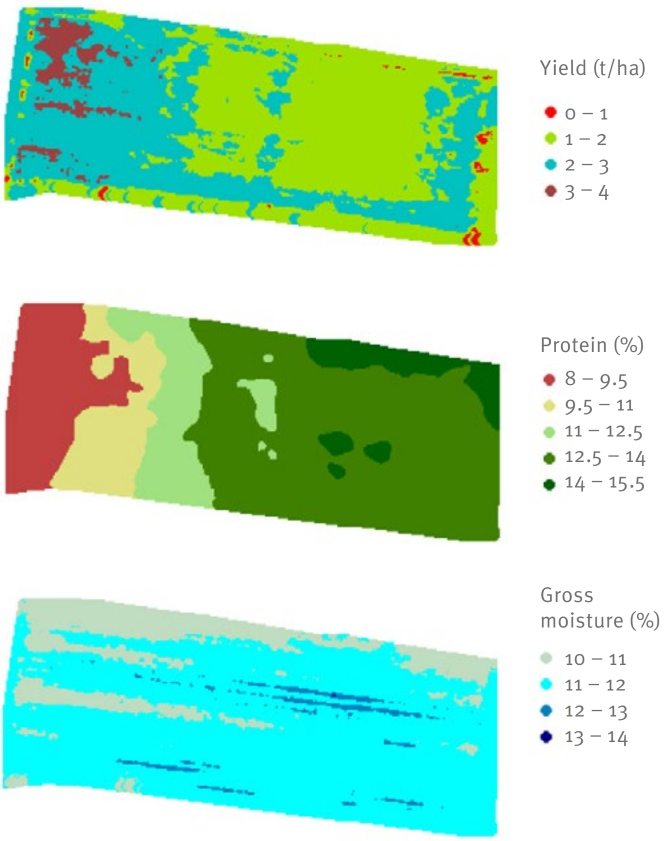

Figure 37. Maps of yield, grain protein and grain moisture for a farm in southern Queensland

10. Nitrogen contribution of ley legumes and pulses

Key messages

- The nitrogen contribution from a legume depends upon the amount of leaf (and root) material returned to the soil, and effective nodulation.
- Nitrogen is removed when grain and hay is removed from the paddock. Grazing animals return much of the nutrients to the soil but may concentrate nutrients in patches and around watering and resting areas.
- A rough rule of thumb for nitrogen fixed by legumes is 2% of biomass ie. 20 kg/tonne of biomass (under conditions of low soil N and effective rhizobia nodulation). The actual contribution to soil nitrogen is closer to 1 to 1.5%.
- Ley pastures can add 0 to 100 kgN/ha largely depending on climatic conditions.
- Pulse crops can add 0 to 30 kgN/ha and contribute most when biomass is high and grain yield is low.
- Lablab is a productive short term ley pasture and can contribute large amounts of N to the soil (40-80 kgN/ha/year).
- Butterfly pea persists for longer than lablab, is productive and can contribute moderate amounts of N (20-60 kgN/ha/ year).
- Soil water depletion by the ley can be a major constraint when returning to cropping after a ley phase.

Introduction

The provision of adequate nutrients to optimise crop performance, either by applying fertilisers or by exploiting inherent soil fertility, is a fundamental requirement of any sustainable cropping system. Central Queensland soils are relatively new (in years of arable production) and fertile by national standards and in the early years of crop production, nutrients were not generally a limiting factor. However, over time, the inevitable nitrogen fertility decline associated with cultivation and nitrogen removal by crops has occurred. An economic response to applied nitrogen fertiliser is now observed on some soil types, in some seasons, and more frequently on open downs soil types (Spackman and Garside, 1995).

A number of factors combine to make the use of ley pasture (including legumes) attractive as a low cost method of restoring soil nitrogen fertility in central Queensland cropping systems, they include:

- the relatively high cost of nitrogen fertiliser
- high variability in seasonal rainfall, making prediction of optimum nitrogen fertiliser application rates difficult
- the fact that the majority of central Queensland grain farms also support a beef cattle enterprise.

However, incorporating pastures into cropping land may be difficult because of:

- infrastructure costs (fences, watering points)
- pasture establishment costs
- pasture establishment difficulties in heavy clay soils
- possible soil compaction if stock are not removed before rain
- weed control issues when re-cropping
- difficulty in re-charging the soil profile prior to re-cropping.

