Australian Government
Cotton Research and Development Corporation

Stoichiometric Ratios of Cotton Soils Under Different Land Management Practices

Australian National University

Summer Scholarship Report **Katie McPherson u5450984**

Project Title: Stoichiometric Ratios of Cotton Soils Under Different Land Management Practices
Start & End Dates: 14/1/16-30/3/16
Scholarship Type: Summer Postgraduate
Budget: $5,000
Organization & Location for the Project: Australian Cotton Research Institute, Narrabri, NSW Deparement of Primary Industries, Narrabri; and Fenner School of the Environment and Society, ANU, Canberra.
Project Supervisor: Dr. Craig Strong, ANU
Project Collaborators: Dr. Nilantha Hulugalle, ANU & Dr. Guna Nachimuthu, NSW DPI.

1. Executive Summary:

Archived soil samples from 0-30 cm that had been collected between the 1993 and 2013 from seven different experiments run by the NSW Department of Primary Industries in Queensland and New South Wales were analysed for soil C, N and P. These soils were taken from plots with differing soil management and crop rotation histories. The 2016 Summer Scholarship with the CRDC was granted to Katie McPherson, a final year Masters Student from the ANU Fenner School. This scholarship was aimed at the investigation of soil stoichiometric relationships of soil C, N and P to test the hypothesis that there is a potential imbalance in soil C:N:P ratios under differing soil management and crop rotations that may inhibit carbon sequestration. The soil archives were collected from the Narrabri storage facility and ground on site in preparation for laboratory analysis at the ANU. For the remainder of her time at the Australian Cotton Research Institute in Narrabri, Katie was exposed to the following laboratory methods that were carried out following an on-site irrigation sequence for the plots C1 and D1:

- Total suspended solids,
- Saturated soil pastes
- Centrifuging soil pastes
- Determination of chloride in water by Sherwood Chloride Analyser model 926 (coulometric method)
- EC and pH measures
- Determination of Na, K, Ca, and Mg in water by flame atomic absorption spectroscopy.

Katie also attended several cotton related seminars and spent time in the field learning about and assisting with related projects taking place at the research station.

Effects on the stoichiometric ratios of cotton cropping soils have been varied throughout the treatments over the plots. At this present time of analysis, the most obvious relationship that was found was between the dryland and irrigated plot soil Carbon storage due to Nitrogen addition. The addition of Nitrogen to dryland soils has been shown to have much less of an effect on soil Carbon storage levels than under an irrigated system. This project aligns with the CRDC Strategic R&D Plan 2013-2018 in Best Practice through sustainable soil management and providing solutions for an

increase in crop productivity yield per hectare through improving resource efficiencies and also building workforce capacity by providing training and support for students undertaking tertiary study.

2. Background:

Soils are able to hold approximately 1,500Gt of Carbon making it the biggest terrestrial sink for Carbon biomass. Approximately half of all soil organic Carbon within managed ecosystems is thought to have been released into the atmosphere (Kirkby et al. 2013) therefore Carbon sequestration has become an important factor in the battle against climate change. Thus far, scientists are losing this battle on the cropping fields with falls in sequestration despite some alternative methods used that were hypothesised to increase sequestered carbon amounts. The transferral of atmospheric Carbon Dioxide to soil organic Carbon has been achieved in stubble incorporation with additional fertilizer application and therefore a change in the ratio of the soil nutrients (Kirkby et al. 2014). In a natural situation, C and N are introduced into the soil system by way of photosynthesis, Nitrogen fixation and precipitation. Soil P, however, does not have a gaseous form and is a fundamental building block of some soil minerals, therefore it is thought that there cannot be a constant ratio of C:N & P meaning the ability of soil to store carbon is lower (Kirkby et.al 2011).

Australia is the third largest exporter of cotton in the world producing yields almost three times the world average (Cotton Australia, 2015). To achieve this status, highly accurate fertilizer applications to ensure both the plants and the soil do not undergo stress from lack of essential nutrients and also to promote a greater yield without wastage on over fertilization have created an ongoing need for research. This research also includes exploration into crop rotations for soil structure and disease maintenance and also for nitrogen fixation. Irrigation quantities and frequencies will also affect the soil nutrient ratios by transporting nutrients deeper into the soil profile or by washing them away into the drainage lines. Suitable soils with a sufficient available water for the growth of cotton are uncommon within Australia meaning that the upkeep of these soils is imperative for future cotton yields.

There were seven experimental sites from which the archived samples were collected throughout New South Wales (NSW) and Queensland (QLD), Australia (Figure 1).

