

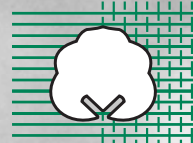
australian cotton cooperative research centre

NUTRIpak

a practical guide to cotton nutrition



Cotton



CRC

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DISCLAIMER

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INTRODUCING NUTRIpak

NUTRIpak is a manual of cotton nutrition, designed to inform cotton growers and consultants of the importance of providing their crops with a sufficient supply of nutrients and improving their fertilizer management. It has been designed to assist growers and advisors to identify nutritional problems through soil and plant tissue testing. It provides guidelines to the critical levels of nutrients in soil and plant material, which indicate nutrient deficiencies or excesses.

NUTRIpak is a compilation of research material relating to the nutrition of cotton in Australia, gathered over the past 20 years. As further information becomes available, it will be provided to registered users of NUTRIpak in the form of Research Reviews and other publications from the Australian Cotton Cooperative Research Centre's Technology Resource Centre. NUTRIpak is complementary to SOILpak for cotton growers and MACHINEpak. Issues that are covered in greater detail by these publications are noted within NUTRIpak.

Growers and industry advisors are encouraged to register with the Australian Cotton CRC to ensure they receive updates and other information packages.

The aim of this manual is to:

- explain the role of each nutrient in cotton nutrition
- examine the nutrient requirements of the cotton crop
- provide an understanding of the processes that affect nutrient availability in the soil and uptake by the plant
- indicate the amounts of each nutrient removed in seed cotton
- describe soil and plant testing procedures that can identify where nutritional deficiencies or imbalances may occur
- provide a means of interpreting the chemical analyses of soil and plant material by indicating the critical levels for each nutrient
- suggest remedial action to alleviate nutritional disorders with appropriate fertilizers. Options for fertilizer management (timing, placement, rates) are given.

It is important for growers to realise that most of the nutrients taken up by cotton from the soil are derived from the decomposition of previous crop residues, soil microorganisms and soil organic matter. Nutrients are continually

being cycled between the crop and soil, as occurs in all biological systems. However, because of the high rates of nutrient removal in seed cotton (Table 1-1), our inherently fertile cotton-growing soils are increasingly becoming depleted in nutrients.

The removal of nutrients depletes soil fertility and fertilizer application may be needed to increase the supply of these nutrients to subsequent cotton crops.

Hence, we can either replace these nutrients as they are removed or wait until each nutrient successively becomes limiting to cotton production, then commence a fertilizer program to overcome the nutrient deficiency. Therefore, it is important to assess nutrient status of the soil from time to time or monitor nutrient levels in the crop. Often, nutrient deficiencies are not identified until symptoms appear, by which time, some yield reduction will occur despite remedial fertilizer application.

Inappropriate or excessive use of fertilizers can affect profitability and the environment through increased fertilizer costs, contamination of groundwater, excessive vegetative growth of crops and related insect, disease and harvest problems.

Nutrient (kg/ha)	Lint yield (bales/ha)				
	6	7	8	9	10
N	43	54	68	87	116
P	15	17	20	23	26
K	25	30	34	40	47
Mg	9	10	12	14	16
S	4	5	6	8	10
Ca	3	4	4	5	6
(g/ha)					
Fe	150	180	220	270	330
Zn	110	120	130	140	150
B	29	33	37	41	45
Mn	28	32	36	40	44
Cu	16	18	20	22	24

Table 1-1. Nutrients removed in seed cotton in experiments at Narrabri. Yield ranged from 5.5 to 10.4 bales/ha.

USE OF FERTILIZERS IN THE AUSTRALIAN COTTON INDUSTRY

The main fertilizers used in cotton production are:

Nitrogen (N), phosphorus (P), potassium (K) and zinc (Zn). The cost of fertilizer to the cotton industry is substantial as high application rates are often used. However, fertilizers may constitute only a small proportion of the costs incurred in producing cotton (Table 1-2).

A survey of 50 growers in the Macquarie Valley (Holden, 1994) indicated the general use of fertilizers and application rates within the cotton industry at that time. The data from that survey showed;

- N application rates for the first, second and third cotton crops following a rotation crop were 123, 158 and 176 kg N/ha
- 60% of the growers used P fertilizer at an average of 16 kg P/ha as mono-ammonium phosphate (MAP) or di-ammonium phosphate (DAP)
- Only 6% of growers applied zinc, which was normally applied with the P fertilizer

This is indicative of the high inherent fertility of these soils. With increased cropping intensity, nutrients progressively become deficient and fertilizer application is required to maintain productivity. Growers in warmer districts and longer seasons normally use higher N fertilizer rates.

SOILS USED FOR COTTON PRODUCTION IN AUSTRALIA

The soils on which cotton is grown in Australia are inherently fertile. They are dominated by cracking clays (Vertosols) which are naturally fertile, alkaline, with a high clay content and, initially, where the soil supported brigalow/belar associations, high organic matter content. These soils were formed from fertile alluvium and wind blown dust under conditions of relatively low rainfall. Hence, nutrients are not leached as in soils formed in more tropical areas.

Other soil types on which cotton is grown include red-brown earths (in the Macquarie, Namoi and Gwydir valleys) and in many of the Queensland districts Solodic and Solodised-Solonetz form a part of the soil spectrum (See Chapter E1 Australian Cotton Soil in SOILpak).

These soils supported natural vegetation of woodland and grassland. Prior to cotton cropping, the previous land use was grazing and dryland wheat cropping.

RESEARCH RELATED TO SOILS AND THE NUTRITION OF COTTON IN AUSTRALIA

Soils and cotton nutrition research has been sponsored by CRDC for many years and continues to do so as part of an on-going program to ensure the Australian cotton industry remains viable and retains or improves the physical and chemical fertility of the soils on which it is based.

Table 1-2.
Estimated use and cost of chemical fertilizers in the Australian cotton industry in 1999.

Nutrient	Approximate amount of nutrient applied to cotton	Approximate cost to cotton growers	Percentage of growers using fertilizers (estimated)
N	56,000 t	\$50M	100
P	4,000 t	\$8M	50
K	2,500 t	\$4.5M	10
Zn	500 t	\$0.5M	30
Other	250 t	\$0.3M	20

BASIC COTTON NUTRITION

ORGANIC MATTER AND NUTRIENT CYCLING

Organic matter provides energy to sustain the microbial activity that enables the biological cycling of nutrients between mineral and organic forms. It is also a source of plant nutrients, a site for ion exchange, a chelating agent for metal ions and confers structural integrity to the soil (see SOILpak - chapter E5).

The largest pool of most nutrients is the soil organic matter. Biological activity results in the release of nutrients (mineralisation), which are available for uptake by a crop. The crop and soil microorganisms themselves require nutrients, and convert some mineral nutrients back into organic forms (immobilisation).

The soil organic matter comprises a variety of living organisms (eg plant roots, animals, bacteria, fungi etc) and dead or decaying material (eg crop stubble, humus) from which mineral nutrients are released. Humus is composed of organic material derived from plant and animal cells. It is the end point of microbial activity and is stable and relatively resistant to further biological decomposition. Because the mineralisation process is biological, it is affected by temperature and water conditions – low temperatures and dry soil slow the mineralisation and immobilisation processes. These processes operate concurrently, cycling nutrients between the organic and mineral pools.

ORGANIC MATTER CHELATES NUTRIENTS

Chelates are complexes of organic matter and metal ions (such as zinc, iron, manganese and copper). Chelates can help maintain the supply of these nutrients in a form available to plants. If unchelated, these ions would quickly precipitate out of the soil solution to form insoluble minerals that are not available for crop uptake.



RETENTION OF NUTRIENTS IN SOIL

Clay minerals and organic matter have both positive and negative charges on their surfaces, enabling them to attract and retain both positive ions (cations or metallic ions) and negative ions (anions or non-metallic ions). Humus retains mineral nutrient ions to its charged surfaces in similar fashion to clay particles. It contributes to the cation exchange capacity (CEC) of a soil, although clay will contribute substantially more to the total CEC of the soil. Soils normally contain more negative than positive charges. Anions and cations with more than one charge (+ or -) are retained more strongly by the soil.

CATION EXCHANGE

Cation exchange capacity (CEC) is the ability of soil constituents to attract and retain cations – H^+ , Al^{3+} , K^+ , Na^+ , Ca^{2+} and Mg^{2+} . Soils having high clay and organic matter contents will possess higher CEC than sandy soils of low organic matter content.

ANION EXCHANGE

Anion exchange also takes place on the clay minerals and organic matter (as with CEC) but anions are attracted and retained to the positively charged sites. Anions include nitrate (NO_3^-), chloride (Cl^-), phosphate (PO_4^{3-}) and sulfate (SO_4^{2-}). Anions with single charge (eg nitrate, sulfate and chloride) are more prone to leaching down the soil profile, whereas anions with multiple charges (eg phosphate - PO_4^{3-}) strongly resist leaching.

BASE SATURATION

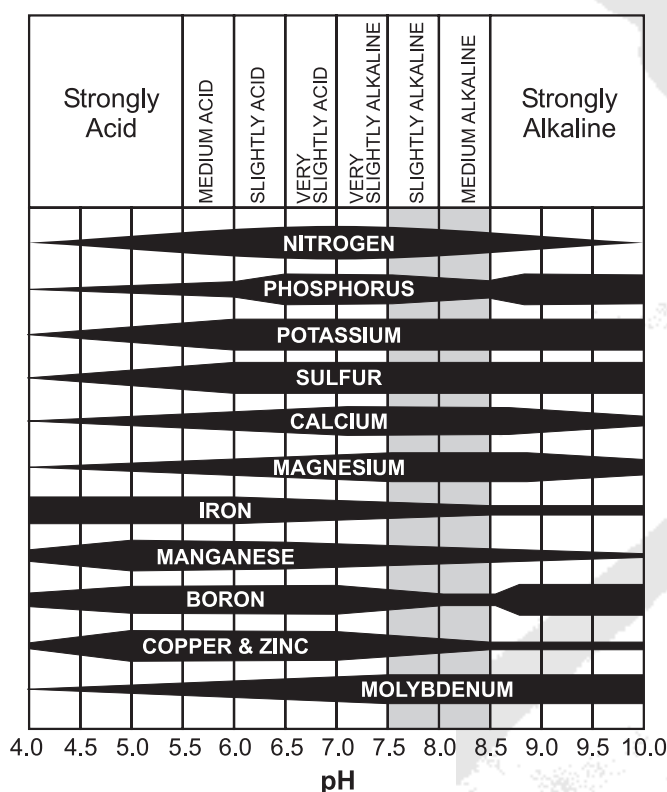
Base saturation is defined as the total CEC occupied by the cations K^+ , Na^+ , Ca^{2+} and Mg^{2+} . The base saturation reflects the extent of weathering and leaching that has occurred in the soil. Base saturation is related to soil pH and is an indicator of soil fertility. The availability of the nutrient cations K^+ , Na^+ , Ca^{2+} , Mg^{2+} to the crop increased with higher base saturation.

SOIL PH

Soil pH governs the equilibrium of chemical reactions in the soil. The availability of nutrients to the plant is also affected by soil pH (Figure 2-1).

Most Australian cotton is grown on cracking clays with a pH of 7.5- 8.5 - under these conditions, the availability of some micronutrients may be low. However, the application of banded fertilizers affects the soil pH in the fertilizer zone, and can temporarily alter micronutrient availability. For example, after the application of anhydrous ammonia, the pH may rise above 9. As ammonia is nitrified to nitrate, the pH in the band may fall to neutral (pH 7). This change in soil pH following the application of nitrogenous fertilizer may improve the availability of some micronutrients.

Figure 2-1.
Soil pH influences the availability of most nutrients. The width of the bar indicates the relative availability of each nutrient as affected by soil pH (after Truog).



NUTRIENT SUPPLY TO THE CROP

For nutrients to be absorbed by plant roots from the soil solution, they must come in contact with the plant root surface either by:

- **Root interception:** As roots grow through the soil, they intercept and absorb the nutrient ions they encounter.
- **Mass Flow:** Water moves through the soil to the plant roots as the plant transpires. The nutrients dissolved in the soil water are carried to the root surface as a result of the mass flow of water to the plant root. Nutrients that are abundant in the soil solution (eg Ca^{2+} and Mg^{2+}) may be carried to the root by mass flow in sufficient quantities to satisfy the crop's requirement. In contrast, the P concentration in the soil solution is very low, so mass flow contributes a minimal amount of the P required by the crop.

- **Diffusion:** As a plant root absorbs nutrients from the surrounding soil solution, a diffusion or concentration gradient is set up. Nutrients diffuse from areas of high concentration within the soil, to the area of low concentration, near the root.

THE RHIZOSPHERE

The rhizosphere is the zone of soil surrounding the root where soil microorganisms flourish in great abundance, relative to the rest of the soil. Microorganisms proliferate here due to exudation of nutrients, sugars and other materials from the root. The rhizosphere is a zone of intense biological activity and cycling of nutrients.

MYCORRHIZAE (VAM)

Mycorrhizae (vesicular arbuscular mycorrhizae) are soil fungi that form symbiotic relationships with roots of the cotton plant. The fungi improve the supply of nutrients to the plant, which supplies carbohydrate to the fungi. The VAM form networks of fungal hyphae that grow out from the root to distances of 2 cm. This network of greatly assists the crop to take up nutrients because of the greatly increase the volume of soil explored. The uptake of P and Zn is delayed in crops poorly infected by VAM.

Long fallow disorder of cotton is associated with poor mycorrhizal colonisation, since long periods of bare, weed-free fallows or growth of non-mycorrhizal crops reduce the amount of VAM in the soil. The decline in VAM fungi has serious implications for rain grown cotton production, where it is important to fallow fields to store moisture. Inoculation with VAM is not successful. The best means of keeping VAM active in the soil is to keep crops growing in a rotation system with short fallows.

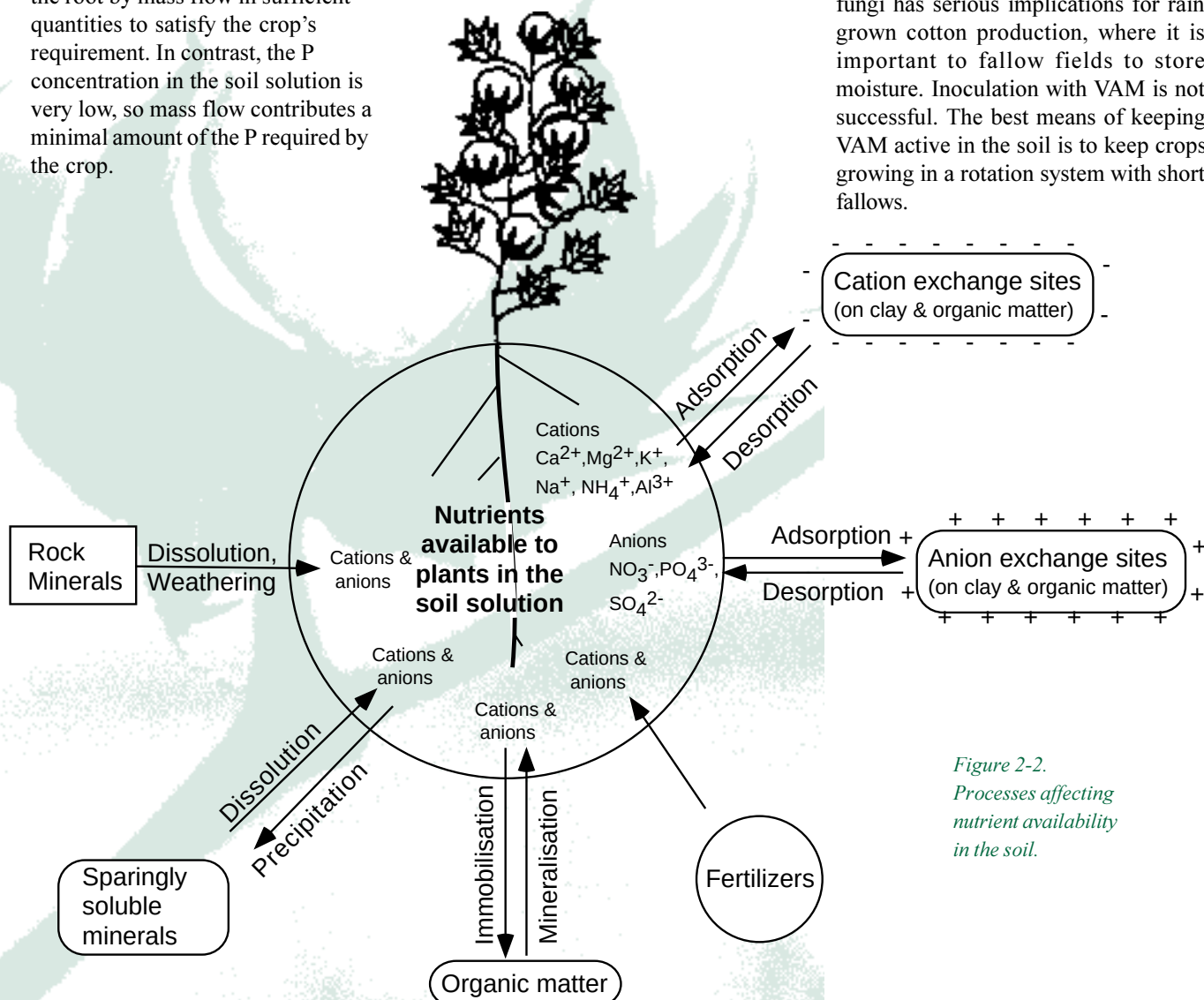


Figure 2-2.
Processes affecting
nutrient availability
in the soil.

NUTRIENT UPTAKE BY COTTON

Cotton takes up nutrients as cations and anions from the water held between soil particles - the soil solution. The plant must expend a considerable amount of energy to take up nutrients. Nutrients are normally in much greater concentration in the plant tissue than in the soil solution. Only a small fraction of the total nutrient content of the soil is found in the soil solution. As nutrients are removed from the soil solution, they are replaced from labile forms held within the soil, which include:

- organic matter
- low solubility minerals
- cation and anion exchange sites on clay particles and organic matter

Processes that release nutrients into the soil solution are usually reversible. Where high concentrations of a nutrient exist in the soil solution (especially after fertilizer application) that nutrient may be precipitated as an insoluble mineral, making it unavailable to the crop until the soil solution becomes depleted (see Figure 2-2). NUTRIpak will outline the processes that apply to individual nutrients in following sections.

FACTORS INFLUENCING NUTRIENT UPTAKE BY COTTON

Nutrient uptake may be restricted where:

- a deficiency of one nutrient will reduce the uptake of other nutrients by limiting crop growth
- nutrient uptake slows as the crop matures and are cycled from vegetative to reproductive organs within the plant
- oxygen is required to maintain metabolic processes including nutrient uptake, hence waterlogging will slow nutrient uptake
- poor soil physical structure (ie compaction) or chemical toxicities in the soil (eg salinity or sodicity) may limit root and shoot growth and nutrient uptake, even where sufficient nutrients are available

Carbon, oxygen and hydrogen make up 90% of the plant's dry matter, but are not considered to be mineral nutrients. In cotton farming systems, deficiencies of N, P, K, S, Mg, B, Zn, Fe and Cu have been identified. The relative concentrations of each nutrient at various stages of growth are listed in the *Interpretation of soil, petiole and leaf analyses* chapter of this manual.

NUTRIENT DISTRIBUTION WITHIN THE PLANT

Nutrients vary in their mobility within a plant. Some nutrients have very low mobility and deficiency is seen in new growth. Deficiencies of highly mobile nutrients within the plant are observed in the older growth (Table 2-1).

It is therefore imperative to sample the youngest mature leaf (fully expanded leaf) (normally 5th leaf from the terminal) when assessing crop nutrient status (see section on *leaf and petiole analysis* in this manual).

The cotton plant can take up nutrients quickly, as demand requires. The highest demand period for most nutrients occurs from flowering to boll fill (ie during the period of fastest growth). Nutrients are stored in leaf tissue and other organs until required by the developing bolls. Storage is important to provide nutrients to the crop in periods when crop uptake is reduced (eg cloudy weather, waterlogging episodes). This is especially significant for N, P and K where the supply of these nutrients may not be able to meet the demand (eg potassium at boll fill and the premature senescence syndrome). See the chapter on *Premature Senescence* in this manual.

Table 2-1.
Nutrient mobility in the plant defines where plant tissues express deficiency symptoms.

Mineral Nutrient	Nutrient mobility within plant	Plant organ where deficiency symptoms usually appear
N, P, K, Mg	High	old leaves
S	Low	Young leaves
Fe, Zn, Cu, Mo	very low	Young leaves
B, Ca	extremely low	Young leaves and terminal

NITROGEN (N)

Cotton is grown on fertile clay soils in Australia, which have become depleted in N and organic matter over time. They are no longer able to supply the cotton crop's need for N. Because of the direct effects of N on crop development, it is imperative to apply adequate N fertilizer. To achieve maximum yield, cotton growers may need to supply N fertilizer to each crop at rates up to 200 kg N/ha.

Over supply of N will encourage rank growth and fruit shedding, reduce lint yield, hamper defoliation, encourage insects and diseases and delay maturity.

THE ROLE OF NITROGEN IN THE PLANT

Nitrogen is an integral component of proteins, which are essential for healthy crop growth and physiological development. Nitrogen is also needed to synthesise the chlorophyll required for photosynthesis. New leaves may contain up to 6% N. It is a very mobile nutrient and moves from older to newer leaves as the plant ages. Nitrogen is taken up throughout the growing season and is transported and stored in the leaves. The N requirements for boll development are partially met from N stored in the leaf canopy.

