Benefits of foliar applied Boron and Potassium fertiliser on fruit retention and development on Cotton.

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Abstract

Cotton (Gossypium hirsutum) is the leading plant fibre crop grown commercially worldwide primarily for its fibre use. It is harvested as 'seed cotton' which is then 'ginned' to separate the seed and lint. Long lint fibres are spun to produce yarn that is knitted or woven into fabrics. The quality and yield of the cotton plant is limited by low fruit retention which is known to be caused by a lack of micro-nutrients, particularly boron (B) and potassium (K) when short term water-logging occurs during irrigation. There are only a few studies conducted in the past that concentrate on B effects on the physiological processes of cotton including deficiency analysises. The development of new varieties especially Bt cotton has significantly changed the intensity of nutrient requirement in the fruiting process, probably leading to "hidden" or marginal inadequacy of micronutrients such as B and K in fruits. This study aimed to investigate the effects of supplementary foliar B and K on fruit retention and development of the new Bt varieties. It examined the effect of foliar B and K on yield components, including; fruit numbers, retention, and final yield, and quality index including; lint strength, length and micronair. Very few significant results appeared but some positive signals from K effect on boll-filling show promise. This study was carried out in a field trial on black clay soils in the Macintyre cotton growing region during a 2005/2006 cotton season and future improvements on this experiment may see significant results that will give us a better understanding of the K and B effects on cotton development, which may lead to improvements in agronomic practices.

This project is the original work James Duddy, except as otherwise Stated and has not been submitted at any other University.

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1.0 Introduction

1.1 Boron

1.1.1 Boron's role in plants

Unequivocal proof that Boron (B) is an essential micronutrient was provided by Warrington in 1923 (Shorrocks, 1997) and B deficiency has been reported in over 80 countries and on 132 crops over the past 60 years. It is estimated that about 15 million ha are annually treated with B (Shorrocks, 1997). Reports of B deficiency in commercial crops in Australia have largely been restricted to the slopes of the Great Dividing Range from north Queensland to Tasmania (Chapman et al., 1997). Requirements of crops for B differ markedly among plant species, and dicotyledons generally require more B than monocotyledons (Shelp, 1993). It is understood that an adequate supply of B is critical for optimal cotton (dicot) growth and yield development (Zhao, 2002).

Much of the information collected to date about the role of B in plants has been done so via the removal of B supply and then studying the responses following its re-introduction. However, it is the least understood of the mineral nutrients, which is surprising see as though on a molar basis dicotyledons have the highest requirement for B than any other micronutrient (Marschner, 1995). However, previous research that includes removal and reintroduction of B, has revealed a long list of postulate roles for B including sugar transport, cell wall synthesis and structure, lignification, carbohydrate metabolism, phenol metabolism and membrane integrity (Parr and Loughman, 1983). This may mean that B is either involved in a number of metabolic pathways, however, it is more widely accepted that primary responses to B deficiency result in a cascade of effects, rather like phytohormones (Marschner, 1995). Therefore, probable primary roles of B in plants are cell wall biosynthesis and structure, and plasma membrane integrity (Marschner, 1995).

Due to Boron's primary roles in plant cells, when a deficiency occurs in higher plants it adversely affects cellular functions and physiological processes (Dugger, 1983; Marschner, 1995). It decreases or inhibits the growth of vegetative and reproductive plant parts, depending on the timing and extent of B deficiency (Dell and Huang, 1997). Boron deficiency also inhibits root growth by limiting cell enlargement and cell division in the growing zone of root tips, and in severe cases it ceases, leading to death of the root tip (Dell and Huang, 1997). Expansion and elongation of newly initiated leaves is also inhibited by a B deficiency as it plays an important role in cell wall structure and plasticity (Loomis and Durst, 1992; Brown, 1994) and indirectly affects the photosynthetic capacity of plants (Dell and Huang, 1997). The early inhibition of root growth, compared to shoot growth, increases the shoot to root ratio and is hypothesised that it enhances the susceptibility of plants to environmental stresses such as water deficit in soil and other nutrients with marginal supply (Dell and Huang, 1997).

1.1.2 Importance for cotton.

Boron Deficiency strongly influences cotton growth and yield worldwide (Shorrocks, 1997). This is due to the Boron's role in the processes outlined above that correlate to the vegetative stage of the cotton plant but B also plays a significant role in the plants reproduction stage. It has often been observed that reproductive growth, especially flowering, fruit and seed set and seed yield, is more sensitive to B deficiency than vegetative growth (Dear and Lipsett, 1987; Noppakoonwong et al., 1997); Woodbridge et al., 1971). Boron has a particular importance in pollen germination and pollen tube growth, resulting in successful fruit setting (Johri and Vasil, 1961). Therefore, during the flowering and fruiting process of cotton, a B deficiency may increase fruit shedding and reduce lint yield and fibre quality (Miley et al., 1969). The requirement of B for flowering is indicated by the sensitivity of pollen development to low B and the generally high concentrations of B that occur in the reproductive parts of the flower (Dell and Huang, 1997). Factors that affect the impact of a low external B supply on sexual reproduction in flowering plants likely to include; Capacity of roots to aquire B from soil, Phloem mobility of B (Brown and Shelp, 1997), The relative sink size in floral parts for photosynthate; capacity to redistribute B from vegetative tissues to reproductive organs, rate of transpiration of by floral organs and the functional requirements of reproductive tissues. Most of this is yet to be examined and fully defined. However, Zhao (2002) does report that the critical B level of uppermost fully expanded main stem leaf blades, which affect plant growth and physiological processes, was about 17-20 mg kg-1 during squaring and fruiting.

1.2 Potassium

1.2.1 Potassium role in plants

Potassium is an important factor in plant metabolism, growth and development, thus ultimately affecting yield and quality. Potassium has been shown to play a significant role in the opening and closing of stomata (Humble and Rasschke, 1971), which would therefore have an affect on stomatal conductance (Peaslee and Moss, 1968) and as a result of K deficiency, stomatal dysfunction would increase the plants sensitivity to water stress. Plant response to K deficiency is a decrease in photosynthetic rate (Peaslee and Moss 1968, Longstreth and Nobel 1980, Huber 1984) which has been related to lowered stomatal conductance (Moss and Peaslee 1965, Peaslee and Moss 1968, Raschke 1975). Stomatal number and aperture size may also be affected by K nutrition (Cooper et al., 1967) implying that sufficient K results in better CO2 diffusion into the leaf and higher rates of photosynthesis (Bednarz, 1998). However reduced mesophyll conductance may be the primary factor causing the reduction in photosynthesis (Terry and Ulrich 1973, people and Koch 1979, Longstreth and Nobel 1980). In 2001 Zhao et al found that the decreased leaf photosynthetic rate was associated to dramatically low chlorophyll content, poor chloroplast ultra-structure, and restricted saccahride translocation, rather than limited stomatal conductance in the k deficient leaves.

1.2.2 Importance for Cotton

Due to the indeterminate growth habit of cotton plants it is understood that there is a continual high demand for K throughout the season and as a major mineral nutrient, the level of K uptake impacts growth, development, lint yield and fiber quality (Kerby and Adams, 1985, and Cassman et al., 1990). Potassium deficiency limits yield through decreased leaf area expansion and CO2 assimilation capacity, low productivity is often associated with low fiber quality (Bradow and Davidonis, 2000; Reddy et al., 2004). The developing boll is also a major sink for K, especially the seeds (Usherwood, 2000) and because K is involved in plant water relations and carbohydrate translocation, K deficiency, unlike N deficiency, restricts fruit production to a greater extent than vegetative growth (Kerby and Adams 1985, Pettigrew 1997).

The quality of cotton produced has always been important to the manufacturing industry, especially fibre length. However since the introduction of rotor spinning technology in 1970's, micronaire and strength both have increased in importance relative to other quality characteristics (Deussen, 1986). Pettigrew (1996), from his studies, has reported that K deficiency decreased lint yield, fibre elongation, shortened span length. Fibre development originates from the outer seed coat and occurs in three distinct processes; elongation, secondary wall thickening or maturation, and then drying (Davidonis et al., 2004). Fibre elongation occurs between anthesis to 20-25 days (DeLanghe, 1986) in which potassium is required to increase turgor pressure for growth and elongation (Ramey, 1986). From 15-20 days after anthesis to about 50 days, thickening of the secondary wall occurs (Read, 2006). During this stage Cellulose is deposited at slightly different angles, playing a major role in the strength of the fibre (Davidonis et al, 2004). Micronaire is the thickeness of the fibre and is a composite measure of maturity and fibre. Maturity is determined by the amount of secondary wall thickening (Davidonis et al, 2004). This would give reason to why there is an optimal micronaire level, and fibre qualities outside those levels will attract discounts. Restricted saccharide translocation and reduced photosynthesis as a result of K deficiency (Zhao, 2001) would negatively impact fibre length and secondary wall thickening therefore affecting the resulting micronaire.

A 2 year study conducted by Read et al (2006) observed reductions in cotton yield and micronaire in K-deficient cotton and that is was consistent with reports that K deficiency causes premature termination of reproductive growth (Pettigrew, 2003), low boll weight (Kerby and Adams, 1985) and decreased translocation of sugars out of the leaf (Pettigrew, 1999). Also, Reddy and Zhao (2005) reported the critical leaf K for cotton photosynthesis, biomass and stem growth was 12 g kg−1, and for leaf area expansion the critical value was 17 g kg-. However, new cultivars have characteristics of faster fruiting, higher boll load, higher lint yield, reduced root growth and ion uptake, which are contributing factors to the reportedly increased K deficiencies (Oosterhuis, 1994) and was also speculated by Maples et al. (1988–1989), that the K requirement late in the growing season exceeded plant uptake. In sink levels of K may further be reduced when water-logging periods occur, particularly during irrigations and when wet weather follows.

1.3 Application method

1.3.1 Foliar sprays

A sufficient supply of B and K during these stages of fruit and boll development would offset the negative impacts outlined previously. It would also allow a higher percentage of 1st position fruit to be retained. First position bolls are heavier and are produced in higher quantities than bolls in any other position later in the crop (Ritchie et al. 2004). First Position bolls contribute from 66 to 75% of the total yield and tend to fill out more and be heavier than bolls from other positions (Ritchie et al., 2004). One method of applying B and K to correct the deficiency is through foliar applications, seeing as though root uptake is reportedly insufficient..

Foliar application of mineral nutrients by means of sprays offers a method of supplying nutrients to higher plants more rapidly than methods involving root application (Marschner, 1995). In a soil that is low in nutrient availability foliar sprays can be an immediate and temporary fix especially when B deficiency inhibits root growth and uptake. Also, as a result of sink competition for carbohydrates, root activity and thus nutrient uptake by the roots decline with the onset of the reproductive stage (Marshner, 1995) therefore having a compounding effect on B supply to reproductive floral parts. Foliar sprays containing nutrients can compensate for this decline (Trobisch and Schilling, 1970).

Considerations have to be made into the compound choice when applying foliar fertilisers. There are two types of primary sources of B which are either completely soluble materials or crushed ores that contain insoluble gangue (Shorrocks, 1997). Common commercial products are listed in table 1. For this experiment solubility will be a key feature for a spray/foliar application. This is to ensure that the nutrient will be involved in the stomatal uptake. Borax and boric acid dissolve easily in soils and are ready for uptake but higher rates of leaching can occur, especially in irrigation situations. Solubor is a product developed to increase dissolution and is a hybrid between borax and boric acid (Shorrocks, 1997). The resulting solution has high saturated B concentrations and readily forms super saturated solutions, which are valuable features for a spray grade product (Shorrocks, 1997). Common K source used commercially include KNO_3, K_2SO_4, $K_2S_2O_3$ and KCl. Howard in his studies found that KNO_3 had a greater impact than the others on cotton yield and qualities, however may be due the N component. In this experiment K_2SO_4 was selected due to the fact that it did not contain N and had minimal impact on others unaccounted for factors such as pH. Availability of products can also be a factor in the final decision.

