1686 Efficacy of foliar fertilization in cotton

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Newly released, high-yielding transgenic cotton cultivars are said to have a higher nutrient demand during the boll-filling period (between flowering and maturity) due to their higher boll retention rate and larger boll load than conventional cultivars. During this period, nutrients are translocated from leaves to bolls, leading to speculation that foliar fertilization could be used as an effective tool for raising the nutrient status of the leaves at this critical period, and increasing the yield and fibre quality of the cotton crop. In this study, two macronutrient foliar fertilisers (P, K and a control) were sprayed onto Sicot 71BR cotton at two sites in north-west New South Wales in the 2005-2006 season. Foliar applications of did not increase productivity or fibre quality of the Bollgard II ® cotton. The pattern of macronutrient accumulation in the lint, seed and boll wall components of the developing cotton bolls from a Sicot 71BR cotton crop was also measured to assess the critical period of nutrient demand and the pattern of nutrient accumulation in bolls. This lack of plant response and ineffective uptake was attributed to the hot, dry environmental conditions and/or a lack of existing nutrient deficiency at either site.

Key Words: Cotton, *Gossypium hirsutum*, foliar fertilizers, fibre quality, nutrition, boll development, nutrient accumulation, nutrient translocation, seed oil.

Introduction

Salts of many essential plant nutrients are soluble in water and may be applied to plant leaves directly as a foliar fertilizer. This practice has become widespread in the American cotton industries over the past 20 years as a means of correcting crop nutrient deficiencies and supplying nutrients to plants during peak demand when root uptake may not be adequate . Foliar fertilization has many advantages over traditional soil fertilisation including:

- low cost of application;
- plant response is fast, and therefore deficiencies may be rectified quickly;
- no soil fixation;
- independent of root uptake, and so may be applied when root functioning is declining or impaired; and
- may be mixed with other agrochemicals.

The risks of foliar fertilization are phytotoxicity and leaf burn, insolubility of some compounds, high solution pH, difficulty in application of a high volume of nutrient and inefficient plant absorption due to leaf age, crop stage, water stress or climatic conditions .

Correct nutrition of a cotton crop is essential for ensuring high yields and high quality fibre. Newly released Bollgard II® cotton cultivars are reported to have higher boll numbers and boll retention rates than conventional cultivars. It is speculated that these cultivars have a higher overall nutrient demand, particularly during the boll development stage, making adequate nutrient supply to these crops a significant factor in achieving high yields . During the boll-filling period, translocation of nutrients from leaves to bolls intensifies at the same time as production of assimilates and photosynthates slows and sometimes stops. This halt in photosynthesis is attributed to the translocation of nitrogen to developing bolls . This research proposed that nutrients applied to leaves could prevent their senescence and decline in photosynthesis, allowing photosynthesis and carbon fixation to be extended, thereby increasing seed cotton yields.

Research into the efficacy of foliar fertilizers in cotton has shown a range of plant responses and production benefits in commercial cropping situations, leading to debate as to the usefulness of foliar fertilization in large scale operations . Cotton plant responses to foliar fertilizers have been inconsistent and variable. A study conducted at twelve sites across the American cotton belt showed yield increases with foliar applications of potassium at only 40% of the sites . Similarly yield responses to foliar applications of micronutrients have ranged from an increase of 140kg/ha in lint yield in response to foliar zinc to a decrease of 160 kg/ha in lint yield in response to foliar applied boron . These inconsistencies have been linked to environmental conditions , physiological characteristics of the crops and chemical properties of the foliar sprays . An understanding of the factors affecting the penetration of foliar sprays and the incorporation of the nutrients into metabolic pathways in cotton plants and other crops may aid in clarifying the effectiveness of foliar applied fertilizers at meeting plant nutritional requirements.

Information about the accumulation of both macronutrients and micronutrients would aid crop management decisions about timing of fertilizer applications to meet the demand from developing bolls. Knowledge about the timing of translocation of nutrients to the developing bolls is one of these areas. Nutrients accumulate in bolls, and the total nutrient content of the mature seed and lint is easy to establish through nutrient analysis at the end of the season. Knowledge about the timing of the accumulation could give insight into peak demand periods from the developing seeds, and the windows of opportunity in which application of these nutrients could enhance the concentration of these nutrients in the seeds or lint. The hypotheses were that application of foliar fertilizers to high yielding cotton crops would increase yield and quality and that nutrients moved in synchrony into the bolls (walls, seed and lint).

