Premature Senescence in Cotton in Relation to Potassium Availability in Soil

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Introduction

In Australia, premature senescence (PS) is occurring with increasing frequency in cotton crops. By the time PS is noticed, it is generally too late to take corrective measures and the use of plant tissue testing as a diagnostic tool has not been widely successful in predicting K deficiency (Kerby and Adams, 1985). Therefore, it is important to detect beforehand susceptible fields, so that timely action can be taken to avoid substantial yield losses, as insufficient K is believed to be one of the main contributing factors of PS.

Currently commercial soil testing laboratories use the value of 150 mg kg^{-1} available K to identify whether a soil is K deficient or not. While PS is more common on soils with available K less that this value, Wright (1999) reported that some of the soils with levels of available K greater than this, are still showing signs of PS and that the plants affected by PS had a 55-66% heavier total boll mass. This would suggest that the disorder may be caused by the nutrient demands of a heavy boll load.

The poor correlation between available K and the occurrence of PS indicates that the current method for determining the amount of available K is inadequate. The research was undertaken to investigate the relationship between soil mineralogy, different forms of K in soil, and the occurrence of PS in cotton in northern New South Wales. The objective of this project is to develop a methodology to determine the K levels in the soil which reflects PS in the cotton crops and to test the hypothesis that the soil under the cotton affected by PS has different mineralogy than the soil which does not show PS.

Material and Methods

Soil samples were taken from fields affected by PS and paired with similar soils under cotton crop not affected by PS (Non-PS). Soil samples were also taken from the Australian Cotton Research Institute station, which shows PS symptoms intermittently depending on weather conditions and crop variety. The experimental sites are located in northern NSW Australia, 25 km west of Narrabri (ACRI Station), 10 km north of Moree, 15 km east of Pilliga, 10 km south east of Warren and 20 km north west of Trangie. Samples were taken at depths of 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm and 90-120 cm.

The soil samples were air-dried and crushed to pass through a 2 mm sieve. Soil pH and electrical conductivity (EC) were determined in 1:5 soil water extracts following shaking for 30 minutes. The particle size distribution was determined by the sedimentation procedure using the pipette method after dispersing the soil with sodium hexametaphosphate (Gee and Bauder, 1986). The organic carbon was determined by the wet oxidation method as described by M^{c}Cleod (1975). The separation of the soils into their various size fractions was undertaken by soil suspension and wet sieving. The soil suspensions were allowed to stand, so the sand and silt would drop out of suspension, leaving the clay in suspension to be decanted off. The coarse sand fraction was separated from the silt by using a 200 µm sieve and 20 µm sieve for the fine sand.

The cation exchange capacity (CEC) and exchangeable cations including K were determined using 1M ammonium chloride (pH = 7), (Rayment and Higginson, 1992).

The mineralogy of the soil was determined using both basally and random oriented specimens. X-ray diffraction (XRD) patterns were obtained with a Siemen d5000 diffractometer using a CuKα radiation. The oriented clay specimens were examined after Mg saturation, glycerol solvation following Mg saturation and K saturation followed by heating at 335°C and 550°C for 4 hours (Brown and Brindley, 1980). The random powders were packed in a circular aluminium holder and filled using a sieve and razor blade to minimise preferred orientation. The samples were scanned in 0.02° 2θ steps at a speed of 0.6° 2θ per minute. The random powders were scanned from 4 – 65° 2θ and the oriented samples from 3 – 30° 2θ for Mg saturated samples and from 3 – 15° 2θ for all other pre-treatments.

Water-soluble K (H_2O-K) and Exchangeable K (Exch-K) were determined according to the procedures described by Rayment and Higginson (1992). The values for Exch-K presented in Table-3 were calculated by subtracting the water soluble K values from the exchangeable K obtained by 1 M NH_4Cl method. The HNO_3 extractable K was determined by gently boiling 2.5 g of air-dry soil in 25 ml of 1 M HNO_3 at 115°C for 15 min (Helmke & Sparks, 1996). Non-Exchangeable K (Non-Exch-K) was calculated by subtracting the exchangeable K from the HNO_3 soluble K. Total-K was determined by digesting soil samples in a mixture of HF and $HClO_4$ (Jackson, 1958). Potassium analysis was done using atomic adsorption spectrophotometry (AAS) and using Cs as an ionising suppressant.