			B (%)
Refined products	$Na_2B_4O_7 \cdot 5H_2O$	Sodium tetraborate pentahydrate	14.9
	$Na_2B_8O_{13} \cdot 4H_2O$	Solubor	20.8
	$Na_2B_4O_7 \cdot 10H_2O$	Sodium tetraborate decahydrate	11.3
	$Na_2B_4O_7$	Sodium tetraborate	21.4
	$B(OH)_3$	Boric acid	17.5
Crushed ores	$2CaO \cdot 3B_2O_3 \cdot 5H_2O$	Colemanite	variable
	$Na_2O \cdot 2CaO \cdot 5B_2O_3 \cdot 16H_2O$	Ulexite	variable
	$2CaO \cdot B_2O_3 \cdot 2SiO_2 \cdot H_2O$	Datolite	variable
	$CaO \cdot MgO \cdot 3B_2O_3 \cdot 6H_2O$	Hydroboracite	variable
	$2MgO \cdot B_2O_3 \cdot H_2O$	Ascharite	variable

Table 1: Commonly used borates (Shorrocks, 1997)

1.3.2 Difficulties

However, there are many difficulties associated with foliar applications. This can include; low penetration rates, run-off from hydrophobic surfaces, washing off by rain, rapid drying of spray solutions, limited rates of re-translocation of certain mineral nutrients such as calcium from the sites of uptake (mainly mature leaves) to other plant parts and localized toxicity 'burning' (Marschner, 1995). These difficulties also add to the complexity of controlling external input of B into the cotton. Currently there is minimal literature of factors that affect the impact of a low external B supply on sexual reproduction on cotton and also into the identification of the stages of reproduction that are sensitive to reduced B. This increases the difficulty of knowing when to apply the foliar micronutrients to have a maximum effect which is also compounded by the fact that there is limited knowledge on the translocation times from leaves to the reproductive parts.

1.4 Reasons for research or objectives of research

The reason for this research is to study the effects of foliar applied B and K aiming to offset the negative impacts of B and K deficiency. Boron deficiency has been shown to play a major role in the reproduction stages of cotton development severely affecting cotton yield and quality. Boron deficiency can arise from lower nutrient availability in the soil however it is also exacerbated by periods of waterlogging from irrigation. It has also been shown that during reproductive stages, as a result of sink competition for carbohydrates, that nutrient uptake by the roots declines. Due to the reproductive cells formed during square development being very sensitive to environmental conditions it is well known that B deficiency is a largely responsible for high amounts of fruit shedding. As described before, 1st position bolls contribute more to the final yield than secondary or tertiary positioned bolls. It also well known that K plays an important role in plant function and deficiencies can cause a reduction in CO2 assimilation, reduced photosynthesis and decreased translocation of important assimilates, such as sugars and carbohydrates. It also documented that K plays an important role in fibre development thus affecting yield and quality of that fibre. This experiment's objective involves foliar applying B and K to determine the effects on cotton in the hope of retaining higher numbers of fruit and achieving a higher percentage of 1st position bolls and improving the yield and quality of commercial cotton.

1.4.1 Possible problems

Possible problems that may arise in this experiment are other environmental conditions such as high temperature, humidity, and other nutrient deficiencies have a more pro-founding effect on the reproduction processes than B's affect. Previous reports of fiber property trends in studies are some times contradictory due to the interactive effects of genotype, weather, and soil (Minton and Ebelhar, 1991; Pettigrew, 2003; Reddy et al., 2004). Fiber properties may also vary due to the indeterminate growth habits of cotton and the various cultivars available. It is difficult to predict the effects of K deficiency on fiber development and lint quality without knowledge of the timing and intensity of stress (Ramey, 1986) due to bolls being in either of the three stages, elongation, fibre thickening or mature.

2.0 Materials and methods

2.1 Field

2.1.1 Field Details

Figure 1: Geography - Google Earth map of the Irrigation areas of "South Callandoon".

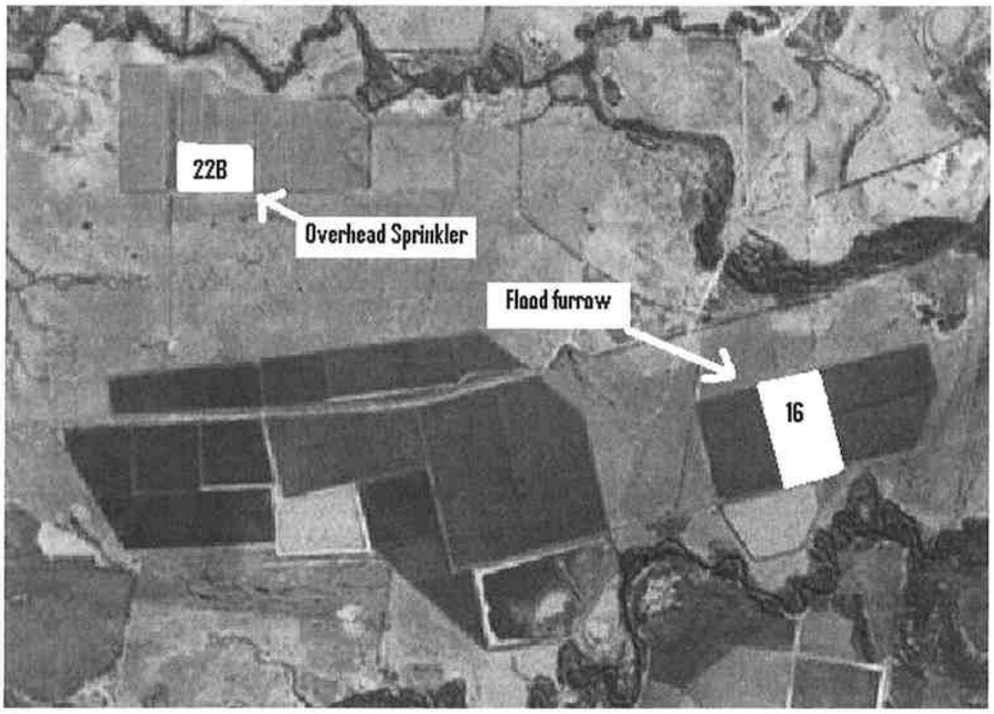


Table 2: **Dimensions and description of field**

Field 16	Flood Furrow	Field 22B	Over head Sprinkler
Row Length	688m	**Row Length**	642m
No of rows	1055	**No of rows**	392
Total Area	72.6Ha	**Total Area**	25.2Ha
Gradient	Sloping down to the west	**Gradient**	Sloping down to the west

2.1.2 Soils

The next sheet (Table 3) shows the results for the soil test done in theses fields. Important factors for comparison are highlighted. This includes K levels, B levels, P results and cation exchange capacity.

Table 3: Soil tests carried out prior planting.

Field Number and Depth			Block ID:	16 0-30cm	16 30-60cm	22B 0-30cm	22B 30-60cm	*Desirable*
			Crop:	Cotton	Cotton	Cotton	Cotton	*Level*
			Client:	B. Duddy	B. Duddy	B. Duddy	B. Duddy	*Heavy Soil*
	Nutrient		Units	*JA2478/1*	*JA2478/2*	*JA2478/11*	*JA2478/12*	
Soluble Tests & Morgan 1 Extract	Calcium	Ca	ppm	1760	1762	2026	3529	*1150*
	Magnesium	Mg	ppm	863	862	715	892	*160*
	Potassium	K	ppm	73	74	101	113	*113*
	Phosphorus (Morgan)	P	ppm	0.3	0.4	0.4	0.2	*15*
	Phosphorus (Bray 1)	P	ppm	4	4	7	2	*45 note 8*
Soluble Tests & Colwell + Bray 2 Phoshorus Extract	Phosphorus (Colwell)	P	ppm	21	14	26	14	*80*
	Phosphorus (Bray 2)	P	ppm	20	20	29	15	*90 note 8*
	Nitrate	N	ppm	8.2	9.4	8.8	2.2	*15*
	Ammonia	N	ppm	1.3	1.2	3.2	2.6	*20*
	Sulphate Sulphur	S	ppm	28	30	14	1054	*40*
	pH (1:2 water)		units	8.30	8.31	8.39	7.71	*6.5*
	Conductivity (1:5 water)		µS/cm	300	321	253	1304	*200*
	Organic Matter		%	1.44	1.07	1.16	0.74	*5.5*
Ammonium Acetate Equiv. Extract	Calcium	Ca	$cmol^+/Kg$	20.02	21.98	19.16	18.52	*15.6*
		Ca	kg/ha	8969	9848	8582	8298	6250
		Ca	ppm	4004	4397	3831	3704	3125
	Magnesium	Mg	$cmol^+/Kg$	13.56	14.81	10.29	11.03	*2.4*
		Mg	kg/ha	3645	3980	2766	2966	580
		Mg	ppm	1627	1777	1235	1324	290
	Potassium	K	$cmol^+/Kg$	0.63	0.70	0.74	0.75	*0.6*
		K	kg/ha	555	609	648	659	470
		K	ppm	248	272	289	294	235
	Sodium	Na	$cmol^+/Kg$	4.07	4.41	3.05	3.96	*0.30*
		Na	kg/ha	2096	2272	1572	2040	138
		Na	ppm	936	1015	702	911	69
	Aluminium	Al	$cmol^+/Kg$	0.09	0.08	0.11	0.09	*0.6*
		Al	kg/ha	17	17	23	19	108
		Al	ppm	8	8	10	8	54
Acidity Titration	Hydrogen	H^+	$cmol^+/Kg$	0.00	0.00	0.00	0.00	*0.6*
		H^+	kg/ha	0	0	0	0	12
		H^+	ppm	0	0	0	0	6
	Cation Exchange Capacity		$cmol^+/Kg$	38.37	41.98	33.35	34.36	*20.0*
Percent Base Saturation	Calcium	Ca	%	52.2	52.4	57.4	53.9	*77.0*
	Magnesium	Mg	%	35.3	35.3	30.8	32.1	*12.0*
	Potassium	K	%	1.7	1.7	2.2	2.2	*3.0*
	Sodium	Na	%	10.6	10.5	9.1	11.5	*1.5*
	Aluminium	Al	%	0.2	0.2	0.3	0.3	*6.5*
	Hydrogen	H+	%	0.0	0.0	0.0	0.0	
	Calcium/ Magnesium Ratio		ratio	1.48	1.48	1.86	1.68	*6.42*
SMP	BUFFER pH		units	7.44	7.44	7.49	7.50	*6.7*
Micronutrients- DPTA +Hot $CaCl_2$ Extracts	Zinc	Zn	ppm	0.5	0.4	0.4	0.4	*6.0*
	Manganese	Mn	ppm	6.3	6.4	8.8	5.8	*25*
	Iron	Fe	ppm	39.5	40.0	32.4	24.3	*25*
	Copper	Cu	ppm	1.9	1.9	1.8	1.5	*2.4*
	Boron	B	ppm	0.92	0.51	1.00	2.33	*2.0*
Acid Extract	Molybdenum	Mo	ppm	..	..	..	..	*2.0*
	Cobalt	Co	ppm	..	..	..	..	*40*
	Selenium	Se	ppm	..	..	..	..	*2*
$CaCl_2$ Extract	Silicon	Si	ppm	-6.28573	-6.28573	-6.28573	-6.28573	.. *50*
Total Nutrients	Total Carbon	C	%	0.82	0.61	0.66	0.43	*3.1*
	Total Nitrogen	N	%	0.08	0.05	0.07	0.05	*0.30*
	Carbon/ Nitrogen Ratio		ratio	10.5	11.4	9.8	9.0	*10 to 12*

Agronomic procedures

Table 4: Agronomic Procedures Field 16

Paddock Summary 16 F16 (72.60 ha)

Date	Activities	Machinery/Contractor	Details
01/ 8/05	Aerial Spraying RC	Aircair Goondiwindi	
			Li 700 0.06 l/ha 100%
			Roundup CT 1.00 l/ha
			Surpass 0.50 l/ha
31/ 8/05	Fertilise RC		
			Custom Blend 05/06 350.0 kg/ha
09/ 9/05	Bedshaping RC		
16/ 9/05	Fertilise RC		
			Custom Blend 05/06 350.0 kg/ha
03/10/05	Plant RC (RC Mach)		
			Cotton [71BGRR] 12.0 plants/m2
08/10/05	1st Water RC		
04/11/05	Aerial Spraying RC	Aircair Goondiwindi	
			Roundup Ready 1.50 kg/ha 100%
21/11/05	Crop Water RC		
			Urea - Elders 100.0 kg/ha
21/11/05	Crop Water RC		
13/12/05	Cultivate RC		
			Diuron 1.00 kg/ha 100%
			Bandit WG 1.00 l/ha
13/12/05	Cultivate RC		
18/12/05	Crop Water RC		
18/12/05	Crop Water RC		
			Urea - Elders 60.0 kg/ha
22/12/05	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.40 l/ha 100%
			Regent 0.03 l/ha
22/12/05	Aerial Spraying RC	Aircair Goondiwindi	
			Quickstart Hi Trace 1.3 kg/ha
29/12/05	Crop Water RC		
			Urea - Elders 60.0 kg/ha
29/12/05	Crop Water RC		
08/ 1/06	Crop Water RC		
08/ 1/06	Crop Water RC		
			Urea - Elders 40.0 kg/ha
11/ 1/06	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.60 l/ha 100%
			Ovasyn Options 1.00 l/ha
			Thiodan EC 2.10 l/ha
18/ 1/06	Crop Water RC		
28/ 1/06	Crop Water RC		
31/ 1/06	Aerial Spraying RC	Aircair Goondiwindi	
			Agro K50 3.00 l/ha 100%
			Ovasyn Options 1.00 l/ha
			Wizard 0.60 l/ha
07/ 2/06	Crop Water RC		
15/ 2/06	Aerial Spraying RC	Aircair Goondiwindi	
			Quickstart Hi Trace 5.8 l/ha
24/ 2/06	Crop Water RC		
06/ 3/06	Aerial Spraying RC	Aircair Goondiwindi	
			Reign 1.50 l/ha 100%
14/ 3/06	Crop Water RC		
18/ 4/06	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.50 l/ha 100%
			Dropp Ultra 0.22 l/ha
			Prep 720 Defoliant C 0.75 l/ha
27/ 4/06	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.50 l/ha 100%
			Dropp Ultra 0.15 l/ha
			Prep 720 Defoliant C 3.00 l/ha
03/ 5/06	Aerial Spraying RC	Aircair Goondiwindi	
			Bs 1000 0.04 l/ha 100%
			Prep 720 Defoliant C 2.00 l/ha

