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AGRONOMY & SOILS

SHORT COMMUNICATION

Soil Properties Under Cotton-Corn Rotations in Australian Cotton Farms

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ABSTRACT

During the past decade sowing corn (*Zea mays* L.) in rotation with cotton (*Gossypium hirsutum* L.) has gained popularity among many Australian cotton growers. Research on cotton-corn rotations in Australia is sparse, although anecdotal evidence suggests that subsequent cotton yields are increased. Our objective was to quantify the impact of sowing a corn rotation crop on soil properties of Vertisols under cotton-based farming systems on 18 farms within Australian cotton-growing regions. Each site had either corn or cotton sown during the preceding summer. Soil was sampled in transects from the surface 0.3 m. Soil organic carbon concentrations and storage were higher, and exchangeable cation concentrations lower after corn than after cotton but soil structure was not significantly affected. The yield increases reported by cotton growers are, therefore, unlikely to have been caused by the soil properties measured in this study. Enhanced cycling of nutrients such as N and P through higher soil organic matter and microbial activity cannot, however, be ruled out.

Sowing cereal crops such as wheat (*Triticum aestivum* L.) in rotation with cotton (*Gossypium hirsutum* L.) is commonly practiced by many Australian cotton growers (Hulugalle and Scott, 2008). During the past decade, however, summer cereals such as corn (*Zea mays* L.) have gained popularity as rotation crops (Anonymous, 2005). The most recent surveys (2012-13) suggest that 19% of the farms surveyed grew corn in rotation with cotton (Roth Rural, 2013). Research on the benefits of sowing corn rotation crops in Australian cotton farming systems is, however, sparse. Anecdotal evidence from Australian cotton growers suggests that in comparison with rotations such as continuous cotton and cotton-wheat, sowing corn increased subsequent cotton yields by up to 25% (Anonymous, 2005, 2012; Roth Rural 2013). This observation was confirmed by Hulugalle *et al*. (2014) who reported that sowing corn in conventionally-tilled continuous cotton systems increased cotton yield by 22%. Yield increases in permanent bed systems were, however, lower; *viz*. 12% in continuous cotton and 4% in cotton-wheat rotations. However, a great deal more information is available from the United States (US), where research on corn as a rotation crop has been conducted since the 1950's (Martin *et al*., 2002). A majority of results (approximately 80%) suggest that sowing corn rotation crops increases lint yield of subsequent cotton (Entry *et al*., 1996; Martin *et al*., 2002; Davis *et al*., 2003; Pettigrew, *et al*., 2006; Reddy *et al*., 2006; Abrahamson *et al*., 2007; Stetina *et al*., 2007; Wright *et al*., 2007; Mitchell *et al*., 2008; Boquet *et al*., 2009).

Suggested causes for the better growth and yield increases of cotton in corn-cotton rotations include reductions in reniform nematode (*Rotylenchus reniformis*) numbers (Davis *et al*., 2003; Stetina *et al*., 2007), better control of weeds (Reddy *et al*., 2006; Tingle *et al*., 2004) and reductions in black-root rot (*Thielaviopsis basicola*) incidence (Hulugalle *et al*., 2014). With respect to soil fertility, the results are generally inconclusive. Except for soil carbon which increased in virtually all studies (Causarano *et al*., 2006; Reddy *et al*., 2006; Abrahamson *et al*., 2007; Wright *et al*., 2008; Adeli *et al*., 2009), soil macronutrient concentrations either decreased or did not change significantly after corn, but micronutrient concentrations decreased (Reddy *et al*., 2006; Wright *et al*., 2008; Adeli *et al*., 2009). Soil structure was assessed in only a single study which indicated that it improved after corn (Adeli *et al*., 2009).

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The objective of the present study was to quantify the impact of sowing a corn rotation crop on soil properties of Vertisols under cotton-based farming systems in eastern Australia. The assessment was made on a number of farms within major Australian cotton-growing regions (Fig. 1).