For potassium sorption isotherms samples from 0-15 cm (top-soil) and 30-60 cm (sub-soil) depths for each of the sites were used. 5 g soil samples were shaken for 1 hr in 25 ml of 0.01 M $CaCl_2$ containing varying amounts of K (0 to 0.01 M K) as KH_2PO_4. The amount of K sorbed by soil was calculated from the difference in K concentration in the equilibrium and initial solutions. The data from the sorption experiment was plotted using the simple isotherm of equilibrium concentration by K adsorbed.

Results and Discussion

General Soil Properties:

All the soils were classified as being Black Vertosols, with relatively uniform profiles. The clay contents ranged from 31.3% to 60.1% with a mean value of 44.2% for the PS sites and 34.9% to 67.3% with a mean value of 51.6% for the Non-PS sites. The clay content for the Pilliga site was similar for surface samples from both PS and Non-PS sites, however, the clay content increased with depth at the Non-PS site and decreased at the PS with depth. For other sites, such as the Trangie site the clay contents were uniform at all depths, at the PS site having around 35 % clay and Non-PS site having around 52 % clay throughout the profile. Soil pH (1:5, $CaCl_2$) values ranged between 5.7 to 7.9 with a mean value of 6.9 for the PS sites and 5.9 to 8.2 with a mean value of 7.4 for the Non-PS sites. The pH at the sites generally increased with depth, except for Warren PS and Trangie PS sites, where it remained nearly constant at all depths. Organic carbon (OC) values ranged between 0.1 - 2.6 % and values were similar for PS and Non-PS sites. The OC content decreased with depth at all the sites and the decrease in OC values with depth was more rapid at PS sites compared to Non-PS soils. The electrical conductivity (EC) varied from 30.5 to 210.0 dS m^{-1} in the surface sample and generally increased with depth. Some subsoil samples had EC values as high as 829 dS m^{-1}.

The CEC of soil samples ranged between 148.6 - 336.3 mmol$_c$/kg with a mean value of 249.5 mmol$_c$/kg for the PS sites, and ranged between 164.5 - 398.1 mmol$_c$/kg with a mean value of 271.4 mmol$_c$/kg for the Non-PS. Even though the range and means appears similar for the PS and the Non-PS sites, it was found that there were statistically significant differences between PS and Non-PS paired sites except for the Moree samples.

Table 1. General soil properties for the studied samples.

		Moree		Pilliga		Warren		Trangie		Narrabri
		Non-PS	PS	Non-PS	PS	Non-PS	PS	Non-PS	PS	
pH	Minimum	5.88	5.68	7.36	7.16	6.44	6.66	7.34	6.07	7.16
(1:5, $CaCl_2$)	Maximum	7.73	7.89	8.15	7.76	7.89	6.78	7.84	6.47	7.81
	Mean	7.09	7.33	7.80	7.49	7.26	6.71	7.64*	6.20*	7.50
EC	Minimum	266	30	184	161	50	63	108	39	81
(1:5 H_2O, dS m^{-1})	Maximum	446	246	829	371	278	205	572	210	280
	Mean	355*	140*	471	274	161	114	269	100	162
OC	Minimum	0.3	0.2	0.7	0.1	0.1	1.0	0.3	0.3	0.5
(%)	Maximum	2.4	2.6	2.4	1.2	1.2	1.7	2.3	2.6	1.1
	Mean	1.0	1.0	1.4	0.6	0.6	1.1	0.8	1.0	0.7
Clay	Minimum	34.9	32.2	55.4	51.3	37.5	43.0	49.0	31.3	60.7
(%)	Maximum	53.2	60.1	67.3	55.3	51.8	45.9	55.5	44.0	76.8
	Mean	46.2	48.0	62.3*	48.7*	45.8	44.1	52.1*	35.9*	66.1
CEC	Minimum	209.7	193.3	339.2	178.8	164.5	263.7	202.4	148.6	370.7
(mmol$_c$/kg)	Maximum	273.6	303.1	398.1	336.3	255.7	272.4	285.6	247.9	393.7
	Mean	243.5	262.8	370.6*	281.0*	213.9*	267.8*	257.7*	186.6*	378.6

* Shows a statistically significant difference between the Non-PS and PS sites.