Table 5: Agronomic Procedures Field 22

Paddock Summary 22 Lat F22 (48.40 ha)

Date	Activities	Machinery/Contractor	Details
07/ 9/05	Trashworker		
14/ 9/05	Fertilise RC		
			Custom Blend 05/06 350.0 kg/ha
03/11/05	Plant RC (RC Mach)		
			Cotton [71RR] 12.0 plants/m2
10/11/05	Aerial Spraying RC	Aircair Goondiwindi	
			Roundup Ready 1.50 kg/ha 100%
29/11/05	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.50 l/ha 100%
			Dipel SC 2.00 l/ha
05/12/05	Aerial Spraying RC	Aircair Goondiwindi	
			Roundup Ready 12.00 kg/ha 100%
09/12/05	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.60 l/ha 100%
			Dipel SC 2.00 l/ha
			Vivus 0.18 l/ha
10/12/05	Irrigation		
15/12/05	Irrigation		
15/12/05	Crop Water RC		
			Urea - Elders 45.0 kg/ha
15/12/05	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.60 l/ha 100%
			Dipel SC 2.00 l/ha
			Vivus 0.15 l/ha
15/12/05	Irrigation		
15/12/05	Fertiliser		
			Urea 45.0 kg/ha
19/12/05	Irrigation		
20/12/05	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.60 l/ha 100%
			Reign 0.30 l/ha
			Steward 0.65 l/ha
21/12/05	Irrigation		
21/12/05	Crop Water RC		
			Urea - Elders 60.0 kg/ha
23/12/05	Irrigation		
27/12/05	Irrigation		
29/12/05	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.60 l/ha 100%
			Steward 0.65 l/ha
30/12/05	Irrigation		
01/ 1/06	Irrigation		
02/ 1/06	Fertiliser		
			Urea 60.0 kg/ha
05/ 1/06	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.60 l/ha 100%
			Pix 0.30 l/ha
			Steward 0.65 l/ha
13/ 1/06	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.60 l/ha 100%
			Endosulfan 350 EC 2.10 l/ha
29/ 1/06	Aerial Spraying RC	Aircair Goondiwindi	
			Affirm 17 EC 0.70 l/ha 100%
			Agro K50 3.00 l/ha
			Ovasyn Options 1.00 l/ha
			Wizard 0.30 l/ha
04/ 2/06	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.60 l/ha 100%
			Steward 0.85 l/ha
			Vivus 0.20 l/ha
04/ 3/06	Aerial Spraying RC	Aircair Goondiwindi	
			Dimethoate 0.50 l/ha 100%
			Dipel SC 1.90 l/ha
			Reign 1.50 l/ha
05/ 3/06	Irrigation		
11/ 3/06	Irrigation		
11/ 3/06	Chemical Spraying		
			Dipel SC 1.65 l/100l 100%
			Vivus 0.14 l/ha
11/ 3/06	Irrigation		
13/ 3/06	Chemical Spraying		
			Vivus 0.14 l/ha 100%
13/ 3/06	Irrigation		
16/ 3/06	Irrigation		
20/ 3/06	Irrigation		
26/ 3/06	Irrigation		
31/ 3/06	Aerial Spraying RC	Aircair Goondiwindi	
			Parathion 1.10 l/ha 100%
			Predator 300 5.00 l/ha
12/ 4/06	Fertiliser		
			Urea - Elders 54.0 kg/ha
18/ 4/06	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.50 l/ha 100%
			Dropp Ultra 0.22 l/ha
			Prep 720 Defoliant C 0.75 l/ha
02/ 5/06	Harvest RC	T RYAN - NAYR PTY LT	
03/ 5/06	Aerial Spraying RC	Aircair Goondiwindi	
			Canopy Oil 0.50 l/ha 100%
			Finish 1.60 l/ha
			Resource 0.27 l/ha
10/ 5/06	Cartage RC	BMC PARTNERSHIP	
12/ 5/06	Root Cutting	Patty Ryan	
24/ 5/06	Mulching RC	DUDDY MANGEMENT	
29/ 5/06	Yield - Cotton		7.59

2.2 Experiment Design

In this experiment there is the application of foliar K and foliar B at two different stages, flowering and boll filling. This lends itself to this number of 8 different treatments shown in the diagram tree (figure 2) below.

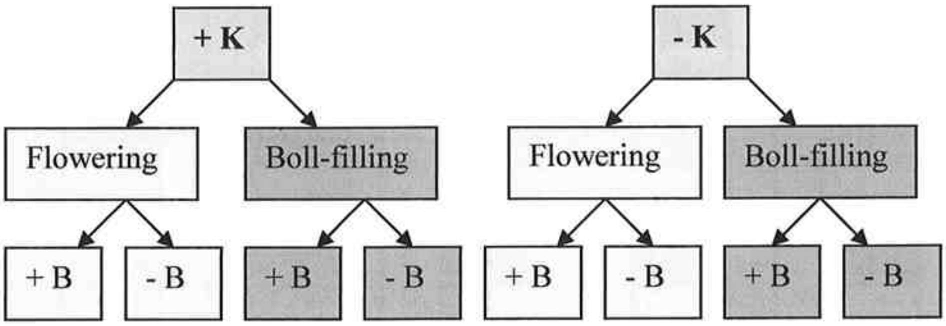


Figure 2: The different treatments

To ensure there is plenty of data and to reduce noise and error there was three replicas in this experiment and each replica had two rows. Between replicas there was a minimum of 2 rows acting as a buffer and a 30 m buffer around the whole plot to reduce edge effect of the cotton field. This is due to edges being susceptible to different treatments including different insect pressure, chemical rates, and weather and machinery effects. The resulting plot design before randomisation is shown below. Minitab was then used to randomize the plots.

Figure 3: Field design before randomization

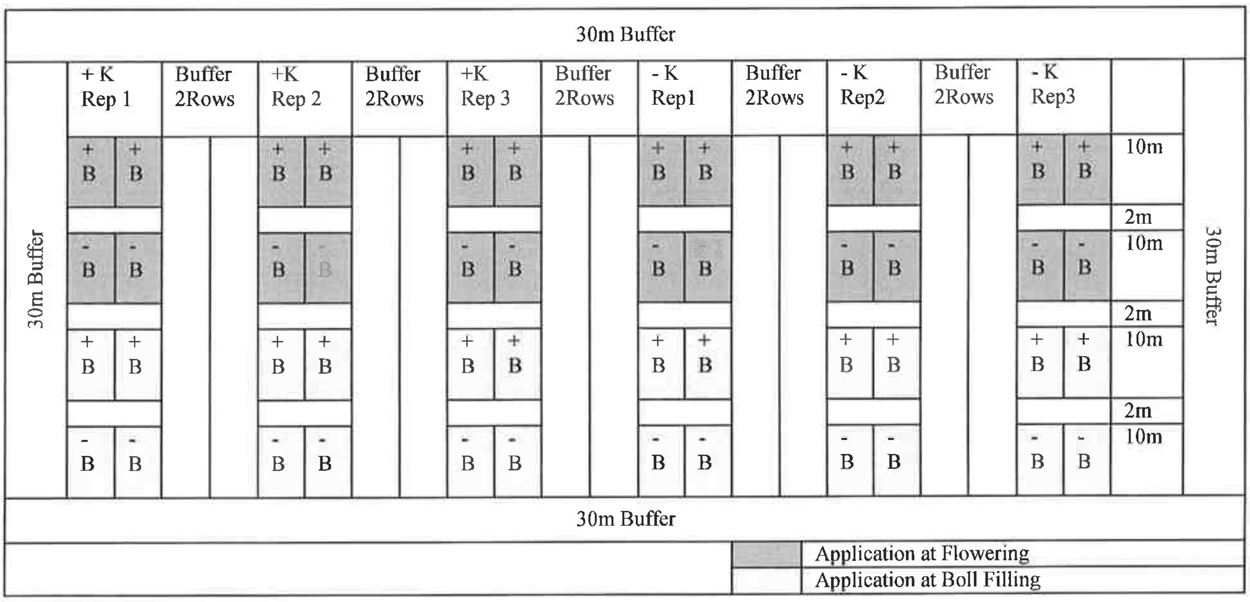
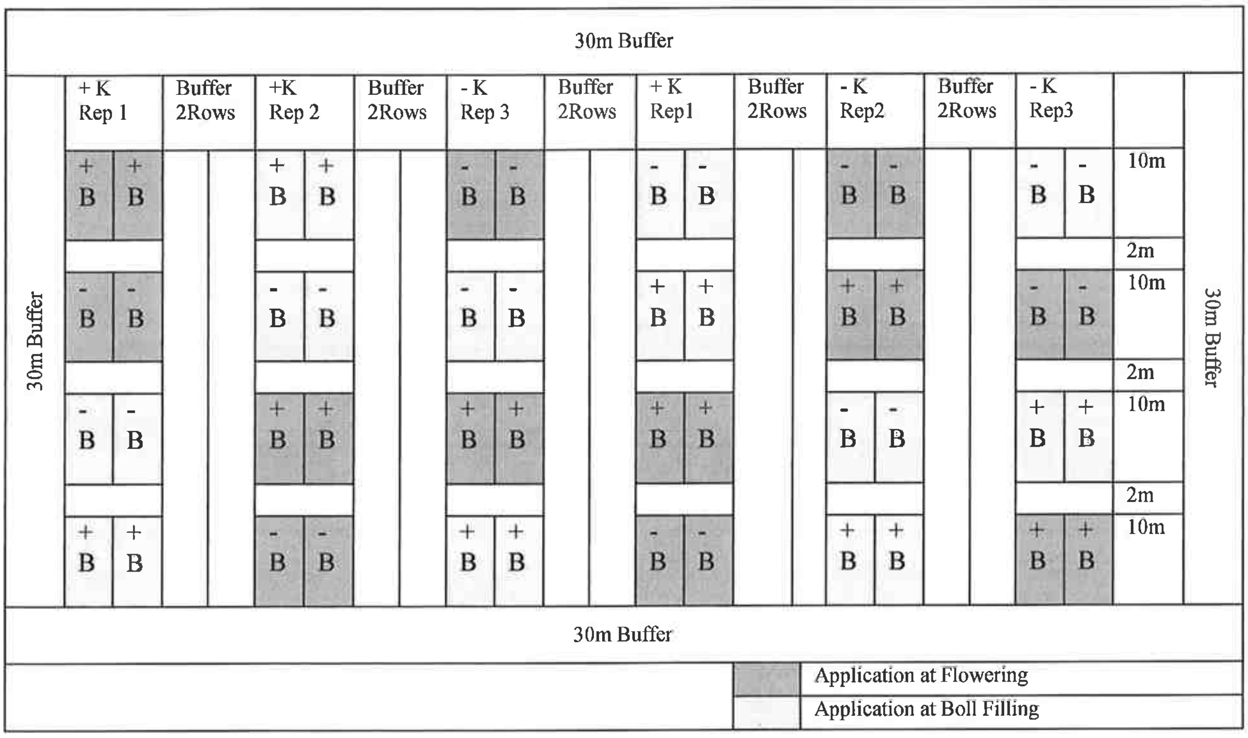


Figure 4: Plot design after randomization by minitab



2.3 Application methods

Treatments were either applied at flowering or boll-filling. Visual assessment is required due to cotton being an indeterminate crop. Solubor a product produced by Borax had a B composition of 20.9%. The application rate of 2kg/ha requires 19.15g/plot. This was then mixed up to a volume of 200mls using distilled water. This amount of water (100L/ha) was chosen for simplicity for plot application (200mls) and is within an economical range for commercial application methods. The K component of Potassium Sulphate was 41.5% and was applied at 10kg/ha resulting in 48.2g/ 20m2 plot. As with B, this was also mixed up to 200mls of distilled water per plot.

