Soil Quality and Profitability in a Sodic, Grey Clay in Merah North, NSW, due to Sowing Rotation Crops and Applying Gypsum

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Introduction

Sustainability in any farming system is dependent upon a number of interacting factors which include climate, soil quality, plant nutrition, management, weed and disease incidence, and economic factors. In cotton-based farming systems it has been assumed that a "sustainable" system is represented by a cotton-rotation crop sequence, whereas a "degradative" system is exemplified by continuous cotton (Cooper 1999). As a consequence many cotton growers sow rotation crops after irrigated cotton assuming that they will improve soil quality, minimize disease incidence and maintain profitability of cotton (Cooper 1999). The crop most commonly sown in rotation with cotton is wheat, although legumes such as dolichos, faba bean and chickpea have become more popular in recent years (Cooper 1999).

Although past research has addressed issues such as soil structure, nitrogen and water use (McGarity et al. 1984; Constable et al. 1992), information on the comparative advantages and disadvantages of a range of rotation crops, and the sustainability of such crop sequences over extended periods has been limited. Several long-term on-farm experiments were, therefore, established during 1993 in New South Wales and Queensland to evaluate the sustainability of selected rotation crop-cotton sequences with issues such as soil quality (physical, chemical and biological), weeds and disease incidence, cotton agronomy and economic benefits receiving a high priority (CRC for Sustainable Cotton Production 1994). The objective of the study reported in this paper was to quantify the changes in soil quality, cotton lint yield and profitability from 1993 to 1999 of six irrigated cotton-rotation crop sequences sown in a sodic grey clay in Merah North, NW NSW. Crop sequences were selected following discussions with local cotton growers. The indices used to evaluate sustainability included soil quality, soil microbiology and disease incidence, yield and profitability. This paper presents data on soil properties (soil organic C, structure as air-filled porosity of oven-dried soil, exchangeable Ca, Mg, K and Na, pH, electrical conductivity ($EC_{1:5}$) and $EC_{1:5}$/exchangeable Na in the 0-0.6 m depth), lint yield and profitability (as gross margins/ha and gross margins/ML of irrigation water).

The experiment was located at "Beechworth", Merah North (149°18'E 30°11'S) in the Namoi valley of New South Wales. The site has a semi-arid climate (rainfall of 615 mm). The soil is a deep uniform grey clay. Clay, silt and sand contents were 62%, 16% and 22%, respectively, in the 0-0.3 m depth: and 65%, 19% and 16%, respectively, in the 0.3-0.6 m depth. In May 1994, exchangeable sodium percentage, EC (1:5 soil water), soil organic C and $CaCO_3$ equivalent were 8.3, 0.15 dS/m, 0.8% and 6.2%, respectively, in the 0-0.3 m depth; and 14.9, 0.18 dS/m, 0.57% and 6.8%, respectively, in the 0.3-0.6 m depth. The six cropping systems sown after minimum tillage were: continuous cotton (R1), long-fallow cotton (R2), cotton-green manured faba bean

(R3), cotton-dolichos-green manured faba bean in the 1st year followed by cotton-wheat (R4), cotton-dolichos (R5), cotton-fertilized dolichos (with P and K removed by cotton replaced as fertilizer) (R6). They were first sown in June 1993, after the site had been laser-levelled, following 6 years of continuous cotton with intensive tillage (disc and chisel ploughing, and ridging every year; deep ripping every 4-5 years) and burning or incorporation of crop residues. Cropping practices (mechanized farm operations; frequent herbicide and pesticide application; N fertilizer application as anhydrous ammonia etc.) used in local cotton production systems were followed.

Cotton was fertilized with water-run urea at a rate of 140 kg N/ha in November 1993, and with anhydrous ammonia at a rate of 150, 120, 120, 140 and 120 kg N/ha in August 1994, 1995, 1996, 1997 and 1998, respectively. In addition zinc sulphate heptahydrate and zinc oxide were applied to cotton in August 1995 and 1996 at a rate of 6 kg Zn/ha, and gypsum to all plots in July 1997 and December 1998 at a rate of 2.5 t/ha. The experimental design was a randomized complete block design with 4 replications. Individual plots consisted of 24 rows (sown on 1-m beds until May 1995 and 2-m beds thereafter) which were 431 m long. The plots were furrow irrigated at a rate of approximately 1 ML/ha of water during each irrigation event.

