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GRAIN SORGHUM NUTRITION GUIDE

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GRAIN SORGHUM HYBRIDS

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GRAIN SORGHUM NUTRITION

High yielding crops of sorghum require adequate nutrition and should any nutrient be found lacking, appropriate fertilisers need to be applied. Rates of fertiliser will vary depending on locality, soil type, previous crop and fertiliser history. The nutrients that most frequently limit production are nitrogen (N) and phosphorus (P). Sulphur (S), potassium (K) and zinc (Zn) may also be limiting in some soils or under some growing conditions.

Crop Uptake

For each tonne of yield, the sorghum plant requires defined quantities of nutrients. Nitrogen (N) and potassium (K) are nutrients required in the greatest quantities followed by sulphur (S), phosphorus (P), calcium (Ca) and magnesium (Mg). Total uptake for each nutrient can be calculated by multiplying the nutrient uptake in Table 1 by the grain yield (t/ha). The amount calculated also represents the quantity of nutrient likely to be removed if the crop was to be harvested as silage or hay.

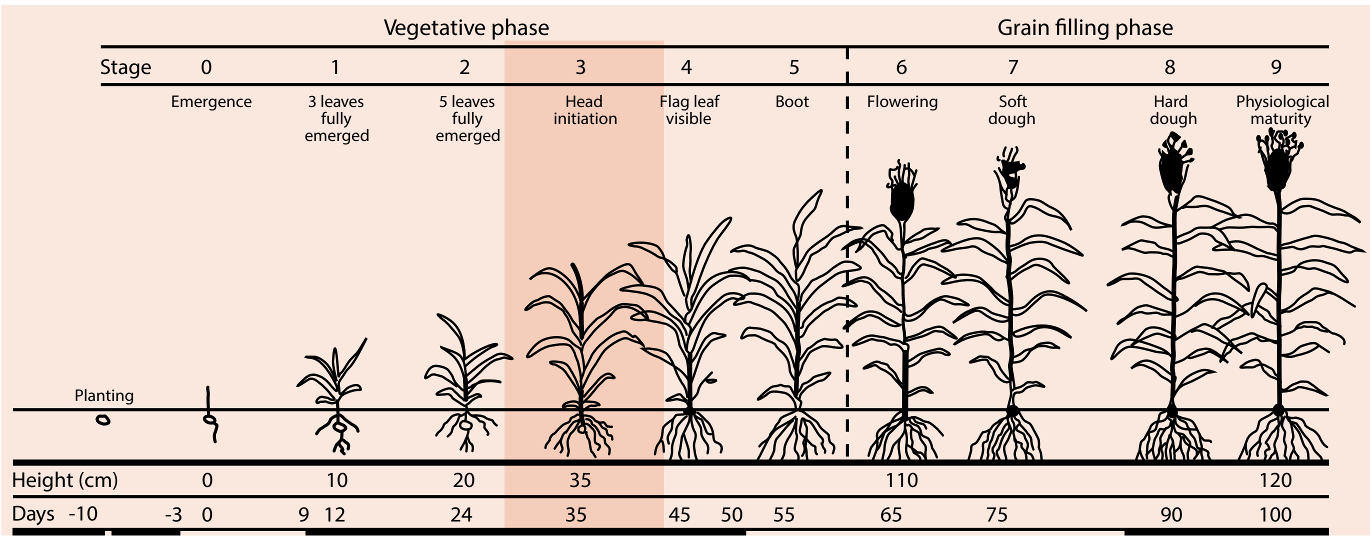
Table 1 - Typical nutrient uptake for most commonly applied nutrients in sorghum in NSW and Qld.

Nutrient	N	P	K	S	Zn
Uptake	30 kg/t	4.5 kg/t	16.3 kg/t	5.2 kg/t	24 g/t

The timing of nutrient demand in sorghum is similar to other cereals with N and K occurring ahead of dry matter accumulation and phosphorus uptake. Sorghum takes up 75% of its nitrogen requirement in the vegetative period prior to floral initiation (about 6 leaves open). A shortage of nitrogen during this period significantly reduces growth in stems and leaves and consequently in the number of flowers produced and so leads to a reduction in yield. For the remaining nitrogen demand, take up between flowering and maturity is most important, for a shortage of plant available nitrogen during this period results in large reductions in the protein content of the grain. Fifty percent of its potassium requirements are during the vegetative period prior to floral initiation, while the uptake of phosphorus peaks at early flowering, with 45% of the total phosphorus demand being taken up during booting and flowering (Figure 1).

