Leaf nutrient concentrations in cotton cultivars grown on slightly sodic soils

I.J. Rochester and G.A. Constable
Australian Cotton Cooperative Research Centre, CSIRO Plant Industry, Narrabri NSW AUSTRALIA
Correspondence author greg.constable@csiro.au

ABSTRACT

Much of the Australian cotton crop is grown in relatively fertile clay soils, although phosphorus and potassium contents are marginal in many cotton-growing soils. Also, soil sodicity is becoming more problematic, as well as declines in soil fertility through removal of nutrients in high-yielding crops. We evaluated commercial cotton cultivars grown in four replicated field experiments by assessing the nutrient content of the youngest mature leaf at early flowering. About 20 leaves were collected, dried and milled. Nitrogen content was determined by Kjeldahl analysis, other nutrients by ICP analysis following acid digestion. Higher leaf sodium concentrations at some sites were associated with lower leaf potassium and phosphorus concentrations. Cultivar differences were greatest in potassium and magnesium, but significant differences were found in sodium, phosphorus, calcium, boron, iron and copper concentrations. Some Roundup Ready® cultivars had higher sodium and iron concentrations and lower potassium concentrations than conventional cultivars. Similarly, Ingard® cultivars generally had lower potassium content. CSIRO bred cultivars generally had lower sodium concentration than Deltapine-bred cultivars. Importantly, the nutrient concentrations observed in these experiments were generally above the published critical levels indicating deficiency. Cotton breeders need to be aware of the range of soil fertility conditions under which their cultivars are to be grown. Thus, breeding cotton cultivars that can accumulate higher concentrations of nitrogen, phosphorus, potassium and other nutrients from deficient soils would be advantageous.

Introduction

Balanced nutrition is important to maximize yields. For high yielding cotton systems, large amounts of nutrients are removed in produce, which emphasizes the need to anticipate and prevent deficiencies or imbalances. Optimum fertilizer rates are important, as excessive use of nitrogenous fertilizers can be associated with environmental problems such as the greenhouse gas nitrous oxide emission or nitrate contamination of groundwater. Phosphorus can be associated with blue-green algae outbreaks in waterways.

Many of the soils used for growing cotton in Australia are alkaline medium to heavy clays (vertisols) with sodic subsoils; exchangeable sodium percentage (ESP) of surface (0-30 cm) soils range from two to 20 and both soil pH and ESP increase with depth. The soils are chemically fertile, although nitrogen and phosphorus fertilizers are commonly used and some soils require potassium application. The condition commonly termed "premature senescence" is generally associated with high fruit loads on plants of small to medium stature. It is also associated with low leaf potassium concentration (Wright, 1999) or low leaf potassium and phosphorus concentration (McLeod, 2001) and maybe analogous to potassium deficiency syndrome in the USA (Cassman, 1986; Weir *et al*., 1986; Hodges, 1992; Oosterhuis, 1995; Bednarz and Oosterhuis, 1996). It has been recognized for some time that sodium may substitute for potassium in its physiological role (Joham and Amin, 1964; Bednarz and Oosterhuis, 1998). Our current research is aimed to revise critical soil and tissue nutrient levels.

In this paper, we present preliminary data to suggest the possibility that sodium taken up by cotton plants can negatively affect their potassium and phosphorus nutrition. If true, this idea could be expanded to modify potassium and phosphorus critical tissue concentrations depending on leaf sodium concentrations and further, to possibly screen breeding populations to select for lower sodium uptake.

Experimental procedure

In 2001/02, two sites of low soil sodicity (4 or 6.6% ESP) were selected. At site 1, 22 cultivars were sown, including Ingard and Roundup Ready and Ingard-Roundup Ready stack cultivars. At site 2, eight conventional cultivars were sown; the cultivars listed in Table 1 were common to both sites. In 2002/03, two sites varying principally in soil sodicity (either 1.5 or 5% ESP) were sown with the same 16 cotton cultivars. The cultivars Sicot 189, Sicala V-2, Sicala 40 and Siokra V-16 were sown as a factorial experiment including the conventional, Ingard, Roundup Ready or Ingard-Roundup Ready stack, at each site. Each cultivar was replicated four times in each experiment of randomized complete block design. At early flowering, twenty youngest mature leaf blades (normally the fifth leaf from the terminal) were collected and dried and milled for chemical analysis following acid digestion using Kjeldahl and ICP techniques. This paper concentrates on sodium, potassium and phosphorus concentrations in the cotton leaves.