MATERIALS AND METHODS

The experimental sites were located on 18 cotton farms in the Darling Downs and McIntyre valley in Queensland, and the Namoi and Macquarie valleys, and the Murrumbidgee irrigation area in New South Wales (NSW) (Fig. 1). The southernmost farm was located near the town of Coleambally (34°48’19.39”S, 145°52’57.94”E) in the Murrumbidgee Irrigation Area of NSW and the northernmost, near Condamine in the Darling Downs of Queensland (26°49’6.26”S, 150°8’48.70”E). Out of the 18 farms, 2 were dryland and the remainder irrigated. All sites had four distinct seasons with hot summers (average daily maximum during January, the hottest month, of 32 to 35 ◦C) and mild winters (average daily maximum during July, the coldest month, of 15 to 19 ◦C) and fell within the semi-arid sub-tropical regions of Australia. Average annual rainfall within this region ranges from 410 to 620 mm. In southern Queensland and NSW, cotton is usually sown during October and picked during May of the following year whereas corn is sown during September and harvested during March or April of the following year. Each site had either corn or cotton sown during the preceding summer in adjacent fields. Prior to this, cotton had been sown in both fields for at least two years. Three of the sites had cotton sown continuously for a period of three years or more. In all sites, this was the first corn crop sown in the corn field. Land preparation ranged from permanent beds (raised beds that remain in place for several seasons before renovation or realignment requires them to be ploughed down and reconstructed) to conventional tillage (disc-ploughing followed by chisel ploughing and bed construction with a listing rig) in the irrigated sites to zero tillage in the dryland sites. Pupae busting, cultivation of the soil surface for heliothis moth control, occurred at all sites after cotton picking during May. Fertiliser application to both cotton and corn were restricted to N as urea, and averaged 180 kg N/ha before sowing and 60 kg N/ha during cotton flowering in January. The soils were self-mulching grey, brown and red Vertisols and classified as fine, thermic, smectitic, typic haplusterts (Soil Survey Staff, 2010) with clay concentrations that ranged from 350 to 870 g kg^{-1}. The areas of each field ranged between 40 and 100 ha with field length ranging from approximately 400 to 1000 m. Soil was sampled from the farms in the Namoi valley during September of 2011, the Macquarie valley and the Murrumbidgee Irrigation Area during September 2012 and the McIntyre Valley and Darling Downs during September 2013. Samples were taken with a narrow-bladed or draining spade from the 0-0.1 m and 0.1-0.3 m depths in a transect that bisected each cotton or corn field at 100 m intervals, commencing 50 m from the head ditch and terminating 50 m from the tail drain. They were not combined into composite samples but analysed separately.

Figure 1. Australian commercial cotton growing regions (highlighted).

Two soil clods (volumes between 5 x 10^{-5} m^3 to 1.2 x 10^{-4} m^3) were sampled from each depth in each sampling point in the transect. These clods were packed in bulk soil from the same depth to avoid shattering and transported back to the laboratory where they were oven-dried for 48 h, weighed, coated with paraffin wax and volume determined by displacement in water (Cresswell and Hamilton, 2002). The oven-dried weight (M_s) and clod volume (V) were used to calculate bulk density (M_s/V). In the 0–0.1 m depth, the volume of air-dried aggregates (1–10 mm diameter) was determined with the kerosene saturation method (McIntyre and Stirk 1954). Aggregate weights were converted to an oven-dried equivalent using an air-dry water content determined on subsamples. Bulk density of aggregates was determined by dividing the oven-dried equivalent of aggregate weight by its air-dry volume, as soil shrinkage curves had indicated that there was no significant difference in volume between air-dried and oven-dried aggregates (Hulugalle and Entwistle 1997). Bulk density for the 0–0.1m depth was expressed as a weighted mean of the bulk densities of aggregates and clods (2:1 aggregates:clods).

The bulk soil used to pack the clods was air-dried, passed through a sieve with 2-mm apertures and analysed for pH (0.01M $CaCl_2$) and electrical conductivity of a 1:5 soil:water suspension ($EC_{1:5}$), and exchangeable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) after extraction with alcoholic 1M NH_4Cl at pH 8.5 (Rayment and Lyons, 2011). These data were used to derive the sodicity indices: exchangeable sodium percentage, ESP [= (exchangeable Na/∑exchangeable cations) x 100], and electrochemical stability index, ESI (= $EC_{1:5}$/ESP) (Blackwell *et al.*, 1991). A subsample was passed through a 0.5-mm sieve and total soil organic carbon (SOC) concentration determined by the wet oxidation method of Walkley and Black (Rayment and Lyons, 2011). Storage of SOC (‘stocks’) in any one depth was estimated as the product of bulk density, sampling depth interval, and SOC concentration. The SOC storage was reported as that in the 0–0.3m depth (sum of storage in the 0–0.10 and 0.10–0.30m depths.

Data were analysed using a generalised linear model (GLM). The fixed model consisted of the preceding crop (*i.e.* cotton/corn), sample depth (*i.e* 0-0.1 m/0.1-0.3 m), and their interaction, with clay concentration as a covariate. The random model consisted of region (*i.e.* southern/northern[1]), farms within regions, and irrigation (*i.e* Y/N) within the northern region farms. The results for pH, exchangeable Na, ESP and ESI were transformed before analysis to achieve normality as follows: pH as $x' = x^4$, and exchangeable Na, ESI and $EC_{1:5}$ as $x' = \mathrm{sqrt}(x)$. None of the other variables were transformed before analysis. Predicted means and standard errors of the means were calculated and significance tested at the 5% level. Pairwise comparisons for significant effects were conducted using least significant difference ($P = 0.05$). Analyses were conducted with ASREML 3 (Gilmour *et al.*, 2006).

RESULTS AND DISCUSSSION

In comparison with soil sampled after cotton, soil sampled after corn had lower $EC_{1:5}$, and exchangeable Ca, Mg, K and Na concentrations in both 0-0.1 m and 0.1-0.3 m depths (Table 1). No Ca, Mg or K amendments or fertilisers had been applied to any of the fields during the preceding three years. These results mirror those of Wright *et al*. (2007) who reported that cotton-corn rotations not continuous cotton reduced cation concentrations in the surface 0.15 m of an Inceptisol in Texas. Adeli *et al*. (2009) in a Mollisol and Reddy *et al*. (2006) in an Alfisol reported, however, that cation concentrations were not significantly affected by corn rotation crops. The variation among the four studies is puzzling and cannot be easily explained.