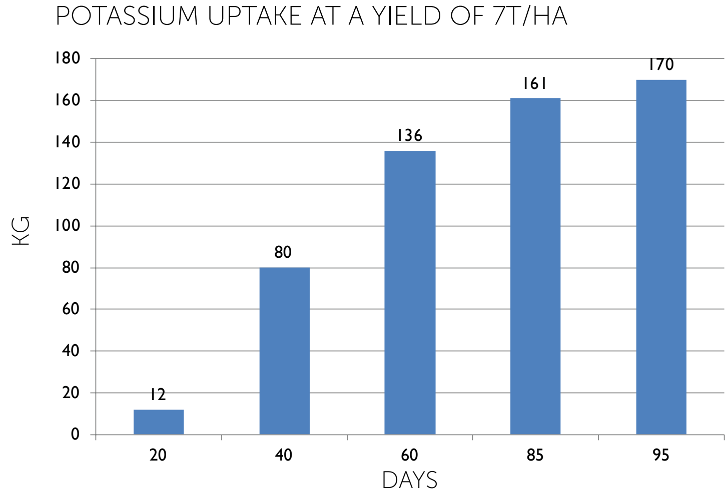
Minor variations to this pattern may result from differences in tillering between varieties. Tillering generally extends the uptake period for all nutrients.

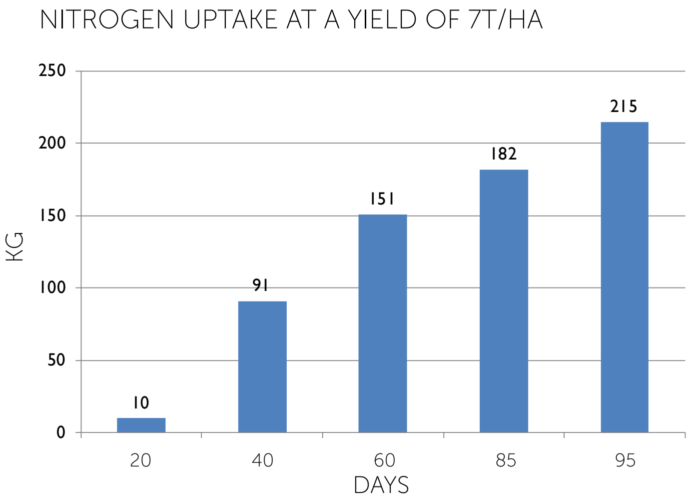
SORGHUM GROWTH AND DEVELOPMENT CHART

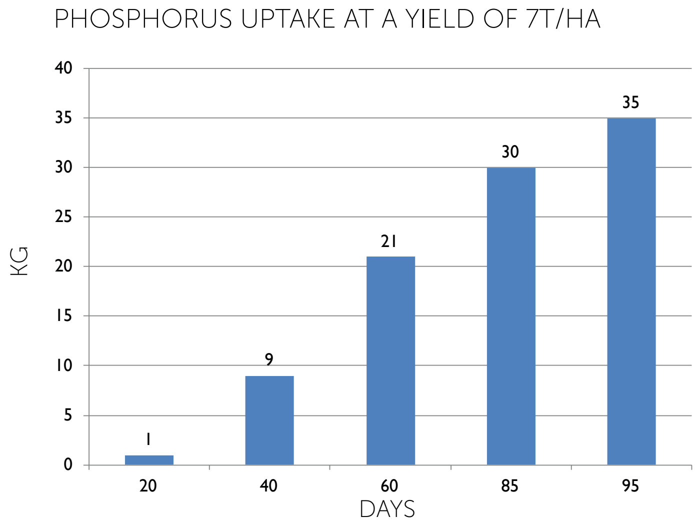


Source: NSW DPI Grain Sorghum Ag Facts.

Figure 1 – Nitrogen, phosphorus and potassium uptake patterns for a 7 t/ha grain sorghum crop (More profit per Drop)







Sorghum demand for nitrogen varies more widely than for other nutrients being dependent on the grain yield and grain nitrogen content. Crop nitrogen demand is related to the grain nitrogen content (kgN/t) and the N efficiency at which soil and fertiliser N is taken up and transferred to grain. The nitrogen supply required to produce a range of yield and protein levels is given in Table 2.