Below is a table of the dates the plots were treated.

	Flowering	Time	Bollfilling	Time
Field 16 (Furrow)	7/1/2006	4.30pm	15/2/2006	10:30am
Field 22 (Sprinkler)	7/1/2006	10.30 am	25/2/2006	10:30am

Table 6: Application Dates and Time

NB: Field 16 received a localized rainfall event of 1.5mm shortly after application on the 7/1/2006. It was assumed that the nutrients would have been washed off or affected. Therefore they were reapplied again the next day.

Sampling methods involved taking the youngest fully expanded leaf, floral parts and stem to be used in nutrient analysis to determine the nutrient composition. A few background sample were taken before treatments on that day for back-grounding. All plots were sampled 7 days after application to determine the uptake of the nutrients from the treatments. Samples were immediately dried in oven at 60oC to preserve the sample until analysis could be carried out.

2.4 Analytical methods

2.4.1 Sample analysis

To measure the nutrient composition of the plant parts the best method available to this project is Inductively Coupled Plasma (ICP) analysis. There are two forms of ICP; Optical emission (OE) and Mass Spectrometric (MS). ICP-OE can detect all elements within the plant tissue and is much better than other methods such as colorimetric, Potentiometric and Atomic spectrometric (Sah and Brown, 1997). It can also detect hard to detect elements such as B, S, Mo due to its low detection limits (Sah and Brown, 1997). ICP-MS is a higher level of testing and can measure mass-to-charge ratio on the ions and therefore is more than what is required for this experiment and most likely more expensive. ICP-OE is much more appropriate test as it has many advantages. It can detect between 20 and 40 elements very quickly. It may take as little 30 seconds once the solution is prepared. Because the samples are not soluble in a solvent they have to be prepared through other techniques such as acid digestion, ashing, or fusion. In these analyses, nitric acid digestion will be used as its advantages include retention of 'volatile' analytes (Gaines, 2003). Also Nitric acid is popular because of its chemical compatibility, oxidizing ability, availability, purity and low cost (Gaines, 2003) and will suit small sample of approximately 1gram.

2.4.2 Harvesting and collection

Cotton pickers harvest the crop at the optimum maturity date. Therefore these plots were picked from 0-2 days prior to the machines. This was to synchronise the results with a commercial operation. Without a mechanical harvester for the plots, time and labour restricted the harvest to just 1m^2 for each plot. Manual harvesting was also slowed due to the plant mapping which involved counting and recording 1st, 2nd 3rd/other positions and scars also in those positions. The information from plant mapping allows analysis of retention, boll weight, seed weight/boll, lint weight/boll and scaring/retention percentages for each position.

2.4.3 Classing

The cotton picked was taken to Proclass at Goondiwindi for detail analysis on the quality of the cotton harvested. Final lint weight and seed was determined by ginning the small samples through a small mechanical gin. The processed cotton is then put through a HVI (High Volume Instrument) machine that determines qualities such as lint strength, length, micronaire and uniformity. The cotton is also classed visually based on colour and trash.

2.4.4 Water management

Soil water content was continually monitored throughout the experiment. This was done by a capacitance probe placed in each field in close proximity to the plots. These probes are used in the irrigation management on “South Callandoon”, however, they will provide information on water logging periods throughout the season.

2.4.5 Data processing.

Due to the design of this experiment the data was analysed using a factorial two level analysis in minitab. It looked for at the potential benefits of K and B. The design also allowed us to investigate interaction effect of the two fertilisers. The data from the two fields were also combined to improve the degrees of freedom.

3.0 Results

3.1 Nutrient uptake

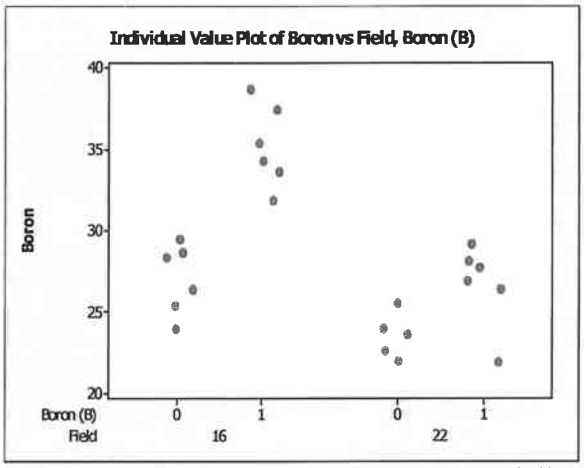


Figure 5: Boron level mg/kg of YFEL fully expanded leaf tissue. 0 = treatments excluding B. 1 = Treatments with B at Flowering

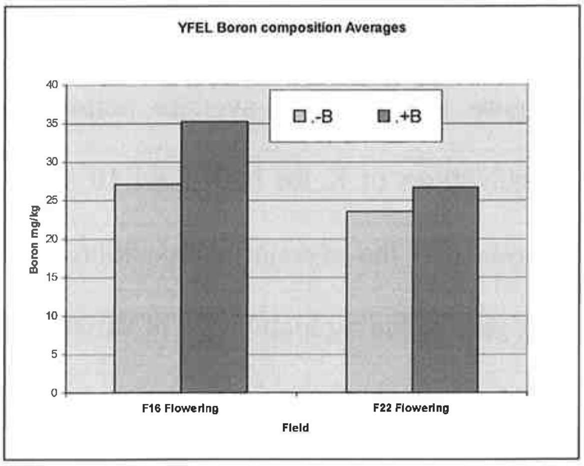


Figure 6: Average leaf tissue Boron composition at the flowering stage.

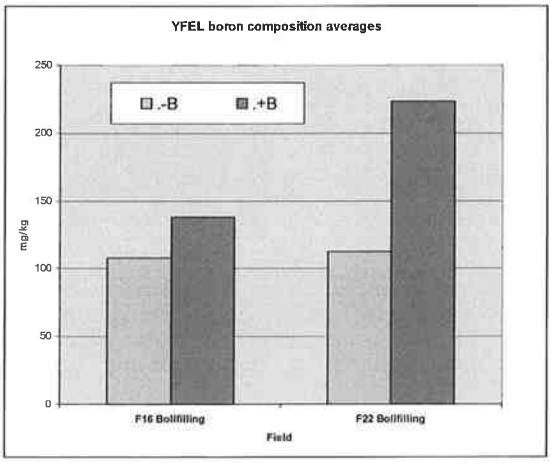


Figure 7: Average leaf tissue B composition at the boll filling stage.

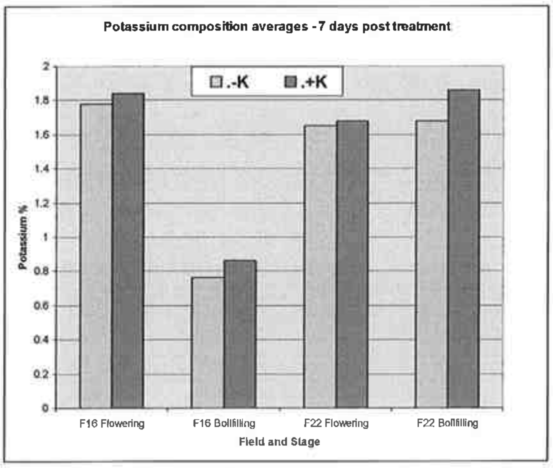


Figure 8: Average Potassium compositions of YFEL at the both flowering and boll-filling.

It was statically evident that the uptake of B was successful as shown in figure 5. This figure displays the nutrient compositions of the YFEL tissue sample from +/- treatments of B at flowering. Figure 6 show that the averages of the untreated plots were 27.07mg/kg and plots treated with had B an average B composition of 35.25mg/kg. The composition average for field 16 and 22 flowering plots was 23% and 11.9% higher respectively for plots that were treated with the B. For The field 16 and 22 boll-filling (figure 7) the composition averages were 22% and 49% higher respectively for the plots treated with B. The flowering uptake was statistically proven with a resulting P value of 0.003 and the variance being accounted with strong R^2 values (R-sq = 98.93% and R-sq(adj) = 97.54%).

Figure 8 shows the average potassium composition for plots treated with or without applications of K for both field 16 and 22 and both flowering and boll filling. Although it shows that the average compositions are higher for treated plots, they weren't statistically proven, including high levels of variance. Refer to appendix for statistical calculations.

No significant results were found at all for any of the treatments for either field. Although not ideal, the data was then combined for both fields to achieve more degrees of freedom. As a result some signals were found in flowering and boll-filling stages.

3.2 Flowering

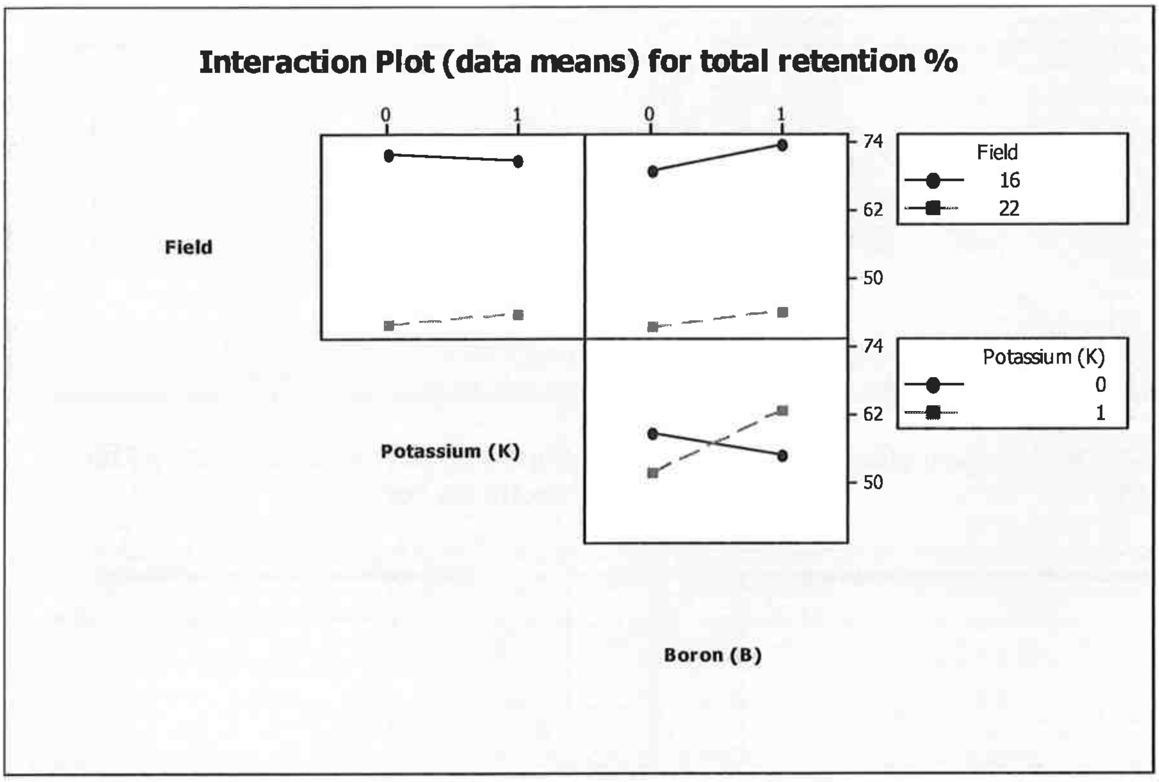


Figure 9: Single effects and interaction Plot. 0=no treatment and 1=treatment.

Results show that the total retention percentage was influenced by an interaction effect from the B and K. Figure 9 depicts an actual decrease in retention with just B and that the control was actually higher than the potassium only treatment. The treatments of B and K yielded the highest. The interaction effect was slightly significant with a P value of 0.070.

3.3 Boll-filling

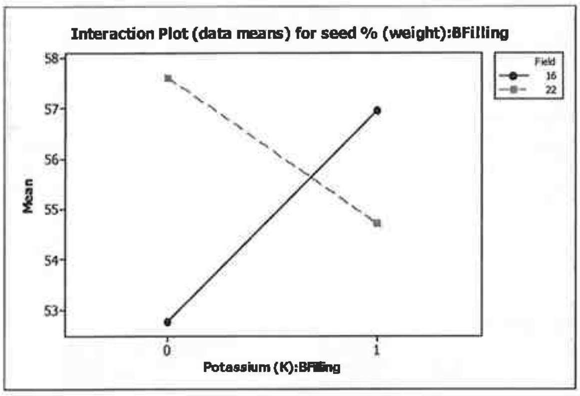


Figure 10: K Treatment effect on Seed weight %.