UPTAKE AND REMOVAL OF NITROGEN

To achieve optimum cotton yields an uptake of about 180 kg N/ha is needed. Most N taken up by the crop comes from the surface (0 to 50 cm) soil from where organic matter is mineralised and fertilizer is applied.

Cotton prefers to take up nitrate-N (rather than ammonium-N) and does so in phase with crop dry matter production; as the crop matures N

uptake slows. Most of the N is transported to the leaves (hence the use of petiole nitrate testing). A young cotton plant can take up more N than it needs and excess N is remobilised from the leaf canopy later if uptake does not meet the crop's requirements. The production of new leaves and squares slows at 'cut out' which should coincide with the exhaustion of the soil N supply. Thus, low soil N can hasten cut out and limit yield. Most N is taken up between 50 and 110 days after sowing and about 60% of this N is removed in the seed cotton (Table 3-1).

NITROGEN DEFICIENCY SYMPTOMS

Deficiency symptoms include small, pale yellow leaves. N deficient plants are stunted with few vegetative branches and fruiting branches will be fewer and shorter. As N deficiency progresses, older leaves become yellow, as N is remobilised to new growth. Leaves with severe N deficiency turn various shades of autumn colours.

Crops that are adequately fertilised will exhaust the pool of available N in the soil as bolls start to open, when the lower leaves begin turning yellow. This is a good indication that the crop has received adequate N fertilizer. Mobilisation of N from older leaves, stems and roots is a feature of normal growth. Crops that are over-fertilised with N will remain green throughout the growing season, hence crop maturity, defoliation and picking are delayed.

NITROGEN FERTILIZERS AND APPLICATION

The major N fertilizers used in cotton production are anhydrous ammonia (82% N) and urea (46%N). The N released from both fertilizers becomes available to plants quickly. Urea and anhydrous ammonia perform similarly in an agronomic sense and are normally equally well recovered by cotton.

Anhydrous ammonia (NH_3) is the most popular option for irrigated cotton, especially where high rates of N are needed. About 80% of N fertilizer is applied as anhydrous ammonia. It is as effective and no more expensive than other N fertilizers, and most growers possess the equipment needed for its application. Loss of ammonia is negligible when anhydrous ammonia is applied deeper than 15 cm. However, the soil water content is important: ammonia applied to very dry soil may allow ammonia to escape through the voids between large clods, or in very wet soils, ammonia may escape via the slot made by the fertilizer shank if not covered over with loose soil.

Urea ($\text{CO}[\text{NH}_2]_2$) is normally hydrolysed to ammonium within days of application. It is then nitrified in the soil and assimilated by the crop. Urea can be dissolved in the irrigation water (water-run urea), side-dressed or aerially applied (in which case it must be quickly incorporated or watered-in). Urea should not be applied to the surface of wet or moist soil where volatilisation losses can reach 75% of N applied. Urea can be applied to a dry soil surface but it should be incorporated as soon as possible using cultivation or irrigation.

Water-run urea works efficiently as the N is distributed throughout the soil volume from which the crop extracts water. The N does not volatilise from the water and is delivered evenly to the length of the field. However, some N will be unavoidably wasted as supply channels and tail drains are fertilised, hence, tail water should be recirculated.

Water-run anhydrous ammonia does not work efficiently, as the ammonia is distributed poorly down the field and severe losses occur via ammonia volatilising from the irrigation water (up to 25% per hour).

*Table 3-1.
Nitrogen removed in
seed cotton from an
experiment at
Narrabri where yields
ranged from 5.5 to
10.4 bales/ha.*

	Lint yield (bales/ha)				
	6	7	8	9	10
N removed (kg/ha)	43	54	68	87	116

The three methods for applying urea with irrigations are:

- applied to dry soil surface by either spreader or aircraft then irrigated in as soon as possible. Avoid applying to moist soil and/or allowing a delay before irrigation as shallow incorporation in moist soil can lead to losses with ammonia volatilisation
- supply of urea solutions is possible in some regions that allow metering of the solution via a constant head tank and float valve. Application rates can be altered by adjusting the flow of the irrigation water or the flow of the fertilizer solution
- solid urea can be applied via N buggy type equipment that dispenses urea directly to the water flowing through the irrigation channel

Urea is best added to the water at a drop structure or culvert to improve the mixing process. The efficiencies of the three methods are similar.

Starter fertilizers, such as mono ammonium phosphate (MAP) and diammonium phosphate (DAP), supply a small amount of N to cotton seedlings.

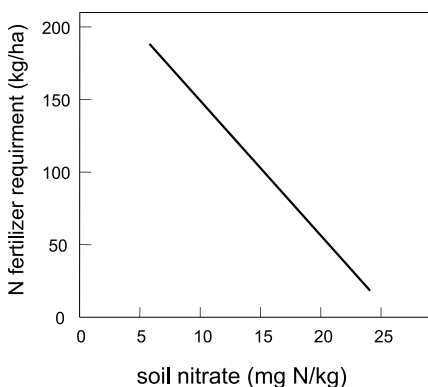


Figure 3-1.
The relationship between N fertilizer requirement and soil nitrate-N concentration in an unfertilized clay loam soil, sampled in September, one month prior to sowing cotton.

DETERMINING NITROGEN FERTILIZER REQUIREMENTS FOR COTTON

Most growers use rates based on their experience from previous cotton crops but also consider soil condition and previous rotation crops. The N fertilizer required by cotton can be predicted with greater precision by using pre-sowing soil nitrate analyses (figure 3-1). N fertilizer rates can be modified, as indicated by petiole nitrate analyses. Dryland cotton commonly requires about half the N rate applied to irrigated crops.

NutriLOGIC

NutriLOGIC is a module of the CottonLOGIC computer program available through the Australian Cotton Cooperative Research Centre's Technology Resource Centre at the Australian Cotton Research Institute, Narrabri.

NutriLOGIC allows the grower to enter soil nitrate-N and petiole nitrate-N data and estimates the N fertilizer required for cotton based on this data, the cotton-growing region and the month the sample was taken. The NutriLOGIC program makes allowance for soil factors (texture, compaction and predisposition to waterlogging), the time the soil was sampled and the district in which the cotton is grown. Hotter areas require slightly more N to maximise lint yield. The program does not contain a calibration for soil sampled earlier than July.

The N fertilizer rate indicated by NutriLOGIC allows for an average loss of N through denitrification and leaching during the crop-growing season based on soil type. Soil texture impacts substantially on N fertilizer losses, which are lower in lighter clays than in heavy clays. Greater losses occur from poorly structured or poorly drained soils compared to well-structured and well-drained soils.

Figure 3-2.
The N fertilizer requirement for cotton grown on a clay loam soil as related to petiole nitrate-N concentration at 750 day degrees from sowing (first flower).

SOIL NITRATE ANALYSIS

Pre-sowing (September) soil nitrate content is closely related to crop N uptake and ultimately, yield. N fertilizer requirements can be estimated from soil nitrate-N (figure 3-1). High levels of soil nitrate indicate a high level of N fertility. If fertilizer has been applied before sampling in September, nitrate test values will be extremely high and variable and are not suitable for estimating N fertilizer requirement.

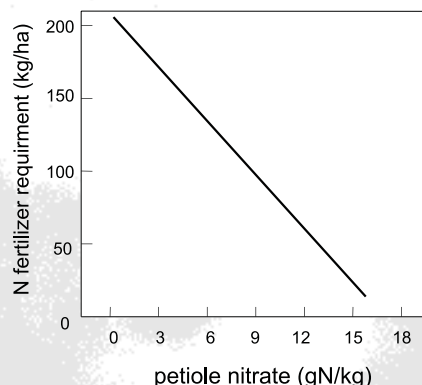
PETIOLE NITRATE ANALYSIS

Petiole nitrate analysis allows growers to determine whether a crop has received sufficient fertilizer N to produce its optimum yield. Monitor N status early in the growing season so that any N deficiency can be rectified before growth is severely affected.

The critical value for petiole nitrate at first flower (750 day degrees from sowing) is about 20,000 ppm. Below this value, nitrogen applications may be necessary. The NutriLOGIC computer program can be used to help estimate this requirement (see NutriLOGIC chapter in this manual).

Sampling procedures are detailed in the *leaf and petiole analysis* section of this manual.

The relationship displayed below in Figure 3-2 will change slightly for different soil types, but moreso for time of petiole sampling. The NutriLOGIC program adjusts the N fertilizer recommendation by accounting for the day degrees since the crop was sown.

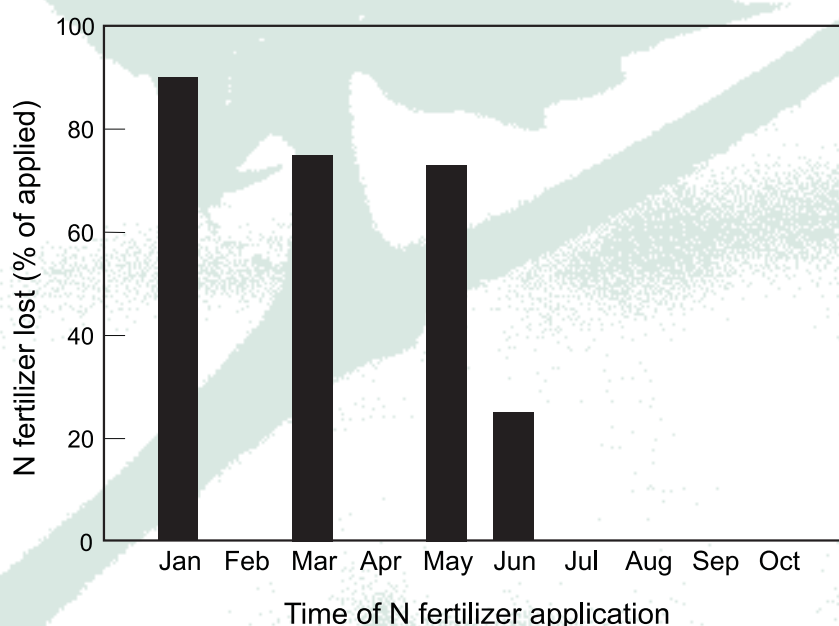


NITROGEN FERTILIZER MANAGEMENT

TIMING OF N FERTILIZER APPLICATION

Growers should aim to apply N fertilizer as close as practical to sowing in order to reduce N losses and maximise the effectiveness of N fertilizer. Often, N losses are substantial when fertilizer is applied before July. Growers should apply their N fertilizer into cool soil in the three months prior to sowing to reduce N losses. Applying N in warm/moist soil during the summer/autumn months before the crop is sown can be wasteful and costly for the grower. Early application unnecessarily exposes fertilizer to N loss episodes over many months, when soil conditions favour denitrification.

Severe N losses (primarily through denitrification) can occur between the time of fertilizer application and the crop being sown, particularly during wet winters. The practice of applying N fertilizer in the summer while preparing fields after cereal cropping is not recommended because of the potential for much of this N to be lost (see Figure 3-3).



SIDE-DRESSING N FERTILIZERS

When side-dressing N fertilizer, growers must take into account the time for fertilizer N to become available to the plant. Most growers aim to side-dress N prior to flowering, when the crop may take up as much as 4 kg N/ha/day. By applying N early to the crop, the damage caused by fertilizer tyres pruning the roots is minimised. As the plant ages, its ability to take up N decreases, even if N deficient. However, nitrogen taken up before this period and stored within the plant can be relocated within the plant.

Side-dressing can produce comparable responses to N compared with pre-plant applications, assuming there is sufficient N in the seed bed to allay N deficiency. Side-dressing can be a problem in wet summers when soil structure can be damaged. In these cases, water-run urea is often a better option than applying urea or anhydrous ammonia.

TIMING N FERTILIZER APPLICATION TO AVOID CROP DAMAGE

Where growers opt to place anhydrous ammonia (or urea) below the plant line prior to sowing, they should ensure sufficient time has elapsed for the ammonia to dissipate from the soil where the root system will develop. This may

take up to three weeks for high N application rates.

Nitrogen applied more than three to four months before sowing is subjected to greater N loss through denitrification and leaching.

Nitrogen side-dressed after squaring may not be as well recovered by the crop as N applied pre-sowing.

PLACEMENT OF N FERTILIZER

N fertilizers should be placed a short distance from where seedling roots will grow, especially when N is applied close to sowing. Generally, the best responses and recoveries are achieved from urea or anhydrous ammonia either placed:

- under the row if more than one month before sowing, or
- to the side of the crop row, if close to sowing

Depth of N fertilizer application is important. The developing seedlings may become N deficient where they cannot access N fertilizer placed too deeply. Shallow placement of N fertilizer may result in damage to the developing seedlings. Also, substantial N losses can be experienced during application of anhydrous ammonia (or urea). Further, N may be washed down the furrows from the head to the tail of the field during flood irrigation, especially where high nitrate concentrations persist following shallow N fertilizer application.

N fertilizer needs to be placed near the developing cotton roots, but not so close that ammonia toxicity will damage the root system. Ideally, the fertilizer band should be below and to the side of the developing roots, allowing the root system to grow into the band. Roots will proliferate through the fertilizer band as the ammonia is nitrified.

*Figure 3-3.
Percentage of N lost from early fertilizer applications as determined by fertilizer remaining in October. Almost complete loss of fertilizer N may eventuate from early applications in years having above average winter rainfall. (Source: Freney – Australian Cotton Conference 1992).*

Band placement of N fertilizer reduces N loss. Where 2-metre beds are used, the centre of the bed is the ideal position for N application. Placement of N in the furrow often achieves poor responses to fertilizer.

Urea should not be placed with the seed. Urea is extremely soluble and if applied near the crop row prior to sowing and watered-up, it may be moved into the seedling root zone. This can result in seedling damage, especially where high N rates are used. Water-run urea does not cause this problem.

FOLIAR APPLICATION OF N FERTILIZERS

Crops experiencing difficult growing conditions may respond to foliar applications of N, particularly when irrigating poorly drained fields. Poor soil aeration and waterlogging can limit nutrient uptake for some days after irrigation.

Foliar applications of soluble N fertilizers have been used to overcome N stress caused by short-term waterlogging from early crop irrigations. As the plant rapidly absorbs foliar N such applications can overcome a deficiency faster than soil applied N.

Waterlogging due to irrigation or rainfall often creates a short-term deficiency as roots lose their ability to absorb N when the soil is saturated. In these conditions denitrification loss is also increased. Foliar application is most effective when applied a day before the waterlogging event (irrigation). Applications of 8 to 10 kg N/ha (before first and/or second irrigation) at early squaring and early- to mid-flowering, can overcome the effects of waterlogging. Urea-ammonium nitrate solution used at 20 litres/ha is generally sufficient to meet plant requirements for the 3 or 4 days until the waterlogging event to pass. Application of foliar N fertilizer in wet cloudy weather is unlikely to benefit the plants, as they require sunlight to metabolise the nitrogen.

Higher rates of N can burn the foliage, consequently applications should occur in the late evening as cool humid

conditions lessen this risk. Foliar N applications are not recommended after flowering (mid to late January). Little or no yield response is achieved, although the crop may become visibly greener. Little loss of N via volatilisation occurs with foliar applications of ammonium sulfate, ammonium nitrate and urea-ammonium nitrate solutions to advanced crops.

APPLYING N FERTILIZER NEAR SOWING

In winters with above average rainfall, growers may not be able to apply fertilizer prior to sowing. In this situation growers need to explore other options available for N application, including side-dressings of ammonia and starter fertilizers (MAP) and other fertilizer management practices.

Mono-ammonium phosphate (MAP) rates of up to 40 kg /ha can be safely applied with seed where seedbed moisture is good. Because of the phosphate's acidifying effect, the alkalising effect of the ammonium is neutralised, thereby reducing the ammonia concentration within the seed-fertilizer band. Applications of di-ammonium phosphate (DAP) do not produce enough acid and should not be substituted for MAP applications with seed.

FERTILIZER DAMAGE CAUSED THROUGH AMMONIA TOXICITY

The most influential factor in fertilizer injury of seedling cotton is the presence of gaseous ammonia near developing roots. When ammonia-producing fertilizers (urea, anhydrous ammonia, MAP) are applied in alkaline soils, a proportion of the N remains as ammonia in the soil water and air spaces within the soil. The pH of the soil within a band of ammonium-producing fertilizer increases towards the centre of the band, causing the ammonium-ammonia equilibrium to increase the ammonia concentration.

Crop root systems are extremely sensitive to ammonia and patches of dead seedlings may become evident where N has been applied too close to the plant row. As the ammonium is nitrified, the soil pH declines, commonly below that of the soil surrounding the fertilizer band.

COST OF OVER-FERTILISING WITH NITROGEN

Too much N and water can cause rank vegetative growth and shedding of young bolls. This will delay full fruit load and crop maturity. The fruit will be smaller and the fibre more immature, largely because leaves and bolls are shaded by the excess vegetative growth. Diseases, such as boll rots, may be more common.

Minor effects of increased N supply are increased boll size and increased seed/boll numbers. The effect of N on lint quality is variable. A rank crop resulting from too much nitrogen can create problems for insecticide application, defoliation and aggravate some diseases such as boll rots and Verticillium wilt. Over fertilized cotton maybe more attractive to insects which can be more difficult to control.

The application of growth regulators (such as mepiquat chloride) may reduce the problems associated with rank growth in over-fertilised cotton.

EFFICIENCY OF N FERTILIZER USE BY COTTON

The most efficient use of N fertilizer is achieved by applying the correct rate at a time when N loss will be minimal, *ie* after June when cooler conditions slow the nitrification and denitrification processes.

The crop uses less than half the fertilizer N applied. Large quantities are lost from the system through either leaching or biological denitrification (the process where soil nitrate N is converted into gaseous forms of N and returned to the atmosphere).

Cotton crops recover about 33% of N applied on average; about 25% remains in the soil at crop maturity, but in an unavailable (organic) form. The remainder of N applied (*ie* 42% of N applied) is assumed lost from the system through denitrification and leaching.

About two-thirds of N taken up by cotton is derived from the soil organic N pool (*ie* non-fertilizer N). This N is mineralised from soil organic matter before and during crop growth. The N fertilizer applied meets only about one-third of the crop N requirement.

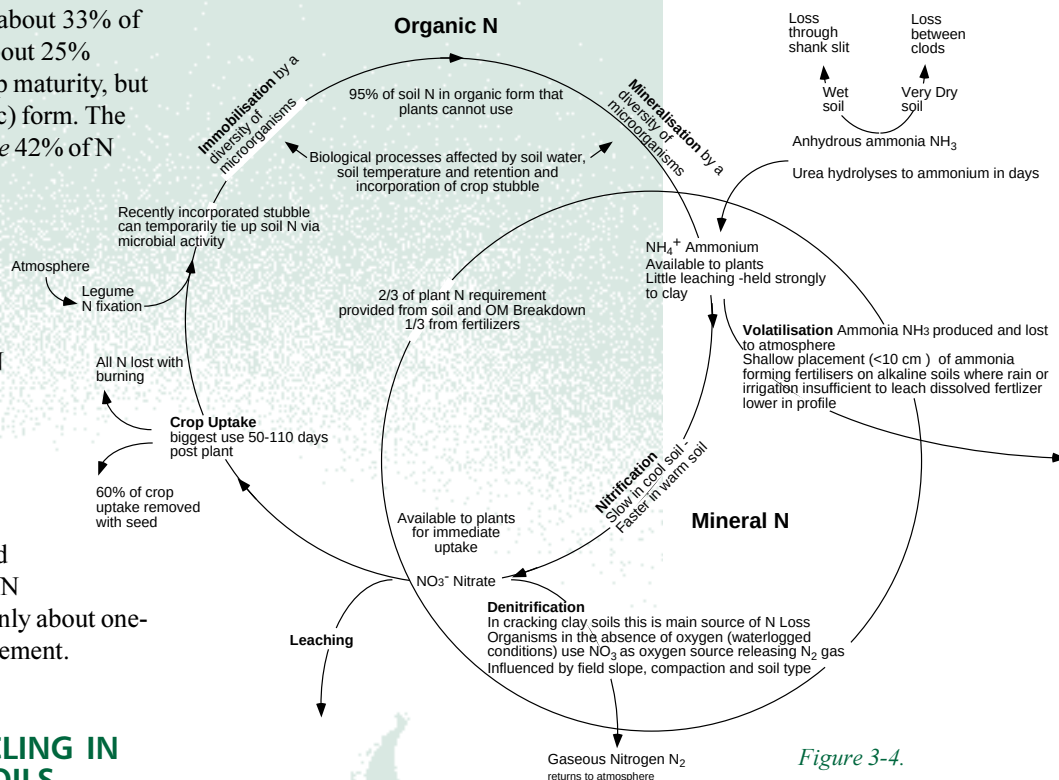


Figure 3-4.
The N cycle indicating pools and processes of relevance to cotton production

NITROGEN CYCLING IN COTTON SOILS

A complex cycle exists in the soil, where N is transformed through numerous pathways, converting organic matter (*eg* crop stubbles) into plant-available forms of N (*ie* nitrate and ammonium). N can be added to the system as N fertilizer or by growing legume rotation crops, and can be removed by nitrate leaching, denitrification and in harvested seed cotton. The cycle in Figure 3-4 is not closed as various processes are constantly adding or removing N.