Soil organic C concentration, however, was higher in the 0-0.1 m depth of soil sampled after corn but did not differ between crops in the 0.1-0.3 m depth (Table 1). There were no significant differences in the 0.1-0.3 m depth between post-cotton and post-corn soil with respect to soil organic C. Soil carbon storage in the surface 0.3 m was 53 t/ha after corn and 50 t/ha after cotton ($P < 0.001$; SEM = 0.07). Higher soil organic C after corn has been reported by many authors (Causarano *et al*., 2006; Reddy *et al*., 2006; Abrahamson *et al*., 2007; Wright *et al*., 2008; Adeli *et al*., 2009). This is probably because corn returns more above and below-ground biomass carbon to the soil than cotton (Hulugalle *et al*., 2011, 2014).

1 Northern regions were defined as the Darling Downs, and McIntyre and Namoi valleys, and the southern regions as the Macquarie valley and the Murrumbidgee irrigation area

Table 1. Effect of corn rotation crop and sampling depth on soil properties. Sampled during September 2011, 2012 and 2013 from adjacent or split fields sown with corn or cotton on farms located in the Namoi, Macquarie and McIntyre valleys, Murrumbidgee irrigation area, and Darling Downs

Rotation crop	Depth (m)	pH[z]	$EC_{1:5}$ (dS/m)[z,y]	Soil organic C (g/100g)	Bulk density (Mg/m^3)	Exch. Ca ($cmol_c/kg$)	Exch. Mg ($cmol_c/kg$)	Exch. K ($cmol_c/kg$)	Exch. Na ($cmol_c/kg$)[z]	ESP[x]	ESI[z,w]
Corn	0-0.1	(1797a) 6.5	(0.360a) 0.13	1.18a	1.55a	17.1a	10.4a	1.28a	(0.734a) 0.44	2.5a	(0.285a) 0.08
	0.1-0.3	(1907b) 6.6	(0.356a) 0.13	0.95b	1.81b	17.5a	10.9b	0.82b	(1.187b) 1.41	3.7b	(0.227b) 0.05
Cotton	0-0.1	(1867a) 6.6	(0.398b) 0.16	1.09a	1.54a	19.0b	10.7c	1.36c	(0.891c) 0.80	2.7a	(0.294a) 0.09
	0.1-0.3	(1940b) 6.7	(0.384b) 0.15	0.93b	1.81b	18.8b	11.1c	0.98d	(1.329d) 1.71	3.9b	(0.242b) 0.06
SEM[y]		(29.2)	(0.007)	0.018	0.010	0.33	0.12	0.025	(0.047)	0.11	(0.006)
ANOVA: P <											
Rotation crop (R)		n.s.[u]	0.001	0.01	n.s.	0.001	0.05	0.001	0.01	n.s.	n.s.
Depth (D)		0.01	n.s.	0.001	0.001	n.s.	0.001	0.001	0.001	0.001	0.001
R x D		n.s.	n.s.	0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[z] Values in parentheses are transformed values. pH was transformed as $x' = x^4$, and exchangeable Na, ESI and $EC_{1:5}$ as x'= sqrt(x) before analysis.

[y] $EC_{1:5}$, electrical conductivity of a 1:5 soil:water suspension.

[x] ESP, exchangeable sodium percentage.

[w] ESI, electrochemical stability index

[v] SEM, standard error of the means.

[u] n.s., non-significant. Values within the same column followed by the same letter do not differ significantly (P = 0.05)

Soil physical properties such as bulk density, and indicators of aggregate stability (ESP, ESI) did not differ between soil sampled after cotton and that sampled after corn (Table 1). The only other study that assessed soil structure in cotton-corn rotations reported, however, that sowing corn improved both aggregate stability and total porosity (Adeli *et al*., 2009). The difference in soil physical responses between our study and that of Adeli *et al*. (2009) may be related to the fact that the latter was conducted on a rainfed Mollisol in which a strong correlation was present between soil organic carbon and the above mentioned soil properties whereas our sites were mainly irrigated, self-mulching Vertisols in which no such correlation was observed. Soil structure development in Vertisols is more dependent on frequency and intensity of wet/dry cycles than on inputs of soil carbon (Sarmah *et al*., 1996).

The yield increases reported by cotton growers are, therefore, unlikely to have been caused by the soil properties measured in this study. Enhanced cycling of nutrients such as N and P through higher soil organic matter and microbial activity cannot, however, be ruled out (Adeli *et al*., 2009; Wright et *al*., 2007, 2008).

CONCLUSIONS

Soil organic carbon concentrations and storage were higher, and exchangeable cation concentrations lower after corn than after cotton. Soil structure and chemical properties that influenced aggregate stability were not significantly affected by corn. The yield increases reported by cotton growers are, therefore, unlikely to have been caused by the soil properties measured in this study. Enhanced cycling of nutrients such as N and P through higher soil organic matter and microbial activity cannot, however, be ruled out.

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