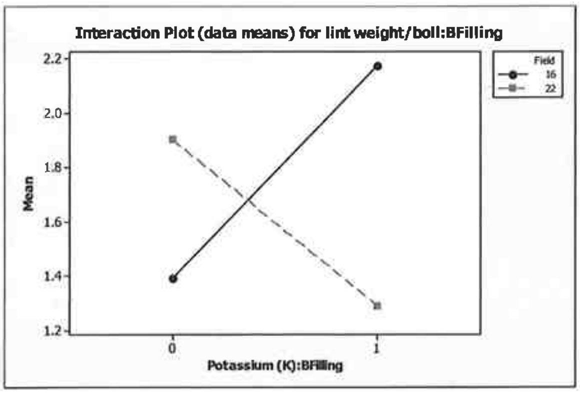


Figure 11: K Treatment effect on Lint weight per boll.

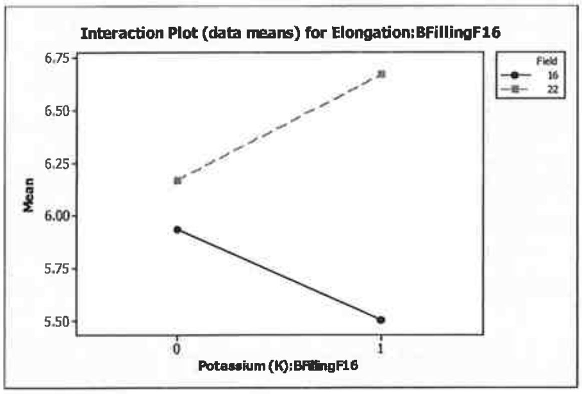


Figure 12: K effect on Elongation.

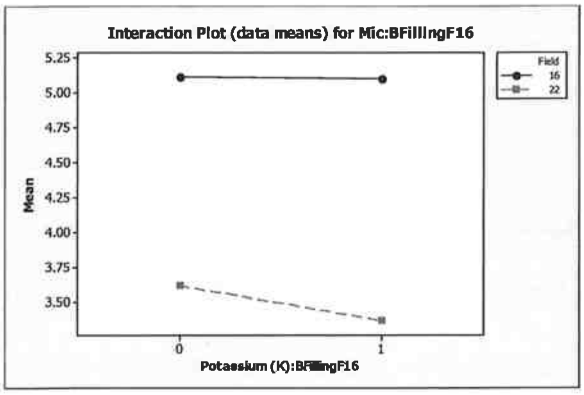


Figure 13: K effect on Micronaire.

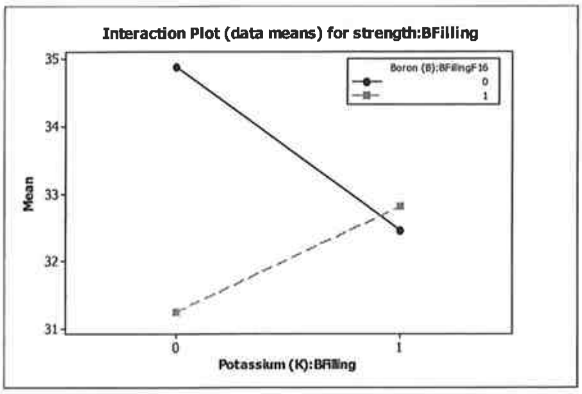


Figure 14: B and K interaction for Fibre strength.

Some positive signals were found within field 16 and 22 and some results that are contradictory to previous literature. Field 16 revealed a 4% increase in seed percentage and Field 22 has a 3% decrease within the K treatments as shown in figure 10. The resulting P Value was 0.11 which is slightly significant considering the noise involved in a field trial.

Figure 11 depicts the effect of K treatments and shows a positive effect on field 16 and negative effect on 22. The mean strength for Field 16 increased from 1.4 to 2.2. Field 22 had decreased from 1.9 to 1.3 (p value = 0.051).

Potassium had a positive effect on elongation for Field 22 (figure 12) with the mean increasing from 6.2 to 6.65 (p value = 0.026) and field 16 had a negative result with the mean decreasing from 5.9 to 5.5.

There was no effect of potassium (Figure 13) on the mean micronaire level for field 16 however field decreased from 3.6 to 3.4 which is moving away from the optimum level and would invoke a price discount.

Figure 14 depicts an interaction effect between B and K. This is using combined data from both fields 22 and 16. Strangely enough the control was the highest and K only resulted in a decrease of strength. K and B however result in and increase compared to the B only treatment.

3.4 Water management.

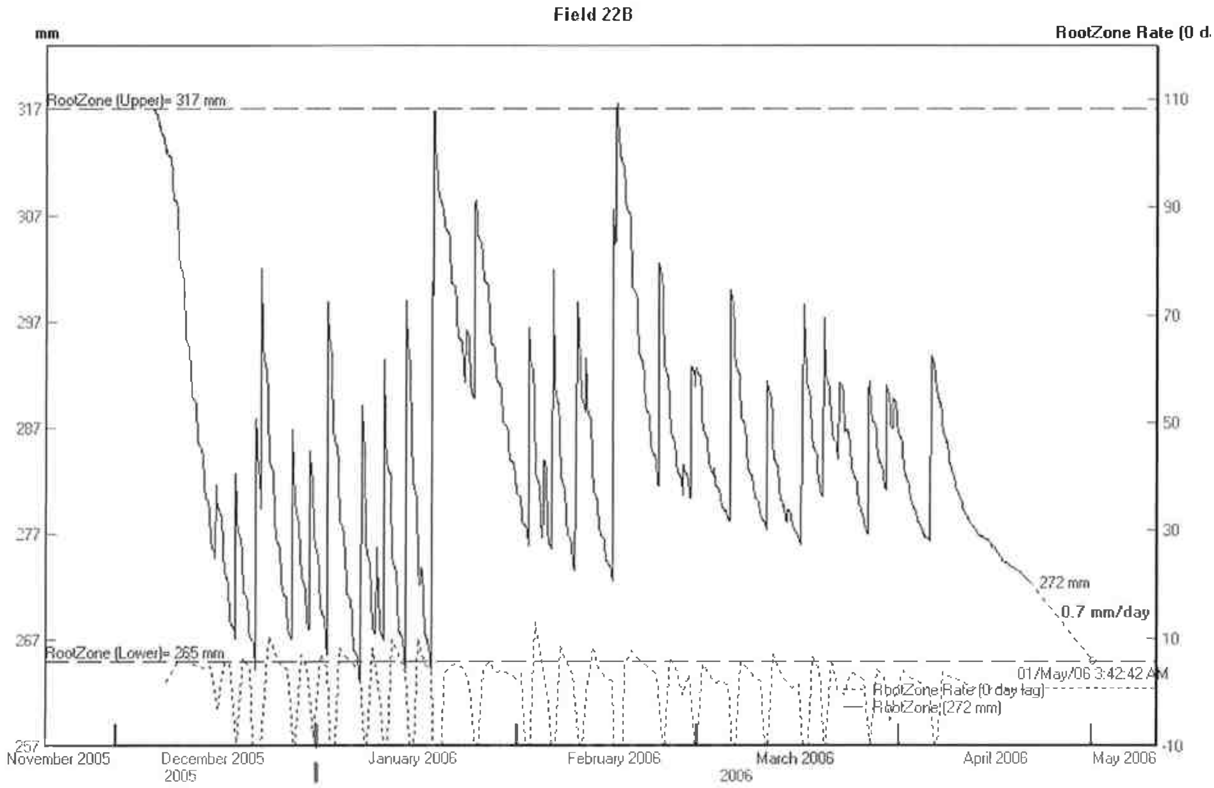


Figure 15: Soil water levels during the season for Field 22b

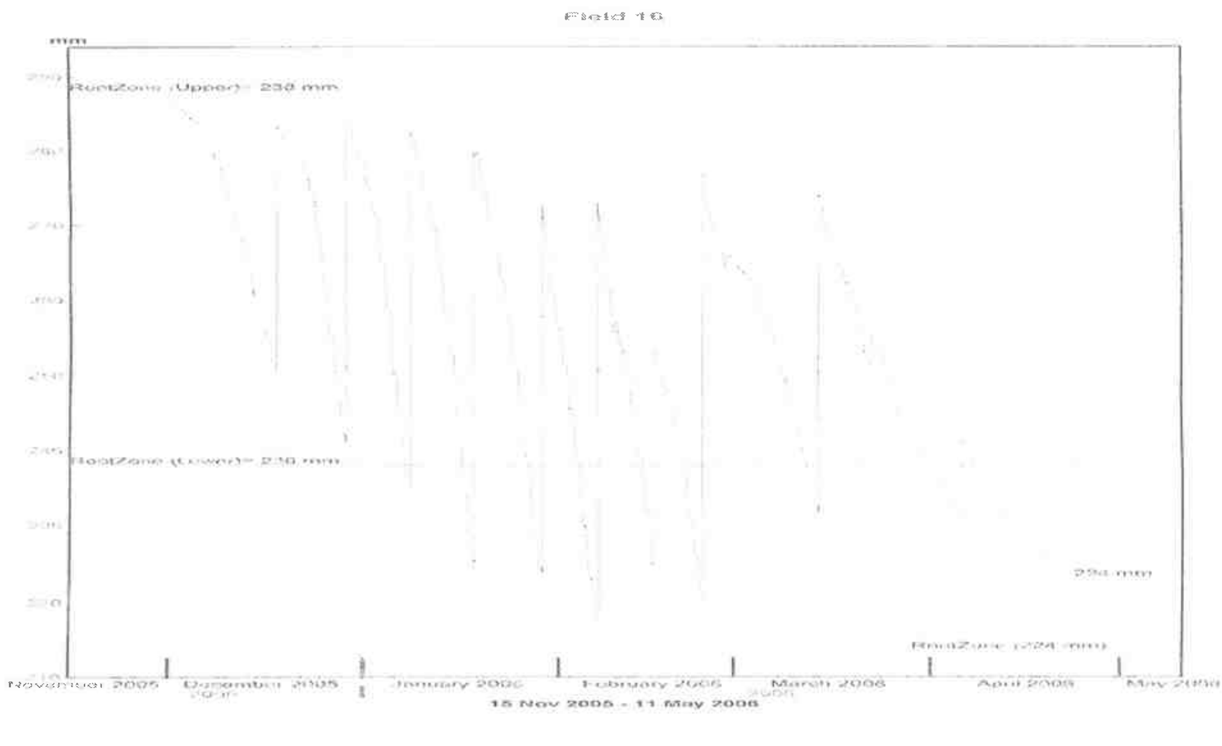


Figure 16: Soil water levels during the season for Field 16.

Figure 15 and 16 depicts the soil water level throughout the growing season. As you can there are no periods of true water-logging and periods of water deficit stress.

4.0 Discussion

The significant uptake of B into the plant leaf tissue reveals that the B application and rates was an effective choice. No toxicity was recorded and the levels were raised modestly. However on the other hand there was no significant evidence showing a change in the K composition of the leaves, although the graphs indicate increases, which suggest that may be the applications method or mixture may have not been ideal. However a few significant results in terms of quality and retention indicate otherwise and that uptake was successful. This could be possible, seeing as though Howard and Gwathamey (1995) reported decreases in leaf tissue K levels 7 days after application and it was suggested that it was the result of re-translocation of K from the leaves to the floral and reproductive parts.

With the data combined the only significant result found was an interactive result between B and K. This effect showed that addition of B only reduced retention but was still higher than the potassium treatment. The only treatment to increase compared to the control was the B and K treatment that was testing the interaction effect. This data was significant to a P level of 0.07 and a high level of noise for this field trial is present. A study conducted by Howard et. al, (1998) tested found that a Foliar applied B plus K solution further increased total lint yields by 5% relative to applying foliar B alone.

The lack of response to the treatments in the flowering stage may very well be attributed to the K and B concentrations of the plants being above critical levels. Reddy and Zhao (2005) reported the critical leaf K for cotton photosynthesis, biomass and stem growth was 12 g kg−1 or 1.2%, and for leaf area expansion the critical value was 17 g kg- or 1.7%. The two average compositions for untreated plots in field 16 and 22 flowering were 1.77% and 1.65% respectively. The treated plots again were higher but were to cause no significant effects. This was very much similar for B as Zhao (2002) reported that the critical level in which physiological process are affected are 17-20mg kg-1. The B levels for untreated plots were higher than this at 25mg kg-1 for Field 16 flowering and 23mg-kg-1 for Field 22 flowering.