The Narrabri site showed both PS and Non-PS characteristics between seasons. The soil properties at the Narribri site were similar to the Non-PS Pilliga site (Table 1). The site is characterised by high clay content with mean value of 66.1 % and high CEC values of mean value of 378.6 mmol$_c$/kg.

Table 2. Groupings of the studied samples based on their quantitative clay mineralogy.

Group	Sites	Clay Mineralogy		
		Smectite & Interstratified Minerals	Illite	Kaolinite
1	Narrabri (1), Pilliga Non-PS (4)	XXXX	XXX	XX
2	Moree PS (2), Moree Non-PS (3), Pilliga PS (5)	XXXXX	XX	XX
3	Warren Non-PS (6), Warren PS (7), Trangie Non-PS (8), Trangie PS (9)	XXXX	XXX	XXX

XXXXX – very high mineral (> 80%), XXXX – Dominant mineral (50 – 80%), XXX – Common mineral (15 - 50%), XX – Present (5 – 15%), X – Traces (<5%)

The mineralogy of the clay fraction of the studied samples consisted predominantly of smectite with lesser amounts of illite and kaolinite. Minor amounts of quartz and interstratified clay minerals were also present at the sites. Vermiculite was present in small quantities at the Pilliga PS, Trangie PS and both Warren sites.

Based on the quantitative clay mineralogy of various samples, we classified the samples into three groups (Table 2). Group 1 consists of soils dominated by smectite followed by illite and small proportions of kaolinite; Group 2 consists of soils with very high amounts of smectite followed by the presents of nearly equal proportions of illite and kaolinite and; in Group 3, smectite was the dominant clay mineral closely followed by illite and kaolinite.

Forms of Potassium:

The water-soluble K (H_2O-K) values ranged from 0.06 to 2.64 mg/kg for Non-PS sites with a mean value of 0.64 mg/kg, while for PS sites values ranged from 0.03 to 1.83 mg/kg and a mean value of 0.41 mg/kg. The H_2O-K form for Non-PS sites constituted 0.285 % of Exch-K, 0.012 % of Non-Exch-K and 0.0043 % of the Total-K and PS sites constituted 0.353 % of Exch-K, 0.0099 % of Non-Exch-K and 0.0035 % of the Total-K. There was a significant correlation between H_2O-K and clay content ($R^2 = 0.47$), OC ($R^2 = 0.54$), CEC ($R^2 = 0.55$), Exch-K ($R^2 = 0.83$) and Non-Exch-K ($R^2 = 0.80$). The correlations between H_2O-K and other soil properties including K forms showed that Exch-K and Non-Exch-K were the only properties which had similarities between PS and Non-PS sites. The biggest difference between PS and Non-PS in correlations was found to be with clay content, clay mineral species and CEC. However, the only site which showed a statistically significant difference ($P < 0.05$) between the paired sites for H_2O-K was Pilliga site having.

The exchangeable K (Exch-K) content in soils were different for the PS and Non-PS sites with the Non-PS being higher, however, only the Pilliga site was found to be statistically significant different ($P < 0.0001$). For PS sites Exch-K ranged between 43 and 277 mg/kg with a mean value of 104 mg/kg and Non-PS sites ranged from 46 to 687 mg/kg with a mean value of 236 mg/kg. Considering the value 150 mg/kg as being deficient in K for cotton (Wright, 1999), we find that 30 % of the sites would be classified differently. This would indicate that exchangeable K levels in the soil are not the only factor involved in the occurrence of PS in cotton of these areas. The proportion of the exchangeable K as a part of the other K pools in the soil for Non-PS was found to be 4.08 % of Non-Exch-K and 1.65 % of the Total-K and for PS to be 2.91 % of Non-Exch-K and 1.03 % of the Total-K. There was a significant correlation between Exch-K and OC ($R^2= 0.34$), clay content ($R^2= 0.63$), CEC ($R^2= 0.72$), H_2O-K ($R^2= 0.83$) and Non-Exch-K ($R^2= 0.90$). Between the paired PS and Non-PS sites the correlations between exchangeable K and soil properties including other K pools was found to differ for all soil properties except for H_2O-K, Non-Exch-K and Total-K. The biggest difference between PS and Non-PS in correlations was found to be with clay content, CEC and Kaolinite.