ORGANIC N AND MINERAL N

Normally, more than 95% of soil N is in an organic form which plants cannot use. Organic N must first be ‘mineralised’ before it becomes available to the plant. This is a biological process performed by diverse microorganisms present in the soil. Ammonium (NH_4^+) and nitrate (NO_3^-) are available to the crop for immediate uptake.

organic N $\Rightarrow$ mineralisation $\Rightarrow$
plant-available (mineral) N

Because soil organisms also require N, they compete for the available mineral

N and convert a portion of this N back into organic forms. The process where plant available (mineral) N is converted into an unavailable organic form by the soil’s microbial populations is called ‘immobilisation’.

mineral N $\Rightarrow$ immobilisation $\Rightarrow$
organic N

These two opposing processes operate continually within the soil, creating a balance between plant available (mineral) N and organic soil N. Mineral N converted into organic N is not lost from the system, but becomes available as other soil organisms recycle the organic N back into a plant available N.

While some organic N is readily decomposed, much organic N is highly resistant to decomposition. Because these processes are biological, the balance is affected by the soil water content, soil temperature and particularly, the retention and incorporation of crop stubbles. The N fertility of soil can be improved by legume cropping as well as N fertilizer application. This is covered in depth in the section on legume rotation crops.

The nitrification process involves the conversion of ammonium (whether from anhydrous ammonia or urea) to nitrate. This process may take two months after fertilizer application in cool soil, but only two to three weeks in warm soils. Nitrification will proceed more slowly where N is applied at high rates, because of the high pH and ammonia concentration in the soil around the fertilizer band. In unfertilised soils, very little ammonium normally exists because of the dominance of the nitrification process.

Nitrate (NO_3^-) is the most common form of mineral N in alkaline soils. Ammonium (NH_4^+) derived from the fertilizer or organic matter is quickly oxidised to nitrate by nitrifying microorganisms. Mineral N levels fluctuate throughout the year, with concentrations lowest in August/September. This corresponds to the recommended sampling time for soil nitrate analysis.

LOSSES OF N FROM THE SYSTEM

Nitrogen can be lost from the system in various ways:

- removal of produce – (seed cotton)
- denitrification – (especially through waterlogging of irrigated soils)
- leaching – (nitrate washed through soil profile - especially sandy soils)
- volatilisation – (ammonia lost from soil surface after fertilizer application – especially urea)
- burning stubble (see Cotton stubble management chapter)

Denitrification is a biological process whereby nitrate-N is converted to nitrogen gases and N is lost to the atmosphere. It is the most significant N loss process in clay soils. High soil temperatures and saturated soil

encourage denitrification. Following flood irrigation and/or heavy rainfall, the soil profile may become waterlogged. The pore spaces in the soil become devoid of oxygen as air is forced from the profile. Increased soil water content may also stimulate mineralisation of organic N, which also consumes oxygen. Under these circumstances, the denitrifying microorganisms start to use nitrate as a source of oxygen. This reduces the amount of mineral N available for the cotton crop.

The loss of fertilizer N during crop growth is variable and is site dependent. In several experiments at Narrabri, between 12% and 65% of N applied was lost from the system, as well as some non-fertilizer N. Fields with poor drainage, low slope, poor soil structure, compaction, high organic matter content etc. may be predisposed to severe denitrification losses. Soil clay content (texture) is closely related to denitrification loss. Australian research has shown that inhibitor chemicals applied with the fertilizer can reduce the loss of N fertilizer through denitrification in cotton-growing soils.

NITRATE LEACHING

The nitrate ion, NO_3^- is not strongly held to clay and organic matter and is subject to movement within the soil profile. Downward movement of ions (leaching) is a problem in coarse-textured soils (loams and sands) in well structured clay soils. In clay soils where movement of soil water is slow, nitrate movement is also slow. During flood irrigation, surface soil high in nitrate is washed into cracks with the irrigation water, thereby transporting nitrate (and soil) into the subsoil.

High levels of nitrate at depth are commonly reported in dryland cropping soils where long fallows are used. This nitrate may have accumulated over many years, even before the soil was cultivated. Most N taken up by the crop is derived from the surface 50cm of soil. The use of deep nitrate by cotton has not been measured, but roots will take up nitrate in proportion to the use of water from deeper in the profile.

Ammonia volatilisation can result in significant N loss from alkaline soils. Where high concentrations of ammonium exist at the soil surface, ammonia gas can escape into the atmosphere. Volatilisation is a purely chemical process driven by environmental parameters, such as soil pH, temperature and ammonium concentration and wind speed. Ammonium-forming fertilizers (eg urea) applied to the surface of alkaline soils, or at shallow (<10cm) depth, may be lost as ammonia gas.

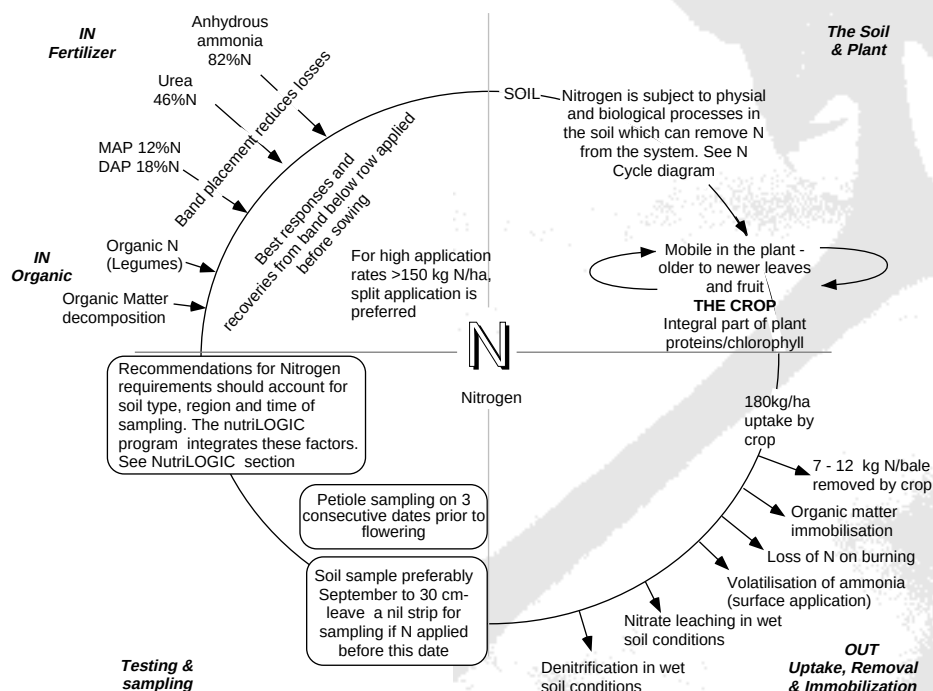


Figure 3-5.
Summary of Nitrogen management issues.

IMPROVING SOIL N FERTILITY WITH LEGUME CROPS

N FIXATION BY LEGUME CROPS

All legume crops have the capacity to 'fix' atmospheric nitrogen (N_2) and incorporate this N into their tissues via an association with bacteria (*Rhizobium* spp.) that normally exist in the soil. As legume seedlings develop their root system, the Rhizobia bacteria infect the root hairs. Nodules form on the roots as the bacteria reproduce. The Rhizobia contain an enzyme (nitrogenase) that converts N_2 into a plant-available form of N. The conversion process requires a high input of energy in the form of carbohydrate which is 'donated' by the plant. In turn, the plant is rewarded with a supply of N from the nodules. Both partners benefit from this symbiotic relationship.

INOCULATE LEGUME SEED BEFORE SOWING

Cotton-growing soils often contain low amounts of these Rhizobia bacteria, hence selected strains of the bacteria should be applied when the legume crop is sown. As most legumes are quite specific in the strain of Rhizobia that can infect the root, growers should apply the appropriate Rhizobia inoculum at the recommended rate. The inoculum can be applied either to the seed just before sowing or diluted and injected into the soil with the seed at sowing.

SOIL NITRATE IN LEGUME SEEDBED

Because soil nitrate-N concentrations are normally low following a cotton crop, a legume crop sown after cotton will need to derive most of its N requirement from N fixation. Where high levels of plant-available N (nitrate) are present in the soil, the crop will use that N in preference to fixing N.

WATER STRESS

Legume crops grown under moisture stress from either waterlogging or drought will not fix as much N as crops grown in good soil moisture conditions. Nutrient deficiencies in the legume crop will also affect N_2 fixation. Similarly, soil salinity drastically reduces N_2 fixation.

SOIL STRUCTURAL IMPROVEMENT

Legume crops offer other beneficial effects, such as improving soil structure (tilth) that makes ploughing and root growth of following crops easier. Green manuring of some legume crops may also reduce the effects of some cotton pathogens. Legume crop stubble should be incorporated into the soil to reduce the incidence of seedling diseases (such as *Pythium* and *Rhizoctonia* spp.) which may be encouraged by the presence of stubble left on the soil surface.



Faba beans

SLOW-RELEASE OF NITROGEN

Because legume-N is added to the soil in an organic form, it must go through the mineralisation process before that N is available to the following crop(s). As this may take several years or several crops, the addition of legume-N can be thought of as a slow-release form of organic N fertilizer. Losses of N from legume stubbles are substantially less than from the equivalent input of chemical fertilizer-N.

COMMERCIAL LEGUME CROPS

Surveys of commercial legume crops grown in rotation with cotton indicate that high levels of N_2 fixation are possible in this system. Although substantial quantities of N can be removed in grain, normally there is a net input of N into the system (Table 3-2).

Species	No. of crops	Prop. crop N fixed	N fixed	Residual fixed N
		(%)	(kg/ha)	(kg/ha)
		mean	mean	mean
<i>Summer</i>				
soybean	6	83	371	194
peanut	2	80	273	168
(late sown)	3	40	84	33
(saline)	1	14	37	-20
adzuki bean	4	20	12	5
mung bean	5	51	47	12
pigeon pea	5	14	16	
cowpea	3	74	160	
lablab	9	73	140	
<i>Winter</i>				
faba bean	35	74	177	113
lupin	3	71	176	97
field pea	5	75	161	
lentil	1	61	169	
<i>Winter forage</i>				
clover	9	86	118	
medic	3	84	149	
vetch	4	89	171	

Table 3-2.

Means and ranges of the proportion of crop N fixed, N_2 fixation and residual fixed N (including estimates of below ground N) in 98 legume crops grown in rotation with cotton. Where no estimates of residual fixed N are provided, no grain was harvested and the crops were green manured (all fixed N was returned to the soil). Data from Rochester et al. 1998.

NITROGEN MANAGEMENT



Damaged roots of cotton seedlings caused by placement of the fertilizer band too close to the seed.

Photo Stephen Allen.



Uneven nitrogen fertilizer application and/or soil compaction can produce stripes (waves) across cotton fields.

Photo Ian Rochester.



Over use of nitrogen fertilizer can delay maturity of cotton, hamper defoliation and reduce yields.

Photo Ian Rochester.



Cotton growing on soil of high (left) and low (right) nitrogen status.

Photo Ian Rochester.

IMPROVING SOIL WITH LEGUME CROPS

Nodules formed on faba bean roots by nitrogen-fixing Rhizobia bacteria.
Photo Ian Rochester.



Faba beans are commonly used as a winter grain legume in cotton systems.
Photo Ian Rochester.



Vetch is a highly efficient nitrogen-fixing winter legume cover crop. *Photo Ian Rochester.*



Vetch is mown and incorporated into the topsoil prior to sowing cotton.
Photo Ian Rochester.

Peanuts can be grown in rotation with cotton.
Photo Ian Rochester.



PHOSPHORUS (P)

THE ROLE OF PHOSPHORUS IN THE PLANT

Phosphorus (P) plays a central role in conserving and transferring energy in cell metabolism. P deficiency causes a reduction in seedling vigour, plant establishment and root development. Deficient plants are usually stunted, dark green in appearance and exhibit delayed flowering, boll set and maturity.

In short or cool, wet seasons, good P nutrition is essential to avoid delayed crop maturity.

Both phosphorus and potassium are important in late-season crop nutrition, as they are implicated in the premature senescence syndrome. As the crop matures, phosphorus is translocated from the leaves to the developing bolls. Where crop P uptake is reduced through waterlogging or overcast weather during boll filling, there may be insufficient P in the leaves to support the demand for P from the bolls. This reduces P in the leaves so that photosynthesis and plant metabolism declines and the crop prematurely senesces.

UPTAKE AND REMOVAL OF PHOSPHORUS

High yielding cotton crops typically take up 25-30 kg P/ha and remove about 20-25 kg P/ha in the seed cotton, equivalent to approximately 2 kg P/bale. On soils with a long history of cotton production, this amounts to a substantial reduction in soil P reserves. Peak P uptake (0.3-0.6 kg P/ha per day) occurs between mid-flowering and boll filling.

PHOSPHORUS DEFICIENCY SYMPTOMS

P deficiency symptoms for cotton include stunted plants with dark green foliage, which may later become discoloured. Where the deficiency is not corrected, fruiting is delayed and restricted.

CRITICAL P LEVELS IN THE PLANT

Plant tissue tests can also assess crop P status. The concentration of P in the youngest mature leaf (YML) is relatively independent upon the stage of crop development and is normally around 0.33% P for healthy cotton crops.

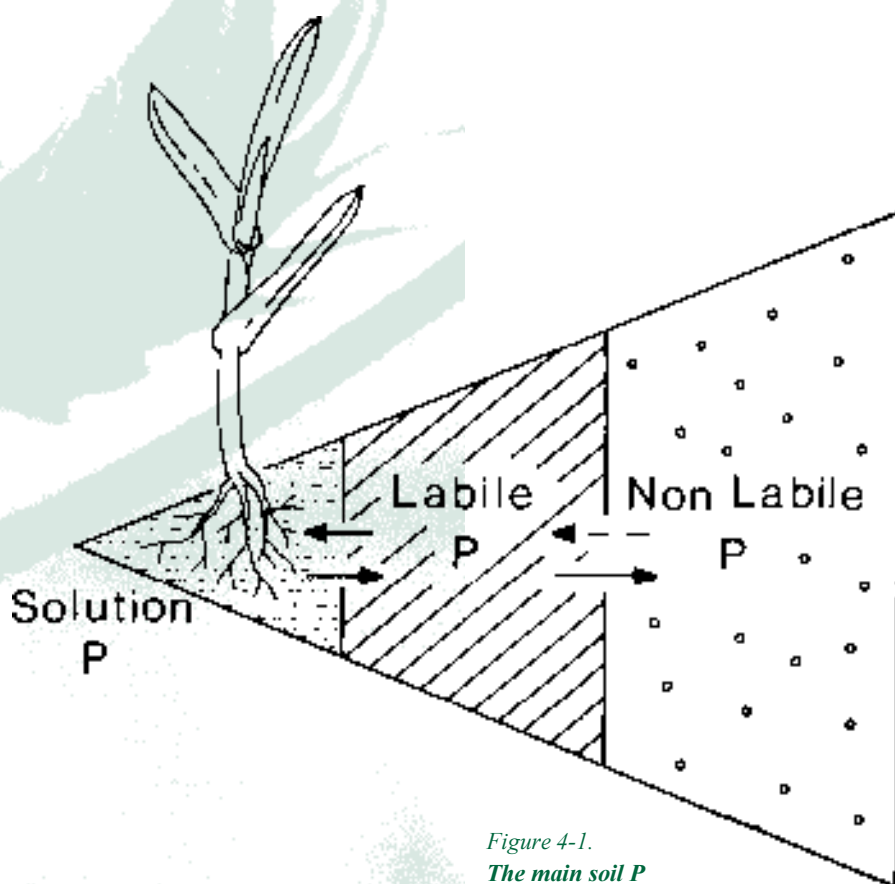


Figure 4-1.
The main soil P
pools.

Figure 4-2.
Phosphorus is cycled between soil and crop pools.

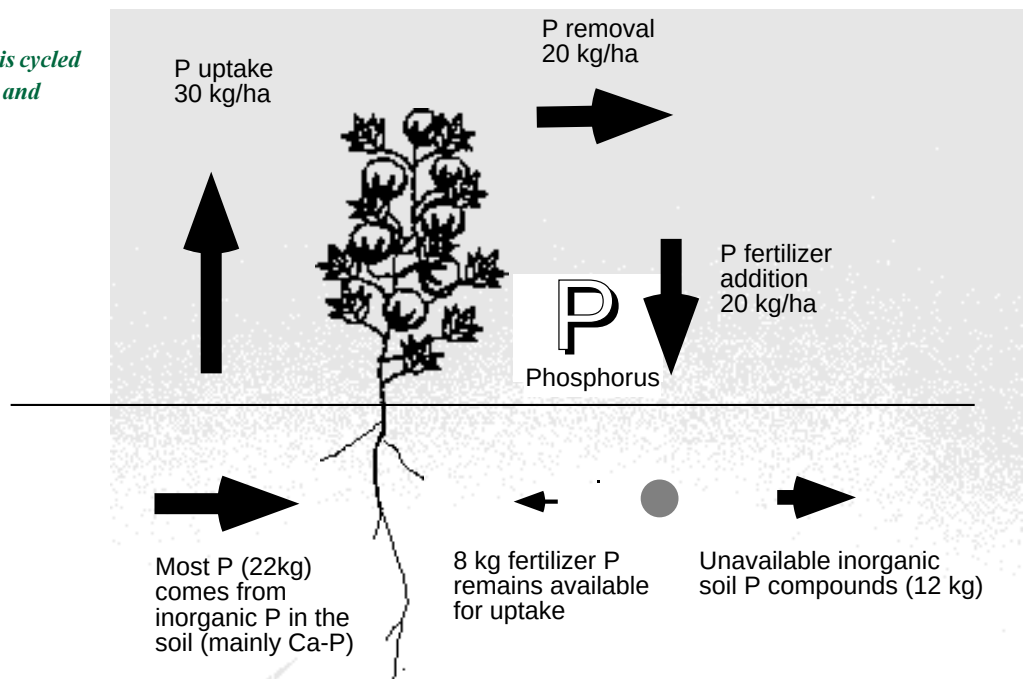
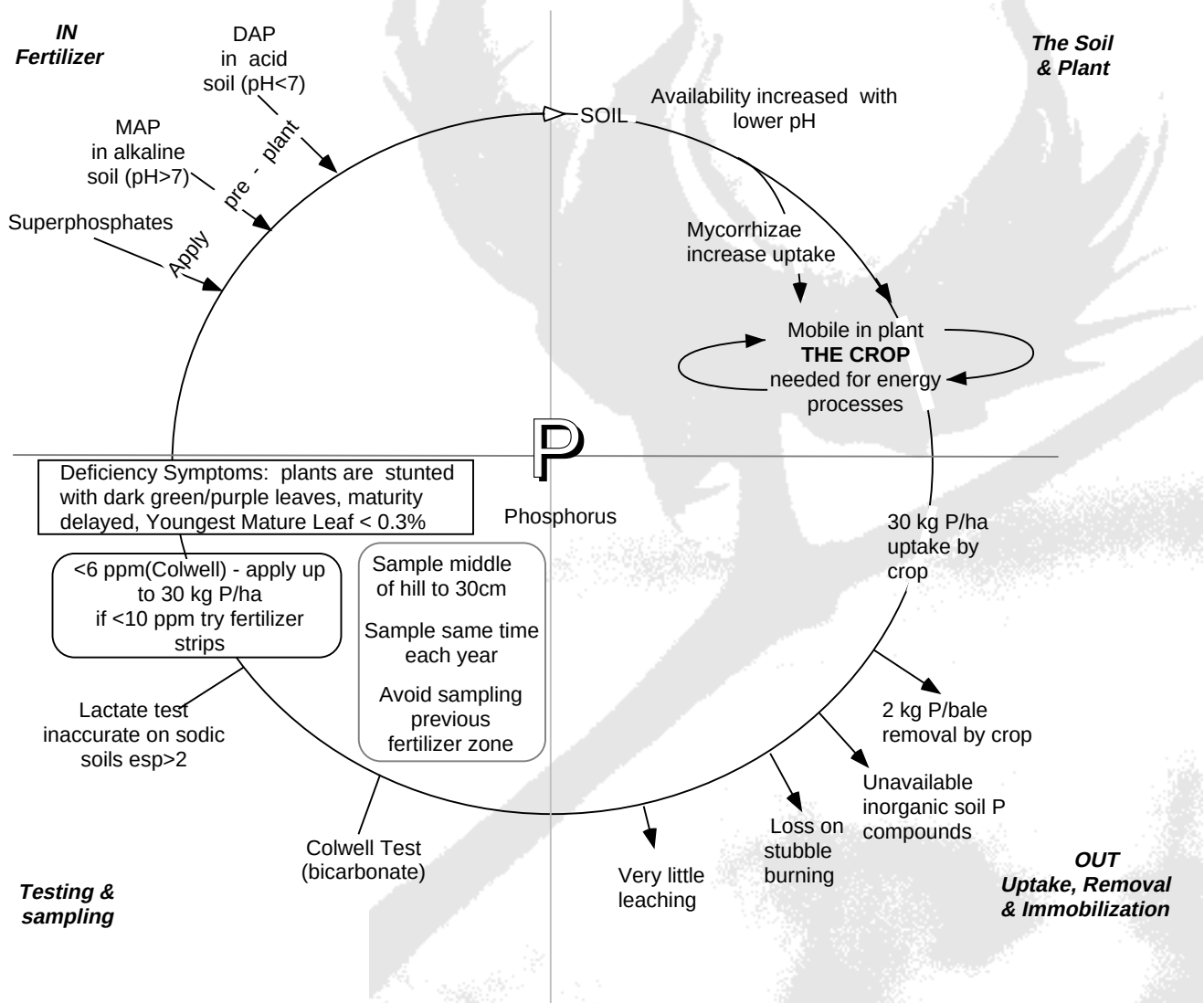


Figure 4-3.
Summary of Phosphorus management issues.