Table 2 - Crop N demand required from all sources required for a range of grain yield and protein targets. (Uptake efficiency varies with protein target according to Kelly et al 2001).

Target yield (t/ha)	Grain protein %				
	8	8.5	9	9.5	10
1	19	22	25	29	33
2	38	44	50	58	67
3	56	66	75	86	100
4	75	87	100	115	133
5	94	109	125	144	167
6	113	131	150	173	200
7	132	153	175	202	233
8	151	175	200	231	267
9	169	197	225	259	300
10	188	218	250	288	333

NUTRIENT REMOVAL

Crop Removal

With soils in many sorghum growing regions now exhibiting responsiveness to a wider range of nutrients, the starting nutrient rate for crop nutrition strategies is frequently replacement of that removed in the grain. This can be based on published typical nutrient removal rates such as those in Table 3, or can be related to removal measured at a farm or paddock level by measuring grain nutrient content. The range in removals displayed in Table 3 were collected from grain samples sourced from a range of research trials with a large range of growing conditions, varieties, soil and fertiliser regimes. The range suggests that some investigation of removal at a paddock level is likely to improve calculation of appropriate maintenance rates.

A maintenance or replacement strategy is generally suitable for nutrients other than N with marginal to adequate soil status. This is typical of situations where crop sometimes show small responses to nutrient addition. The dynamic nature of the nitrogen cycle requires fertiliser N to be managed based more on the seasonal assessment of yield potential and likely soil nitrogen supply.

Table 3 - Typical nutrient removal (kg/t for NPKS and g/t for Zn) for most commonly applied nutrients in sorghum in NSW and Qld (MPCN 2015).

Nutrient	N	P	K	S	Zn
Removal	15	2.9	3.3	1.3	18
Range	9 - 26	1.9 – 4.0	2.6 – 4.1	0.9 – 1.7	13 - 24
% of crop uptake removed	50	65	20	25	75

Establishing the need for increased nutrient supply

The need to supplement the native soil nutrient supply to maximise yield can be identified using a number of methods. Most directly via test strips and indirectly through the use of soil and plant tissue analysis. Waiting until the onset of clear foliar symptoms will cost up to 20 % yield penalty for a number of years before the clear symptoms emerge.

Critical levels of important nutrients for the dominant soil types in sorghum growing areas are presented in Table 4. The values are general and may vary in response to a range of other soil chemistry and biology variables. Soil sampling depths indicated are important in ensuring the interpretability of laboratory analyses particularly for soil immobile nutrients such as P, K and Zn.

Table 4 - Soil analysis critical values for nutrients most limiting to sorghum grown on vertosol soils in summer dominant rainfall areas. Those values in brackets are for are for grey vertosols.

Nutrient	Sample depth		
	0-10 cm	10-30cm	0-60 cm
Phosphorus (Colwell) mg/kg	15 -22 (10-15)	10	
Phosphorus (BSES) mg/kg	25	30	
Sulfur (MCP) mg/kg			3
Potassium (exchangeable) cmol(+)/kg	0.2	0.1	
Zinc (DTPA) mg/kg	0.8 (0.3)		

Plant tissue analysis is generally used as a diagnostic tool where plant growth appears to be affected by nutrient deficiency. Where used correctly it has the advantage of reflecting the root uptake-soil supply relationship of the crop. The values in Table 5 represent the lowest nutrient concentrations for youngest expanded blade below which yield may be reduced.

Emerging technologies that use spectral reflectance or transmission also appear to have some application in nutrient management of sorghum where in-crop nutrient application possible. This technology is most developed for N but commercial availability of decision support in sorghum is currently limited. Yara N-Sensor ™ and Ag Leaders OptRX ® Crop Sensor proximal sensors, and SPAD chlorophyll meter, RapidEye ® Satellite Sensor and WorldView-2 Satellite Imagery are examples of remote sensing platforms that have been developed to provide crop N status in other crops.

Table 5 - Plant tissue analysis lower value of adequate range for sorghum (Reuter and Robinson 1997) for youngest mature blade sampled from 3 leaf till panicle initiation.

N %	P %	K %	S %	Ca %	Mg %	Cu mg/kg	Zn mg/kg	Mn mg/kg	Fe mg/kg	B mg/kg	Mo mg/kg
2.8	0.23	1.3	0.15	0.3	0.16	2	18	15	55	1	0.15

ROLE OF NUTRIENTS IN SORGHUM

NITROGEN

Nitrogen is a key nutrient in a large number of plant functions including being central to production of amino acids and protein, formation of chlorophyll, is a component of vitamins and affects energy relations in the plant.