Materials and Methods

To test the efficacy of foliar fertilizers on Bollgard II® cotton, a field experiment was carried out at two sites in the cotton-growing region of north-west New South Wales during the 2005-2006 season. Since temperature and water stress have been shown to effect the efficacy of foliar fertilizers , two locations, the Australian Cotton Research Institute (ACRI), Narrabri (149°59′E, 30°12′S) and a commercial cotton property at Carroll (150°46′E 30°96′S) were selected, for their variation in climatic growing conditions. The soils were fertile alkaline dark grey-brown cracking medium clays, classified as a fine, thermic, montmorillonitic Typic Haplustert, or as a grey vertosol under the Australian classification system . The Carroll site had more exchangeable Na than that at Narrabri but was below levels that would impair growth of the crop. Nitrogen and zinc are the only fertilizers routinely applied to these soils.

Sicot71 BR cotton (*Gossypium hirsutum* L.) was sown to produce a population of 10 plants/m^2 at both sites. Summer maximum temperatures at Narrabri were 2-3°C higher than at Carroll; minimum temperatures were similar with Narrabri sometimes 1°C higher than Carroll. Both sites were flood-irrigated according to local schedules.

Potassium (as Agrodex K50) and phosphorus (as NaH_2PO_4) as foliar fertilizers were applied separately at a rate of 2 kg element / ha; the spray rate was 3750 L/ha. A non-ionic surfactant (NuFarm ChemWet1000 – 1000 g/L alcohol alkoxylate soluble liquid wetting agent) at a rate of 1ml/L was also applied with the foliar fertilizers. The foliar fertilizers (and control) were applied in a randomised complete block design with four replications at each site. Each block was 4 rows x 60 m, each of which was subdivided into the three treatments. Each plot consisted of 4 x 1 m spaced rows of cotton x 20 m long; the outer two designated as buffer rows to prevent fertilizer drift between blocks. Fertilizers were applied three times at Narrabri (1280, 1523 and 1845 Growing Degree Days - GDD) and twice at Carroll (1166 and 1618 GDD). At each time of application, the temperatures were in the above 36^{o}C with high radiation (>30 MJ/m^2) at Narrabri and slightly less at Carroll.

Prior to harvesting, 10 plants were randomly selected from each plot, and the number of nodes and bolls per plant counted. Plots in Narrabri were individually mechanically harvested on May 5th, 2006 using a single-row plot picker. Random 2 m sections of each plot in Carroll were hand picked on May 11th, 2006. Harvested cotton from both sites was ginned individually, and lint percentage, seed cotton turnout, seed and lint weight measured. Lint yield/ha was calculated for each plot.

Another experiment examined the timing of nutrient accumulation in cotton bolls at the Narrabri site. The experiment used a Time Series Design, with random sampling from four blocks. Blocks were 1 m x 30 m areas of Sicot 71BR cotton sown at 10 plants/m. The design included four replicate samples of bolls from 11 time periods. Six hundred white flowers were tagged on 13th January, 2006 (1341 GDD from sowing); flowering had commenced about 3 weeks prior to this. Only mainstem first position flowers were tagged. Plastic tape was tied around flower pedicels to know the age of developing bolls. Random samples of bolls from each block were collected at the sampling dates given in Table 1. Bolls were oven dried at 70^{o}C, then separated by hand into fuzzy seed, lint and boll wall (including internal membranes) components. Seed, lint and boll wall dry weights were recorded.

Nutrient Analysis

Seed, lint and wall components were analysed for N using Kjeldahl analysis and P, K, S, Ca, and Mg concentrations using Inductively Coupled Plasma Mass Spectrophotometry (ICP-MS).

Data Analysis

Seed, lint and wall dry weights, nutrient content and nutrient concentration were analysed using non-linear and linear regression analysis in Genstat® version 8.1 (2006) and Microsoft Excel® (2005).

Results and Discussion

The physical and chemical properties of the top 30 cm of soil from both sites are presented in Table 2. Values of the properties of this soil when compared to the soil nutrient critical values recommended by the Australian Cotton CRC for cotton crop growth do not show any limitations.

Application of foliar fertilizers had no effect on lint yield (mean yield at Narrabri was 1890 kg/ha [8.32 bales/ha] and at Carroll it was 1420 kg/ha [6.25bales/ha]) ($P>0.05$). Likewise, there was no effect of foliar fertilization on any quality parameter viz length, strength, micronaire or length uniformity ($P>0.05$).