PHOSPHORUS FERTILIZERS

If P deficiency is suspected, either due to declining soil P levels or poor crop vigour, then P fertilizer may be required. P can be applied in small test strips to assess the need for P. Mono-Ammonium Phosphate (MAP - N:P:K - 9:22:0) is the most common P fertilizer used since it forms a slightly acidic product and remains in solution longer than superphosphate. Recommended rates are 10-20 kg P/ ha (45-90 kg MAP/ha). This should be banded to a depth of 10 cm and 10 cm off the planting line, close to sowing. If P fertilizer is applied over the whole field, leave a nil strip to determine if P application can improve crop growth.

Banding is more effective than broadcast application since soil/fertilizer contact is reduced which increases the availability of the fertilizer P. Plant roots proliferate around the band of P fertilizer.

Low rates of P can be applied with the seed (up to 9 kg P/ha or 40 kg MAP/ha) where there is good seedbed moisture. There is a danger that the ammonia released from the MAP will affect germination and seedling establishment. For this reason, DAP (18:20:0) should not be applied with seed. Side-dressing P fertilizer between sowing and squaring may not be as effective as applying P pre-sowing.

Foliar P fertilizers are not commercially available in Australia.

MONITORING SOIL P

The highest concentrations of P occur in the surface 30 cm of soil but significant amounts may also be found in the subsoil. Cultivation, land forming and laser levelling will affect the distribution of P within the profile. The tests most commonly used to determine plant-available soil P are the Colwell (bicarbonate extractant) and Lactate (more acidic extractant) tests. The Colwell P test gives the better indication of P availability to cotton. P fertilizer should be applied when Colwell P is less than 10 ppm. When Colwell P is less than 6 ppm, higher rates of P fertilizer may be warranted.

Soil pH, texture and buffering capacity influence soil P availability and the likelihood of crop response to P fertilizer application. Most Australian cotton soils have sufficient P to meet the P requirements of cotton. Available P may fluctuate during the year depending on soil temperature and moisture status. Hence, soil samples should be collected at the same time of year and under similar soil conditions to assess soil P status over seasons.

Soil samples should be taken during the fallow prior to sowing to determine whether P fertilizer is required for the next cotton crop. Soil samples should be taken from the top of the hill to a depth of 30 cm, which represents the rooting zone of young cotton plants. Several samples should be taken across the field or area within a field (see section on soil sampling and analysis in this manual).

SOIL P AVAILABILITY

Approximately 40% of the area planted to cotton in Australia receives some P fertilizer. However, the response to fertilizer P is often variable, even in the same field over seasons.

Australian cotton-growing soils have a high clay content, high cation exchange capacity (CEC) and are alkaline (pH > 7.5). Under alkaline conditions, P availability is often low, despite the soil having high total P content. Soil P can be classified into three pools:

- available P (P as phosphate in the soil solution is available to plants)
- labile P (moderately available P, that moves in and out of solution depending on soil pH, temperature, moisture and removal by plant roots)
- poorly available P (comprises very insoluble P minerals and organic P that is not available to plants)

The three pools are linked, but the first two are the most important when considering P nutrition of cotton (Figure 4-1). As plants grow, their roots deplete the available P in the soil solution. P from the labile fraction moves into solution, thereby maintaining the concentration of available P in the soil. When the soil solution P concentration is increased (as after application of P fertilizer), some available P will be transferred into the labile pool until the system is again in balance (Figure 4-2).

Australian cotton soils have a high P buffering capacity. This means that:

- as cotton plants grow and remove P from the soil solution, this pool of P is quickly replenished from the labile P pool
- when P fertilizers are applied to alkaline soils, much of the fertilizer P moves into the labile P pool

With continued cotton cropping, the labile P pool may be depleted quickly (unless P fertilizer is added), reducing the ability of the soil to maintain adequate available soil P levels.

MYCORRHIZAE (VAM) AND P UPTAKE

Phosphorus is an immobile element within the soil and so increasing soil/root contact can increase uptake of P by a crop. Many crops, including cotton, achieve this through an association with mycorrhizal fungi. The fungal hyphae infect the root and accumulate nutrients for the plant. The fungi increase the volume of soil accessible to the crop several fold and are essential for cotton plants to accumulate sufficient P (and zinc) from the soil.

The response of cotton to P fertilizer is more likely where mycorrhizal colonisation is reduced with low soil temperatures or following long fallow periods. *Long fallow disorder* has been associated with poor mycorrhizal colonisation, since long periods of bare, weed-free fields, or growth of non-mycorrhizal crops, such as Canola, reduce the amount of VAM in the soil. The critical soil P limits may be higher where mycorrhizal colonisation is reduced (Colwell P 10-15 ppm).

SUMMARY OF P MANAGEMENT ISSUES

- most Australian cotton soils have sufficient P to meet the P requirements of cotton
- crop response to P fertilizer is likely where Colwell P concentrations are less than 6 mg/kg
- where Colwell P levels are between 6-10 mg/kg to determine if P fertilizer is required, nil strips should be left in the field
- banding 20-40 kg P/ha close to planting is the most effective means of applying P if soil P is limiting to plant growth.

PHOSPHORUS

CHAPTER 4



*Cotton leaf showing advanced phosphorus deficiency - note red/purplish colour.
Photo Philip Wright.*

*P-deficient cotton. Older leaves are dark red/purplish coloured, new leaves are light green.
Photo Ian Rochester.*



CHAPTER 4 PHOSPHORUS

Growth response of cotton to P fertilizer. Plant on right was grown in unfertilized soil (Colwell P - 6 mg/kg). Photo Chris Dorahy.



P-deficient cotton plants have purple/red leaves, bolls are fewer and smaller and maturity is delayed. Photo Chris Dorahy.



POTASSIUM (K)

Potassium (K) is relatively abundant in most Australian cotton growing soils. Potassium is also the most abundant nutrient in the plant after nitrogen. This section deals with potassium deficiency as encountered where soil potassium levels are low, such as in parts of the Emerald irrigation area. Premature senescence is a potassium-related disorder that can occur where soil K reserves are sufficient for normal growth - it is discussed in a later section.

THE ROLE OF POTASSIUM IN THE PLANT

Potassium is a mobile element within the plant and can readily move between plant organs. It has an important role in a number of enzymes including those involved with energy transfer. It is vital for transferring carbohydrates throughout the plant as well as osmotic regulation (maintaining turgor). Potassium is also involved in nitrogen metabolism and protein synthesis.

Overseas research has indicated that K fertilisation reduces the incidence and severity of cotton diseases including *Verticillium* (California) and *Fusarium* and associated nematodes (Egypt). Maintaining adequate plant K concentration can reduce the incidence of damping off diseases.

The provision of adequate K levels has been shown to increase boll weight, fibre quality, fibre length (dependant on maintenance of cell turgor) and maturity (degree of fibre secondary wall thickening dependant on carbohydrate supply).

UPTAKE AND REMOVAL OF POTASSIUM

Cotton can take up more than 200 kg K/ha, of this 21-24% (3.4-7.3 kg K/bale) is removed in the seed cotton.

Potassium is absorbed as an ion from the soil solution and its uptake is affected by competition with the other cations in the soil solution including NH_4^+ , Na^+ , Mg^{++} and Ca^{++} .

POTASSIUM DEFICIENCY SYMPTOMS

The potassium ion is mobile in the plant and K will move to new growth from the older leaves. Hence, K deficiency first appears in older leaves. Initially, the leaf margins and interveinal areas show a yellowish white mottling, then a rusty bronze colour. Necrotic spots between the leaf veins cause the leaf to appear rusted or dotted with brown specks at the leaf tip, margins and between the leaf veins. As the leaf breaks down, the margins and leaf tip shrivel. Eventually the whole leaf dies and is shed as the condition moves up the plant. In severe deficiencies, young leaves are affected and the terminal dies. Premature shedding of leaves prevents boll development, resulting in small immature bolls, many of which fail to open.

The symptoms of severe deficiencies are only likely to occur in highly weathered coarse-textured soils, in wetter environments. These soils normally have low K reserves, a low cation exchange capacity and available K is readily leached.

The youngest mature leaf (YML) is often the first to show symptoms where deficiency appears later in the season.

CRITICAL K LEVELS IN THE PLANT

Plant critical levels may vary between cotton varieties. Petiole tests for potassium will indicate deficiency at the time of sampling. Unlike N, they cannot be used to predict future K needs. Marginal levels of K in petioles generally range from 40,000 mg/kg (4% K) at first

flower to 20,000 mg/kg (2% K) at first open boll. Cotton can metabolise K at high rates and this can confuse fertilizer recommendations.

In the soil critical levels will depend on the soil test and the soil type. For clay soil, 0.25 to 0.37 meq K^+ /100g is identical to 97.5 to 145 mg K^+ /kg. K deficiency can be induced where exchangeable Mg is more than 20% of the cation exchange capacity (CEC). Likewise, Mg deficiency can be induced where exchangeable K exceeds 10% of the CEC.

The crop requirement for potassium can be estimated by taking into account the following factors:

- Normal yield (3.4-7.3 kg K/bale is removed)
- Nature of the soil
- soil K fertility
- clay mineralogy and origin of soil (illitic clays may decrease K availability). For sandy soil, fertilizer management should aim to replace K removed at harvest. Clay soils will normally supply the amount of K removed by cropping, except for illite-dominated soils
- stubble retention is important as up to 50% of the K contained in the crop residues is lost when the stubble is burnt – ie loss of 100 kg K/ha.

POTASSIUM FERTILIZERS

Potassium chloride (muriate of potash) is the most widely used source of K. Potassium sulfate and potassium nitrate are used less commonly. Potassium phosphate is less likely to be leached, as its anion is less active and consequently, the K ion has more chance of being adsorbed onto the cation exchange complex.

In soils deficient in potassium, apply 50-80 kg K/ha in a band to the side of the crop row at sufficient depth to avoid seedling damage. K deficiencies observed later in the season can be treated with foliar applications of K.

Potassium nitrate (KNO_3) and potassium sulfate (K_2SO_4) and potassium thiosulfate ($\text{K}_2\text{S}_2\text{O}_3$) are of similar effectiveness, but potassium chloride (KCl) and potassium sulfite (K_2SO_3) may not be as effective. Data from USA indicates that two applications of 10 kg KNO_3 /ha at 3-4 weeks after first flowering was beneficial. Australian results have been inconsistent.

K is best applied prior to sowing, unless the soil is light, as K can be leached. In this case, K would be better side-dressed after sowing to coincide with the K demand of the crop. Banding is the preferred option in soils that 'fix' K.

SOIL POTASSIUM

There are various forms of potassium in the soil including:

- K in the soil solution (K^+) measured at levels of 10-40 mg K/kg soil
- Exchangeable K held on the negatively charged sites on clay and organic matter
- Non-exchangeable available K is held on the clay particles in positions that are not readily accessible to plant roots. This K can move into the soil solution following a concentration gradient. Weathered minerals also have K^+ in this form that becomes available slowly
- Mineral K is slowly released from minerals which can contain 7-13% K
- K fixation in soil. Fertilizer K can become unavailable to plants as it moves between clay plates (in 2:1 clays see SOILpak third edition Chapter E4 Clay Minerals). These sites may have previously been depleted of K^+ and replaced by other cations. This only happens in illite, montmorillonite (common in Australian cotton soils) and vermiculite clays and weathered micas. This process does not occur in acid soils.

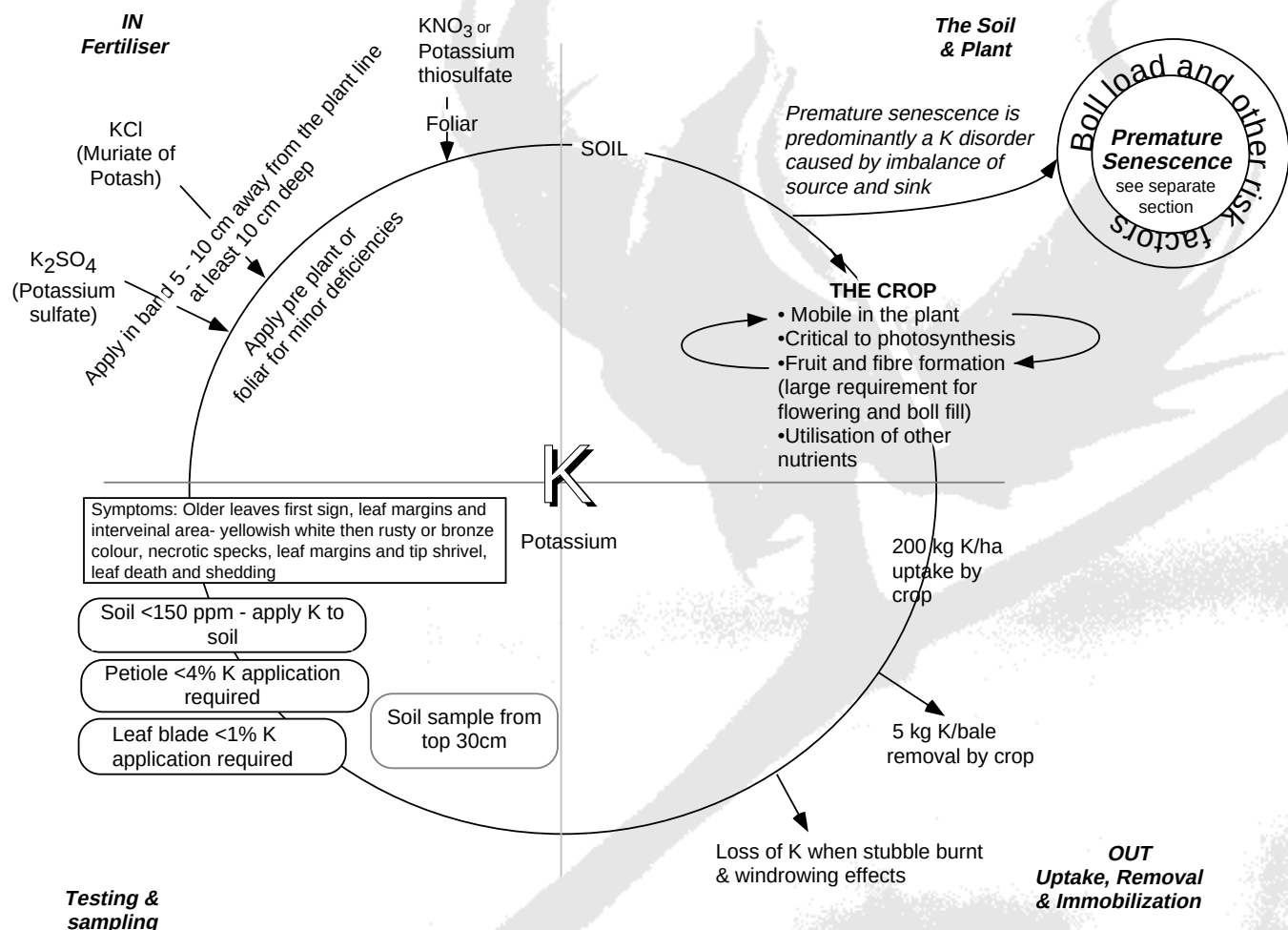


Figure 5-1.
Summary of Potassium
management issues.

POTASSIUM



Response to potassium fertilizer at Emerald. The area on the left was fertilized with 80 kg K/ha.



Potassium deficiency is expressed more severely in some cotton cultivars.



Alternaria (and other pathogens) can be more prevalent in potassium-deficient cotton.

OTHER ESSENTIAL NUTRIENTS

Nitrogen, Phosphorus and Potassium have been discussed in previous chapters.

Other essential plant nutrients, namely zinc, iron, copper, boron, calcium, magnesium, sulfur, manganese and molybdenum are discussed in sequence. The relative quantities of each essential nutrient taken up by cotton and removed in seed cotton is shown in Table 6-1.

Nutrient	Uptake	Removal
Macro-nutrients	kg/ha	kg/ha
N	200	100
K	200	50
P	30	20
S	40	10
Ca	220	10
Mg	30	12
Micro-nutrients	g/ha	g/ha
Zn	125	100
Cu	50	20
Mn	450	60
Fe	600	80
B	400	100
Mo	10	5

Table 6-1.

Uptake and removal of essential nutrients by high-yielding irrigated cotton crops.

ZINC (Zn)

THE ROLE OF ZINC IN THE PLANT

Zinc (Zn) is an essential plant nutrient, required in small amounts. It is a constituent of enzymes and is involved with the synthesis of Indole Acetic Acid (IAA), a plant hormone that controls growth.

UPTAKE AND REMOVAL OF ZINC

Cotton crops normally take up 100-150 g Zn/ha. Of this, about 100 g Zn/ha (13 g Zn/bale) may be removed in seed cotton. Most of the zinc is taken up from first square to peak boll fill.

ZINC DEFICIENCY SYMPTOMS

The leaves show interveinal chlorosis (yellowing between the leaf veins), are often cupped and may indicate bronzing. Zinc deficient plants are often shorter than unaffected plants, indicating that growth has been suppressed. Crops may grow out of zinc deficiency, especially when cotton is grown after long fallows, but yield, maturity and fibre quality may be affected.

CRITICAL ZINC CONCENTRATIONS IN THE PLANT

Adequate concentrations range from 20-60 mg Zn/kg in youngest mature leaf at first flower. Zinc concentrations below 20 mg/kg in leaves indicate the crop may not be taking up sufficient quantities of zinc. The concentrations of phosphorus and zinc should be in the ratio of about 100:1. Also, the concentrations of manganese and zinc should be in the ratio of about 1.2:1 – very high values are indicative of long fallow disorder.

ZINC FERTILIZERS

Zinc deficiency symptoms can be alleviated with foliar zinc sprays. A range of foliar fertilizers are available commercially, many with other trace elements. Care should be taken to apply sufficient zinc to supply the crop's requirement.

Zinc sulfate heptahydrate (23% Zn) or monohydrate (36% Zn) at a rate of 1 kg/ha is effective and inexpensive. Using it in a directed spray may be sufficient to overcome current zinc deficiency in cotton.

Zinc oxide (ZnO) is very insoluble in the soil. However, plant roots have the ability to solubilise ZnO in their vicinity. Between 10 and 20 kg zinc oxide/ha is normally applied which should maintain adequate available Zn concentrations for several years.

Zinc is better applied to the soil as a broadcast application and worked in to the soil. Banding of zinc with phosphatic fertilizers can immobilise zinc in the soil.

Following land development, either zinc oxide or zinc sulfate should be applied and worked into the surface soil.

SOIL ZINC

Zinc is very immobile in the soil and concentrates in the surface soil although lesser amounts can be detected in deeper soil layers. The removal of the surface soil while developing fields with laser levelling reduces the quantity of zinc available to the crop.

Two tests have been developed to assess soil zinc availability. The DTPA extraction is considered more accurate, having a critical concentration of 0.5 mg Zn/kg. The critical concentration for the EDTA extraction is 4 mg Zn/kg.

VAM

Mycorrhizal fungi normally infect many crop root systems, including cotton. The fungal strands (hyphae) act as long root hairs and aid nutrient uptake of cotton by increasing the volume of soil explored by the root system. Their role is to improve the uptake of poorly soluble nutrients (mainly P and Zn) by solubilizing minerals in the soil and allowing greater nutrient uptake by the plant.

Plants with poor VAM infection may show Zn deficiency symptoms. As VAM infection increases with time, the Zn

deficiency symptoms may disappear, but as development of the crop is slowed, some loss of yield may result.

Land forming and tillage may disrupt and destroy the continuum of fungal hyphae in the soil, such that the infection of VAM can be reduced in the next cotton crop, which may be expressed as Zn deficiency.

LONG FALLOW DISORDER

This syndrome is often manifested as zinc deficiency. Long fallows reduce the amount of VAM fungi in the soil, reducing the ability of cotton plants to take up zinc and phosphorus during early season growth. The crop usually grows out of the deficiency, but often with a yield penalty.