Factors affecting the nitrogen contribution from ley pastures and pulse crops

Ley pasture may consist of grass, legume or a mixture of grass and legume species, which is usually introduced between phases of cropping, to restore soil chemical and physical fertility, primarily by increasing soil carbon and/or nitrogen during the ley period.

A (ley) legume is a plant that grows with symbiotic rhizobia bacteria that incorporates ('fixes') atmospheric nitrogen for use by the plant. When residue from these legumes is returned to the soil, mineralisation occurs that makes extra nitrogen available for subsequent crops. Thus, legume residues may partially replace the nitrogen requirement of subsequent cereal crops.

Nitrogen contribution from decaying legume plants will generally become available to subsequent crops at a faster rate than decaying grass pastures or cereal stubbles. This is because the lower carbon to nitrogen (C:N) ratio of the legume material better matches the C:N ratio of the food for microorganisms. The decay rate is optimised as no nitrogen has to be accessed from the soil. If material with a high C:N ratio (such as cereal stubble or grass residues) is incorporated, nitrogen for cell synthesis in micro-organisms is obtained from the soil, temporarily 'tying-up' nitrogen that would otherwise be available to plants thus reducing availability of nitrogen in soil.

However, combining a grass with a legume species is an important strategy because the grass becomes a reservoir for the nitrogen fixed by the legume growing in combination with the grass. This encourages continued nitrogen fixation by the legume. Thus a greater quantity of nitrogen is ultimately returned to the soil, when legumes are in mixtures with grass. The additional fibrous grass material also contributes positively to soil physical structure and soil carbon level.

Nitrogen contribution from decaying pasture may become available to subsequent crops at a slower rate than a comparable rate of mineral fertiliser. This may better match crop nitrogen requirements as the crop grows. Nitrogen (mainly from decaying roots) may also be placed deeper in the soil. Thus cereal crops will access this nitrogen later in their development when demand for nitrogen is high. If dry matter material does not mineralise rapidly nitrogen may be 'tied-up' in microbial biomass creating a temporary nitrogen deficiency in the cereal crop.

Balance of nitrogen removed and nitrogen retained

The nitrogen contribution of legumes will depend upon the quantity of vegetative biomass produced that remains in the paddock for decomposition. Removal of grain from a legume (pulse) crop is a loss of nitrogen from the paddock. The net nitrogen balance following a pulse crop can vary widely. For example Schwenke et al (1998) measured a range of net nitrogen balance from -47 to + 46 kgN/ha and -12 to 94 kgN/ha following chickpea and faba bean respectively. Nitrogen accrual from pasture systems is generally positive although widely variable. Lloyd et al (2007) cite the range of nitrogen contributions of 15 kgN/ha for grass only pasture on a sandy loam soil up to 95 kgN/ha from lucerne on a heavy clay soil. Losses of nitrogen of 10 and 20 kg/ha in faeces and urine were reported by Steele and Wallis 1988, cited by Doughton and Holford (1997). The nitrogen returned by animals is often accumulated in patches such as shade lines.

Most nitrogen fixed by the legume is transferred from nodules/roots to plant tops; chickpea roots and nodules contained only 6% of the quantity of N contained in plant tops. Therefore, fate of N contained in legume tops is critical to the role legumes play in the N economy of the farming system. Hence, there is likely to be a greater N contribution from a grazed ley legume than from a harvested grain legume, since a very high proportion of pulse N is contained in pulse seed; 66-89% of N fixed by chickpea crops was removed in seed (Doughton and Holford 1997).

Interaction with water

It is a common experience that, deeprooted perennial pasture will deplete soil water stores more than an annual crop. In dry seasons it may take some time for the soil moisture profile to be recharged after a ley pasture phase. Hence, the first crop following a pasture phase may incur a yield penalty because of less available water at planting. In very dry situations, crop planting may need to be delayed a season or more until the profile is recharged. This has occurred following lucerne-based pastures in southern Queensland and following butterfly pea in trials in central Queensland. Removing ley pasture when soil moisture is high or is likely to be recharged may minimise the risk of a yield penalty in the next grain crop.

Potential losses of contributed nitrogen

The nitrogen mineralised from pasture legumes is subject to the same potential losses as that from nitrogen fertiliser. However, the risk of loss can also be lower after a ley phase because of the slow rate of mineralisation of organic to mineral nitrogen.