Nitrogen stress in sorghum is characterised by:

• Reduced dry matter and head number.

• A light green to yellow colouration.

• Yellowing and necrosis of lower leaves beginning at the tip.

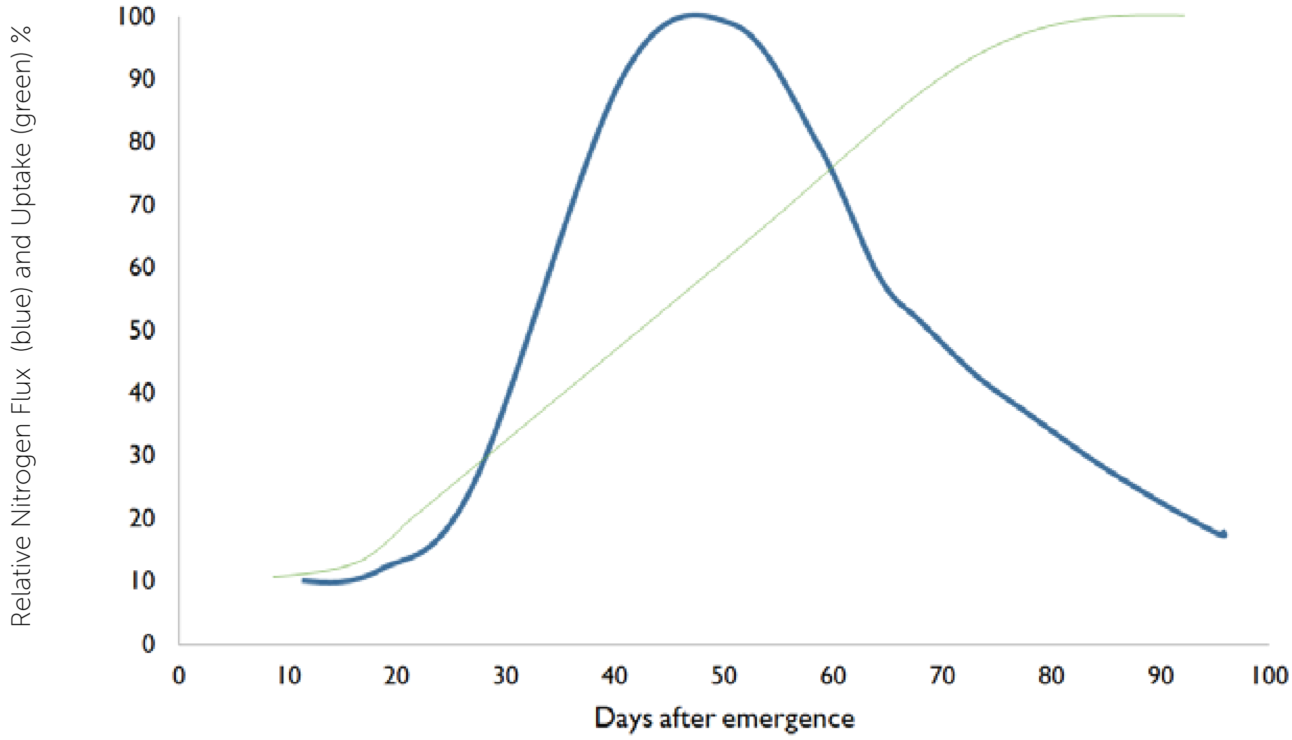
• Delayed flowering of the primary tiller. The delay to flowering has been measure to be 10 – 14 days in some varieties

• Low grain protein.

Figure 2 – Nitrogen deficiency in sorghum.

Figure 3 shows the typical N uptake rate (N flux) pattern for a grain sorghum plant. It appears that the plant does not use much N during the first 20 days, but by the time the plant is 45 – 55 days it has reached its maximum N uptake rate and by 60 days old, it has used close to 60 per cent of the total N. This pattern of uptake, the soils ability to retain N and growing season rainfall patterns should guide N application strategy.

Figure 3 - Typical nitrogen flux and uptake patterns for sorghum. Maximum daily uptake rate occurs around 50 days.