Factors that may aggravate Zinc nutrition

- Zn forms insoluble minerals in alkaline soils
- High rates of P fertilizers
- Cool, wet periods can reduce root growth and uptake of zinc due to low mobility in the soil
- Inhibition by high concentrations of other cations (Cu, Fe, Mn, Ca and Mg) in the soil

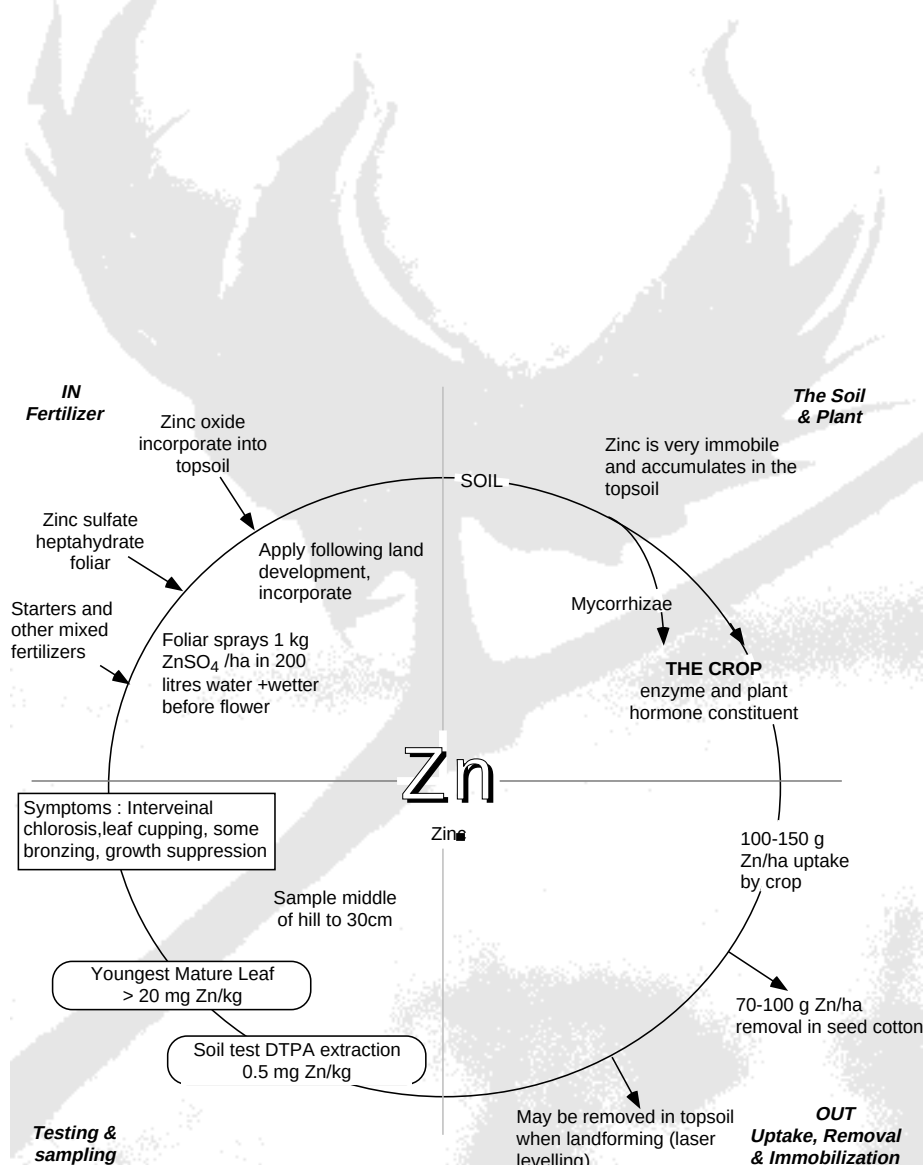


Figure 6-1.
Summary of Zinc
management issues.

OTHER ESSENTIAL NUTRIENTS

ZINC



Interveinal chlorosis (yellowing) is most commonly associated with zinc deficiency.

Photo Greg Constable.



Severe bronzing and cupping of leaves in zinc-deficient cotton.

Photo David Larsen.



Zinc-deficient cotton is often shorter and symptoms normally appear on the younger leaves.

Photo David Larsen.

IRON (Fe)

Iron (Fe) deficiency is most commonly associated with young cotton that has recently been subjected to waterlogging.

THE ROLE OF IRON IN THE PLANT

Iron is required for chlorophyll synthesis, and is involved in production of some enzymes involved in energy cycles. A continuous supply of iron is required for chlorophyll production.

UPTAKE AND REMOVAL OF IRON

Crops take up an average of 600 g Fe/ha of which about 80 g Fe/ha is removed in the seed cotton. Plants can absorb Fe through roots or foliage, and most Fe is taken up prior to boll filling.

IRON DEFICIENCY SYMPTOMS

The young leaves of iron deficient plants become yellow between the veins (chlorosis). This is confined mainly to the young growth, as iron is immobile within the plant. The veins usually remain green, unless the deficiency is severe. The whole leaf may eventually turn white. Although the plant may contain high concentrations of iron, most of it is in an unavailable form. Chlorophyll production is halted, the leaves lose their green colour. Iron deficiency has been observed in a wide range of crops and is most commonly associated with alkaline or calcareous soils.

CRITICAL IRON CONCENTRATIONS

Iron deficiency is indicated in the plant where the iron concentration is less than 30 mg Fe/kg in the youngest mature leaf at first flower. Concentrations in excess of 50 mg Fe/kg indicate adequate iron nutrition. The P/Fe ratio can aid identification of problems with iron nutrition; values of about 30 are desirable,

whereas very high values (greater than 60) indicate iron deficiency and leaves may show symptoms of iron chlorosis.

For soil analyses, the critical concentrations are 2 mg Fe/kg (DTPA extraction) or 80 mg Fe/kg (EDTA extraction).

IRON IN THE SOIL

Iron is plentiful in the soil, but mainly in forms not available to plants. Iron deficiency can be induced by high concentrations of other cations, particularly manganese. Applications of phosphorus and zinc can reduce iron uptake. Phosphorus reacts with soluble iron, producing insoluble iron minerals.

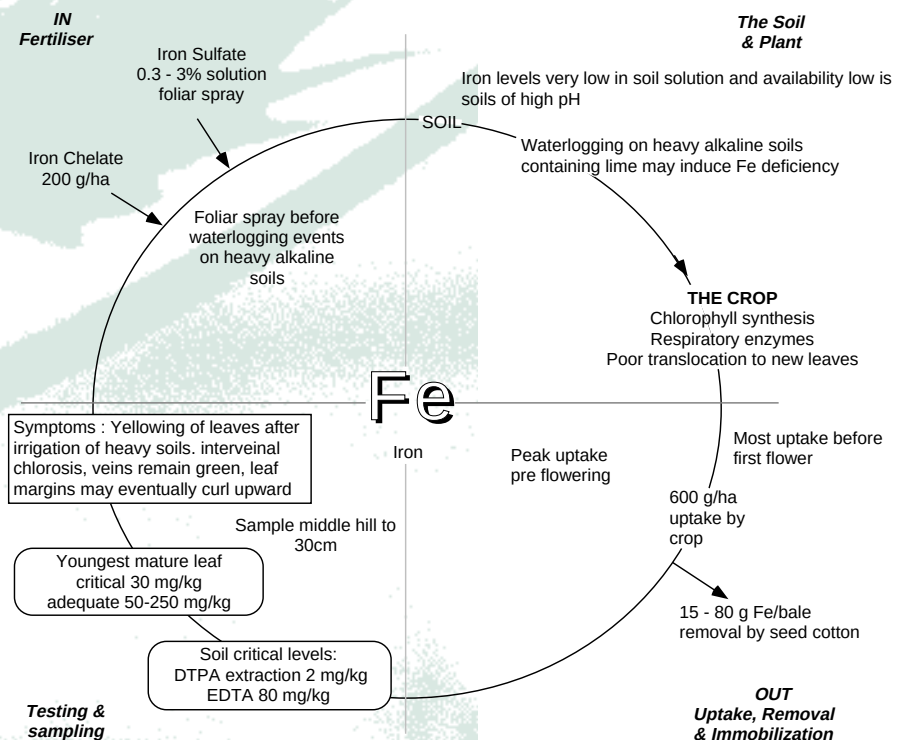
LIME-INDUCED IRON CHLOROSIS

When a soil is waterlogged, the passage of carbon dioxide out of the soil is blocked. The CO₂ concentration builds up in the soil solution forming bicarbonate ions. This increases soil pH, which in turn increases the concentration of bicarbonate and alkalinity in the leaf tissues. Under these conditions, iron becomes unavailable (ie the active iron (Fe²⁺) is converted to the inactive forms (Fe³⁺ and others) and symptoms of chlorosis appear. For further details, see the 'Waterlogging of Cotton' section in this manual.

IRON FERTILIZERS

Foliar application of iron sulfate before first flower or soil application of 200g Fe/ha as iron chelate should overcome iron deficiency symptoms.

Figure 6-2.
Summary of Iron
management issues.



OTHER ESSENTIAL NUTRIENTS

CONTINUED

IRON

Interveinal chlorosis (yellowing) in cotton leaves associated with iron deficiency.

Photo Greg Constable.



Iron deficiency in cotton. New leaves grow normally following removal of the stress (waterlogging).

Photo Greg Constable.



Iron deficiency may be evident on weeds as well as cotton.

Photo Greg Constable.



COPPER (Cu)

Copper (Cu) deficiency has not been observed in Australian cotton, although marginal levels of Cu are often observed in soil and plant analyses.

THE ROLE OF COPPER IN THE PLANT

Copper is a constituent of plant enzymes and is involved in carbohydrate metabolism. Copper deficiency can interfere with protein synthesis.

UPTAKE AND REMOVAL OF COPPER

Copper is required in trace amounts. Cotton crops take up about 50 g Cu/ha and about 20 g Cu/ha is removed in seed cotton.

CRITICAL COPPER CONCENTRATIONS IN PLANTS AND SOIL

Concentrations of more than 5 mg Cu/kg in the youngest mature leaf indicate sufficient copper uptake.

In the soil, a critical value of 0.3 mg Cu/kg using DTPA extraction or 2 mg Cu/kg using EDTA extraction. Copper is tightly bound to soil constituents and little is lost by leaching. Copper availability is reduced in alkaline soil.

COPPER DEFICIENCY SYMPTOMS

Symptoms include reduced growth and chlorosis of lower leaves. In severe cases, dieback of the terminal bud is preceded by peculiar distortions and tissues die at the tip or base of the terminal.

COPPER FERTILIZERS

Where deficient, copper can be applied as copper sulfate, as a foliar spray at 2 kg Cu/ha. Copper chelates or copper oxide are recommended for soil application at the same rate.

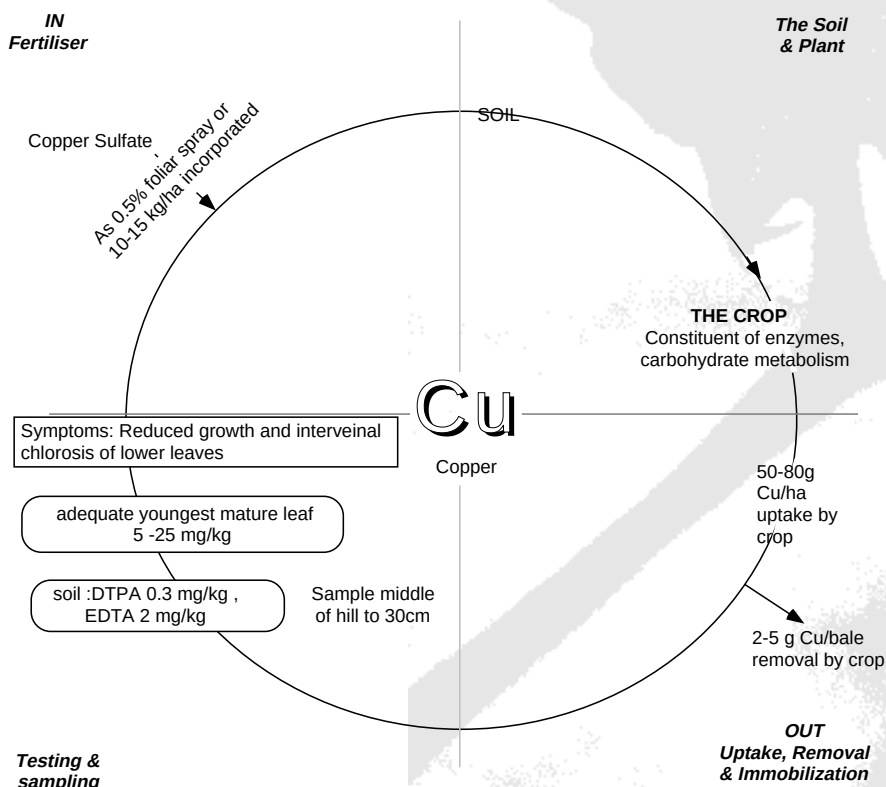


Figure 6-3.
Summary of Copper
management issues.

BORON (B)

Boron (B) is present in most soils in extremely small quantities. Most plant available B is derived from the organic matter and minerals. Because B is water soluble, it can be leached into the subsoil beyond the depth of crop roots.

THE ROLE OF BORON IN THE PLANT

Boron is involved in the uptake of calcium and is essential for fruiting, but is relatively immobile in the plant.

UPTAKE AND REMOVAL OF BORON

Irrigated cotton takes up to 400g B/ha and less than 100 g B/ha is removed in seed cotton. Boron is taken up throughout the season.

BORON DEFICIENCY SYMPTOMS

The first symptoms of B deficiency appear in new growth, as B is relatively immobile in plants. Young leaves become light green at their base. Older leaves become twisted and distorted. Flowers are deformed with the corolla shortened and folded inwards. Young petioles are irregularly thickened, darkly banded with dying pith. In severe cases, petioles split and young bolls are shed. Mild B deficiency can produce rank growth and deformed bolls. Deficiency symptoms vary with the stage of growth and the severity of the deficiency. B deficiency may occur during prolonged dry periods. Boron deficiency is most commonly a problem in sandy soils prone to leaching, although B availability is reduced in alkaline soils.

The range between B deficiency and toxicity is narrow. Toxic concentrations of B result in leaf cupping, chlorosis and death of leaf tissue in localised spots.

CRITICAL BORON CONCENTRATIONS IN THE PLANT

Boron deficiency symptoms may be observed in the youngest mature leaf (YML) at first flower where the B content is less than 15 mg B/kg and 18 mg B/kg for petioles. Boron content of 20-60 mg B/kg in the youngest mature leaf at first flower indicates sufficient B uptake.

Boron toxicity symptoms appear at concentrations >1000 mg B/kg in the plant and 70 mg B/kg in the soil.

BORON FERTILIZERS

Boron deficiency can be corrected by applying borax, boracic acid or other soluble B salts. Usual application rate is about 1 to 2 kg B/ha. Boron fertilizers are best applied to the soil before sowing. Foliar applications may be less successful. High fertilizer rates can cause Boron toxicity.

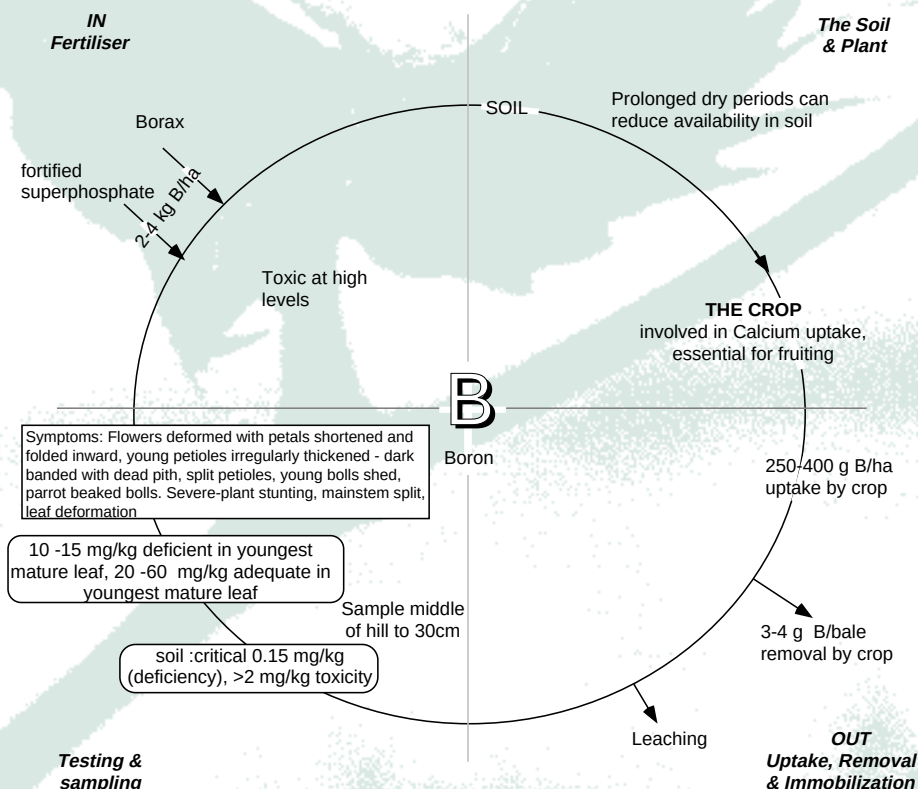


Figure 6-4.
Summary of Boron management issues.

CALCIUM (Ca)

Calcium (Ca) is abundantly available in most Australian cotton growing soils. These soils are alkaline (high pH) and often contain large amounts of lime. Limestone concretions (small white or grey round pellets) are evident in many soils.

THE ROLE OF CALCIUM IN THE PLANT

Calcium stabilises cell walls, improves cell membrane permeability and cell extension during germination of seeds, and the growth of seedlings and roots.

UPTAKE AND REMOVAL OF CALCIUM

Irrigated cotton crops can take up more than 220 kg Ca/ha, but remove only about 10 kg Ca/ha in harvested seed cotton (about 0.6 kg Ca/bale). Most of the calcium remains in the leaves and stems.

CALCIUM DEFICIENCY SYMPTOMS

Calcium deficiency has not been observed in Australian cotton. When induced in the glasshouse, calcium deficiency symptoms are expressed by petioles collapsing.

CRITICAL CALCIUM CONCENTRATIONS IN THE PLANT

Because calcium is rarely limiting, critical concentrations have not been established for cotton. However, 23,000 to 30,000 mg Ca/kg (ie 2.3-3% Ca) in the youngest mature leaf (YML) at first flower is considered adequate for cotton.

CALCIUM FERTILIZERS

Fertilizers that contain Calcium, eg lime (CaCO_3) and gypsum (CaSO_4) are normally applied at rates of 2 to 5 t/ha to improve soil structure and reduce soil sodicity (high sodium content).

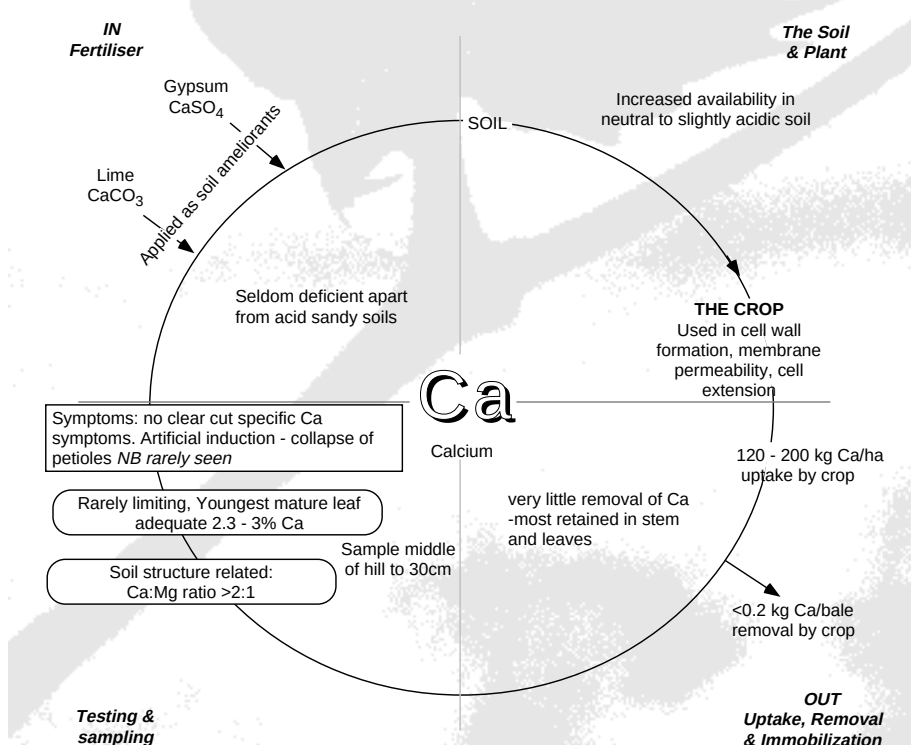


Figure 6-5.
Summary of Calcium
management issues.

MAGNESIUM (Mg)

Magnesium (Mg) deficiency has not been observed in field-grown cotton in Australia. Soils are generally high in Magnesium.

THE ROLE OF MAGNESIUM IN THE PLANT

Magnesium is an essential constituent of chlorophyll and Mg deficiency reduces photosynthesis. It is also important for cell respiration, nitrogen metabolism and oil synthesis. Plants with oily seeds, such as cotton, have a high requirement for Mg.

UPTAKE AND REMOVAL OF MAGNESIUM

Uptake of Mg ranges from 24-40 kg Mg/ha. Between 1 and 1.6 kg Mg/bale is removed in seed cotton (about 12 kg Mg/ha is removed, on average). Ammonium and potassium ions in the soil can depress the uptake of Mg.

MAGNESIUM DEFICIENCY SYMPTOMS

Magnesium is very mobile in the plant and is readily translocated from older to younger leaves. Deficiency symptoms (purple/red leaves with green veins) appear in the older leaves first, but have not been recorded in Australian cotton. The affected older leaves may senesce prematurely. Normal leaf senescence produces orange-red leaves that may be mistaken for magnesium deficiency. Plants recover slowly from deficiency after applying magnesium fertilizer. High application rates of magnesium fertilizers can cause magnesium toxicity in the crop.

CRITICAL MAGNESIUM CONCENTRATIONS IN THE PLANT

Critical concentrations for Magnesium have not been determined however adequate concentrations for the youngest mature leaf should be around 5000-9000 mg/kg (0.5–0.9%) at first flower.

The ratio of magnesium to other cations in the soil is important. Magnesium should comprise 4 to 5% of CEC; K:Mg ratio should be less than 1:5; Ca:Mg ratio should be more than 1, but to avoid problems with soil structure, it is desirable for the Ca:Mg ratio to be greater than 2.

MAGNESIUM FERTILIZERS

Very little magnesium fertilizer is used in Australian cotton production. Where fertilizers are required, dolomite lime (CaMgCO_3) or magnesium sulphate (MgSO_4) (foliar) is recommended.

SOILS OF HIGH MAGNESIUM CONTENT

High magnesium content is a significant problem in Australian cotton production. A low Ca:Mg ratio (less than 2) usually indicates high Mg content of the soil. To overcome this, apply either gypsum or lime (but not dolomite).