Changes in soil quality

Soil structure

Soil structure, measured as air-filled porosity of oven-dry soil was significantly affected by cropping sequence in most years (Figure 1). Major differences were, however, present only in 1996 when R1 (continuous cotton) was lowest and the 2 cotton-dolichos sequences (R5, R6) had highest air-filled porosity in the sub-soil. These differences are probably related to the traffic load and intensity in these cropping systems.

In later years higher values of air-filled porosity were consistently present in the sub-soil of long-fallow cotton (R2) and cotton-wheat (R4). Differences between cropping sequences were, however, small in 1997, 1998 and 1999. The major changes in structure in this experiment occurred with time (Table 1). Initially (in 1994) due to the laser levelling in 1993, structure in the surface 0.15 m of all treatments was relatively poor. With time and avoidance of deep tillage (which tends to bring sodic soil to the surface) soil structure in this upper layer improved. A significant factor in improving soil structure was the increase in $EC_{1:5}$/Exchangeable Na, partly due to irrigation with moderately saline bore water and addition of gypsum in July 1997. A major increase in air-filled porosity occurred in the surface 0.15 m between 1996 and 1997. Similarly between 1997 and 1998 a large increase in air-filled porosity occurred in the 0.15-0.30 m depth, presumably due to the addition of gypsum. Between 1998 and 1999 decreases in sub-soil air-filled porosity occurred (Table 1). We believe that this was due to compaction caused by trafficking over wet (near saturated) soil during land preparation and cotton sowing in September-October 1998. The site was inundated during the regional floods of July and August 1998.

Figure 1. Effects of cropping sequence on air-filled porosity of oven-dry soil from 1996 to 1999. Horizontal bars are standard errors of the means. ◆ - R1; ■ - R2; ▲ - R3; □ - R4; △ - R5; ● - R6.