Ley legumes suited to central Queensland In central Queensland, the dominant ley legumes are:

- Butterfly pea *(Clitoria ternatea)*.
- Lablab *(Lablab purpureus)*

Butterfly pea has shown potential as a ley pasture species to improve the nitrogen and organic carbon content of cropping soils in the region. Butterfly pea is a perennial, summer growing legume well adapted to the climate and clay soils of the central Queensland grazing and cropping zones (Collins and Grundy, 2005). Butterfly pea rotations should allow shallow soils in central Queensland to be more successfully incorporated into the cropping sequence. This will enable soils with moderate subsoil constraints to be more successfully cropped by maintaining soil fertility in the longterm. Water is a major driver of biomass production which in turn determines the extent to which soil fertility is increased.

Butterfly pea is a vigorous, adapted, persistent, perennial, summer growing legume, which grows best on fertile soils with high water-holding capacity. It is easy to establish. It is very palatable and highly digestible with higher leaf nitrogen and lower digestible fibre then most other tropical legumes. It is non toxic, does not cause bloat, is capable of producing excellent animal weight gains and will tolerate periodic heavy grazing.

It can be a prolific seed producer (seed harvest of 500-900 kg/ha) and given appropriate management and good seasons, seedling establishment will be very high. When planted into deep fertile soils and given good grazing management, stands will last five to seven years or longer. Stand life will be shortened to one to five years in shallow soils, if there are significant subsoil chemical constraints (salinity or sodicity) or with heavy continuous grazing. Butterfly pea rotations are well suited to shallow soils of central Queensland or where moderate subsoil constraints are present enabling these soils to be more successfully cropped over the long-term. Water availability, being the major driver of biomass production, will determine the extent to which soil fertility will be increased after butterfly pea.

Butterfly pea has a role in providing low risk income from grazing and the capacity to improve soil fertility without the application of costly nitrogen applications. As fertility improves the opportunity for cropping without fertiliser input becomes possible. Butterfly pea pastures can be used to either rebuild fertility where fertility has run down and nitrogen has become deficient or to maintain soil fertility in fertile soils to take advantage of good seasons to ensure optimum water use and maximise crop yield when prices for grain are high and cattle prices low

A trial at Baralaba in 1998 showed an increased nitrogen supply after butterfly pea equivalent to 30 kg/ha of nitrogen applied to a subsequent wheat crop (Braunack et al 2008).

Comprehensive establishment and management information can be found in:

The Butterfly pea book (Ed. R. Collins & T. Grundy), Department of Primary Industries and Fisheries QLD. This is available through Department of Primary Industries and Fisheries Queensland offices.

Lablab is a highly productive forage legume that has been used to restore fertility of CQ cropping soils. In most districts of CQ lablab behaves as an annual plant but occasionally as a bi-annual plant; replanting every one or two years is a costly downside to its use.

Lablab is the most productive of the forage legumes grown in central Queensland and performs best when planted early (mid- December). Two cultivars, Highworth and Rongai are annuals, which persist for 8 to 18 months, whereas cv. Endurance is less productive but may persist for longer, 1 – 3 years. Highworth is the most popular cultivar planted for grazing purposes.

Lablab is palatable although animals may take a few days to acquire a taste. It has a very large seed (4000-6000 seeds/kg) and is easy to establish. Best grazing practice will allow leaves to be grazed but have animals removed before the major stems are grazed. Lablab can produce excellent animal weights gains and restore soil fertility.

In a trial at in south-west Queensland, the following soil nitrogen contribution was measured and compared to Butterfly pea (Table 22).

Table 22. Nitrogen contribution to the top 1.5 m soil December 1998 to November 2000

	Lablab (Endurance)	Butterfly pea
Nitrate N increase (kg/ha	116	32

Source: Whitbread pers. com

A trial in 1999/2000 at Fernlees showed that sorghum grain yield post-lablab was equivalent to that for continuous cereal fertilised with 35 kg of nitrogen fertiliser (Braunack et al 2008).

Ley legumes less suited to central Queensland

Legumes that have been largely unsuccessful as ley legumes in central Queensland include:

1. **Lucerne** *(Medicago sativa)*. Lucerne has been planted in many areas of central Queensland but will only persist and remain productive on soils with good internal drainage. It is generally limited to a small area of alluvial soil. Most soils in central Queensland lack good internal drainage which can cause temporary water logging following rainfall, and subsequent death of lucerne plants. On soils with poor drainage, diseases induced by the summer-dominant rainfall result in rapid decline of lucerne stands, which have a life ranging from a few weeks to less than two years.