Nitrogen fertiliser strategies for rain-grown crops should be based on a realistic target yield, based primarily on stored soil moisture with some allowance for summer rainfall and previous paddock history. For irrigated crops, the quantity of water and timing of irrigations are also influential in setting a target yield. The grain protein content of sorghum and other cereals crops (Table 6) can be used as a reliable indicator of the adequacy of available N to optimize yield for seasonally available water. Grain protein in sorghum of less than 9 % generally indicates that the crop would have likely yield more with increased N availability

Table 6 - Target grain protein for yield optimisation with nitrogen for a range of cereal crop grown in rotation with sorghum.

Crop	Target Grain Protein %[1]
Sorghum	10
Maize	9
Barley	10.5
Wheat	11.5

Nitrogen fertiliser rates are generally determined for sorghum as part of a partial N budget. The crop N demand is provided for a range of yield and grain proteins in Table 2. This N demand needs to be matched by a combination of residual soil mineral N (as measured by a soil test), N released from the soil organic matter and previous crop residues with any deficit being supplied by fertiliser N.

NITROGEN FERTILISER STRATEGIES

Nutrient Source

Urea, anhydrous ammonia and ammonium sulphate are the most commonly used N fertilisers applied for sorghum preplant and sidedressed. Topdressing with urea and ammonium sulphate needs to be assessed for the potential for ammonia volatilisation loss. When applied in the same soil banded or broadcast and incorporated, there is no evidence of consistent differences between the products in crop N response.

Efficiency enhanced N products are designed to modify the release pattern of N from the product to either increase synchronisation of N availability with crop demand and/or help lower the risk of losses from denitrification. To date these product have generally been successful in reducing nitrous oxide emissions but have as yet not been demonstrated to provide profitable and predictable dollar returns in raingrown sorghum crops.

Nitrogen application rate

Raingrown generally 40 to 150 kg N/ha
Irrigated generally 100 to 250 kg N/ha

Table 7 – Estimated N supply from a range of soil mineral N values for sampling 0-90 cm in a cereal based rotation.

Soil mineral N mg/kg	Estimated crop available N (kg/ha)
1	15
5	62
10	121
15	179
20	238
25	296

Nitrogen application method

Pre-plant applications are generally best banded into the soil to reduce immobilisation if high stubble loads are still present. Nitrogen bands should generally not be placed at a greater width than plant row spacing. For skip row configurations application bands should be placed to ensure that each row of sorghum has access to a fertiliser band. Preplant broadcast application without incorporation should be avoided for urea and sulphate of ammonia on alkaline calcareous soils due to increased losses by volatilisation.

Application of straight N products in contact with the seed, particularly when sown at wide row spacing, should be avoided due to the risk of reducing crop establishment.

When applying N post emergence using soil disturbing bands, application depth should to sufficient to ensure soil coverage of fertiliser in the application trench and at enough distance from the established crop to avoid root damage. It is advisable to locate the extent of lateral roots before application.

Application equipment should be configured to minimise dribble banded N contacting the crop. Liquid nitrogen products are generally sufficiently concentrated to cause osmotic burn and localised ammonia toxicity. More extensive burn is create by inappropriate rates of N applied in foliar application (Figure 4).

Anecdotal evidence suggests that for broadcast application, rates of urea should be kept below 100 kg/ha when crops are between growth stages 2 and 3. Smaller split applications may lower the risk of fertiliser burn in the whorl.

Figure 4 – Foliage damage from a foliar urea application to sorghum to alleviate effects of waterlogging.

Nitrogen application timing

The total fertiliser N requirement is frequently applied pre or at planting in raingrown crops due to the unfavourable logistics of in-crop N application and unreliability of rainfall to promote efficient uptake. Given the N uptake pattern in Figure 3, in raingrown crops the highest N efficiency can be achieved by a split application strategy where about one-half of the total N applied preplant or at sowing, the remainder applied sidedressed by the sixth-leaf stage. Follow-up rainfall to carry the N into the root zone is required to obtain the benefit of N applied in-crop.

Studies of effectiveness of sidedressing raingrown sorghum are limited but in trials conducted in NW NSW 2005 – 08 it was concluded "Results from trials in 2005 and 2006 have shown that sorghum responses to top-dressed nitrogen were restricted to 1/11 sites with the responsive site having the lowest starting soil N of all locations" and "In 2007 grain yields were maintained at the same level as upfront N application by tactically splitting N prior to booting. This, combined with previous trial work, indicates that there is no yield benefit above upfront N application but that there is potential to maximise yields under improved seasonal conditions with split N applications" (McMullen et al. 2014).