Some results were found for the boll filling stage which gave some significant signals. Some were aligned with previous research and hypothesis however some were contradictory. K treatments increased the seed weight percentage for field 16 but however this decreased for field 22. This result was again shown identically by lint weight /boll. From the Tissue sampling it was recognized that Field 22 had a much higher K composition of approximately 1.6 for the untreated compared to Field 16 with a lower mean composition of approximately 0.8%. The seed weight % and Lint weight boll increased for field 16, which is in line with previous research and predicted hypothesis. A greater positive effect was seen on field 16 due to the inadequate K composition of the plants shown by tissue sampling. However, treatments on field 22 had a decreasing effect on seed weight % and boll lint weight. One observation of field 22 was that it was very indeterminate even through to maturity with late flowering and emerging bolls. It may be possible that the K treatments increased retention which meant that the plants available carbohydrates and sugars were spread among increased number of bolls. However, results show no significant increases in retention or yield but this could be attributed to noise in the field data.

K treatments also revealed positive effects on elongation for field 22 however field 16 revealed a decrease in elongation. For field 22 the application may have been applied when a higher percentage of bolls were still in the elongation phase which is anthesis – 20-25 days (DeLanghe, 1986). The decrease in the field 16 elongation is perplexing and may be due to an unidentified effect of K. It may have also advanced secondary wall thickening therefore decreasing the time for elongation. The increase in elongation would account for the decrease in micronaire (figure 9) as the other stages (maturation) wouldn't have the access to the increased K levels. Fibre property trends found in cotton nutrition studies have sometimes been reportedly contradictory and are due to interactive effects of genotype, weather and soil (Minton and ebelhar, 1991, Pettigrew, 2003; Reddy et al., 2004). Ramey (1986) points out that it is very difficult to predict the effects of K deficiency on fiber development and lint quality without knowledge of the timing and intensity of stress. However with future research it may be possible for farmers may be able to change their agronomic practices to enhance quality without sacrificing yield through the use of K level monitoring. Interactive effects between K and other nutrients and water would be vital in determining the best agronomic practice to use K in adjusting quality.

Due to the very dry season very minimal rainfall was received therefore no real water-logging events occurred. These occur when a rain period develops after and irrigation. Because there was no real periods of water-logging the root uptake would have been as efficient as possible throughout the season. The soil water moisture of field 22 and only ever reaches saturation 3 times throughout the season and no periods of water deficit stress thus being in optimal moisture conditions constantly. This would be why the K levels of tissue sampled at boll filling stage were far higher and adequate for field 22. Flood irrigation in field 16 created set backs for root uptake thus the reason for a lower than adequate K composition of approximately 0.8%.

Soils test prior to planting revealed that B and K levels were suboptimal. The fertilizer regime may have been sufficient on 'South Callandoon". The prior dry winter fallow period may have attributed to these low levels because there was minimal replenishment of exchangeable K from the fixed pool. Fixed K is held between platelets of 'shrink-swell' clay minerals (Syers, 1998). The level of replenishment depends on clay platelets expanding and therefore is soil water dependent (Mehta et al., 1992). As a result, irrigation would therefore increase available K throughout the season to some effect.

Many changes could be implemented to improve this trial which may result in significant findings and be of greater value. As sugeested by Shafer and Reed (1986), modifying the pH of the foliar solution will enhance adsorption. Howard (1993) had greater success when solutions were buffered to a pH 4, compared with ph of 9.4 for the unbuffered solution. Leaf burn is then eliminated because alkaline pH levels result in phytotoxicity (Howard, 1993). Solution can also be buffered by adding 'penetrator plus' a surfactant which had greater results of K adsorption at pH 5.5 than at pH 9.4.

Sampling would also have to be improved. Due to the high mobility of K leaf tissue would have to be sampled at 3 days not 7 days otherwise K will be translocated to other parts of the plant. Another suggestion would be to incorporate continual sprays throughout the season to eliminate timing and stage of development factor. Larger plot sizes and mechanical harvesting will reduce the infield variability and noise and fruit mapping can be done on smaller scale. More replicas would also increase degrees of freedom which was a limiting factor in some of the analysis in this trial. More importantly, stronger results may be seen on a lower fertility soil with a different soil structure such as sandy soils. Cross seasonal; trials are also needed to integrate the weather factor into the results. The 05/06 crop received very warm and dry conditions which minimized water logging periods but more importantly it wasn't a normal growing year which was reflected by the poorer grades of cotton received across the district.

5.0 Conclusion

This experiment has shown that positive results can be achieved by using foliar applications of B and K. The result in this experiment suggest that Farmers may be able to change their agronomic practices by using intense K level monitoring to affect the quality outcome without sacrificing yield. This however would need far more research to determine interaction effects of Nutrients, water and weather and the effects of the timing of stress. Results may be more pronounced or enhanced if the suggested improvements to this trial are carried out. Cross seasonal trials would also needed to be carried out reduce the weather and seasonal impact.

6.0 Acknowledgements

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7.0 References

Bednarz et al., 1998 C.W. Bednarz, D.M. Oosterhuis and R.D. Evans, Leaf photosynthesis and carbon isotope discrimination of cotton in response to potassium deficiency, *Environ. Exp. Bot.* **39** (1998), pp. 131–139

Brown, P.H., and Shelp, B. J. 1997. Boron Mobility in Plants. *Plant and Soil*, 193, 85-101.

Cassman et al., 1990 K.G. Cassman, T.A. Kerby, B.A. Roberts, D.C. Bryant and S.L. Higashi, Potassium effects on lint yield and fiber quality of Acala cotton, *Crop Sci.* **30** (1990), pp. 672–677.

Chapman et al. 1997. Challenging the dogma of narrow supply range between deficiency and toxicity of boron. Boron in Soils and Plants. Pp 151-155.

Cooper, R.B., Blaser, R.E., Brown, R.H., 1967. Potassium nutrition effects on net photosynthesis and morphology of alfalfa. Soil Sci. 31, 231–235.

Dear, B and Lipsett, J., 1987. *The effet of Boron Supply on the growth and seeed production of subterranean clover (Trifloium subterrneum L.).* Aust. J Agric Res. 38, pp 537-546

Dell, B., Huang, L. 1997. "Physiological response of plants to low boron", *Plant and Soil,* vol. 193. pp103-120.

Dugger W. M. 1983. *Boron in Plant Metabolism.* Encyclopedia of Plant Physiology, News Series, vol. 15B. Eds. A Lauchli and R L Bieleski. Pp. 626 – 650. Springer-Verlag, Berlin

D.D. Howard, C.O. Gwathmey, R.K. Roberts and G.M. Lessman, Potassium fertilization of cotton produced on a low K soil with contrasting tillage systems, *J. Prod. Agric.* **11** (1998), pp. 74–79

Gaines, P,2003 Reliable Measurements - A Guidebook for Trace Analysts. Retrieved from http://www.ivstandards.com/tech/reliability/default.asp on 20/9/10

Howard, D.D. 1993. Foliar fertilization of cotton as affected by surfactants and foliar solution pH. p. 77–90. *In* L.S. Murphy (ed.) Foliar fertilization of soybeans and cotton. PPI/FAR Spec. Publ. 1993-1. Potash & Phosphate Inst. and Foundation for Agronomic Res., Norcross, GA.

Howard, D.D., and C.O. Gwathmey. 1995. Surfactant effect on potassium uptake by cotton from foliar KNO3 applications. J. Plant Nutr. 18:2669–2680.

Huber, S.C.: 1984 Biochemical basis for effects of K deficiency on assimilate export rate and accumluation of soluble sugars in soybean leaves – Plant Physiol. 76: 424-430.

Humble, G.D., Raschke, K., 1971. Stomatal opening quantitatively related to potassium transport. Plant Physiol. 48, 447–453.

Kerby and Adams, 1985 T.A. Kerby and F. Adams In: R.D. Munson, Editor, *Potassium Nutrition of Cotton*, Potassium in Agriculture. Am. Soc. Agron., Madison (1985) pp. 843–860.

Johri, B.M., Vasil, I.K., 1961. Physiology of pollen. Bot. Rev. 27, 325–381.

Longstreth, D.J., Nobel, P.S., 1980. Nutrient influences on leaf photosynthesis. Effects of nitrogen, phosphorous, and potassium for *Gossypium hirsutum* L. Plant. Physiol. 65, 541–543.

Loomis, W.D. and Durst, R.W. 1992. *Boron and Cell Walls.* Curr. Top in Plant Biochemistry Physiology. Vol.10. pp149-178.

Maples, R.L., W.R. Thompson, Jr., and Joe Varvil. 1988–1989. Potassium deficiency in cotton takes on a new look. Better Crops Plant
Food 73:6–9.

Marschner, H. 1995. *Mineral Nutrition of Higher Plants, 2nd Edition.* Academic Press, London

Mehta SC, Singh N, Singh M (1992) Effect of wetting and drying on the dynamics of potassium in some soils of Haryana. *Journal of Potassium Research* **8**, 290–294.

Miley, W.N., Hardy, G.W., Sturgis, M.B., Sedberry Jr., J.E., 1969. Influence of boron, nitrogen, and potassium on yield, nutrient uptake, and abnormalities of cotton. Agron. J. 61, 9–13.

Noppakoonwong R.N., Rerkasem B, Bell R W, Dell B and Lonergan J F. 1997. *Prognosis and Diagnosis of Boron Deficiency in Blackgram (Vigna Mungo L Hepper) in the field by using plant analysis.* Proceeding of Boron in Soils and Plants. Eds. RW Bell and B Rerkasem. Kulwer Academic Publishers, Dordrecht, The Netherlands.

Oosterhuis, 1994 D.M. Oosterhuis, Potassium nutrition of cotton in the USA with particular reference to foliar fertilization. In: G.A. Constable and N.W. Forrester, Editors, *Proceeding of the World Cotton Research Conference 1*, CSISO, Canberra (1994), pp. 133–146.

Parr, A.J. and Loughman, B.C. 1983. *Boron and Membrane Functions in Plants.* Metals and Micronutrients: Uptake and Utilisation by Plants. (Annual Proceedings Phytochem. Soc. Eur. No.21; Eds. D.A. Robb and W.S. Pierpoint.) pp 87-107.

Peaslee, D.E., Moss, D.N., 1968. Stomatal conductivities in K deficient leaves of maize (*Zea mays* L.). Crop Sci. 8, 427–430.

Raschke, K.: 1975 Stomatal action. – Annu Rev. Plant Physiol. 26: 309-340.

Reddy et al., 2004 K.R. Reddy, S. Koti, G.H. Davidonis and V.R. Reddy, Interactive effects of carbon dioxide and nitrogen nutrition on cotton growth, development, yield and fiber quality, *Agron. J.* **96** (2004), pp. 1148–1157

Reddy, K.R., Zhao, D., 2005. Interactive effects of elevated CO2 and potassium deficiency on photosynthesis, growth and biomass partitioning of cotton. Field Crops Res. 94, 201–213.

Ritchie, G., Bednarz C., Jost P., Brown S. 2004. *Cotton Growth and Development.* University of Georgia, Georgia

Sah, R.N. and P.H. Brown. 1997. Techniques for boron determination and their application to the analysis of plant and soil samples. Plant and Soil:.193:15-33

Shorrocks, V.M. 1997. *The Occurrence and correction of boron deficiency*. Plant and Soil. Vol.193. pp121-148.

Syers JK (1998) 'Soil and plant potassium in agriculture.' (The Fertiliser Society: Newcastle-upon-Tyne: UK)

Terry, N., Ulrich, A. 1973: Effects of potassium deficiency on the photosynthesis and respiration of leaves of sugar beet – Plant Phyiol 51: 783-786

Shelp, B.J., 1993. *Physiology and Biochemistry of Boron in Plants.* Gupta, U.C. (ED.), Boron and its Role in Crop Production. CRC Press, Boca Raton, FL, pp 53 – 85

Trobisch, S., and Schilling, G. 1970. *Beitrag zur Klarung der phsyiologischen Grundlage der Samenbildung beir einjahrigen Pflanzen und zur Wirkung spatter zusatzlicher No-Gaben auf diesen Prozess am Beispiel* Sinapis alba L. Albrecht-Thaer-Arch. 14 253 – 265.

Woodbridge C.G., Venegas A and Crandall P.C. 1971. *The Boron Content of Developing Pear, Apple and Cherry Flower Buds.* J. Amer. Soc. Hort. Sci. 96, 613 – 615.

Zhao D., and Oosterhuis, D. 2002. *Cotton Carbon Exchange, Non-structural Carbohydrates, and Boron Distribution in Tissues During Development of Boron Deficiency.* Field Crops Research Journal 78 pp 75 – 87.