Accumulation of dry matter into boll walls, lint and seeds is shown in Figure 1. More than 90% of the dry weight of the walls is accumulated in the first 12 days with only small increases thereafter. Lint dry weight accumulation starts virtually as the wall dry weight slows; lint accumulation occurs sigmoidally over a period of about 20 days. On the other hand, seed dry weight increases over a 50-day period, reflecting a much longer period of seed formation.

Patterns of macronutrient accumulation in terms of both concentration and content into the boll walls, seed and lint are shown in Figures 2 and 3. The pattern of nutrient concentration varied substantially between different nutrients (eg nitrogen v sulphur, calcium v magnesium). In some instances, nutrient dilution occurred especially for nitrogen, potassium and phosphorus early in growth of the seeds. Concentrations of N, P and Mg were consistently higher in seeds than in lint or boll walls. On the other hand, the concentrations of S and Ca were much higher in the boll walls for much of the season. The lint fraction had relatively low concentrations of all nutrients except for an early peak – this may be attributed to early active loading of nutrients into the lint followed by its subsequent cellular expansion resulting in its decline in concentration.

Total nutrient content (Figure 3) shows that nitrogen and potassium are present in the greatest quantities but the proportions of these nutrients in different fractions is dissimilar. For example, nitrogen is found predominantly in the seed whereas boll walls have more than twice the quantity of potassium relative to the seed. In all cases, lint has the lowest quantities as well as the lowest concentrations. Seeds have much greater proportions of magnesium relative to calcium; calcium tends to accumulate in the boll walls.

Examination of the sequential accumulation of nutrients in developing Sicot 71BR bolls showed that the accumulation of nutrients in bolls is neither constant throughout boll filling, nor is the pattern the same for all nutrients. While the asynchronous pattern of nutrient translocation to developing seeds in wheat, soybean and maize has been documented , there has been little previous research into the sequential accumulation of nutrients in cotton seeds. The current findings on nutrient accumulation and asynchronous translocation of nutrients to the developing cotton bolls are significant, both for the development of foliar fertilizer programs as well as a better understanding the links between physiological development of the bolls and demand for specific nutrients.

The bolls examined in these experiments were from a newly released transgenic cotton cultivar, Sicot 71BR. Previous studies carried out on conventional cultivars into the accumulation of nutrients in bolls found that over 60% of the accumulated nutrients were in the walls and seed components of the bolls . The findings of this experiment show that the development of bolls from this modern cultivar was similar to the conventional cultivars. Of the macronutrients examined, between 60 and 80% of the total boll nutrient content was found in the seed and wall components, with the lint accounting for the remainder. The bolls also developed physiologically in similar ways to the patterns established for conventional cultivars .

Overall the bolls showed similar patterns of dry weight accumulation and physiological development when examined as a whole, but this study also examined the development of boll parts when partitioned into seed, lint and walls. Maximum seed dry weight was recorded at 2132 day degrees from sowing (700 day degrees or 50 days after flowering); however, seed dry weight remained relatively constant at about 95% of the maximum from 1936 growing day degrees after sowing (504 day degrees, or 36 days after flowering). This confirms the findings of Benedict *et al.* that the fertilised ovule in a cotton boll reaches its full length and volume 18 to 20 days after fertilisation but increases in weight until it detaches from the ovary wall just prior to boll opening.

The high nutrient demand speculated of high yielding transgenic cultivars during boll filling is attributed to rapid seed development .

The foliar fertilizers applied in this experiment were ineffective at supplying nutrients to the developing cotton crops during the boll development period, since plant uptake of the nutrients applied was minimal and inconsistent (data not presented) and no yield increases or increases in fibre quality were measured. This is contrary to the hypothesis that the foliar application of nutrients would increase the productivity of the cotton plants. Similar results have been found in several American studies on the efficacy of foliar fertilizers. On the other hand other studies have found yield and quality responses to the application of foliar fertilizers . This practice has not been previously investigated on Bollgard II® cotton in Australia.

The lack of response to foliar applied nutrients may be attributed to the very high temperatures at the times of application. Furthermore, under such conditions, much more cuticular wax may have been deposited thus reducing the effectiveness of the wetting agent.