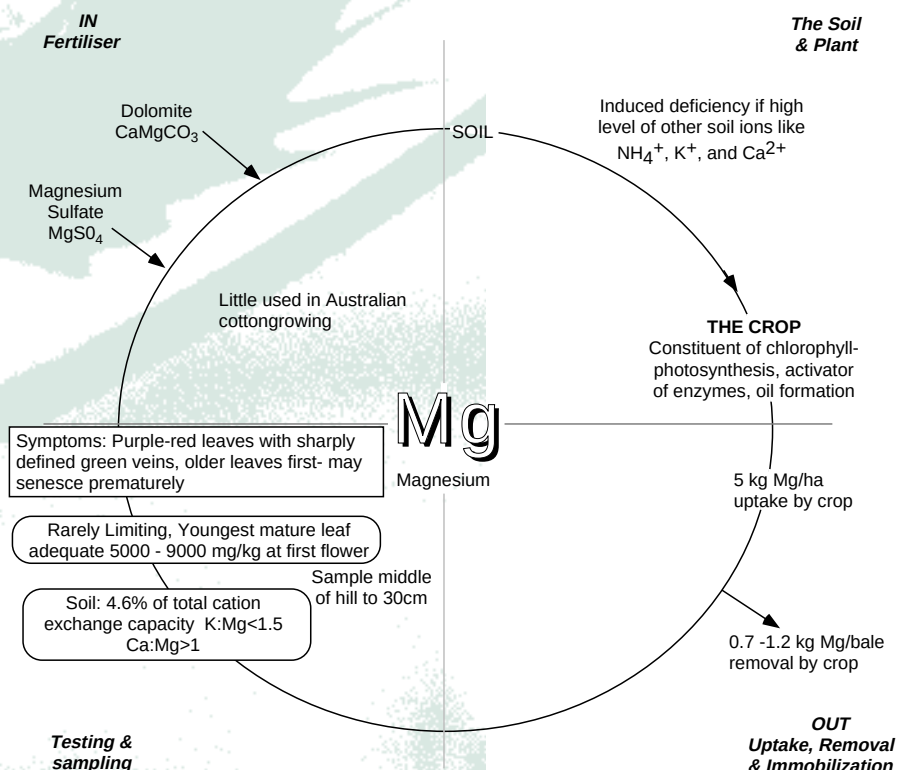


Figure 6-6.
Summary of Magnesium management issues.

OTHER ESSENTIAL NUTRIENTS

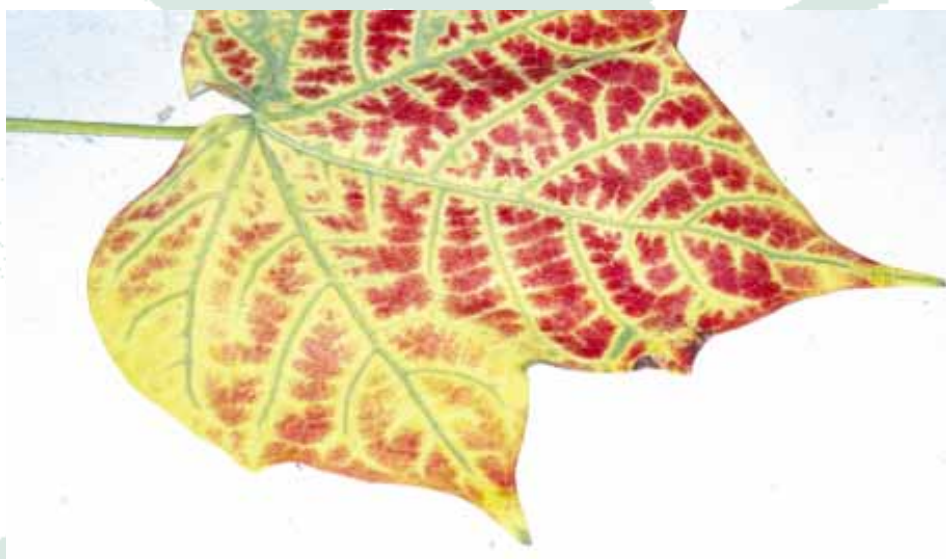
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MAGNESIUM



Early phase of magnesium deficiency.

Photo Ian Rochester.



Advanced stage of magnesium deficiency.

Photo Ian Rochester.

SULFUR (S)

Sulfur (S) has been observed in Australian cotton, particular in sandy soils where sulfate can be leached to the subsoil and in dryland cotton.

THE ROLE OF SULFUR IN THE PLANT

Sulfur plays an important role in photosynthesis and is required for protein synthesis, activation of enzymes, production of vitamins and synthesis of oils.

UPTAKE AND REMOVAL OF SULFUR

Irrigated cotton takes up 30-50 kg S/ha and removes about 10 kg S/ha (about 1 kg S/bale) in seed cotton. Plants take up S as sulfate, which is derived either from the mineralisation of soil organic matter, or sulfate dissolved in irrigation water and rainfall.

SULFUR DEFICIENCY SYMPTOMS

Sulfur is relatively immobile in the plant, and deficiency symptoms first appear as yellowing of the young leaves, while older leaves remain green. Plants appear spindly with short, slender stems. Severely deficient plants have fewer fruiting branches and boll size is reduced. S deficiency is rare in irrigated cotton, although S deficiency has been noted in dryland crops, possibly due to leaching of sulfate down the soil profile during fallow periods.

CRITICAL SULFUR CONCENTRATIONS IN THE PLANT

Concentrations less than 2000 mg S/kg (0.2%) in the youngest mature leaf at flowering may produce deficiency symptoms. Adequacy concentrations range from 2000-4000 mg S/kg (0.2–0.4%S) in the youngest mature leaf at flowering.

If S fertilizer is needed but cannot be supplied with other nutrients, the most suitable fertilizer is gypsum.

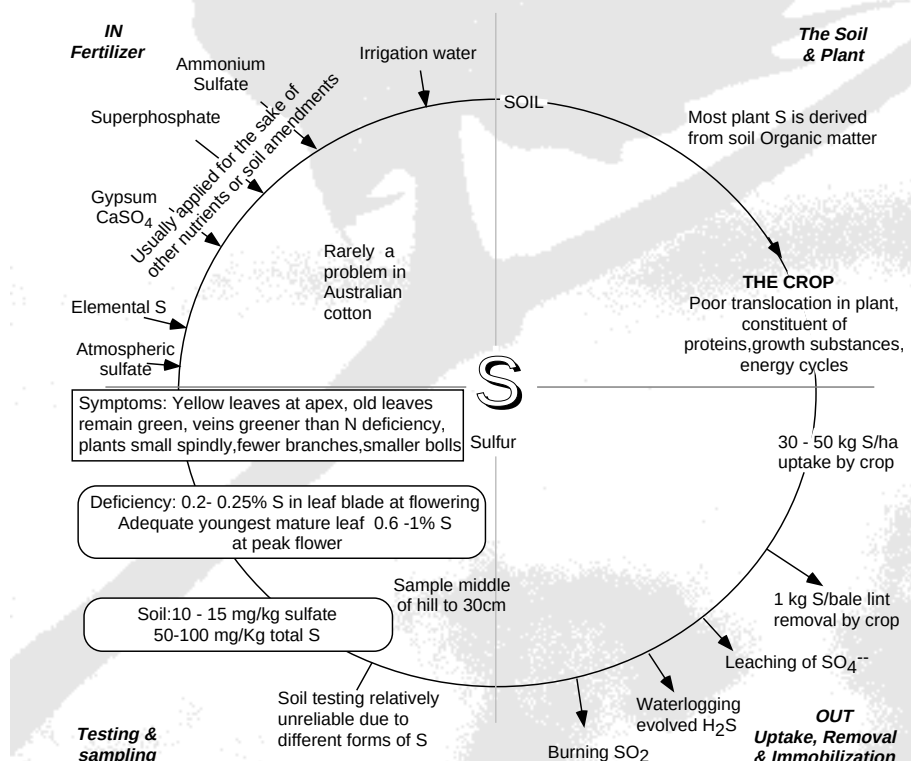
SOIL SULFUR

Sulfur occurs in many forms in the soil. Available sulfur (sulfate - SO_4^{2-}) content of 10-15 mg sulfate-S/kg or 50–100 mg/kg total S indicates adequate sulfur nutrition.

SULFUR FERTILIZERS

Soil S content can be augmented by fertilizers applied to supply other nutrients such as ammonium sulfate and superphosphate; by soil ameliorants such as gypsum; in rain and particularly in irrigation water.

Figure 6-7.
Summary of Sulfur
management issues.



OTHER ESSENTIAL NUTRIENTS

CONTINUED

SULFUR

*Sulfur-deficient cotton plant
(foreground - yellow) compared with
sulfur-fertilized plant (back).
Photo Guy Roth.*



MANGANESE (Mn)

Manganese (Mn) rarely limits cotton growth in Australia. High levels of Mn can accumulate in waterlogged cotton.

THE ROLE OF MANGANESE IN THE PLANT

Manganese is a constituent of enzymes associated with carbohydrate and protein synthesis.

UPTAKE AND REMOVAL OF MANGANESE

Cotton takes up about 450g Mn/ha. While actively growing, cotton requires about 4 g Mn/ha/day. Mn is taken up throughout the growing season, but peak requirement is between squaring and boll filling. About 60 g Mn/ha is removed in seed cotton (8 g Mn/bale).

CRITICAL MANGANESE CONCENTRATIONS

Manganese deficiency is rarely seen in the field but is more likely to occur on highly alkaline soils. The critical concentration for the youngest mature leaf (YML) is 25 mg Mn/kg. At first flower, the Mn content of the YML should be between 50 and 350 mg Mn/kg. The range of manganese concentrations in plant defining deficiency and toxicity is relatively narrow.

Soil having less than 2 mg/kg DTPA-extractable Mn indicates a manganese fertilizer is required.

MANGANESE DEFICIENCY / TOXICITY

Mn deficient plants show leaf cupping and interveinal chlorosis, starting with the younger leaves. The terminal bud remains alive but the upper or bud leaves turn yellow and may have necrotic spots.

Manganese toxicity is more common in acid soils. Under these conditions, cotton leaves become crinkled, mottled and chlorotic and may subsequently die. High concentrations of manganese can induce iron and zinc deficiency in plants.

MANGANESE IN THE SOIL

Several forms of manganese exist in the soil, of which only one, (Mn²⁺) is taken up by plants. Most soils supply sufficient manganese for plant growth. Manganese deficiency can be induced

where the soil pH is raised through the application of lime or N or P fertilizers. During flood irrigation, the availability of manganese may dramatically increase in the soil and crop uptake may exceed requirement, with the potential for producing toxic Mn concentrations in the plant.

MANGANESE FERTILIZERS

Manganese deficiency can be overcome by applying a soluble Mn fertilizer in a band using 5-10 kg Mn/ha. Alternatively, two or three foliar applications of 1-2 kg Mn/ha as manganese sulfate may be more effective where soils are alkaline. No yield responses by cotton to Mn application have been reported in Australia.

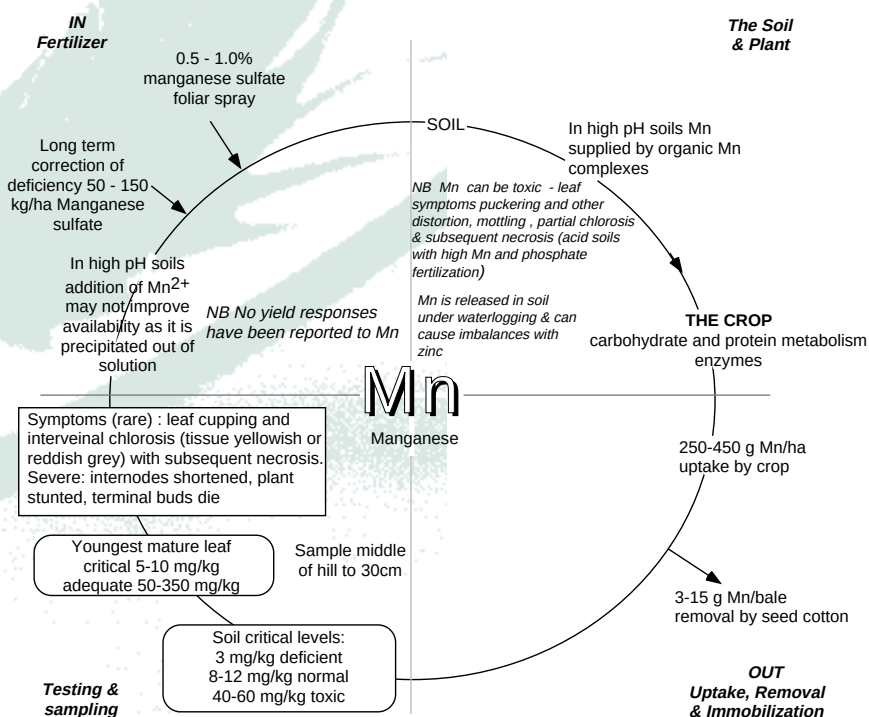


Figure 6-8.
Summary of Manganese management issues.

MOLYBDENUM (Mo)

Molybdenum (Mo) deficiency has not been encountered in field-grown cotton in Australia.

ROLE OF MOLYBDENUM IN THE PLANT

Molybdenum has several important roles:

- it is essential for effective nitrogen fixation by rhizobia bacteria associated with legume roots. Active nodules contain 6–20 mg Mo/kg
- it is also required for synthesis and activity of the nitrate reductase enzyme
- role in phosphorus metabolism in the plant

UPTAKE AND REMOVAL OF MOLYBDENUM

As little as 10 g Mo/ha is taken up by cotton. Only a portion of this (possibly only 2-5 g Mo/ha) is removed in seed cotton. Uptake of Mo is increased with phosphate application.

MOLYBDENUM DEFICIENCY SYMPTOMS

Where molybdenum deficiency occurs, it would normally be detected in legume crops, as they have a higher requirement for Mo. Nitrate will accumulate in Mo-deficient plants, which exhibit signs of nitrogen deficiency. Where Mo deficiency has been induced, leaves show interveinal chlorosis, followed by the development of a greasy leaf surface with interveinal thickening, leaf cupping and eventually white or grey necrotic spots on the leaf margin.

Figure 6-9.
Summary of Molybdenum management issues.

CRITICAL MOLYBDENUM CONCENTRATIONS

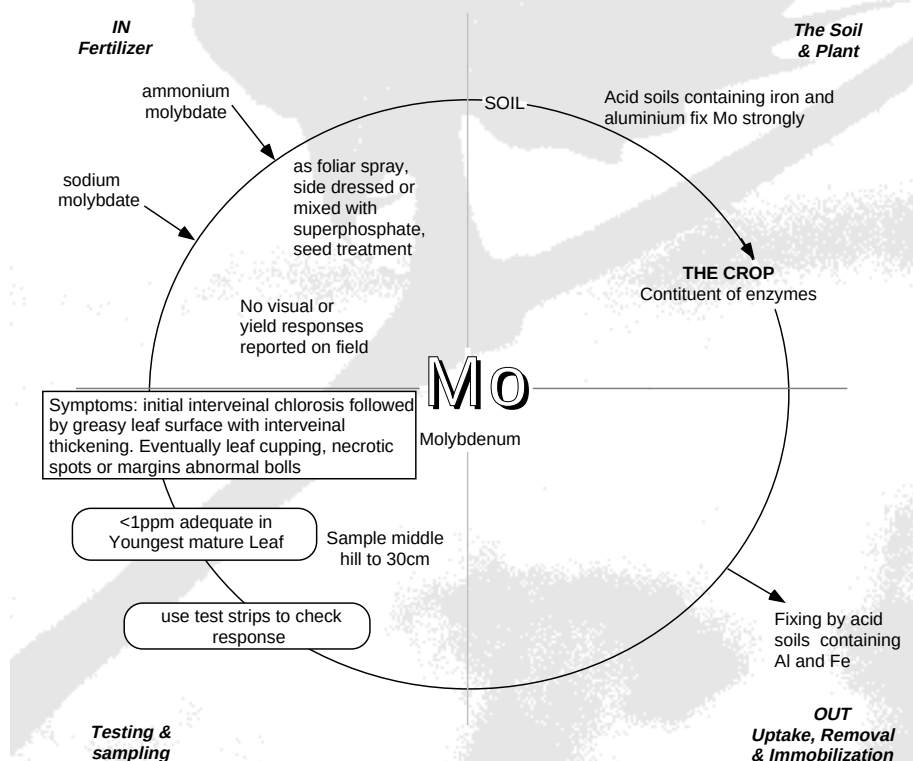
Molybdenum occurs in very low concentrations in the plant and soil. Analyses of soil and plant material by commercial laboratories indicate molybdenum concentrations below the limit of detection of their equipment. Healthy plants may contain as little as 0.1 mg/kg. Young cotton leaves may contain 2-3 mg Mo/kg.

MOLYBDENUM IN THE SOIL

Acid soils containing free iron and aluminium oxides strongly fix molybdenum.

MOLYBDENUM FERTILIZERS

Molybdenum deficiency can be overcome by application of ammonium molybdate or molybdenum trioxide, which are added to superphosphate. Molybdenum can also be applied as foliar sprays or as a seed treatment. Overuse of molybdenum fertilizer can induce an imbalance with copper.



SOIL SAMPLING AND ANALYSIS

TIMING OF SOIL SAMPLING

Sampling to assess soil fertility (ie availability of N and other nutrients) is more effective when performed at the same time each year, preferably before the crop is sown. Where an indication of the N fertilizer requirement is sought, the preferred time to sample soil is from July to September. When fertilizer is to be applied prior to this, a small, unfertilised area should be left from where soil samples can be collected.

WHERE TO SAMPLE SOIL

A grid or zigzag sampling system is recommended (see Figure 7-1). For fields that are not uniform with respect to soil type, topography, management history or crop growth, the field should be divided into homogenous groups based on these criteria. Separate soil samples should be collected from each area of the field and labelled accordingly. It is often advantageous to sample areas of poor as well as good crop growth where a problem has been observed in previous crops. Avoid collecting samples on sites such as old fence lines, filled in irrigation channels, near trees or old stumps, or if the soil is excessively wet.

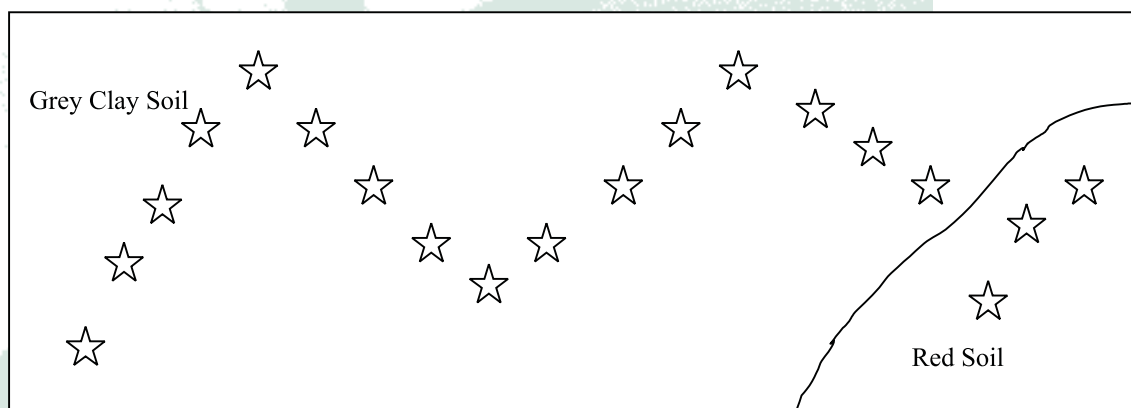
DEPTH OF SOIL SAMPLING

The recommended sampling depth for irrigated cotton is 30 cm. When sampled from the top of the hill, this procedure provides information from the critical root zone area. For dryland fields that have been fallowed, an additional sample to 1 m may better indicate the amount of nitrate-N stored in the subsoil.

NUMBER OF SOIL SAMPLES

The number of samples required depends on soil variability within the field. The concentration of most nutrients (especially N and P) can vary widely, even in apparently uniform fields. In general, at least 10 samples should be collected within a 200 ha area. Cores from similar soil types may be bulked (to reduce the cost of testing) and thoroughly mixed prior to sending to a laboratory. About 500 g is required for a comprehensive soil analysis.

*Figure 7-1.
Example of
sampling pattern
for a 200 ha field.*



SAMPLING TECHNIQUE

A shortened coring tube, similar to those used for inserting neutron probe access tubes is often the most effective method of collecting soil samples. This can be performed quickly by hand. An augur is the next option, but slower. If these tools are not available, then a shovel and a ruler could be used where sampling is required to a depth of 30 cm.

Soil samples should be sent to the laboratory on the day they are collected. If this is not possible, they should be dried at low temperature ($<50^{\circ}\text{C}$) as quickly as possible to minimise chemical changes which occur during storage or transit. Soil samples can be dried in a low temperature oven or spread on plastic sheets in the sun.

Special care is required when determining soil nitrate, which is easily lost from the soil through microbial activity. Soil samples that cannot be dried immediately should be frozen until they can be dried.

PACKAGING SAMPLES

To ensure soil samples are not contaminated, put them in unused plastic bags, seal with heavy-duty rubber bands and label each bag with a permanent waterproof marker. It is useful to keep note of pertinent information such as; field number, date sampled, sample depth, soil structure (good, poor, compacted), cropping history etc. A map grid reference for each sample may be useful so that each chemical analysis forms part of a larger database and subsequent samples can be collected from the same site. If more than 500 g of soil is collected, reduce the amount of soil by mounding the soil into a cone shape on a clean plastic sheet, divide into four and discard opposite quarters.