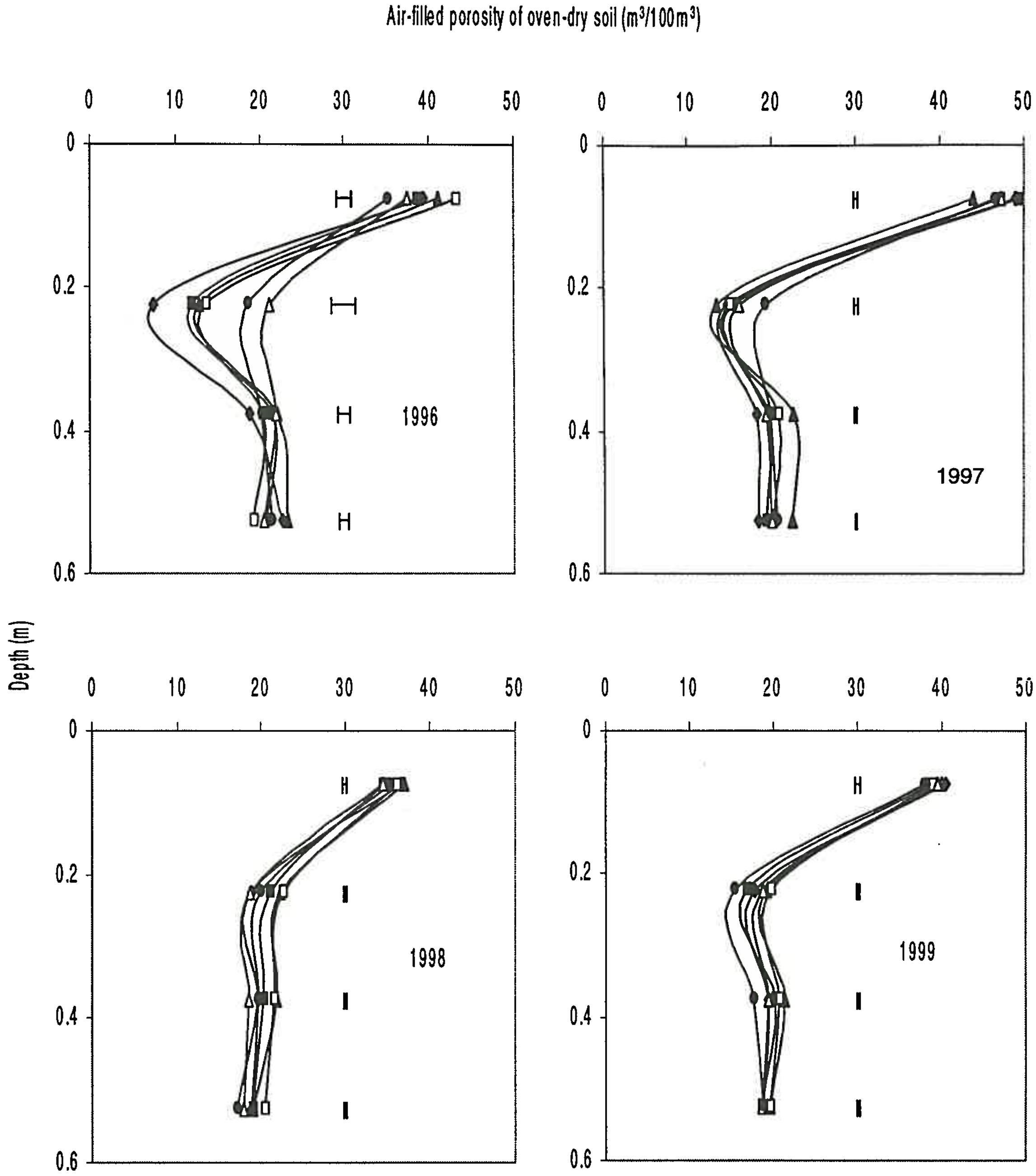


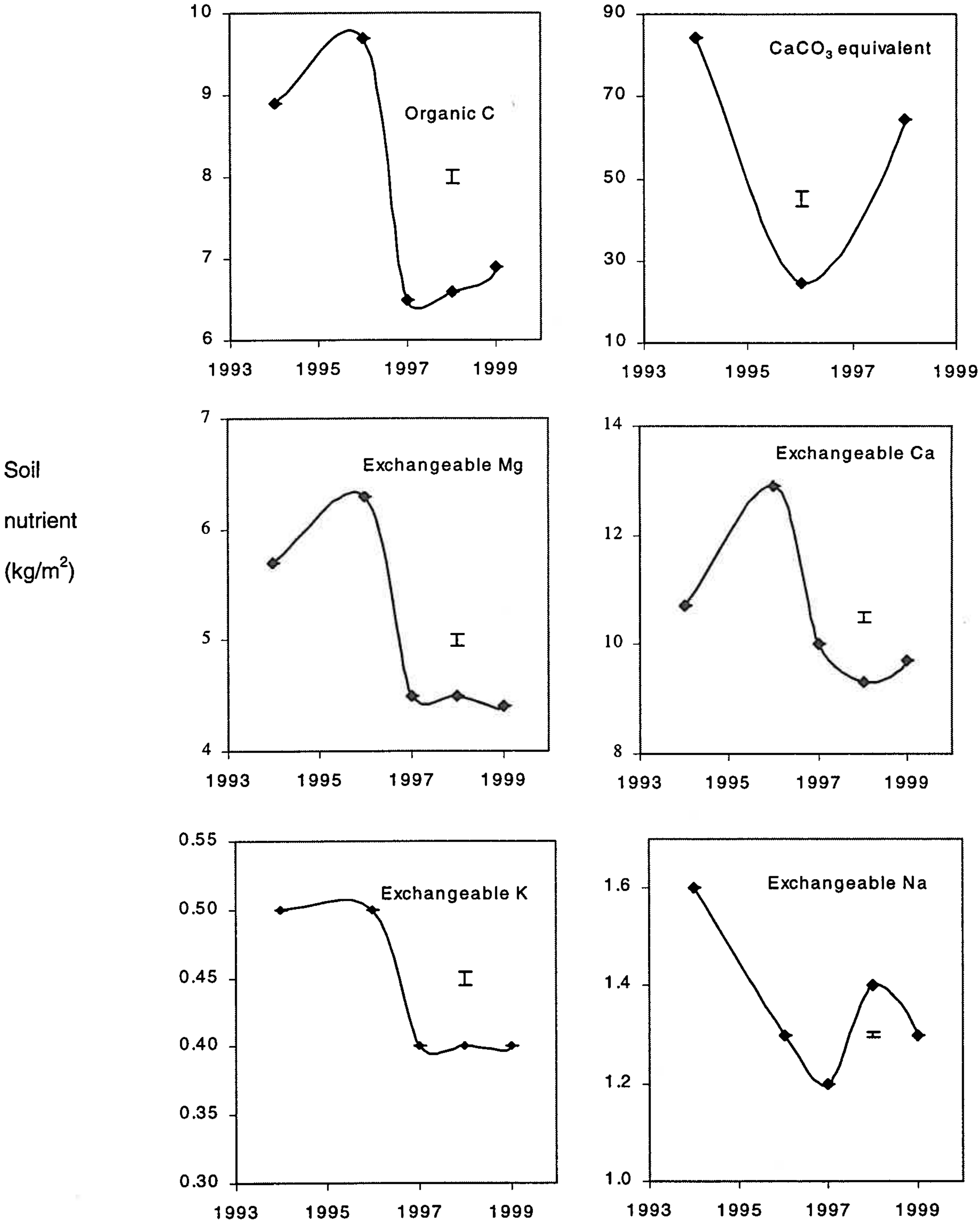
Table 1. Variation of soil pH, electrical conductivity ($EC_{1:5}$), sodicity ($EC_{1:5}$/exchangeable Na and exchangeable sodium percentage) and air-filled porosity of oven-dried soil between 1994 and 1999 in all plots. P < *** and P < ** mean that values within the same row differ significantly at the 99.9% and 99% levels of probability; n.s. means that values do not differ significantly.