Results and Discussion

Associations between nutrients across sites

The associations between phosphorus and potassium and sodium concentrations in leaves are shown in Figure 1. High sodium levels in the leaf were associated with reduced phosphorus and potassium levels. Sodium concentrations in the leaf were consistent with soil sodium levels, and while the soils in which these experiments were conducted are not as sodic as many cotton growing soils in Australia, plant P and K concentrations were significantly reduced with higher concentrations of sodium. There was a closer association between phosphorus and sodium than between potassium and sodium across seasons and sites, indicating the mechanisms are different for each nutrient. Clearly, inherent levels of potassium and phosphorus in the soil will have a strong bearing on this association. The negative effects of sodium on soil structure have been recognized for sometime, yet it is only recently that we have researched the indirect effects of sodium on cotton nutrition. Cotton grown on soils high in sodium may display nutrient deficiencies leading to delayed maturity and reduced yields. Leaf calcium and magnesium concentrations were not reduced at higher sodium levels in the first season, in fact leaf calcium was higher at site 2. In 2002/03, both leaf calcium and magnesium tended to increase with leaf sodium.

Cultivar differences

Most of our experiments have shown some significant cultivar differences in leaf nutrient contents. However these cultivar rankings vary with site and season, so until mechanisms controlling the differences can be understood, only those differences which are consistent can be manipulated. Cultivar differences in leaf potassium, phosphorus and sodium in 2001/02 are summarized in Table 1. Only cultivars common to the two experiments in both years are reported here. The Deltapine cultivar DeltaOPAL consistently had higher sodium concentration and lower potassium and phosphorus concentrations than other cultivars. The okra-leaf cultivar Siokra V-16 consistently had the lowest sodium concentration, the highest phosphorus concentration and high potassium concentration. DeltaOPAL was developed from a cross between an older CSIRO cultivar and a USA-bred cultivar (Leske, 1998). As such, it has had less selection pressure for adaptation to Australian sodic soils than the CSIRO Australia-bred cultivars used in these experiments. Data from site 1 in 2001/02 indicated cultivar differences associated with the Monsanto transgenic traits Ingard® (Bt) and Roundup Ready®. Two out of three cultivars with the Ingard gene had lower concentrations of potassium, while cultivars with the Roundup Ready® gene had higher concentrations of sodium and in one cultivar, lower potassium (Table 2). Averaged over all cultivars, Ingard cultivars had significantly ($P<0.05$) lower (13%) concentrations of potassium and Roundup Ready® cultivars contained significantly ($P<0.05$) higher (14%) concentrations of sodium. In the second year, at the more sodic site (site 2), leaves from the Ingard cultivars contained more sodium and less potassium than conventional cultivars.

There is no obvious reason why a trait for insect or herbicide resistance would directly affect nutrient uptake and leaf concentration when sampled at early flowering. Rather, it is most likely these differences are a consequence of segregation for multigenic control over nutrient uptake and with less selection for performance under varied soil conditions, as was the case with the recurrent parent when it was being developed. To further understand these differences we have initiated more studies with other cultivars and including those with both Ingard® and Roundup Ready® genes. It may be that early-generation transgenic breeding lines could be evaluated for their nutrient concentration balance to select those with desirable characteristics, such as low sodium and high phosphorus and potassium.

We observed wide variation in leaf nutrient concentrations at site 1 in 2001/02 between the 22 cultivars assessed. Analysis of Variance indicated highly significant ($P<0.001$) differences in leaf Fe, B, Cu, Ca, Mg, Na, K, S, and Al. However, values did not fall below those considered adequate for normal cotton growth. Similarly, at site 2, statistically significant ($P<0.05$) differences in B, Cu, Ca, Mg, Na, K and P were observed between the cultivars sown.

Discussion and Conclusions

The consistent negative association between leaf sodium concentration and phosphorus or potassium may have significance in understanding critical leaf tissue levels for these nutrients. It may be that the soil and leaf critical levels of phosphorus or potassium will be higher with elevated leaf sodium as would occur with crops in sodic or saline soils. Our other studies have shown that levels of sodium greater than 4-5% of the cations in the soil substantially impacts on the ability of cotton to take up phosphorus and potassium. High levels of soil magnesium have a lesser effect on the uptake of these two nutrients.