The usefulness of foliar fertilizers in hot, dry condition, such as those typical of the Australian cotton growing region may therefore be limited by climatic factors which create drought responses in the cotton leaves, limiting the penetration and incorporation of foliar applied nutrients. However, the usefulness of foliar application of nutrients to plants growing in soils with high natural fertility, such as the vertosols typical of the Australian cotton growing region, is also questionable.

Table 1 Sampling Dates in chronological and thermal time

Days From Tagging	Date	Growing Day Degrees
0	13/1/06	1341
7	19/1/06	1439
12	24/1/06	1523
15	27/1/06	1574
20	1/2/06	1660
22	3/2/06	1707
27	8/2/06	1802
32	13/2/06	1876
36	17/2/06	1936
42	23/2/06	2031
50	3/3/06	2132
60	13/3/06	2265

Table 2 Chemical characteristics of surface (0-0.30 m) soils at the Narrabri and Carroll sites.

Soil property	Narrabri	Carroll
Texture	Medium Clay	Medium Clay
Munsell Colour	Brown	Grey
pH (1:5 Water)	7.9	8.5
CEC (M eq/100g)	38.8	55.5
Electrical Conductivity (dS/m)	0.27	0.38
ESP %	2.2	7.7
Organic Carbon %	0.90	0.70
Nitrate Nitrogen (mg/kg)	17	2
Sulfate Sulfur (mg/kg)	17	21
Phosphorus (Colwell) (mg/kg)	28	12
Potassium (meq/100g)	1.48	1.95
Calcium (meq/100g)	26.75	37.00
Magnesium (meq/100g)	9.75	12.25
Sodium (meq/100g)	0.85	4.28
Ca:Mg Ratio	2.73	3.03

Captions of Figures:

Figure 1. Dry matter accumulation in seeds, lint and boll walls during the growth of a single boll.

Figure 2. Nutrient concentrations in bolls during their development and maturation that grew from flowers which were tagged on13th January 2006.

Figure 3. Nutrient content of bolls during their development and maturation that grew from flowers which were tagged on 13th January 2006.

Figure 1.

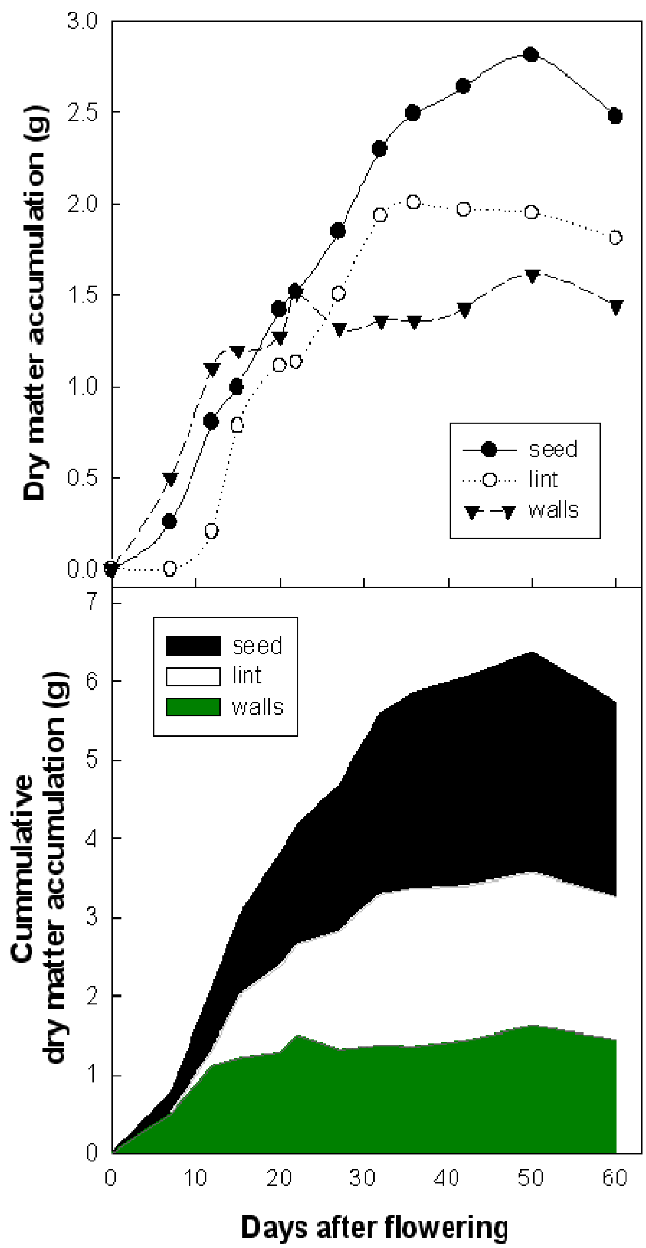
Dry matter accumulation (g)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
seed
lint
walls
Cummulative
dry matter accumulation (g)
7
6
5
4
3
2
1
0
seed
lint
walls
0
10
20
30
40
50
60
Days after flowering

Figure 2.