Soil property	Depth (m)	1994	1996	1997	1998	1999	P<
pH (0.01M $CaCl_2$)	00.00-0.15	6.8	6.5	7.1	7.0	6.7	***
	00.15-0.30	6.7	6.7	7.1	7.3	7.0	***
	00.30-0.45	7.2	6.5	7.4	7.5	7.3	***
	00.45-0.60	7.2	6.5	7.4	7.5	7.6	***
$EC_{1:5}$ (dS/m)	00.00-0.15	0.14	0.09	0.38	0.27	0.26	***
	00.15-0.30	0.16	0.14	0.29	0.32	0.32	***
	00.30-0.45	0.15	0.17	0.37	0.40	0.35	***
	00.45-0.60	0.21	0.27	0.45	0.48	0.38	***
Exchangeable sodium percentage	00.00-0.15	5.4	3.4	3.0	4.1	3.8	***
	00.15-0.30	6.4	5.0	5.6	7.8	6.9	***
	00.30-0.45	9.9	7.4	8.8	11.0	9.5	***
	00.45-0.60	11.9	9.2	10.3	12.7	11.7	***
$EC_{1:5}$/Exchangeable Na	00.00-0.15	0.58	0.60	4.76	2.11	2.26	***
	00.15-0.30	0.58	0.51	1.26	1.05	1.15	***
	00.30-0.45	0.32	0.44	0.99	0.90	0.89	***
	00.45-0.60	0.41	0.67	1.00	0.93	0.77	***
Air-filled porosity ($m^3/100m^3$)	00.00-0.15	13.0	39.2	47.2	35.7	39.3	***
	00.15-0.30	19.6	14.2	15.8	20.6	18.0	***
	00.30-0.45	21.3	20.8	20.1	20.3	19.7	n.s.
	00.45-0.60	20.4	21.3	20.2	18.8	18.9	**

Soil fertility and sodicity

None of the soil fertility or sodicity indices were significantly affected by cropping sequence. The major changes in soil fertility (pH, exchangeable cations, $EC_{1:5}$ and $CaCO_3$ equivalent) and sodicity ($EC_{1:5}$/Exchangeable Na and exchangeable sodium percentage, ESP) occurred with time (Table 1, Figure 2). Between 1994 and 1996, there was a fall in pH, exchangeable Na and $CaCO_3$ equivalent, and an increase in organic C, and exchangeable Ca and Mg. This trend was rapidly reversed between 1996 and 1997, probably due to residual effects of laser levelling. Laser levelling effects are similar to intensive tillage operations, which facilitate and enhance microbial activity, stubble decomposition rates and increase soil organic C initially, followed by further rapid microbial decomposition and mineralization of soil organic C. This causes production of CO_2, and hence, carbonic acid during the decomposition process leading to solubilization of soil carbonates, increases in exchangeable Ca and decreases in exchangeable Na (Chorom and Rengasamy 1997). Once soil organic levels fell to a new low level, the