The mechanism by which elevated levels of sodium in the plant affect plant P and K uptake has not been researched. Multigenic control of sodium exclusion by wheat grown under saline conditions has been demonstrated by Munns *et al.* (2002), and the results presented here indicate that some cotton cultivars may be more able to restrict the accumulation of sodium and possibly benefit the uptake of other nutrients. Thus, there remains scope to breed cotton cultivars that contain lower levels of sodium and higher concentrations of phosphorus and potassium. We have presented circumstantial evidence that this is being achieved where cultivars bred by CSIRO Australia have undergone many generations of selection under varied soil conditions (including sodic sites) compared with Delta Opal, which has one generation of selection under Australian conditions. This reasoning is consistent with CSIRO-bred transgenic cultivars not being equivalent to their recurrent parent in their nutrient concentration profiles. More rigorous screening of breeding lines may produce cultivars for sodic soils that discriminate against sodium uptake and improve their phosphorus and potassium nutrition.

This paper points to the fact that variation exists in the ability of cotton to accumulate nutrients and that current cultivars may have responded to breeding selection pressure aimed at improving productivity from sodic soils. Further research into the mechanisms by which cotton plants take up or exclude nutrients is required, as well as recalibration of soil and plant tissue analyses to improve fertilizer management.

References

- Bednarz, C.W. and Oosterhuis, D.M. (1996). Partitioning of potassium in the cotton plant during the development of a potassium deficiency. *Journal of Plant Nutrition,* **19**: 1629-1638.
- Bednarz, C.W. and Oosterhuis, D.M. (1998). Development of a protocol to study the effects of potassium deficiency in cotton under controlled environmental conditions. *Journal of Plant Nutrition*, **21**: 329-339.
- Cassman, K.G. (1986). Soil, crop management, and plant factors which influence potassium nutrition on vermiculitic soils of the San Joaquin Valley. *Journal of Fertilizer Issues*, **3**: 28-45.
- Hodges, S.C. (1992). Nutrient deficiency disorders. *In* Cotton Diseases. Ed. R.J. Hillocks. Pp. 355-403. CAB International, Wallingford.
- Joham, H.E and Amin, J.V. (1964). Role of sodium in the potassium nutrition of cotton. *Soil Science*, **99**: 220-226.
- Leske, R. (1998). DeltaOPAL. *Plant Variety Journal*, **11**: 23-24.
- McLeod, I.G. (2001). The effect of waterlogging and ion interactions on the development of premature senescence in irrigated cotton. PhD Dissertation. University of New England, Armidale, Australia.
- Munns, R., Husain, S., Rivelli, A.R., James, R.A., Condon, A.G., Lindsay, M.P., Lagudah, E.S., Schachtman, D.P., Hare, R.A. (2002). Avenues for increasing salt tolerance of crops and the role of physiologically based selection traits. *Plant and Soil*, **247**: 93-105.
- Oosterhuis, D.M. (1995). Potassium nutrition of cotton in the USA, with particular reference to foliar fertilization. Challenging the Future – proceedings of the World Cotton Research Conference 1. (G.A. Constable and N.W. Forrester, eds.), pp. 133-146, CSIRO, Brisbane, Australia.
- Weir, B.L., Kerby, T.A., Roberts, B.A., Mikellsen, D.S. and Garber, R.H. (1986). Potassium deficiency syndrome of cotton. *California Agriculture*, **40**: 13-144.
- Wright, P.R. (1999). Premature senescence of cotton. (*Gossypium hirsutum* L.) – predominantly a potassium disorder caused by an imbalance of source and sink. *Plant and Soil*, **211**: 231-239.

Table 1. *The concentrations of potassium, phosphorus and sodium in the youngest mature leaf of cotton cultivars common to two experiments in 2001/02. Means followed by the same letter are not significantly different (*$P<0.05$*).*

Nutrient	Cultivar	Site 1 (mg/kg)	Site 2 (mg/kg)
Potassium	Siokra V-16	16670 b	19775 ab
	Sicot 72	17121 ab	18375 b
	Sicot 70	16590 b	20625 a
	Sicala 40	18438 a	20825 a
	Delta Opal	16569 b	18675 b
Phosphorus	Siokra V-16	3420 a	3150 a
	Sicot 72	3239 ab	2925 b
	Sicot 70	3151 ab	2900 bc
	Sicala 40	3074 b	2900 bc
	Delta Opal	3076 b	2700 c
Sodium	Siokra V-16	1168 b	815 b
	Sicot 72	1329 ab	740 b
	Sicot 70	1248 ab	773 b
	Sicala 40	1297 ab	748 b
	Delta Opal	1415 a	965 a