Bradow, J.M., Davidonis, G.H., 2000. Quantitation of fiber quality and the cotton production-processing interface: a physiologist's perspective. J. Cotton Sci. 4, 34–64.

Davidonis, G.H., Johnson, A.S., Landivar, J.A., Fernandez, C.J., 2004. Cotton fiber quality is related to boll location and planting date. Crop Sci. 96, 42–47.

DeLanghe, E.A.L., 1986. Lint development. In: Mauney, J.R., Stewart, J.McD. (Eds.), Cotton Physiology. The Cotton Foundation, Memphis, TN, pp. 325–350.

Deussen, H., 1986. Stressing high strength, low micronaire may require a rethinking of breeding and marketing methods. In: Spencer, W. (Ed.), Cotton International, 53rd ed. Meister Publishing Co., Memphis, TN, pp. 32–36.

Pettigrew, W.T., 2003. Relationships between insufficient potassium and crop maturity in cotton. Agron. J. 95, 1323–1329.Pettigrew, W.T., Heitholt, J.J., Meredith Jr., W.R., 1996. Genotypic interactions with potassium and nitrogen in cotton of varied maturity. Agron. J. 88, 89–93.

Pettigrew, W.T., Meredith Jr., W.R., 1997. Dry matter production, nutrient uptake, and growth of cotton as affected by potassium fertilization. J. Plant Nutr. 20, 531–548.

Ramey Jr., H.H., 1986. Stress influences on fiber development. In: Mauney, J.R., Stewart, J.McD. (Eds.), Cotton Physiology. The Cotton Foundation, Memphis, TN, USA, pp. 315–359.

Reddy, K.R., Hodges, H.F., McKinion, J.M., 1997. Crop modeling and applications: Reddy, K.R., Koti, S., Davidonis, G.H., Reddy, V.R., 2004. Interactive effects of carbon dioxide and nitrogen nutrition on cotton growth, development, yield and fiber quality. Agron. J. 96, 1148–1157.

Usherwood, N.R., 2000. The influence of potassium on cotton quality. In: Agri-Briefs, Agronomic News, No. 8., Spring 2000. Potash and Phosphate Institute, Norcross, GA, USA.

Appendix I

Nutrients Analysis
General Linear Model: POTASSIUM, BORON, ... versus Potassium (K, Boron (B), ...

Factor	Type	Levels	Values
Potassium (K)	fixed	2	0, 1
Plot(Potassium (K))	random	6	3, 5, 6, 1, 2, 4
Boron (B)	fixed	2	0, 1

Analysis of Variance for POTASSIUM, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Potassium (K)	1	0.011347	0.011347	0.011347	1.02	0.369
Plot(Potassium (K))	4	0.044314	0.044314	0.011079	1.90	0.275
Boron (B)	1	0.000784	0.000784	0.000784	0.13	0.733
Potassium (K)*Boron (B)	1	0.000000	0.000000	0.000000	0.00	0.997
Error	4	0.023349	0.023349	0.005837		
Total	11	0.079794				

S = 0.0764024 R-Sq = 70.74% R-Sq(adj) = 19.53%

Analysis of Variance for BORON, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Potassium (K)	1	2.521	2.521	2.521	0.35	0.584
Plot(Potassium (K))	4	28.453	28.453	7.113	1.33	0.394
Boron (B)	1	200.901	200.901	200.901	37.61	0.004
Potassium (K)*Boron (B)	1	2.168	2.168	2.168	0.41	0.559
Error	4	21.367	21.367	5.342		
Total	11	255.409				

S = 2.31120 R-Sq = 91.63% R-Sq(adj) = 76.99%

Analysis of Variance for ZINC, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Potassium (K)	1	22.743	22.743	22.743	0.94	0.387
Plot(Potassium (K))	4	96.906	96.906	24.226	4.69	0.082
Boron (B)	1	3.719	3.719	3.719	0.72	0.444
Potassium (K)*Boron (B)	1	1.527	1.527	1.527	0.30	0.616
Error	4	20.680	20.680	5.170		
Total	11	145.573				

S = 2.27375 R-Sq = 85.79% R-Sq(adj) = 60.93%

Two-sample T for POTASSIUM vs BackgroundK

	N	Mean	StDev	SE Mean
POTASSIUM	12	1.8083	0.0852	0.025
BackgroundK	6	1.8310	0.0757	0.031

Difference = mu (POTASSIUM) - mu (BackgroundK)
Estimate for difference: -0.022750
95% CI for difference: (-0.109694, 0.064194)
T-Test of difference = 0 (vs not =): T-Value = -0.58 P-Value = 0.576 DF = 11

Two-sample T for ZINC vs BackgroundZINC

	N	Mean	StDev	SE Mean
ZINC	12	36.49	3.64	1.1
BackgroundZINC	6	37.24	1.69	0.69

Difference = mu (ZINC) - mu (BackgroundZINC)
Estimate for difference: -0.756667
95% CI for difference: (-3.436125, 1.922792)

```
T-Test of difference = 0 (vs not =): T-Value = -0.60  P-Value = 0.556  DF = 15
```

One-way ANOVA: BORON_1 versus Method

```
Source  DF      SS      MS      F      P
Method   2  201.62  100.81  11.84  0.001
Error   15  127.68    8.51
Total   17  329.31

S = 2.918   R-Sq = 61.23%   R-Sq(adj) = 56.06%


                         Individual 95% CIs For Mean Based on Pooled
                         StDev
Level  N    Mean  StDev   +---------+---------+---------+---------
0      6  27.067  2.144   (-------*-------)
1      6  35.250  2.511                         (-------*-------)
2      6  30.733  3.826              (------*------)
                          +---------+---------+---------+---------
                         24.5      28.0      31.5      35.0

Pooled StDev = 2.918
Dunnett's comparisons with a control

Family error rate = 0.05
Individual error rate = 0.0276

Critical value = 2.44

Control = level (2) of Method

Intervals for treatment mean minus control mean

Level   Lower  Center  Upper  ------+---------+---------+---------+---
0      -7.776  -3.667  0.442  (--------*-------)
1       0.408   4.517  8.626                  (-------*-------)
                              ------+---------+---------+---------+---
                                 -5.0       0.0       5.0      10.0
```

General Linear Model: BORON, POTASSIUM, ... versus Potassium (K, Boron (B), ...

```
Factor                 Type    Levels  Values
Potassium (K)          fixed        2  0, 1
Plot(Potassium (K))    random       6  3, 5, 6, 1, 2, 4
Boron (B)              fixed        2  0, 1


Analysis of Variance for BORON, using Adjusted SS for Tests

Source                     DF  Seq SS  Adj SS  Adj MS      F      P
Potassium (K)               1   0.214   5.581   5.581   0.84  0.408 x
Plot(Potassium (K))         4  15.693  27.947   6.987   2.40  0.249
Boron (B)                   1  42.849  41.500  41.500  14.27  0.033
Potassium (K)*Boron (B)     1   0.020   0.020   0.020   0.01  0.939
Error                       3   8.726   8.726   2.909
Total                      10  67.502

x Not an exact F-test.


S = 1.70547   R-Sq = 87.07%   R-Sq(adj) = 56.91%

Analysis of Variance for POTASSIUM, using Adjusted SS for Tests

Source                     DF    Seq SS    Adj SS    Adj MS     F      P
Potassium (K)               1  0.002509  0.005782  0.005782  0.85  0.400 x
Plot(Potassium (K))         4  0.030598  0.027010  0.006753  0.97  0.533
Boron (B)                   1  0.017556  0.011344  0.011344  1.62  0.292
Potassium (K)*Boron (B)     1  0.013590  0.013590  0.013590  1.95  0.257
Error                       3  0.020949  0.020949  0.006983
```

```
Total                        10  0.085203

x Not an exact F-test.


S = 0.0835648   R-Sq = 75.41%   R-Sq(adj) = 18.04%

Analysis of Variance for ZINC, using Adjusted SS for Tests

Source                      DF   Seq SS   Adj SS   Adj MS      F      P
Potassium (K)                1   2.7876   0.3183   0.3183   0.11  0.760 x
Plot(Potassium (K))          4   9.1964  12.7766   3.1941   3.69  0.156
Boron (B)                    1   0.1638   0.1654   0.1654   0.19  0.692
Potassium (K)*Boron (B)      1  16.1305  16.1305  16.1305  18.64  0.023
Error                        3   2.5963   2.5963   0.8654
Total                       10  30.8747

x Not an exact F-test.


S = 0.930291   R-Sq = 91.59%   R-Sq(adj) = 71.97%
Two-sample T for POTASSIUM vs BackgroundK

              N    Mean   StDev  SE Mean
POTASSIUM    11  1.6665  0.0923    0.028
BackgroundK   6  1.7305  0.0786    0.032


Difference = mu (POTASSIUM) - mu (BackgroundK)
Estimate for difference:  -0.063955
95% CI for difference:  (-0.157440, 0.029531)
T-Test of difference = 0 (vs not =): T-Value = -1.51  P-Value = 0.160  DF = 11
```

One-way ANOVA: BORON versus Method

```
Source  DF      SS     MS      F      P
Method   2  187.07  93.54  20.36  0.000
Error   14   64.31   4.59
Total   16  251.38

S = 2.143   R-Sq = 74.42%   R-Sq(adj) = 70.76%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level  N    Mean  StDev  ---------+---------+---------+---------+
0      5  23.540  1.352  (-----*-----)
1      6  26.717  2.556            (----*-----)
2      6  31.683  2.206                          (-----*----)
                         ---------+---------+---------+---------+
                              24.5      28.0      31.5      35.0

Pooled StDev = 2.143
Dunnett's comparisons with a control

Family error rate = 0.05
Individual error rate = 0.0275

Critical value = 2.46

Control = level (2) of Method

Intervals for treatment mean minus control mean

Level    Lower  Center   Upper  -----+---------+---------+---------+----
0      -11.337  -8.143  -4.950  (------------*------------)
1       -8.011  -4.967  -1.922               (-----------*-----------)
                                -----+---------+---------+---------+----
                                 -10.0      -7.5      -5.0      -2.5
```

Appendix II

Boll filling

General Linear Model: Av boll numb versus Field, Potassium (K, ...

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Potassium (K):BFillingF16	fixed	2	0, 1
Plot:BFillingF16(Field Potassium (K):BFillingF16)	random	12	3, 5, 6, 1, 2, 4, 3, 5, 6, 1, 2, 4
Boron (B):BFillingF16	fixed	2	0, 1

Analysis of Variance for Av boll number/plant:BFillingF1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	108.901	108.901	108.901	25.92	0.001
Potassium (K):BFillingF16	1	20.221	20.221	20.221	4.81	0.060
Field*Potassium (K):BFillingF16	1	3.374	3.374	3.374	0.80	0.396
Plot:BFillingF16(Field Potassium (K):BFillingF16)	8	33.616	33.616	4.202	4.08	0.021
Boron (B):BFillingF16	1	3.319	3.319	3.319	3.22	0.103
Potassium (K):BFillingF16* Boron (B):BFillingF16	1	0.552	0.552	0.552	0.54	0.481
Error	10	10.299	10.299	1.030		
Total	23	180.282				

S = 1.01485 R-Sq = 94.29% R-Sq(adj) = 86.86%

General Linear Model: seed % (weig versus Field, Potassium (K, ...

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Potassium (K):BFillingF16	fixed	2	0, 1
Plot:BFillingF16(Field Potassium (K):BFillingF16)	random	12	3, 5, 6, 1, 2, 4, 3, 5, 6, 1, 2, 4
Boron (B):BFillingF16	fixed	2	0, 1

Analysis of Variance for seed % (weight):BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	10.065	10.065	10.065	2.47	0.154
Potassium (K):BFillingF16	1	2.543	2.543	2.543	0.63	0.452
Field*Potassium (K):BFillingF16	1	75.701	75.701	75.701	18.60	0.003
Plot:BFillingF16(Field Potassium (K):BFillingF16)	8	32.554	32.554	4.069	0.69	0.691
Boron (B):BFillingF16	1	3.634	3.634	3.634	0.62	0.449
Potassium (K):BFillingF16* Boron (B):BFillingF16	1	18.055	18.055	18.055	3.08	0.110
Error	10	58.634	58.634	5.863		
Total	23	201.188				

S = 2.42145 R-Sq = 70.86% R-Sq(adj) = 32.97%

General Linear Model: lint weight/ versus Field, Potassium (K, ...