INTERPRETING SOIL TESTS

To interpret soil nitrate analyses, use NutriLOGIC to estimate the N fertilizer requirement. Refer to the 'NutriLOGIC – predicting N fertilizer requirements of cotton' chapter in this manual.

For other nutrients, consult the tables in the 'Interpretation of soil, petiole and leaf analyses' chapter of this manual, which indicate critical values for the nutrients analysed with various extraction methods. This will indicate whether a particular nutrient is deficient or in excess. Note: various laboratories use different soil testing procedures (eg extracting solutions) which indicate different levels of nutrient availability. They may also report those values with different units to other laboratories.

SOIL TESTING LABORATORIES

Contact your local rural merchandise supplier. They can organise the samples to be sent for you and will deal directly with laboratories. Ensure the laboratory is registered by the National Association of Testing Authorities (NATA), Australia.

LEAF AND PETIOLE ANALYSES

Plant analyses provide information about the nutritional status of a crop and can indicate nutrient deficiencies which, if identified early enough, may be rectified by applying the appropriate fertilizer.

Leaf and petiole analyses have been calibrated for cotton. Critical concentrations for all nutrients have been identified for cotton at various stages of development. The petiole is normally used to determine the crop's nitrogen (and potassium) status early in the season. Petiole nitrate analysis can be a reliable means of indicating crop N nutrition, and indicate where further N fertilizer application is required. Leaf samples can be taken throughout the growth of the crop, to provide information on a wider range of nutrients. Neither analysis indicates the quantity of each nutrient taken up over the growing period.

LEAF AND PETIOLE SAMPLING

At least 50 petioles are collected from a uniform area within a crop, the petiole chosen is normally the one that connects the youngest mature leaf to the stem. This is usually the fifth unfolded leaf from the top of the plant. Collect petiole or leaf samples only in an actively growing crop that is not stressed either from waterlogging or lack of moisture, or where insect or disease problems are severe.

Up to 50 petioles and 30 leaves normally supply sufficient fresh material for nutrient analysis.

Collect the samples systematically from average sized plants from throughout the crop, following a transect across the field or simply moving up and down and across rows.

If the majority of the plants throughout the crop have been 'tipped-out', then sample from the stem with the most actively growing terminal.

The plants selected should be at the same stage of growth. Where a nutritional problem is suspected, separate collection of healthy and unhealthy plants may aid the diagnosis.

TIMING OF PETIOLE COLLECTION

Concentrations of nitrogen and potassium are highest in very young plants and decline as the plant matures. Therefore, it is important to indicate the stage of crop growth in order to interpret the chemical analysis of the plant tissue. Because petiole nitrate-N declines very rapidly, it is imperative that the stage of growth (days after sowing, or more accurately, day degrees) is noted. The optimal time to sample is between 500-1000 day degrees after planting. Preferably, 3 petiole sampling times, 10 days apart, should be undertaken for each crop, starting at squaring. This allows N deficiency to be corrected before crop development is substantially affected

The most informative means of using petiole nitrate-N analyses is to collect petioles each week, and examine the rate of decline in nitrate-N concentration. The NutriLOGIC program can do this and indicate whether further N fertilizer is required to maximise lint yield in a particular field, starting at squaring. This sampling time allows imminent N deficiency to be corrected before yield potential is reduced.

Because petiole nitrate levels are dynamic, it is important only to collect petioles from crops not subjected to recent environmental stresses (eg cold shock or waterlogging or drought). Because petiole nitrate-N concentrations normally change throughout the day, samples should be collected at the same time each day. Avoid sampling water-stressed cotton, ie do not sample immediately before or after an irrigation. Sample petioles on sunny days only, as overcast weather for more than 48 hours can affect petiole nitrate concentrations. Normally, petiole nitrate-N declines from about 30,000 ppm at squaring to 1000 ppm or less at the end of flowering.

Leaf analysis (as opposed to petiole analysis) provides information on all essential plant nutrients. Analysing

leaves for a wide range of nutrients gives a good understanding of the crop's nutritional status and can be used to plan future fertilizer management.

HANDLING AND PACKAGING

Plant material (petioles and leaves) starts to deteriorate soon after sampling and decomposition and respiration can alter nutrient content. This will affect the analytical results and the interpretation of the results may be misleading.

The samples should be loosely packed in a paper bag or envelope and stored in a cool place (refrigerator) until they are dried or dispatched. Send plant samples to the laboratory as soon as possible: make sure they will not arrive on weekends or public holidays when laboratories are closed.

Plastic bags cause leaves to sweat and should not be used unless the sample is kept cool.

The samples can be dried in an oven at around 60°C for 24 hours or until crisp (microwave ovens are not recommended).

Chemical residues on the leaf, or soil splashed from rain, may affect nutrient analyses. Avoid sampling after foliar fertilizers have been applied. Rinsing leaves with water can reduce residues, but may leach nutrients from the leaves.

LEAF COLOUR METERS

The future development of leaf colour meters (such as the SPAD meter) may prove highly beneficial to cotton growers, whereby measurements of leaf greenness are correlated to crop N nutrition and the need for N fertilizer application. This in-field test may replace the petiole nitrate test, enabling fertilizer management decision to be made without the need for chemical analyses. The application of growth regulators (such as Pix) which affect leaf thickness and colour may interfere with SPAD meter readings.

INTERPRETING LEAF AND PETIOLE RESULTS

To interpret the results of petiole nitrate-N analyses, use the NutriLOGIC program (see the 'NutriLOGIC – predicting N fertilizer requirements of cotton' chapter in this manual).

To interpret the concentrations of other nutrients, refer to the tables in the 'Interpretation of soil, petiole and leaf analyses' chapter in this manual.

INTERPRETATION OF SOIL, PETIOLE AND LEAF ANALYSES

Several laboratories throughout the Australian cotton-growing regions perform routine analyses of soil, petiole and cotton leaves. Because they do not all use the same extraction procedures and operate different analytical equipment, results are not necessarily comparable between laboratories.

SOIL ANALYSIS

The following table relating to soil analyses aims to compare the nutrient concentrations determined by commonly used methods. The critical concentration of each nutrient is indicated, below which a response to fertilizer addition could be expected.

Also, refer to the 'Soil sampling and analysis' chapter of this manual.

PETIOLE AND LEAF ANALYSES

Petiole and leaf tissue analyses are conducted using more uniform methodology and are therefore more comparable between laboratories than soil analyses. However, variation between laboratories may result from the type of analytical equipment used.

Petiole nitrate analysis: Collect petioles from the same mainstem node between squaring and late-flowering (500–1000 day degrees). The NutriLOGIC program allows for petiole nitrate analysis data to be entered and a calculation of the growing day degrees made and the N fertilizer requirement is estimated. Table 9-2 refers to nutrient concentrations found in petiole sampled at 750 day degrees. Refer to chapters 'Leaf and petiole analysis' and 'NutriLOGIC – predicting N fertilizer requirements of cotton'.

Table 9-1.
Soil analysis and
interpretation

Nutrient	Extractant	Critical value	Comments
Nitrogen (N)	Nitrate in aqueous extract	Depends on soil sampling time, but generally >20-30 ppm	Refer to NutriLOGIC. Some labs report values as nitrate rather than N (ie 4.4 times higher)
Phosphorus (P)	Bicarbonate Lactate	6 ppm 10 ppm	Take care with sampling soil in fields where P has been previously applied in bands
Potassium (K)	ammonium acetate	0.2 - 0.4 meq/100g 100 - 150 ppm	
Sulfur (S)	Acetate buffer	5 - 10 ppm	
Calcium (Ca)	ammonium acetate	2 - 3.5 meq/100g 400 - 700 ppm	
Magnesium (Mg)	ammonium acetate	1 - 1.2 meq/100g 120 - 140 ppm	
Zinc (Zn)	DTPA EDTA	0.5 ppm 4 ppm	
Iron (Fe)	DTPA EDTA	2 ppm 80 ppm	
Copper (Cu)	DTPA EDTA	0.3 ppm 2 ppm	
Manganese (Mn)	DTPA Quinol acetate	2 ppm 65 ppm	
Boron (B)	MgCl ₂ CaCl ₂ /mannitol Hot water	1.5 ppm 0.4 ppm 0.15 ppm	
Molybdenum (Mo)		Not reliable	Mo availability increases with soil pH. Usually not a problem in alkaline soils

Table 9-2.

Optimum nutrient concentrations in leaves and petiole samples at flowering.

Leaf analysis: The youngest mature leaf is normally sampled; this usually corresponds to the fifth node from the top of the plant. Leaves can be sampled from squaring to boll fill. The optimum concentration range for the essential plant nutrients is given in Table 9-2.

However, the concentrations of some nutrients change with leaf age and the stage of crop growth. Leaf N, for example, declines with time, whereas leaf Ca increases. An indication of the changes in leaf nutrient concentrations is given in Table 9-3.

Nutrient	Petiole	Leaf	Comments
		Normal range	
Nitrogen (N)	20,000 ppm	3.5 – 4.5 %	Refer to NutriLOGIC for petiole nitrate interpretation
Phosphorus (P)	12,000 ppm	0.28 - 0.5 %	
Potassium (K)	10,000 ppm	1.5 - 3.0 %	
Sulfur (S)		0.6 – 1.2 %	
Calcium (Ca)	5,000 ppm	0.4 - 6.0 %	
Magnesium (Mg)	2,000 ppm	0.4 - 0.9 %	
Zinc (Zn)		20 – 60 ppm	
Iron (Fe)		50 – 350 ppm	
Copper (Cu)		5 – 25 ppm	
Manganese (Mn)		50 – 200 ppm	
Boron (B)		50 – 80 ppm	
Molybdenum (Mo)		0.4 – 0.9 ppm	Very low concentrations, hence Mo is hard to detect/analyse

Table 9-3.

Leaf nutrient concentrations assessed throughout the cotton season - the cotton crop yielded more than 9 bales/ha.

Nutrient	Day degrees from sowing			
	800	1000	1300	1800
Nitrogen (N)	4.0 %	4.13 %	3.73 %	2.72 %
Phosphorus (P)	0.33 %	0.34 %	0.33 %	0.33 %
Potassium (K)	1.77 %	1.90 %	1.73 %	1.27 %
Sulfur (S)	0.66 %	0.80 %	1.01 %	1.25 %
Calcium (Ca)	4.03 %	4.12 %	5.06 %	6.67 %
Magnesium (Mg)	0.92 %	0.94 %	1.04 %	1.11 %
Zinc (Zn)	20 ppm	20 ppm	20 ppm	20 ppm
Iron (Fe)	204 ppm	137 ppm	130 ppm	175 ppm
Copper (Cu)	6.8 ppm	6.7 ppm	6.0 ppm	5.1 ppm
Manganese (Mn)	84 ppm	84 ppm	94 ppm	111 ppm
Boron (B)	70 ppm	81 ppm	80 ppm	80 ppm
Molybdenum (Mo)	1.5 ppm	1 ppm	<1 ppm	<1 ppm

NutriLOGIC - PREDICTING THE N FERTILIZER REQUIREMENT OF COTTON

The N fertilizer requirement of cotton can be predicted from pre-sowing soil nitrate and/or cotton petiole nitrate analyses. This is the basis for the NutriLOGIC program. In determining the N fertilizer requirement, the program takes into account:

- soil factors (eg texture, compaction and predisposition to waterlogging)
- the district in which the cotton will be growing, as hotter (longer season) areas require higher N rates to maximise lint yields
- the time the soil or petiole samples were collected

ABOUT NutriLOGIC

NutriLOGIC is a user-friendly decision aid for nitrogen fertilizer management. NutriLOGIC is a component of CottonLOGIC, a computerised decision support system developed by the CSIRO and Cotton CRC, to provide the cotton industry with access to the latest research.

NutriLOGIC allows growers to interpret their pre-sowing soil nitrate analyses to indicate the N fertilizer requirement of their fields before the cotton is sown. It provides growers with a means of identifying N deficiency in cotton crops based on petiole nitrate analyses. It also contains information on critical levels of all nutrients in soil and plant tissues.

The calibrations within the NutriLOGIC program were derived by Dr Greg Constable and Dr Ian Rochester of CSIRO Cotton Research Unit, Narrabri. The program predicts the economic optimum N fertilizer rate based on the cost of N fertilizer and the price received

for cotton lint. Soil or petiole nitrate levels, regional yield responses and sampling time are the main inputs of the program.

WHAT IS ECONOMIC OPTIMUM N RATE?

Economic optimum N rate is the N application rate where the cost of applying one additional unit of fertilizer equals the return from the lint produced from that additional unit of fertilizer input. The NutriLOGIC program predicts the economic optimum N fertilizer rate, according to the typical N response curve (Figure 10-1).

Because the cost of applying N fertilizer is relatively inexpensive, compared with the return per kg lint, the economic optimum N rate is usually very close (often only 5–10 kg N/ha less) to that needed to produce the maximum yield. If fertilizer prices were to escalate, or if cotton prices were to fall dramatically, the economic optimum yield would be appreciably lower than the maximum yield.

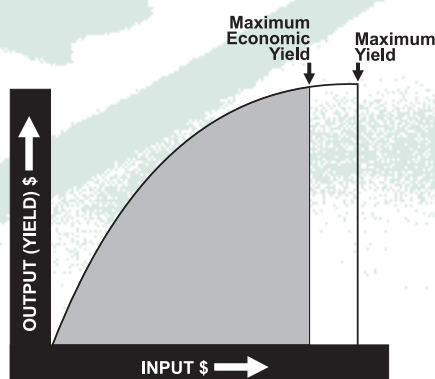


Figure 10-1.

A typical N response curve showing the proximity of the economic optimum N fertilizer rate and the N rate producing the maximum yield.

SOIL NITRATE-N ANALYSIS

Soil samples can be collected between July and September and analysed for nitrate-N (Refer to chapter – Soil sampling and analysis). NutriLOGIC produces an indication of the N fertilizer required by each field (soil sample) based on the nitrate-N concentration from the soil analysis. Three parameters must be entered into the data entry screen:

- Soil nitrate-N (ppm=mg N/kg) (nitrate analyses performed by a specialist laboratory)
- soil type (indicative of soil texture, compaction, drainage – refer to SOILpak)
- regional data (recognised through the CottonLOGIC farm set-up, which is a necessary step before using NutriLOGIC)

NutriLOGIC suggests N fertilizer application rates assuming the soil samples have been taken from 0–30 cm depth in an irrigated production system. NutriLOGIC will modify the N fertilizer rate according to the month the soil samples were taken. NutriLOGIC contains no calibration for soil sampled earlier than July or later than September. An example of a NutriLOGIC calibration is indicated in Figure 10-2, where the suggested N fertilizer application rate declines with increasing soil nitrate-N.

Soil textural classes are somewhat arbitrary, but make allowance for better N fertilizer use efficiency and better drainage in lighter textured soils. Loamy clays and light clays constitute the better soils; medium clays (eg most grey clays) constitute the average soils used for cotton growing; heavy clays (eg black earths and heavy grey clays) present more problems with drainage, waterlogging and poor N fertilizer use efficiency.

PETIOLE NITRATE-N ANALYSIS

Petiole analyses are performed on cotton crops from squaring to mid-flowering. The program requires the input of four parameters:

- petiole nitrate-N (ppm=mg/kg) (nitrate analyses performed by a specialist laboratory)
- soil condition (indicative of soil texture, compaction, drainage – refer to SOILpak)
- day degrees (can be estimated by NutriLOGIC but better accessed from the Australian Cotton CRC web site for your district (www.cotton.crc.org.au/tools))
- regional N response data (district recognised from the CottonLOGIC farm set-up)

The ideal time of the season to start petiole sampling is at squaring. This is usually early to mid December (refer to chapter - Leaf and petiole analyses). It is important not to sample in a crop that is experiencing water stress (ie waterlogged or droughted) or has experienced prolonged cloudy periods in the past few days.

NutriLOGIC will indicate whether the crop appears to have sufficient N or requires additional N fertilizer. The program will use a single test, although greater accuracy will be achieved if three tests are conducted at weekly (or 10 day) intervals. NutriLOGIC will then calculate the rate of change in nitrate-N concentration and suggest a rate of N application where needed.

OTHER NUTRIENTS

At this stage, NutriLOGIC will only provide an interpretation for nitrate analyses. It does however, contain tables showing deficiency information for all other nutrients through the information button.

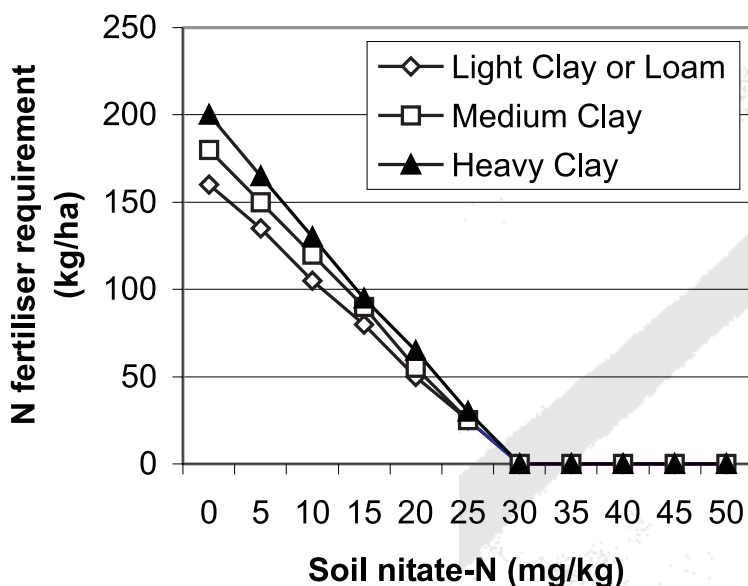


FURTHER DEVELOPMENT

The development of NutriLOGIC is continuing with further evaluation throughout several cotton-growing regions. Experiments are conducted to compare the economic optimum N rate suggested by NutriLOGIC with higher and lower rates of N fertilizer. In most instances, the N rate indicated by NutriLOGIC was close to the economic optimum N rate identified from the field experiments. In time, nutrients other than N will be included in NutriLOGIC.

To access NutriLOGIC, contact the Australian Cotton Technology Resource Centre 02 6799 1534 to register for your copy of CottonLOGIC (free of charge to the Australian cotton industry).

Figure 10-2.
N fertilizer requirement of cotton as suggested by NutriLOGIC. The N fertilizer application rate declines as soil nitrate-N increases. The suggested N application rate is modified by the soil textural class (ie less N is needed on lighter soils). NutriLOGIC contains calibrations for each cotton-growing region.



PREMATURE SENESCENCE

Premature senescence is a potassium-related disorder that can occur in cotton regardless of the supply of potassium from the soil. Other nutrients, including phosphorus, have been found to be deficient in affected plants, although not to the same extent as potassium. The disorder is chiefly caused by the interaction of high boll loads and stresses such as waterlogging, cool, cloudy weather or soil compaction that interfere with the plant's ability to take up potassium, which is required in large amounts between flowering and boll filling. Deficiencies at this time will have detrimental effects on lint yield and fibre quality. There is also evidence of an association with *Alternaria* infection, although both can occur independently.

RISK FACTORS

PLANT DEVELOPMENT

High boll loads are not a direct cause of premature senescence, as many high yielding crops in Australia do not express symptoms. However, high boll loads may contribute to the stress placed upon a crop, which combined with other stresses, may allow plants to succumb to the syndrome.

Fruit retention should be monitored where premature senescence has been a problem in the past. The potential for premature senescence is indicated where the bottom five fruiting branches exceed 70% square retention.

PLANT STRESSES

- **Environmental stress** factors such as cool, cloudy weather and low temperatures in the late season can inhibit the crop's ability to take up potassium, even in soils that are not K deficient
- **Soil compaction** can also restrict K uptake
- **Waterlogging** from rain or irrigation is another stress that prevent K uptake in K rich soils
- **Inadequate N** nutrition for a highly loaded crop

LEAF BLADE AND PETIOLE K

The crop is more likely to be responsive to foliar K when petiole K is less than 4% (normal range 4-7%) or leaf blade K less than 1% (normal range 1-3%) when sampled before first flower. Australian research has shown yield responses in about half of the cases with these concentrations of K. Badly affected plants may have up to 74% less K in their leaves than healthy plants.

COTTON CULTIVARS

Some varieties are less likely to develop premature senescence. It is most important to select varieties less prone to premature senescence where symptoms have appeared in previous cotton crops. As a rule, long season varieties are less likely to develop the disorder. Short season varieties have a higher daily requirement for K during peak boll-fill. Generally, okra leaf varieties are regarded as more susceptible, however breeding programs are addressing this problem.

INGARD®

Ingard varieties often have high early fruit retention and heavy boll load. Comparisons of Ingard and non-Ingard lines from the same parent indicate that the Ingard line is more likely to develop premature senescence than the parent.

SYMPTOMS OF PREMATURE SENESCENCE

It is often too late to correct a problem when symptoms appear. Crops should be monitored for boll load and risk of premature senescence assessed with regard to field history, weather conditions, variety, and soil fertility.

The first visible signs of premature senescence is a slight yellowing of the veins of the youngest leaf. The third or fourth leaf turns yellow then rapidly red or bronze while the underside of the leaf remains green. The bronzing then spreads down the plant and the upper leaves fall from the plant. In severe cases, bronzing occurs in the middle canopy. As the season progresses, premature senescence symptoms can spread and the crop is defoliated. Plants in the edge rows or near gaps are less affected.