*Table 2. Leaf concentration of potassium and sodium as influenced by cultivar and transgenic traits; data from site 1 in 2001/02. Means for a transgenic cultivar significantly (P<0.05) different from their conventional parent are indicated with *.*

Cultivar	Potassium concentration (mg/kg)		Sodium concentration (mg/kg)	
	Conventional	Ingard®	Conventional	RoundupReady®
Siokra V-16	16669	14309*	1168	1175
Sicala 40	18438	14854*	1297	1664*
Sicot 189	15645	15232	1068	1187
LSD (P<0.05)	1480		213	

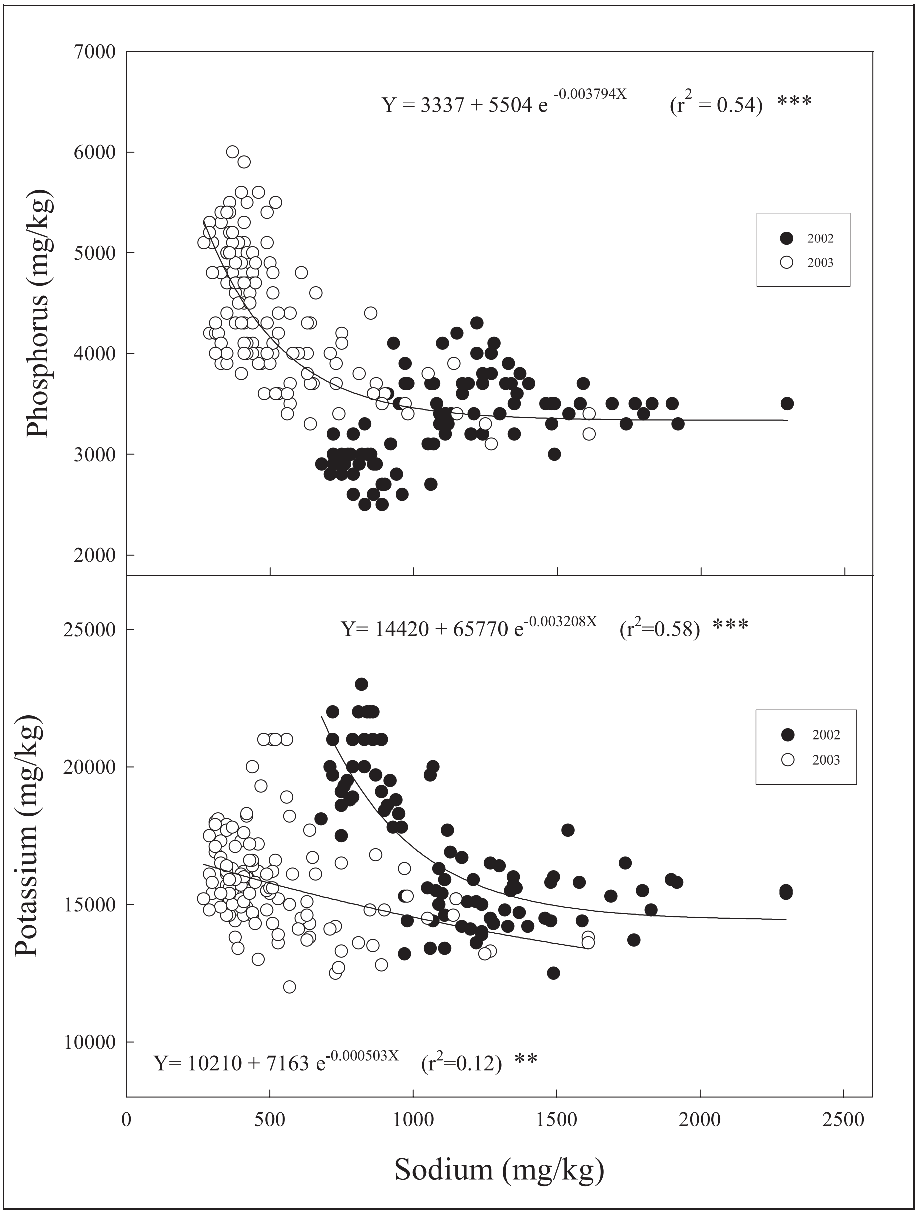

Figure 1. *Phosphorus and potassium concentrations in the youngest mature leaf of cotton from two experiments in each of two successive years; pooled data from all cultivars.*