The Non-Exch-K ranged from 1128.5 to 7589.7 mg/kg with a mean value for 3897.2 mg/kg for the PS sites and Non-PS sites range of 1328.3 to 12473.7 mg/kg with a mean value of 5558.8 mg/kg. There is correlation between the Non-Exch-K and CEC ($R^2= 0.70$), clay content ($R^2= 0.65$), all other K forms ($R^2 = 0.48$ to 0.90) and smectite ($R^2 = 0.30$) and illite ($R^2 = 0.44$). From this it is difficult to draw conclusions on the K sources in the soil. The Non-Exch-K at the Non-PS sites accounts for 12.4 to 92.4 % (mean of 38.7%) of the Total-K and at the PS accounts for 9.8 to 75.8 % (mean of 32.6 %) of the Total-K.

The Total-K for the PS sites ranged from 1800 to 38100 mg/kg with a mean value for 14525 mg/kg and Non-PS sites ranged from 2200 to 30700 mg/kg with a mean value of 15570 mg/kg. There is a good relationship between the Total-K and clay minerals (R^2= 0.32 to 0.97) and other forms of K (R^2= 0.25 to 0.48) of the soil samples. No other properties showed significant relationship with the Total-K.

Table 3. Potassium contents of the various K forms present in studied soils.

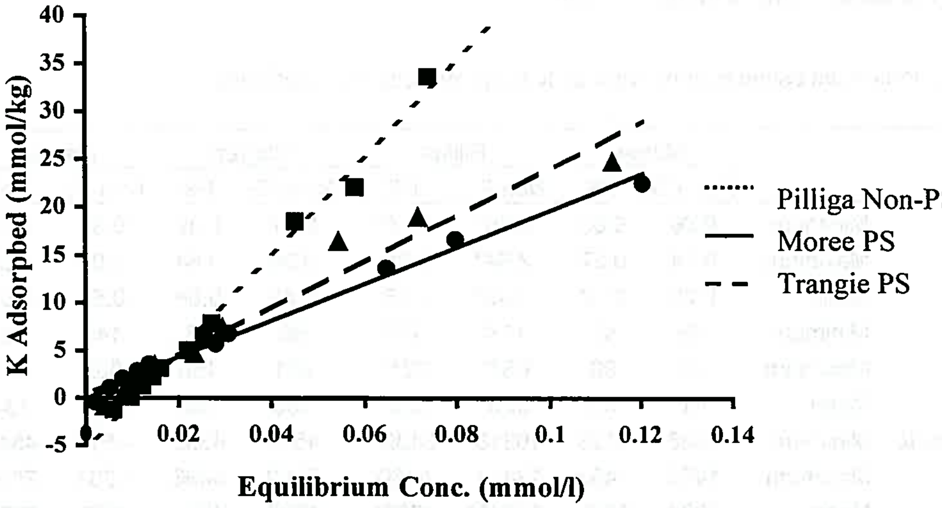
		Moree		Pilliga		Warren		Trangie		Narrabri
		Non-PS	PS	Non-PS	PS	Non-PS	PS	Non-PS	PS	
H_2O-K	Minimum	0.06	0.03	0.70*	0.18*	0.17	0.32	0.34	0.27	0.86
(mg/kg)	Maximum	0.74	0.27	2.64*	0.91*	0.86	0.84	1.09	1.83	1.97
	Mean	0.23	0.12	1.33*	0.36*	0.43	0.56	0.56	0.61	1.34
Exch-K	Minimum	49	43	413*	75*	86	93	148	83	280
(mg/kg)	Maximum	79	90	687*	221*	261	150	302	277	602
	Mean	61	55	525*	120*	138	106	219	134	413
Non-Exch-K	Minimum	1328	1128	10218*	3139*	4559	4396	4518	4345	11282
(mg/kg)	Maximum	1460	1453	12474*	5460	5059	4896	6361	7590	13265
	Mean	1384	1292	11049*	4392*	4827	4646	4975	5259	12144
Total-K	Minimum	2250	1771	12900	7200	18315*	13800*	12536	14383	16811
(mg/kg)	Maximum	11000	8053	18526	38109	23239*	22948*	30671	22895	47647
	Mean	6499	4479	15983	19053	21141*	16642*	18668	17924	26103

* Shows a statistically significant difference between the Non-PS and PS sites.