Table 8 - Effect of tactical N management (averaged across low and high starting N) on sorghum grain yield at Premer in 2007/08 (adapted from Mc Mullen et al 2014).

Nitrogen Treatment	Grain Yield (kg/ha)	Grain Protein (%)
Nil	7.98	7.82
Upfront	9.07	8.63
7 leaf	9.24	8.66
Boot	8.68	8.66
Upfront + 7leaf	9.2	8.49
7 leaf + Boot	8.73	8.5
Upfront + Boot	9.12	8.86

For irrigated crops and high yield potential dryland crops, a three-way split, with a portion of the N being applied at the boot stage provides added flexibility to match N supply to yield potential later in the season. In irrigated crops where N supply is limiting before flowering, addition of N at "boot "stage been shown to be profitable with a sidedressed soil application (Table 9).

Table 9 - Effects of nitrogen supplied at planting and at the "boot" stage on grain yield and protein content (Asher and Cowie 1974).

N applied at planting (kg/ha)	No further N applied		34 kg N/ha at "Boot" Stage	
	Yield (t/ha)	Protein (%)	Yield (t/ha)	Protein (%)
0	0.8	7.7	2.2	14.7
34	1.1	6.6	2.0	12.6
112	4.2	8.8	6.1	12.7
336	9.2	11.3	9.1	16.8

PHOSPHORUS

Phosphorus is vital for the early development of young sorghum. It is involved in photosynthesis, respiration, energy storage and transfer, cell division, and enlargement, promotes early root formation and growth, and increases water-use efficiency.

Symptoms of a lack of phosphorus in sorghum include:

- Blue green colouration with reddening of stems and lower leaves
- Poor vigour
- Restricted root development
- Delayed or uneven flowering

Figure 5 - Phosphorus “starter” response in sorghum.

Phosphorus availability to crops is controlled by the interaction of a range of soil chemical, biological and physical parameters, in combination with weather factors such as temperature and rainfall. Responsiveness to the addition of phosphorus fertiliser is identified by the presence of a number factors that increase the likelihood of sorghum response (Table 10). Additionally, responsiveness is generally categorised as either a “starter” or “season long” response. Starter responses are generally visible as an increase in growth of a crop early-season that does not always increase harvest yield. Starter responses (Figure 5) typically produce grain yield increases of 100 – 500 kg/ha. Season-long responses are generally visible all season and frequently produce grain yield increases greater than 500 kg/ha and hasten flowering.

Table 10 - Major contributing factors to the two types of P response.

Starter response	Season-long response
Cool soil temperature during crop establishment	Low available P in whole soil profile
Low soil available P in surface soil	Long fallow or following non-VAM crop e.g. canola
Deep sowing	
Short and sorghum to sorghum fallows	

For many years it had been thought that sorghum was an efficient forager for soil P and was not particularly responsive despite low soil P (0-10 cm) particularly in short and normal fallow situations. Response to P was more common after long fallows. More recently it has been demonstrated that "season long" sorghum responsiveness to P in raingrown crops is strongly related to the P in the 10 – 30 cm soil layer rather than 0-10 cm alone. Application of P in the 15 – 25 cm soil layer has been found to increase the probability of season long responses when soil P test is low in a 10 – 30 cm soil layer (Table 4). Seasonal rainfall patterns have been found to affect response to P. Table 11 contains modelled estimates of the likely effect some common seasonal rainfall patterns on yield reduction from less than optimum fertiliser P supply.

Table 11 - Estimates of relative yield losses that would be experienced if a combination of starter P and deep P fertiliser was not applied for different soils and season types (adapted from Bell et al. 2014).

Season	PAWC	Estimate of relative yield loss
Dry start	120 mm	5
Wet start, dry finish		10
No serious water stress		15
Dry start	240 mm	10
Wet start, dry finish		25
No serious water stress		15

Figure 6 – Phosphorus deficiency in sorghum.

PHOSPHORUS FERTILISER STRATEGIES

Nutrient Source

The majority of both dry and liquid P starter products are based on ammonium phosphates MAP and DAP. Due to the extra ammonium molecule in DAP there is more risk of crop establishment reduction from DAP than MAP when applied in the seed furrow.

If "starter" products contain ammonium forms of nitrogen and/or potassium, the rate of application and application method needs to be closely assessed as products will reduce crop establishment if the in-row rate is too high.