2. **Burgundy bean** *(Macroptilium bracteatum)*. Burgundy bean can establish well and be productive on clay soils in central Queensland. The potential of current commercial cultivars was first recognised on a open 77 downs soil at *Fernlees* near Emerald. Experienced cattlemen managing a grazing trial at Moura said that while animal productivity was high, burgundy bean was so palatable that it would be difficult to manage in a commercial pasture. Bungundy bean must be periodically spelled to allow the plant to regrow, and careful grazing management is necessary to ensure sufficient seed set to ensure stand survival. When grazing is controlled, stands will last for 1-3 years. Although new seed has a high level of 'hard' seed, this breaks down rapidly in the soil. Germination rain in spring or summer without follow up rain can quickly exhaust the majority of soil seed reserves. Burgundy bean is regarded as an 'erect siratro' and has many similar characteristics.
3. **Medics** Productive medic pastures are possible when high seed numbers are present (more than 100 seeds/m2), grass competition is low, and when good autumn/winter rainfall occurs. To develop high soil seed reserves it is necessary to have sufficient medic plants growing and winter/spring rainfall to allow seed set in previous seasons. Creating bare ground or low grass cover going into autumn when tropical grass growth is at its lowest is a risky practice and should only be practiced on a small area of the farm. Getting all this to come together with sufficient autumn/winter rainfall is achievable occasionally in the southern Dawson Valley and much less frequently in northern parts of the region.
4. **Siratro** *(Macroptilium atropurpureum cv Siratro)* has been planted extensively across Queensland on a range of soils and is frequently seen growing along roadsides but has failed to persist in the adjacent grazed paddock. Siratro is very palatable and flowers and sets seed, most of which is soft seeded at the end of long runners and which is not conducive to high seed yields under grazing. Siratro is a short lived perennial, grows on a range of soils but grows best on fertile alluvials, It will only persist when grazing is lenient and rotational so as to allow seed set. The cultivar Aztec is rust-resistant. It is suited as a component of permanent pastures rather than short-term leys.
5. **Desmanthus** *(Desmanthus virgatus)* will establish if good weed control is practiced during establishment but is persistent and drought hardy once seedlings are sufficiently large. This legume will establish on a wide range of soil including clays, and is more persistent but less productive than butterfly pea in central Queensland. Ensure grass is established early in the pasture mix or that the desmanthus is established in strips with grass. A pure desmanthus pasture will frequently provide poor surface cover and may make grass establishment difficult in drier years.
6. **Caatinga stylo** *(Stylosanthus seabrana)* Suited as a component of permanent pastures rather than short-term leys. Caatinga stylo will grow on clay and clay-loam soils in brigalow country. It is adapted to a wide range of soil types, including loams and sandy-earths, but not sands. It prefers fertile soils, and is suited to areas receiving 500-800 mm rainfall. It is adapted to colder areas where it has better frost survival, seedling regeneration and production capabilities than other stylos. Caatinga stylo has a highly specific inoculum requirement, nodulating only poorly with native strains of rhizobia. Poor nodulation may not be evident initially on fertile soils, as the legume utilises nitrogen mineralised during land preparation.
7. **Cowpeas** *(Vigna sp.)* Cowpea was used more extensively in the past as a quick growing annual forage but is now used infrequently as a pasture forage in central Queensland. Cowpea is adapted to a wide range of soils from sands to heavy, well-drained clays, with a preference for lighter soils. It is very susceptible to frost. Cowpea is very palatable and only in wet seasons and with good grazing management will more than one grazing be possible. Cowpea is susceptible to a wide range of diseases and pests.

Pulse (legume) crops

The major pulse crops grown in central Queensland are; chickpea *(Cicer arietinum)* and mungbean *(Vigna radiata)*. Pulse crops may contribute to available nitrogen and also provide a break in the rotation to reduce diseases of cereal crops. Pulse grains are also profitable in their own right when prices are favourable. Chickpea in particular is very suited to deep sowing because of its ability to emerge from deep in the soil. A disadvantage of pulses is low stubble cover remaining after harvest.

Nitrogen contribution from pulse crops

Trials from Queensland and northern NSW have quantified the nitrogen contribution of pulse crops. The trials results will reflect the growing conditions of that year and hence the proportion of vegetative and grain material returned or removed as a result of climatic conditions and the effectiveness of weed and disease control. Measuring the nitrogen contribution directly is difficult and subject to errors. The option used in Table 23 is the expression as 'fertiliser equivalent' and subsequent cereal yield increase.