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Potassium (K):BFillingF16	fixed	2	0, 1
Plot:BFillingF16(Field Potassium (K):BFillingF16)	random	12	3, 5, 6, 1, 2, 4, 3, 5, 6, 1, 2, 4
Boron (B):BFillingF16	fixed	2	0, 1

Analysis of Variance for lint weight/boll:BFillingF16, using Adjusted SS for

Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	0.2100	0.2100	0.2100	0.67	0.437
Potassium (K):BFillingF16	1	0.0427	0.0427	0.0427	0.14	0.722
Field*Potassium (K):BFillingF16	1	2.9077	2.9077	2.9077	9.26	0.016
Plot:BFillingF16(Field Potassium (K):BFillingF16)	8	2.5132	2.5132	0.3141	3.05	0.051
Boron (B):BFillingF16	1	0.0275	0.0275	0.0275	0.27	0.617
Potassium (K):BFillingF16* Boron (B):BFillingF16	1	0.0009	0.0009	0.0009	0.01	0.928
Error	10	1.0286	1.0286	0.1029		
Total	23	6.7305				

S = 0.320718   R-Sq = 84.72%   R-Sq(adj) = 64.85%

Analysis of Variance for strength:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	3.920	3.920	3.920	1.44	0.264
Potassium (K):BFillingF16	1	1.084	1.084	1.084	0.40	0.546
Field*Potassium (K):BFillingF16	1	0.920	0.920	0.920	0.34	0.577
Plot:BFillingF16(Field Potassium (K):BFillingF16)	8	21.780	21.780	2.723	1.06	0.455
Boron (B):BFillingF16	1	16.170	16.170	16.170	6.31	0.031
Potassium (K):BFillingF16* Boron (B):BFillingF16	1	23.800	23.800	23.800	9.28	0.012
Error	10	25.644	25.644	2.564		
Total	23	93.320				

S = 1.60138   R-Sq = 72.52%   R-Sq(adj) = 36.80%

Analysis of Variance for Elongation:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	2.9400	2.9400	2.9400	16.68	0.004
Potassium (K):BFillingF16	1	0.0067	0.0067	0.0067	0.04	0.851
Field*Potassium (K):BFillingF16	1	1.3067	1.3067	1.3067	7.41	0.026
Plot:BFillingF16(Field Potassium (K):BFillingF16)	8	1.4100	1.4100	0.1762	1.40	0.302
Boron (B):BFillingF16	1	0.1667	0.1667	0.1667	1.33	0.276
Potassium (K):BFillingF16* Boron (B):BFillingF16	1	0.1067	0.1067	0.1067	0.85	0.379
Error	10	1.2567	1.2567	0.1257		
Total	23	7.1933				

S = 0.354495   R-Sq = 82.53%   R-Sq(adj) = 59.82%

Analysis of Variance for Mic:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	15.6817	15.6817	15.6817	1393.93	0.000
Potassium (K):BFillingF16	1	0.1067	0.1067	0.1067	9.48	0.015
Field*Potassium (K):BFillingF16	1	0.0817	0.0817	0.0817	7.26	0.027
Plot:BFillingF16(Field Potassium (K):BFillingF16)	8	0.0900	0.0900	0.0112	0.18	0.988
Boron (B):BFillingF16	1	0.0417	0.0417	0.0417	0.68	0.430
Potassium (K):BFillingF16* Boron (B):BFillingF16	1	0.0017	0.0017	0.0017	0.03	0.873
Error	10	0.6167	0.6167	0.0617		
Total	23	16.6200				

S = 0.248328   R-Sq = 96.29%   R-Sq(adj) = 91.47%

General Linear Model: 1st pos rete, 2nd pos rete, ... versus Field, Plot:BFilli

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Plot:BFillingF16(Field)	random	12	1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6
Boron (B):BFillingF16(Field)	fixed	4	0, 1, 0, 1

Analysis of Variance for 1st pos retention/ist position:, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	12907.4	12907.4	12907.4	125.73	0.000
Plot:BFillingF16(Field)	10	1026.6	1026.6	102.7	6.79	0.003
Boron (B):BFillingF16(Field)	2	27.4	27.4	13.7	0.91	0.435
Error	10	151.2	151.2	15.1		
Total	23	14112.6				

S = 3.88831   R-Sq = 98.93%   R-Sq(adj) = 97.54%

Analysis of Variance for 2nd pos retention/ 2nd pos scar, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	3977.05	3977.05	3977.05	76.30	0.000
Plot:BFillingF16(Field)	10	521.25	521.25	52.13	2.38	0.094
Boron (B):BFillingF16(Field)	2	1.03	1.03	0.52	0.02	0.977
Error	10	219.24	219.24	21.92		
Total	23	4718.57				

S = 4.68227   R-Sq = 95.35%   R-Sq(adj) = 89.31%

Analysis of Variance for total retention %:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	5429.15	5429.15	5429.15	161.71	0.000
Plot:BFillingF16(Field)	10	335.73	335.73	33.57	3.34	0.035
Boron (B):BFillingF16(Field)	2	19.52	19.52	9.76	0.97	0.412
Error	10	100.52	100.52	10.05		
Total	23	5884.92				

S = 3.17051   R-Sq = 98.29%   R-Sq(adj) = 96.07%

General Linear Model: seed weight , lint weight/ versus Field, Plot:BFillin, ..

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Plot:BFillingF16(Field)	random	12	1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6
Boron (B):BFillingF16(Field)	fixed	4	0, 1, 0, 1

Analysis of Variance for seed weight /boll:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	0.1979	0.1979	0.1979	0.16	0.699
Plot:BFillingF16(Field)	10	12.5256	12.5256	1.2526	10.22	0.001
Boron (B):BFillingF16(Field)	2	0.6638	0.6638	0.3319	2.71	0.115
Error	10	1.2254	1.2254	0.1225		
Total	23	14.6127				

S = 0.350064   R-Sq = 91.61%   R-Sq(adj) = 80.71%

Analysis of Variance for lint weight/boll:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	0.20999	0.20999	0.20999	0.38	0.549
Plot:BFillingF16(Field)	10	5.46353	5.46353	0.54635	5.75	0.005
Boron (B):BFillingF16(Field)	2	0.10706	0.10706	0.05353	0.56	0.586
Error	10	0.94989	0.94989	0.09499		
Total	23	6.73047				

S = 0.308203   R-Sq = 85.89%   R-Sq(adj) = 67.54%

General Linear Model: av Boll weig versus Field, Plot:BFillin, ...

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Plot:BFillingF16(Field)	random	12	1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6
Boron (B):BFillingF16(Field)	fixed	4	0, 1, 0, 1

Analysis of Variance for av Boll weight:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	5.2894	5.2894	5.2894	58.03	0.000
Plot:BFillingF16(Field)	10	0.9114	0.9114	0.0911	0.36	0.938
Boron (B):BFillingF16(Field)	2	0.2376	0.2376	0.1188	0.47	0.638
Error	10	2.5221	2.5221	0.2522		
Total	23	8.9605				

S = 0.502204   R-Sq = 71.85%   R-Sq(adj) = 35.26%

General Linear Model: Length:BFill, strength:BFi versus Field, Plot:BFillin, ..

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Plot:BFillingF16(Field)	random	12	1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6
Boron (B):BFillingF16(Field)	fixed	4	0, 1, 0, 1

Analysis of Variance for Length:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	0.011704	0.011704	0.011704	10.08	0.010
Plot:BFillingF16(Field)	10	0.011608	0.011608	0.001161	0.81	0.626
Boron (B):BFillingF16(Field)	2	0.000442	0.000442	0.000221	0.15	0.859
Error	10	0.014308	0.014308	0.001431		
Total	23	0.038063				

S = 0.0378264   R-Sq = 62.41%   R-Sq(adj) = 13.54%

Analysis of Variance for strength:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	3.920	3.920	3.920	1.65	0.228
Plot:BFillingF16(Field)	10	23.784	23.784	2.378	0.50	0.852
Boron (B):BFillingF16(Field)	2	18.514	18.514	9.257	1.97	0.191
Error	10	47.101	47.101	4.710		
Total	23	93.320				

S = 2.17027   R-Sq = 49.53%   R-Sq(adj) = 0.00%

General Linear Model: Mic:BFilling versus Field, Plot:BFillin, ...

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Plot:BFillingF16(Field)	random	12	1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6
Boron (B):BFillingF16(Field)	fixed	4	0, 1, 0, 1

Analysis of Variance for Mic:BFillingF16, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	15.6817	15.6817	15.6817	563.41	0.000
Plot:BFillingF16(Field)	10	0.2783	0.2783	0.0278	0.47	0.875
Boron (B):BFillingF16(Field)	2	0.0683	0.0683	0.0342	0.58	0.579
Error	10	0.5917	0.5917	0.0592		
Total	23	16.6200				

S = 0.243242   R-Sq = 96.44%   R-Sq(adj) = 91.81%

Appendix III

Results for: Flowering1

General Linear Model: 1st pos rete, 2nd pos rete, ... versus Field, Plot, ...

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Plot(Field)	random	12	1, 2, 3, 4, 5, 6, 1a, 2a, 3a, 4a, 5a, 6a
Boron (B)(Field)	fixed	4	0, 1, 0, 1

Analysis of Variance for 1st pos retention/ist position, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	11647.1	11647.1	11647.1	54.72	0.000
Plot(Field)	10	2128.4	2128.4	212.8	1.34	0.327
Boron (B)(Field)	2	318.0	318.0	159.0	1.00	0.402
Error	10	1591.6	1591.6	159.2		
Total	23	15685.1				

S = 12.6158   R-Sq = 89.85%   R-Sq(adj) = 76.66%

Analysis of Variance for 2nd pos retention/ 2nd pos scar, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	3313.8	3313.8	3313.8	64.16	0.000
Plot(Field)	10	516.5	516.5	51.6	0.28	0.972
Boron (B)(Field)	2	55.0	55.0	27.5	0.15	0.865
Error	10	1863.0	1863.0	186.3		
Total	23	5748.2				

S = 13.6493   R-Sq = 67.59%   R-Sq(adj) = 25.46%

Analysis of Variance for total retention %, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	4926.0	4926.0	4926.0	84.45	0.000
Plot(Field)	10	583.3	583.3	58.3	0.52	0.844
Boron (B)(Field)	2	75.5	75.5	37.8	0.33	0.723
Error	10	1129.4	1129.4	112.9		
Total	23	6714.2				

S = 10.6272   R-Sq = 83.18%   R-Sq(adj) = 61.31%

General Linear Model: av Boll weight versus Field, Plot, Boron (B)

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Plot(Field)	random	12	1, 2, 3, 4, 5, 6, 1a, 2a, 3a, 4a, 5a, 6a

Boron (B)(Field)	fixed	4	0, 1, 0, 1

Analysis of Variance for av Boll weight, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	24.1475	24.1475	24.1475	41.31	0.000
Plot(Field)	10	5.8455	5.8455	0.5845	0.95	0.533
Boron (B)(Field)	2	0.1861	0.1861	0.0931	0.15	0.862
Error	10	6.1693	6.1693	0.6169		
Total	23	36.3484				

S = 0.785447 R-Sq = 83.03% R-Sq(adj) = 60.96%

General Linear Model: av bol weight versus Field, Plot, Boron (B)

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Plot(Field)	random	12	1, 2, 3, 4, 5, 6, 1a, 2a, 3a, 4a, 5a, 6a
Boron (B)(Field)	fixed	4	0, 1, 0, 1

Analysis of Variance for av bol weight, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	10.0576	10.0576	10.0576	67.29	0.000
Plot(Field)	10	1.4947	1.4947	0.1495	0.76	0.665
Boron (B)(Field)	2	1.4866	1.4866	0.7433	3.77	0.060
Error	10	1.9715	1.9715	0.1971		
Total	23	15.0105				

S = 0.444013 R-Sq = 86.87% R-Sq(adj) = 69.79%

Flowering

General Linear Model: total retention % versus Field, Potassium (K), ...

Factor	Type	Levels	Values
Field	fixed	2	16, 22
Potassium (K)	fixed	2	0, 1
Plot(Field Potassium (K))	random	12	3, 5, 6, 1, 2, 4, 3a, 5a, 6a, 1a, 2a, 4a
Boron (B)	fixed	2	0, 1

Analysis of Variance for total retention %, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Field	1	4925.97	4925.97	4925.97	69.17	0.000
Potassium (K)	1	0.58	0.58	0.58	0.01	0.930
Field*Potassium (K)	1	12.97	12.97	12.97	0.18	0.681
Plot(Field Potassium (K))	8	569.76	569.76	71.22	0.89	0.560
Boron (B)	1	70.58	70.58	70.58	0.88	0.371
Potassium (K)*Boron (B)	**1**	**329.81**	**329.81**	**329.81**	**4.10**	**0.070**
Error	10	804.52	804.52	80.45		
Total	23	6714.19				

S = 8.96950 R-Sq = 88.02% R-Sq(adj) = 72.44%