Figure 2. Changes in soil organic C, exchangeable cations and $CaCO_3$ equivalent in the 0-0.6 m depth of all treatments between 1994 and 1999. Vertical bars are standard errors of the means.



changes that occurred in the values of pH, ESP, exchangeable Ca, Mg and Na, and $CaCO_3$ were reversed. The fall in exchangeable Na may also have been due to leaching of sub-soil Na brought to the surface by laser-levelling. The increases in $EC_{1:5}$ and $EC_{1:5}$/exchangeable Na between 1996 and 1997, and their maintenance at high levels were probably caused by irrigation with saline water during the 1996/97 cotton growing season (SAR = 3.8 whereas in most other years SAR values ranged from 1.5-2.5), and gypsum applications in July 1997 and December 1998. The increase in exchangeable Na and decrease in exchangeable Ca between May 1997 and 1998 (Table 1, Figure 2), and increase in $CaCO_3$ suggests that the gypsum applied in July 1997 had a negligible effect on exchangeable Ca, but due to the relatively high pH was precipitated out in the form of $CaCO_3$. However, the second application of gypsum in December 1998 appears to have been effective in increasing exchangeable Ca and decreasing exchangeable Na levels, albeit by small amounts.

Profitability

Highest cumulative gross margins/ha were observed with continuous cotton, R1 (Table 2). Among cropping sequences, long-fallow cotton (R2) and cotton-dolichos-faba in the 1st year followed by cotton-wheat (R4) gave the highest gross margins/ha, and lowest was with cotton-faba bean (R3). Lowest gross margins/ML of irrigation water also occurred with R3, whereas highest was with R2 followed by R4. The low average cotton yields with R3 and R1 may have in part been caused by the very low cotton yields (2.8 bales/ha) which occurred after laser levelling in the winter of 1993. These were the only treatments in which cotton was sown during 1993. All other treatments did not have a cotton crop until 1994.

Table 2. Profitability shown as gross margins from June 1993 to May 1999 for the different cropping sequences

Treatment	R1	R2	R3	R4	R5	R6
Number of cotton crops	6	3	4	3	3	3
Cumulative lint yield (bales/ha)	38.2	23.5	24.5	23.2	22.8	23.8
Average lint yield per crop (bales/ha)	6.4	7.8	6.1	7.7	7.6	7.9
Cumulative cotton seed yield (t/ha)	12.6	7.8	8.1	7.7	7.5	7.8
Average cotton seed yield per crop (t/ha)	2.1	2.6	2.0	2.6	2.5	2.6
Cumulative grain yield (t/ha)	-	-	-	3.2	-	-
Cumulative gross margin ($/ha)	9,534	5,935	4,413	5,943	5,437	5,323
Cumulative irrigation water use (ML/ha)	35.4	17.8	25.5	21.2	21.0	21.0
Cumulative gross margin/ML of irrigation water	269	333	173	280	259	254

In general, it can be said that among the rotation crops used in this trial wheat is a more efficient user of land and water resources than other rotation crops, particularly green manured legumes. These results parallel those obtained in a grey clay from Warren in central-western NSW which was far less sodic and was irrigated with water of good quality (Hulugalle *et al.* 1999). R1 is the most efficient user of land whilst at the same time it is a relatively less efficient with respect to water resources. A point that should be noted is that among all the crops studied in this experiment cotton is the best adapted to salinity (Ayers and Westcot 1976), and probably sodicity. It is not entirely surprising, therefore, that a low intensity cotton production system such as long-fallow cotton is a more efficient user of water resources in a moderately saline and highly sodic soil.

Conclusions

- In terms of soil quality and gross margins/ML, long-fallow cotton and cotton-dolichos-faba fb. cotton-wheat were the best
- Highest gross margins/ha were with continuous cotton
- Lowest gross margins/ha and gross margins/ML were with cotton-faba
- Before $EC_{1:5}$ /Exchangeable Na increased in 1997, soil structure was poorest with continuous cotton
- The main causes of soil quality changes between 1994 and 1999 were avoidance of deep tillage, irrigation with moderately saline water and gypsum application
- Rotation crop played a secondary role in modifying soil quality

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