Liquid sources of P provide a slightly lower risk of crop emergence damage at equivalent rates of dry granular P, and may have some logistical advantages but have failed to demonstrate superior responses for an equivalent P application.

Application Rate

Application rates of P in sorghum are generally in the range 5 – 15 kg/ha, frequently well below the replacement of 2.9 kg P/t.

To avoid crop establishment reductions, it is suggested that the maximum rate of seed furrow applied MAP and DAP should be 4g/m and 2.5 g/m respectively (40kg/ha and 25 kg/ha in 100 cm rows). These rates are for medium clay soils with good planting moisture for a narrow tine opener. For different soils and soil moisture conditions and where other nutrients are contained in the product an appropriate adjustment to rates should be made. Seek detailed direction from your fertiliser supplier for more detail.

For deep applied P, the application rate should be sufficient for 3 – 5 years from a single application.

Application Method

The combination of early P requirement for healthy seedling growth and its immobility in soil require fertiliser products be applied with, or in close proximity to seed for "starter" response.

Where surface and deep soil tests indicated potential for enhanced response from deep application of P banding around 20cm depth and at 50 cm row spacing early in a fallow is suggested.

Application Timing

The very low soil mobility of phosphorus in the majority of sorghum producing soils requires starter P to be applied either in the seed furrow or adjacent (20 – 50 mm) to the seed at sowing.

In soils where response to deep P is likely, timing of the application should allow reconsolidation of the seedbed by moisture i.e. at the start or a fallow when there is soil moisture to 20 – 30 cm depth.

POTASSIUM

Potassium is involved in a multitude of functions in the plant ranging from carbohydrate metabolism, break down and translocation of starches, water-regulation, is essential to protein synthesis formation, activates enzymes and controls their reaction rates. Adequate supply also improves winter hardiness and increases disease resistance.

Sorghum crops suffering as shortage of potassium display symptoms such as:

- Interveinal or marginal chlorosis of older leaves.
- Dark green plants with chlorosis along the leaf margins developing to brown striping and necrosis.
- Shortening of internodes and dwarfing plants.
- Smaller heads and low grain number.

Due to a gradual decline in soil potassium levels with crop removal and erosion of topsoils, and historically low potassium fertiliser application rates, an increasing number of soils now require K fertiliser applications. These include red soils (Ferrosols), Open Downs soils of the Central Highland Qld and other upland vertosols that developed in situ. Rain grown summer and winter cereals are less likely to respond to K applications than pulses such as soybeans, navy beans and peanuts under conditions of marginal soil K status. Chickpea has recently been identified as sensitive to low soil K. Being more widely grown in rotations with sorghum, chickpea is now a key indicator of failing soil K supply.

Figure 7 – Symptoms of potassium deficiency.

POTASSIUM FERTILISER STRATEGIES

Nutrient Source

Potassium is generally applied as either muriate of potash (KCl) or potassium sulphate (K2SO4). It is also in reasonable concentrations in many manures and composts. Muriate of potash is generally applied in broadcast or pre-plant banded applications while potassium sulphate is generally preferred in blends with P placed in or near the seed furrow. For deep application the addition of P to the K band can enhance K uptake.

Application Rate

The vast majority of sorghum growing soils have adequate to good supplies of potassium both in the surface and subsurface. Where applied, application rates of K in sorghum are generally in the range 10 – 25 kg/ha which is around the replacement rate of 3.3 kg P/t.

Most potassium fertilisers have a high salt index, increasing the risk of interfering with crop establishment. As a general precaution K should be avoided in on seed furrow placed blends and where necessary rates should be less than 0.25 K g/ linear metre of row (5 kg K/ha in 100 cm rows).

Application Method

Potassium is generally not subject to soil reactions that reduce its long term availability but is of low mobility in moderate to high CEC soils. As with P, responses to K in rain grown crops appear to be more consistent where K is banded in the 15 -25 cm soil layer in combination with and ammonium phosphate product.

Application Timing

In rain grown crops application of K should be complete at crop establishment. There are prospects of sidedressing response in the 1 – 4 leaf stages in irrigated crops provided it is followed closely by an irrigation.