Table 23. Nitrogen contributions from grain legumes in Queensland and NSW, expressed in terms of nitrogen fertiliser equivalents (kgN/ha) or increased cereal yield (per cent)

Legume	Control crop	N benefit in fertiliser equivalent (kgN/ha) #	Yield increase in subsequent cereal (per cent)
Marcellos (1984) [1]			
Chickpea	wheat	50+	103
Faba bean	wheat	50+	87
Strong et al **(1986)** [1]			
Chickpea	wheat	50+	24
Faba bean	wheat	50+	17
Field pea	wheat	50+	31
Dalal (1991) [1]			
Chickpea 1987	wheat	75	50
Chickpea 1988	wheat	75+	39
Chickpea 1989	wheat	75+	61
Holford (1993) [1]			
Chickpea	wheat	35	77
Doughton, Vallis and Saffigna (unpub) [1]			
Chickpea	sorghum	100	53
Doughton and Mackenzie (1984) [1]			
Mungbean (black)	sorghum	68	79
Mungbean (green)	sorghum	68	61
Cox et al **(1998)** [2]			
Chickpea 1996	wheat	0	0
Chickpea 1997	wheat	20	7
Chickpea 1998	wheat	35	23

From: [1] Doughton J and Holford I (1997). [2] Cox et al (1998).
where a + is present, N benefit exceeded that of the highest rate of nitrogen fertiliser used.

Livestock production from pasture legumes

Field trials have given comparisons of growth between pasture species. It must be remembered that such trials are a small 'snap-shot' of the full range of potential production outcomes. Simulation models are currently under development that will give an indication of the longerterm magnitude and variability of pasture species.

In a trial at Gayndah, steers were grazed during 1998 to 2001 on several pasture types that included lablab and butterfly pea (Whitbread and Clem 2004). Lablab produced the highest liveweight gains (LWG) over the four seasons (up to 0.86 kg/head/day). Total LWG was approximately 125 kg/ha/year for lablab and 115 kg/ha/ year for butterfly pea. An additional trial comparing grass only and grass + butterfly pea pastures provided a LWG of 0.4 to 0.7 kg/steer/day with a trend for more production from the grass+butterfly pea mix compared to the grass-only pasture.

At a trial near Moura, steers grazing only butterfly pea only, had a weight gain of 1.02 kg/hd/day while those grazing butterfly pea-grass pasture gained 0.90 kg/hd/day during the first 71 days (Conway 2007). The lowest weight gains (0.55 kg/hd/day) were recorded from steers grazing grass-only pasture (Table 24). The trend was repeated across the other grazing periods although the periods were shorter.

Table 24. Average daily gain (ADG) of steers grazing pastures at Moura central Queensland: December 1999 until May 2000

	18/12/1999 to 17/2/2000 71 days	18/12/1999 to 06/3/2000 89 days	6/3/2000 to 22/5/2000 77 days
	ADG (kg/d)	ADG (kg/d)	ADG (kg/d)
Butterfly pea	1.020 a	0.926 a	0.706 ab
Butterfly pea + grass	0.904 b	0.831 b	0.639 bc
Grass only	0.549 c	0.544 c	0.486 c

Numbers followed by the same letter are not statistically significantly different.

Source: Conway (2007)

Case study

1. Re-cropping after butterfly pea – Baralaba

In 1998, a trial was established near Baralaba (100 km north west of Biloela) in a paddock that had been used for grain production (mainly wheat and sorghum) since the 1950s. Butterfly pea cv. Milgarra treatments were planted at 7 kg/ha on 10 February 1998. Butterfly pea + grass treatments included a mixture of Finecut Rhodes grass, Queensland bluegrass and Bisset bluegrass. Butterfly pea and butterfly pea + grass pastures were removed on Jan 2001, Feb 2002 and Mar 2003 to create 3 periods of pasture (3, 4 or 5 years) prior to planting wheat. Wheat was sown on 2 July 2002, 6 May 2003 and 30 May 2005 in a rotation of unfertilised continuous wheat (CW), or after 3, 4 or 5 years of butterfly pea or butterfly pea + grass pastures. Drought prevented wheat from being sown in 2001 and 2004. Grain yield, grain protein concentration, soil nitrate nitrogen and plant available soil water (PAW) at planting, were measured for each wheat crop.