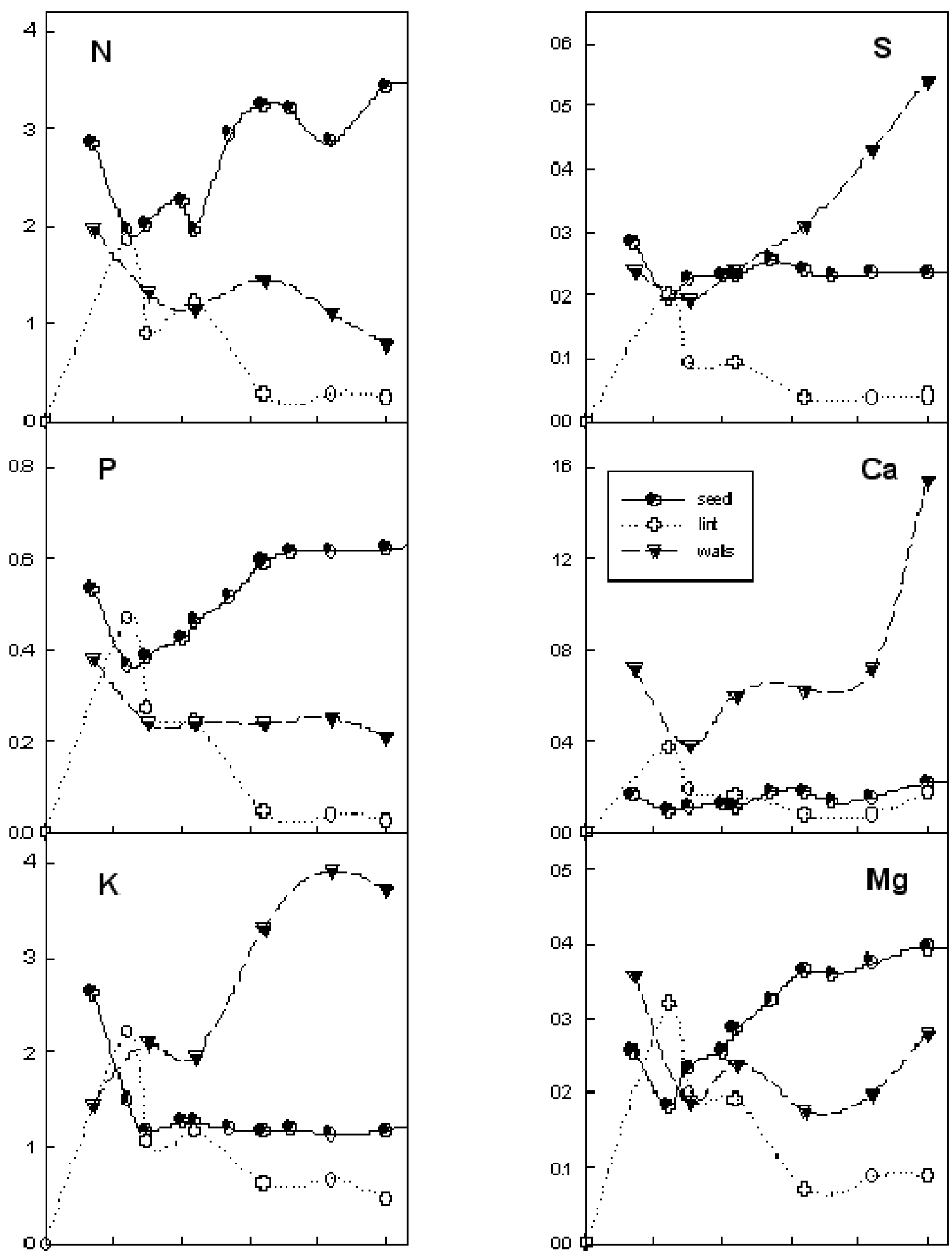

Figure 3.