SULPHUR

Sulphur in the plant is linked to nitrogen in a number of biochemical functions. It is an integral part of amino acids, helps develop enzymes and vitamins and is necessary in chlorophyll formation (though it isn't one of the constituents).
Sulphur deficiency in sorghum is not common in sorghum growing areas but has been recorded in a range of shallower upland soils without a gypsum (calcium sulfate) layer in the subsoil. In deeper soils following periods of flooding, leaching of S increases the probability of low S availability. The practice of "double cropping" also increased the chance of S deficiency in above circumstances.

In the initial stages of S deficiency symptoms are often confused with those caused by N deficiency. Close observation of S deficient plants reveals:

• Commonly occurs as patches in paddock rather than evenly across and area.
• Older leaves are greener than the younger ones
• In plants with severe S deficiency the upper leaves are yellow to white colouration sometimes with pink colouration toward the proximal end.

SULPHUR FERTILISER STRATEGIES

Nutrient Source

Sulphur is frequently associated with other major nutrients such as N, P, K and Ca in fertiliser products in the plant-available sulphate form. Elemental S with a micro-fine particle size can be a useful source of maintenance S but should not be relied upon to correct responsive soils in the short term.

Application Rate

Products containing sulphate-S should be applied at removal rates (1.3 kg S/t). Capital rates of S using gypsum ($CaSO_4$) are frequently at rates 300 – 1000 kg/ha (45 -150 kg S/ha) being based on attaining even application and cost effectiveness.

Application Method

Sulphate is mobile in soil water thereby providing a wide range of application options. Options are generally limited by the other major nutrients in the fertiliser compound. Water running in irrigated crops is not recommended.

Application Timing

Sulphur requirement in the plant is parallel to N so the range of application timing options are the same as for N.

ZINC

Zinc aids biochemical processes in plant growth hormones and enzyme systems, and is necessary for chlorophyll production, r carbohydrate formation and starch formation.

Although required in relatively very small amounts, Zn is essential during the development of the young sorghum plant. Soil tests give some indications as to soil Zn status but requirement is best determine from visual symptoms, test strips and/or leaf analysis. Similar to P, Zn uptake is affected by are range of soil and climatic factors. The effect of fallow length and the crop sequence on VAM being very important. Long clean fallows and sorghum following canola greatly increase the risk of Zn deficiency. Other factors that increase chances of Zn deficiency include cool soil temperature at planting, alkaline soils and high soil availability of P. Effective early Zn nutrition can require multiple application strategies in a single crop in some soils and seasons.

Symptoms of zinc deficiency include:

- Stunting due to reduction in internode length
- White to yellow bands either side of the mid-rib near the base of youngest leaves

Figure 8 – Zinc deficiency in sorghum.

ZINC FERTILISER STRATEGIES

Nutrient Source

Zinc availability from soil applied fertilisers is generally related to it water solubility.
High water solubility (sulphates and chelates) ensures availability to plant roots early in the season when they are most vulnerable to poor soil supply.

Low solubility products such as oxides with small particle size can be effective in some applications.

Application Rate

Zinc is generally applied at rates 5 to 20 times that of removal. Lower rates are generally associated with foliar applications while higher rates are related to soil application. Many soils show the build-up of Zn that results from regular use of Zn fertiliser at rate greater than removal.

Application Method

There are a wide range of effective application methods for Zn. They include

- Broadcast and incorporate capital rates (5 – 10 kg Zn/ha).
- Water inject into seed furrow
- Seed coating
- Banded in blended, coated and compounded starter P products
- Foliar spray

Application Timing

Zinc is generally applied when the crop is small. This is to ensure adequacy as the crop reaches the critical head formation around the 6 leaf stage. Correction of deficiencies up to booting of the primary tiller generally improves yield but yield increase may not match that available from earlier applications.

COMMENT: EFFECTIVE USE OF RECYCLED BIO-SOLIDS

In many sorghum growing areas there is increasing use of recycled bio-solids as nutrient sources. Although these products are generally highly variable in nutrient analysis they can be very economical and effective. Availability of nutrients is related to the amount incorporation in organic forms and the degree of composting. Of the major nutrients the availability of P and K is generally given as 70 – 90 % of regular products whereas N and S is in the order of 20 – 40 % in the year of application. Higher N availability is associated with fresh poultry manure and effluent sludges provided they are incorporated soon after application.

Although P and K availability from bio-solids is high, access by crop to broadcast requires incorporation into the soil making it more popular in irrigated crops.

The application rate of these products should always be with consideration of the total P applied as it is the nutrient with to lowest removal rate with environmental pollution risk where it accumulates in soil.

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NOTES

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