Results

The quantity of nitrogen available to wheat crops planted after three, four or five years of butterfly pea at Baralaba was significantly ($P<0.05\%$) higher only at wheat planting in 2005 (Table 25).

For the 2005 wheat crop, soil nitratenitrogen was generally higher in rotations containing butterfly pea for the longest duration and higher in the butterfly pea alone than the butterfly pea + grass treatment.

Significantly higher PAW at planting for continuous cereal than in post-butterfly pea treatments was presumably the reason for increased wheat yields in 2002 and 2003. High grain protein levels after butterfly pea in 2002 and 2003 (13.3-16.2% protein) are also indicative of a lower water supply following removal of the pasture than for the continuous cereal (9.7-12.9% protein).

Wheat yield was never higher after butterfly pea than in the continuous cereal treatment - in fact in 2002 wheat yields were decreased after butterfly pea in comparison with continuous wheat (Table 26).

Increased nitrogen supply after a butterfly pea pasture will be detected in following cereal crops only if PAW is sufficiently recharged after the pasture to allow the cereal crop the opportunity to fully access nitrogen supplies in comparable rotations. After a period of long fallow PAW was adequately recharged after the butterfly pea for the 2005 wheat crop, but high levels of plant-available nitrogen in all treatments resulted in similar wheat yields in the continuous wheat as for the postbutterfly treatments.

Table 25. Plant available water (mm) and N (kg/ha) at wheat planting following butterfly pea leys of 3, 4 or 5 years duration, with or without grass and continuous wheat (CW) at Baralaba, central Queensland. Numbers followed by the same letter are not significantly different. Baralaba trial, butterfly pea and butterfly pea + grass pastures

Prior pasture/crop treatment	Plant available water (mm)			Plant available nitrogen (kg/ha)		
	2002	2003	2005	2002	2003	2005
Continuous wheat nil N	144a	133ab	123	81	58	121cd
Butterfly pea 3 years	75bc	93cd	90	109	121	147bc
Butterfly pea+grass 3 years	80b	80d	99	60	75	129bc
Butterfly pea 4 years	52c	106c	95	57	108	168abc
Butterfly pea+grass 4 years	60bc	85d	91	40	58	115d
Butterfly pea 5 years	NA	82d	104	NA	71	206a
Butterfly pea+grass 5years	NA	84d	98	NA	50	123cd
lsd (P<0.05)	25	18	25	65	66	50

Table 26. Wheat yield (t/ha) and protein (%) following butterfly pea leys of 3, 4 or 5 years duration, with or without grass or continuous wheat (CW) at Baralaba, central Queensland. Numbers followed by the same letter are not significantly different. Baralaba trial, butterfly pea and butterfly pea + grass pastures

Prior pasture/crop treatment	Wheat yield (t/ha)			Wheat protein (%)		
	2002	2003	2005	2002	2003	2005
Continuous wheat nil N	291a	2.06	3.7	12.9d	9.7d	10.6b
Butterfly pea 3 years	1.65bc	1.71	3.22	15.4b	14.9a	11.5a
Butterfly pea+grass 3 years	1.70b	2.00	3.55	15.0b	13.9a	11.7a
Butterfly pea 4 years	1.37c	1.42	3.35	16.2a	15.0a	11.5a
Butterfly pea+grass 4 years	1.39c	1.96	3.60	13.6cd	13.5ab	11.8a
Butterfly pea 5 years	NA	BD	3.30	NA	BD	11.6a
Butterfly pea+grass 5years	NA	1.82	3.46	NA	13.3ab	11.7a
lsd (P<0.05)	0.3	0.49	0.89	0.8	2.2	0.5

Numbers followed by the same letter are not statistically significantly different.

Re-cropping after lablab – Fernlees south of Emerald

On a shallow and relatively infertile soil at Fernlees, lablab grown prior to sorghum increased the sorghum yield (1999-2000) over that of a continuous cereal rotation (Table 27). Nitrogen fertiliser was applied at 3 levels, 0, 35 and 70 kg/ha to sorghum on both rotations; sorghum grain yield was increased by nitrogen application on the legume rotations when the lodging was taken into account.