The symptoms can be distinguished from other leaf reddening caused by stress as the area around the veins remains green and the underside of the leaf is rarely discoloured.

The symptoms of premature senescence are different to typical K deficiency, which occurs in soils that are K deficient or fix K strongly. The symptoms occur on younger, rather than older leaves and also occur earlier in the season. Crops other than cotton grown on the same soils may not show any symptoms. See the section on potassium nutrition of cotton in this manual.

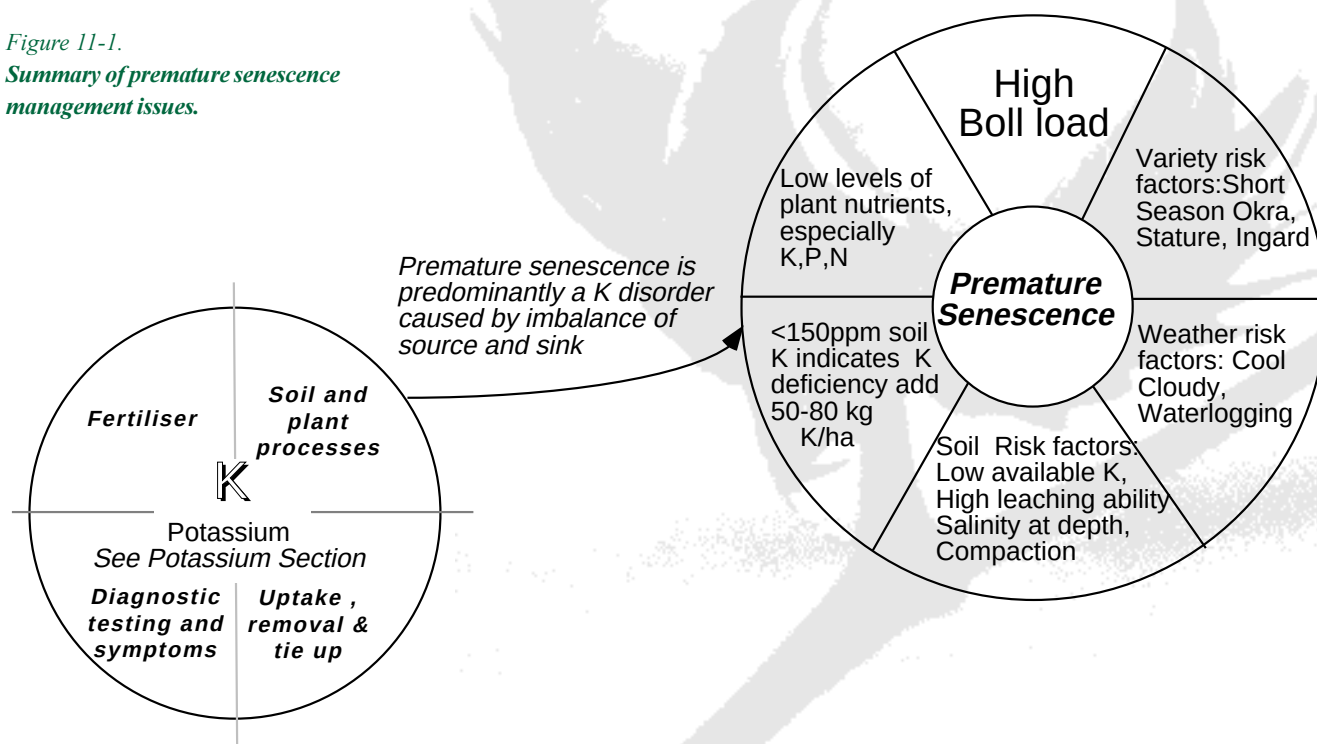
REDUCING THE RISK OF PREMATURE SENESCENCE

Where soil K levels are adequate and fruit load and other risk factors are high, foliar K application can avoid premature senescence before symptoms appear. Foliar application of potassium in the forms of potassium nitrate (KNO_3), potassium thiosulfate ($\text{K}_2\text{S}_2\text{O}_3$) and potassium sulfate (K_2SO_4) have been effective in reducing the risk of premature senescence. Do not apply more than 10 kg K/ha in a water volume of 30-40 L/ha by air, as the KNO_3 may precipitate out

of solution in the tank. Up to four applications may be required 7 to 14 days apart to correct K deficiency, starting at flowering. This approach is expensive and should only be used when there are strong indications that premature senescence is likely to appear later in the season.

If extractable soil K is less than 150 mg/kg in the surface 15 cm, consider the application of high analysis K fertilizer such as KCl. Place the fertilizer in a band 5-10 cm away from the plant line and at least 10 cm deep. A rate of 50-80 kg K/ha should correct the deficiency.

Figure 11-1.
Summary of premature senescence management issues.



PREMATURE SENESCENCE



*Cotton suffering from premature senescence (right) opens earlier with poorer fibre quality than normal cotton (left). High boll load and potassium nutrition are associated with premature senescence.
Photo Philip Wright.*



*A wide range of colours is normally encountered during the senescence of cotton leaves. This reflects the translocation of nutrients from the leaves to bolls.
Photo Ian Rochester.*



The edge row is often not affected (ie greener) in prematurely senescence crops.

WATER-LOGGING OF COTTON

In Australia, most of the cotton is grown using furrow irrigation on heavy clay soils. Because these soils drain slowly, waterlogging can significantly limit irrigated cotton production. Hence, many cotton crops are subjected to some degree of waterlogging. This problem is accentuated by rainfall after irrigation and inadequate land preparation.

Symptoms of waterlogged cotton include a general yellowing of the crop and stunted growth.

Good water management and improved drainage can minimise yield reductions from waterlogging and increase profitability. Waterlogging may reduce crop yield by up to 1 bale/ha. Crop yields may be affected even before symptoms are noticed.

CAUSES OF CROP DAMAGE UNDER WATERLOGGING

Waterlogging can severely restrict crop growth and may kill plants in extreme cases. This is because oxygen (O_2) diffuses 10,000 times more slowly in water than in air. Hence, soil O_2 supply from atmosphere is reduced while other toxic gases (eg CO_2 and ethylene) generated by plant roots and microorganisms accumulate to high and possibly lethal concentrations in the soil.

The major and immediate effect of waterlogging is blocking transfer of O_2 between the roots and the soil atmosphere. Plant roots may become so O_2 deficient that they cannot respire. As a consequence, root growth and absorption of nutrients is decreased. Availability of nutrients in the soil is also reduced.

Waterlogging is often compounded by soil compaction. However, reduced tillage and permanent bed systems may alleviate soil compaction and the severity of waterlogging. Cloudy weather associated with wet seasons may enhance the waterlogging effect as well as the incidence of some cotton diseases. Low rates of evaporation and reduced radiation (sunshine) may encourage waterlogging and reduction in yield.

NUTRIENT AVAILABILITY DURING WATERLOGGING

The decline in soil O_2 concentration effects the oxidation stage of many nutrients. Once molecular oxygen (O_2) is removed from the soil, a sequence of chemical reduction takes place as the intensity of waterlogging conditions increases (Table 12-1). The time to reach each stage in Table 1 will vary considerably, depending on soil type (texture), compaction, soil organic matter, pH and chemical composition. This can range from hours to days. The intensity of each waterlogging event will also vary from one event to the next.

The availability of N, Mn and Fe are directly affected by waterlogging. Zinc availability is reduced due to the formation of insoluble $Zn(OH)_2$ and $ZnCO_3$. In alkaline and/or calcareous soils, the availabilities of Fe and Zn tend to be low, due to adsorption onto clay surfaces or $CaCO_3$. A high concentration of bicarbonate may inhibit Fe and Zn uptake and translocation.

Soil management that promotes good surface and sub-surface drainage will delay the onset of these chemical reduction processes, thereby reducing the severity of waterlogging (see the SOILpak manual).

NUTRIENT UPTAKE DURING WATERLOGGING

The lack of oxygen encountered in waterlogged soil impairs water and nutrient uptake. Nitrogen, potassium and iron uptakes are particularly affected in cotton subjected to waterlogging.

NITROGEN

Besides impairment of root uptake activity, an added penalty under waterlogging is the denitrification of soil mineral nitrogen. Therefore, even after waterlogging has ceased, there may be less nitrogen available for the crop. In this circumstance, much of the yield lost through temporary waterlogging can be recovered by supplying N directly to the

Table 12-1.
Sequence of
chemical reduction
of nutrients as
waterlogging
intensifies.

Chemical reaction	Increasing waterlogging intensity
Onset of NO_3^- reduction to nitrite	↓
Onset of Mn^{2+} formation	↓
Free oxygen (O_2) depleted; normal root respiration slows	↓
Nitrate (NO_3^-) completely reduced	↓
Onset of Fe^{2+} formation (but plants cannot absorb due to low root activity)	↓
Onset of SO_4^- reduction (H_2S formed)	↓
Absence of SO_4^-	↓
CO_2 reduced to methane (CH_4)	↓

leaves as a foliar spray. Yield reduction from waterlogging may be severe but applying foliar fertilizer (about 8 kg N/ha before each of the first three irrigations) can prevent part of that yield loss (Table 12-2).

Foliar N is more effective in increasing the yields of waterlogged cotton when applied one day before irrigation under hot, sunny conditions. Foliar N is less effective when applied during cool, overcast conditions, or when high concentrations of soil N are available to the crop before waterlogging. Therefore, foliar N applications may be beneficial on fields with little slope and where sub-optimum amounts of N fertilizer have been applied. Plant tissue testing may be used as a guide to indicate susceptibility to waterlogging and response to foliar N.

POTASSIUM

Waterlogging is possibly involved in premature senescence of cotton. Under waterlogged conditions, uptake of K by the cotton crop may be reduced, predisposing the crop to the premature senescence syndrome (see section on 'Premature senescence' in this manual).

IRON

The young leaves of iron deficient plants become yellow between the veins (chlorosis). The veins usually remain

green, unless the deficiency is severe. The whole leaf may eventually turn white. Although the plant may contain high concentrations of iron, most of it is unavailable for chlorophyll production and the leaves lose their green colour.

When a soil is waterlogged, the passage of carbon dioxide out of the soil is blocked. The CO_2 concentration builds up in the soil solution forming bicarbonate ions. This increases soil pH, which in turn increases the concentration of bicarbonate and alkalinity in the leaf tissues. Under these conditions, iron becomes unavailable (ie the active iron (Fe^{2+}) is converted to the inactive forms (Fe^{3+} and others) and symptoms of chlorosis appear. The soil syndrome is referred to as lime-induced chlorosis.

Waterlogging can also induce iron chlorosis particularly where soil phosphorus is high. Phosphate reacts with soluble iron to form insoluble iron phosphates. The imbalance between iron and phosphorus in the leaf tissue is observed as very yellow leaves about two nodes from the terminal.

Diagnosing iron chlorosis is complicated because the total iron content of the leaf is not closely related to the physiologically active iron (Fe^{2+}) component of total iron content. To determine the Fe^{2+} content, fresh leaves must be analysed within a few hours of sampling; commercial laboratories cannot do this. The total Fe content of yellow leaves is often similar or higher than that of green leaves, which may incorrectly indicate that iron is not deficient.

Foliar application of 200 g Fe/ha with a ferrous sulphate may return foliage to its normal colour within 2-3 days.

MANAGEMENT OPTIONS TO MINIMISE WATERLOGGING DAMAGE

- field design. A uniform slope of at least 1:1500 is best for draining irrigation water or rainfall from a field. Tail drains should be designed to remove run-off as quickly as possible.
- high beds assist drainage and decrease waterlogging in irrigated fields.
- fast irrigation times decrease waterlogging. Use more or larger diameter siphons, greater pressure head or shorter rows. The aim should be to have water on/off each furrow in four hours.
- foliar N fertilizer. Apply 8kg N/ha where waterlogging is likely. Higher rates of N can burn foliage. Application of the foliar N on a field already waterlogged will not necessarily alleviate existing damage.
- under some circumstances, foliar iron application of 200g Fe/ha (eg 1 kg FeSO_4 /ha) may prevent iron chlorosis and may increase yield. Chelated iron may be applied to the soil pre-sowing.

*Table 12-2.
Foliar N may
reduce yield
loss in
waterlogged
cotton.*

	No foliar N	Foliar N applied
Not waterlogged	8.51 b/ha	8.30 b/ha
Waterlogged	8.01 b/ha	8.33 b/ha

COTTON STUBBLE MANAGEMENT

The system of stalk pulling, raking and burning to remove cotton stubble can have adverse effects on the productivity of cotton fields. The vast majority of cotton growers have developed an alternative system, which involves slashing the cotton stubble near ground level and incorporating the trash into the surface soil.

Returning cotton stubble to the soil provides a source of energy for the microbial biomass, which in turn helps the breakdown of stubble. This maintains the supply of nutrients to the crop.

ADVANTAGES OF RETAINING COTTON STUBBLE

- adds organic matter to the soil
- improves soil tilth
- decreases soil bulk density
- greater biological activity in the soil
- maintains active populations of soil organisms
- supplies energy to the soil microbial biomass
- Enhances nutrient cycling
- improves fertilizer use efficiency
- improves moisture infiltration
- reduces wind and water erosion
- incorporating stubble forms part of the pupae busting operation

DISADVANTAGES OF RETAINING COTTON STUBBLE

- potential to encourage volunteer cotton plants
- may block cultivation equipment or irrigation channels when stubble not incorporated
- potential to reduce herbicide/soil contact where stubble remains on surface
- may exacerbate seedling disease, particularly when stubble is not incorporated

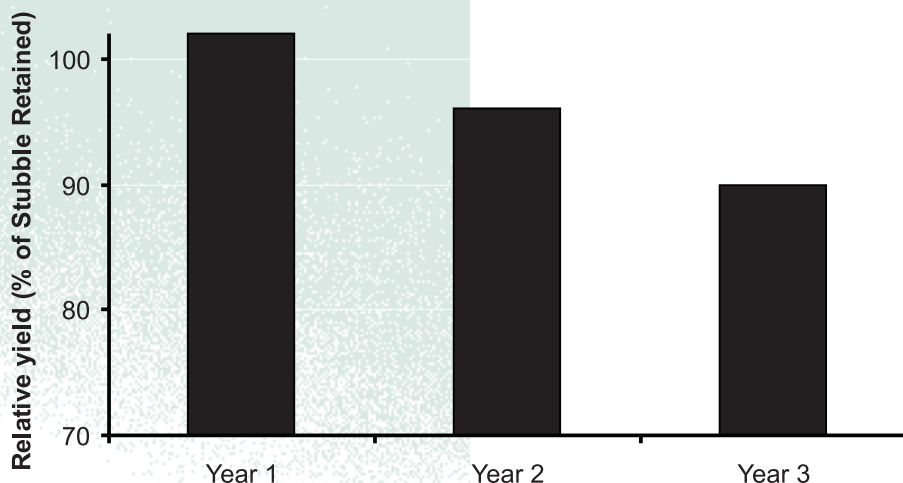


Figure 13-1.

Lint yield was reduced where stubble was removed, relative to retaining stubble.

COTTON STUBBLE MANAGEMENT RESEARCH

An experiment was conducted at Narrabri over three years (1992-1995) to investigate both stubble management systems in relation to cotton growth, lint yield and fertilizer N recovery.

The experiment indicated that removing cotton stubble caused a reduction in lint yield and profitability over time. Compared with the lint yield of the stubble-retained treatment, the yield of the stubble-removed treatment was reduced by 3 and 9% respectively, in the second and third years of the experiment.

The experiment also revealed that the N fertilizer recovery was reduced by 10% where the stubble was removed compared to the retained plots, ie more N fertilizer was lost from the soil where stubble was removed.

PROBLEMS ASSOCIATED WITH RAKING/BURNING COTTON STUBBLE

A major disadvantage of the raking and burning system is that the operation often requires several machinery passes (stalk pull, rake, burn, rake again) which prolongs the time to prepare the field for planting.

Burning stubble not only creates smoke and atmospheric pollution, but also causes the loss of many nutrients. Virtually all (depending on the temperature of the fire) of the nitrogen, phosphorus and sulfur contained in the stubble are released into the atmosphere as gases.

The heat generated by the fires destroys organic matter in the surface soil, which can substantially affect soil properties. Much of the N, P and S contained in the soil organic will be lost to the atmosphere during burning, depending on the heat of the fire.

The raking of stubble into windrows creates variation in fertility across the field, as the nutrients contained in the stubble are concentrated in these rows, whilst depleting the rest of the field. The ash in the windrows contains high concentrations of some nutrients (K, Ca, Mg, Mn and Fe) which have been transported from the surrounding area. This produces uneven growth of following crops, which can be difficult to manage and very difficult to rectify.

COTTON DISEASE CONTROL

There is a perception that raking and burning will assist in the reduction of cotton pathogens. Research has indicated that this is not the case. As most of the leaf material is returned to the soil prior to raking and burning, sufficient inoculum persists in the soil to maintain pathogen levels. Burning stalks has little benefit in reducing inoculum levels for cotton diseases such as verticillium wilt, black root rot, bacterial blight and *Alternaria*, which are retained on the leaves and petioles, most of which have dropped and mixed with the surface soil. Reducing the amount of stubble from cotton or other crops left on the soil surface may help reduce seedling diseases (*Pythium*, *Rhizoctonia*). To reduce levels of *Fusarium* inoculum, retain crop residues on the soil surface as long as possible before incorporation.

RECOMMENDED MANAGEMENT OF COTTON STUBBLE

The most effective means of dealing with cotton stubble will vary according to the severity of each specific disease problem. Hence, growers need to be aware of the diseases that are present on their farms and the risk they pose to their enterprise in order to manage stubble in the appropriate manner. An integrated disease management guideline is being formulated at present and will be published in 2001.

The most environmentally friendly method of managing cotton stubble is to slash the standing stubble close to ground level, leaving the stubble in short (<10 cm) pieces which can be incorporated into the surface soil. For more information on methods of incorporation, refer to MACHINEpak. For a copy of MACHINEpak, contact the Australian Cotton CRC Technology Resource Centre 02 6799 1534.

COTTON STUBBLE MANAGEMENT



*Retention of stubble aids nutrient cycling and reduces soil loss.
Photo Ian Rochester.*



*The burning of cotton stubble accelerates the loss of nutrients to the atmosphere and concentrates nutrients in the windrows.
Photo Stephen Allen.*



*Retained stubble is quickly decomposed by a variety of soil microorganisms. Networks of fungal hyphae can often be seen following stubble incorporation.
Photo Ian Rochester.*

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GLOSSARY OF NUTRITION TERMS

Name	Symbol / acronym	Primary nutrient	Notes
Alternaria		K	A leaf spot disease that can be associated premature senescence
Ammonia	NH ₃	N	Anhydrous ammonia - 82%N
Ammonium	NH ₄ ⁺	N	Mineral form of N
Boron	B	B	
Calcium	Ca	Ca	
Chelate		Many	Organic carrier for fertilizers
Chlorosis		Many	Lightening in the colour of leaf tissue
Copper	Cu	Cu	
Cut out		N	Growth stage of a crop where square and flower production cease
Denitrification		N	Process of nitrogen loss during waterlogging
Di-ammonium phosphate	DAP	P,N	18%N, 22%P – better on acid soils
Diffusion		All	Process of nutrient movement through water
Dolomite	CaMgCO ₃	Ca,Mg	Calcium magnesium carbonate
DTPA extraction	DTPA	Many	Chemical extractant for soil micronutrients
EDTA extraction	EDTA	Many	Chemical extractant for soil micronutrients
Gypsum	CaSO ₄	Ca	Calcium sulfate
Immobilisation		Many	Conversion of mineral nutrients to organic form
Iron	Fe	Fe	Fe ²⁺ is the physiologically active form in plants
Labile			Form of a nutrient that moves between available and non-available pools
Leaching		Many	Movement of nutrients within soil profile & water
Lime	CaCO ₃	Ca	Calcium carbonate
Magnesium	Mg	Mg	
Manganese	Mn	Mn	
Mass flow		All	Movement of nutrients in flow of water
Milligrams per kilogram	mg/kg	All	equivalent to parts per million
Mineral		All	Inorganic form
Mineralisation		All	Conversion of organic to inorganic form
Molybdenum	Mn	Mn	
Mono ammonium phosphate	MAP		9%N, 22%P. Used in alkaline soils (not DAP)
Necrotic		Many	Dying tissue
Nitrate	NO ₃ ⁻	N	Form of mineral N available to plants
Nitrogen, atmospheric	N ₂	N	Comprises 78% of air
Nitrous oxide	N ₂ O	N	Greenhouse gas - product of denitrification
NutriLOGIC		N	A component of the CottonLOGIC software package that estimates N fertilizer requirements from soil or petiole nitrate analyses
Organic		All	Derived from living organisms
Organic matter	OM		Derived from living organisms
Parts per million	ppm	All	equivalent to milligrams per kilogram
Petiole			The stalk connecting the leaf blade and the stem
Phosphorus	P	P	
Pith			Light tissue at the centre of stems and petioles
Potassium	K	K	
Premature senescence		K,P	A potassium-related syndrome connected with high boll loads and weather, cultivar and soil fertility
Sulfur	S	S	
Turgor		K	Rigidity of plant cells brought about by pressure of internal fluids
Urea		N	N fertilizer - 46% N
Urea Ammonium Nitrate	UAN	N	N fertilizer - ~30% N. Used for foliar application
Volatilisation		N	Evaporation of a gas from a solid into the air
Youngest Mature Leaf	YML	Many	Normally the 5 th open leaf from the terminal.
Zinc	Zn	Zn	

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