Potassium Sorption Isotherms:

Sorption Isotherms are part of the quantity-intensity approach (Niederbudde, 1986), which can be used to assess the ability of soils to supply K to plants and to describe the exchange of K from soils by other ions, particularly Ca. However, as Beckett (1964) explains that isotherms should only be used to compare K nutrition for soils of similar Ca status, this can make it difficult to compare the soils. Other information from the isotherms can be used to determine factors of the soils which can be compared. The equilibrium ratio (AR_0) is the point at which the isotherm line crosses the x-axis, if the value is >0.01 mol/l this indicates that K is adsorbed at planar positions on soil minerals, where as, if the value is <0.001 mol/l it indicates that K is adsorbed at edge positions. The AR_0 varied between sites (Figure 1), 2.96E03 at Moree PS, 6.72E03 at Trangie PS and 9.37E03 at Pilliga Non-PS. These values would suggest that the Trangie PS and Pilliga Non-PS sites have K being adsorbed predominantly at the planar positions of the minerals, while the Moree PS site has K being adsorbed predominantly at the edge positions of the minerals. The slope of the isotherm line is an indicator of the ability of the soil to buffer the soil solution K level against depletion, this is called the potential buffering capacity (PBC^K). The PBC^K represents the change in adsorbed K for each unit change in equilibrium solution concentration. The soils which show high values for the PBC^K generally have high CEC values as well as high amounts of readily available K reserves, for which Pilliga Non-PS shows these properties with PBC^K of 505. On the other side, soils showing low PBC^K values will maintain a higher activity in solution than soils with high PBC^K. As a result of K being removed from solution, for example by plant uptake, there is a drop in the value of K activity in solution, and the equilibrium is restored more easily for soils that have lower PBC^K values. This has been show to occur in the soil such as Moree PS with PBC^K of 192 and Trangie PS with PBC^K of 245, especially at the Moree sites.

Figure 1. Potassium sorption isotherms of three soils of contrasting clay mineralogy.



Conclusion

Among the studied soils, the Pilliga sites showed the most differences between the PS and Non-PS sites in terms of different forms of K and K bearing clay minerals. For the other sites it is difficult to make an interpretation on the occurrence of premature senescence based on their K content and clay mineral species. Further work is currently being undertaken to evaluate the K release kinetics and on the fate of applied K in the studied soils.

References:

Beckett, P.H.T. 1964. Studies on soil potassium. I. Confirmation of the ratio law: Measurement of the potassium potential. J. Soil Sci. 15:1-8.

Brown, G. and Brindley, G.W. (1980). X-ray diffraction procedures for clay minerals identification. In *Crystal Structures of Clay Minerals and their X-ray Identification* (Eds. G.W. Brindley and G. Brown). Mineralogical Society, London. pp.305-361.

Gee, G.W. and Bauder, J.W. (1986). Particle-size Analysis. In *Methods of Soil Analysis, Part 1. Physical.* Am.Soc.Agron.-SSSA. Chap. 15, pp.399-404.

Helmke P.A. and Sparks D.L. (1996). Lithium, Sodium, Potassium, Rubidium, and Cesium. pp.551-574. *In* D.L. Sparks et al. (ed.) Methods of Soil Analysis. Part 3 Chemical Methods. SSSA and ASA, Madison, WI.

Jackson, M.L. (1958). Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Kerby, T.A. and Adams, F. (1985). Potassium nutrition of cotton. In *Potassium in agriculture* (Ed. R.D. Munson). ASA, Madison, WI. pp 843-860.

McCleod, S. (1975). Studies on wet oxidation procedures for the determination of organic C in soil. In *Notes on Soil Techniques*. CSIRO Division of Soil. pp.73-79.

Niederbudde, E.A. 1986. Factors affecting potassium release and fixation in soil. Trans. 13th, Int.Congr. Soil Sci., Hamburg, FRG VI:1155-1167.

Rayment, G.E. and Higginson, F.R. (1992). Ion-Exchange Properties. In *Australian Laboratory Handbook of Soil and Water Chemical Methods*. Inkata Press, Melbourne. pp.138-144.

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: 231-239,1999.