Unfertilised grain yield post-lablab was equivalent to that for continuous cereal fertilised with 35 kg N/ha; post-lablab sorghum fertilised with 35 kg/ha was equivalent to that for continuous cereal fertilised with 70 kg N/ha. Thus, this single-crop bio-assay suggested that lablab contributed at least 35 kg N/ha to plant-available nitrogen supply. Increased nitrogen supply in the lablab rotation was gained at little extra cost, as there was no yield loss in the re-cropped cereal as was apparent in the post-butterfly pea pastures at Baralaba.

Table 27. Effect of previous crop of lablab on sorghum grain yield in 1999/2000 season at Fernlees

	Grain yield (t/ha) previous crop	
N rate applied to sorghum (kg/ha)	Cereal	Lablab
0	1.9	2.2a
35	2.3	2.9b
70	2.8	3.3b
lsd (Pairwise P<0.1)	2.18 (n.s.) #	0.61 (P=0.065) #

Note: Both treatments incurred increased lodging with increased nitrogen rate; up to 36% in the cereal treatment and 59% in the legume treatment with 70 kgN/ha. The yields above are adjusted for lodging. The large variability in lodging resulted in the large lsd's.
Numbers followed by the same letter are not significantly different.

2. Re-cropping after pulse crops – Callide Valley

Nitrogen contribution

A trial conducted using three different crop rotations that included chickpea and mungbean, over 3 years near Biloela demonstrated benefit of pulses to plantavailable nitrogen supplies for subsequent cereals (Cox *et al* 1998).

The nitrogen benefit of the pulse crop to subsequent cereal was estimated from the difference in total soil mineral nitrogen after a fallow period following cereal and pulse crops. Except for chickpea in 1995, pulse crops were double-cropped from previous cereal crops. Nitrogen contribution after the pulse crop was largest when dry-matter production was high and grain yield low, i.e. low harvest index (Table 28).

The mean nitrogen contribution postpulse was 35 kgN/ha from chickpea and 34 kgN/ha from mungbean. Armstrong et al. (1999a) reported an average nitrogen contribution one year after four mungbean crops in central Queensland of approximately 30 kg N/ha as soil mineral nitrogen.

The nitrogen contribution, biomass and grain production is shown in Table 28.

Table 28. Dry matter production, grain yield and apparent nitrogen contribution of chickpeas and mungbean at Jambin, central Queensland. Cox et al (1998)

	Chickpea 1995	1996	1997	Mean
Dry matter (kg/ha)	5464	1978	2017	3153
Grain yield (kg/ha)	890	1170	2380	1480
Harvest index[1]	0.14	0.37	0.54	0.32
Apparent N contrib.[2] (kg/ha)	51	16	37	35
	Mungbean 1995/96	1996/97	1997/98	Mean
Dry matter (kg/ha)	5904	N/A	N/A	5904
Grain yield (kg/ha)	1280	880	N/A	1.08
Harvest index[1]	0.18	N/A	N/A	0.18
Apparent N contrib.[2] (kg/ha)	42	25	N/A	34

[1] Ratio of grain to total above ground biomass (DM+grain yield).
[2] Difference in soil mineral N following cereal and p ulse crops grown during the same season.

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Glossary of terms

Autotrophs	Organisms that depend on either light or on oxidation of inorganic or elemental substances for energy and CO_2 as the sole source of carbon
Ammonification	The biochemical process of the conversion of organic compounds to ammonia compounds
Denitrification	The biochemical reduction of nitrate and nitrite to gaseous nitrogen; N_2O and N_2
Heterotrophs	Organisms that require an organic source of carbon for energy and growth
Immobilisation	Conversion of an element from an inorganic form to an organic form, thus rendering the element less available
Mineralisation	Conversion of an element from an organic form to an inorganic form, thus rendering the element more available for plant uptake
N fixation	The biological conversion of elemental nitrogen (N_2) to organic forms readily usable in the biological process
Nitrification	The biochemical oxidation of ammonium to nitrate predominantly by autotrophic bacteria
Symbiotic	two dissimilar organisms living in association for mutual benefit
Rhizobium	Bacteria living symbiotically with plants, usually in root nodules of legumes. They receive energy from the plant whilst converting atmospheric nitrogen to organic forms
15N	A naturally occurring isotope of nitrogen
Rhizosphere	The soil surrounding the root of a plant in which the abundance and composition of microbial population is influenced by the roots

More information

For more information or to get a copy of the *WhopperCopper* software tool, contact the Department of Agriculture and Fisheries on 13 25 23 or visit **www.daf.qld.gov.au**