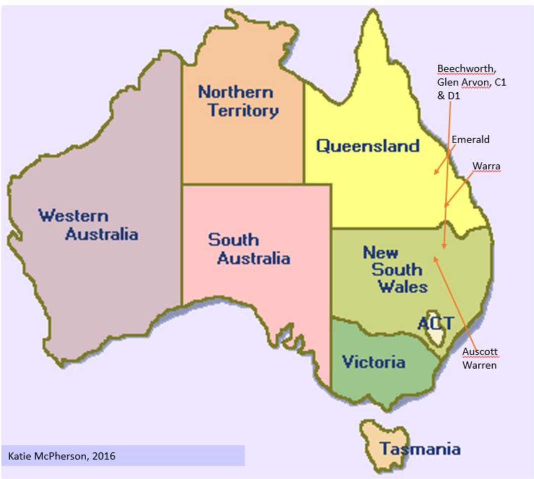

Figure 1 – Locations of plot sampling sites.

C1 & D1:

The first two sites are located at the Australian Cotton Research Institute near Narrabri (1498470E, 308130S) in NSW. The Narrabri region experiences four evident seasons in a subtropical, semi-arid climate with hot summers (mean daily maximum 35°C and minimum 19°C in the hottest month of January) and mild winters (mean daily maximum 18°C and minimum 3°C during the coldest month of July). The mean annual rainfall is 593mm (Kottek *et al* 2006) over self-mulching, endohypersodic grey Versotol very fine soils (Isbell 2002).

Auscott-Warren:

This site is located on a commercial cotton farm in Warren, central-western NSW (147° 46' E, 31° 47' S) which, like Narrabri, experiences a semi-arid climate with mild winters (mean daily maximum 15°C and mean daily minimum 3°C) and hot summers (mean daily maximum 33°C and mean daily minimum 18°C). Mean annual rainfall is 479mm over a grey, self-mulching calcareous Vertosol (Isbell 2002).

Glen Arvon:

This commercial cotton farm is situated near Wee Waa in north-western NSW (30° 13' S, 149° 27' E) and whose climate and rainfall are much the same as Narrabri. The soil also falls into much the same category, a grey, self-mulching Vertosol (Isbell 2002).

Beechworth:

Positioned at Merah North in north-western NSW (149° 18' E, 30° 1' S), this commercial cotton farm encounters a semi-arid climate that has four apparent seasons with a mild winter (mean daily maximum 18°C and minimum 2°C) and a hot summer (mean daily maximum 35°C and minimum 19°C) with a mean annual rainfall of 595mm. Isbell 2002 has classified the soil here as an episodic-calcareous, self-mulching, very fine grey Vertosol.

Elsden Farms:

Situated near Emerald in central QLD (148° 10' E, 23° 31' S), this site is subjected to semi-arid conditions with four distinct seasons including a mild winter (mean daily maximum 22°C and minimum of 7°C) and a hot summer (mean daily maximum 35°C and a minimum of 21°C) with an average annual rainfall of 639mm. The soil here is a deep, very dark grey/ brown Tenosol (Isbell 2002).

Prospect:

This commercial cotton farm is located near Warra in SE QLD (29.93S, 150.93E). Warra experiences a semi-arid, sub-tropical climate with mild winters (mean daily maximum 19°C and minimum 4°C) and warm to hot summers (mean daily maximum 32°C and minimum of 19°C). The mean annual rainfall hovers around 668mm over a grey, shrink-swell, self-mulching, cracking clay sodic Vertosol (Isbell 2002).

3. Aims and Objectives:

During this project, the stoichiometric relationship of the nutrients Carbon (C), Nitrogen (N) and Phosphorus (P) in seven different localities throughout New South Wales and Queensland between 1993 and 2013 were investigated. Each site had several different crop variety treatments and soil management techniques applied (Figure. 2). This investigation took place in order to test the hypothesis that different soil management techniques and crop results in the different C:N:P ratios, some of which may inhibit carbon sequestration. Understanding how these crop management practices affect the C:N:P ratios will allow for an increased ability to better control carbon sequestration.

4. Materials and Methods:

A 20g soil sample was taken from each of the archived samples that were collected at every site for treatments from 1993 to 2013 at a depth of 0-30cm (Figure 2), which was then ground into an 0.5mm grind for total elemental analysis. Two methods for analysis were used. The first being Determination of Total Kjeldahl Nitrogen and Total Phosphorus in Soil Samples by digestion of soil samples followed by the analysis of extracts using the Lachat FIA (Higgins 2014 (p13 -16)). The second method used was a Leco automated elemental analysis of Nitrogen and Carbon which is known to be a more reliable method of elemental analysis than the digestion method (Jimenez and Ladha, 1993).

The results were then statistically analysed using a linear regression model of the form $y = ax+b$ and sorted into the following runs for analysis:

Year: Each site with the exception of Elsden Farms had at least two years-worth of data which was categorised into year one and year two for comparison of the nutrient ratios between the first and second year.

Treatment: The sites underwent three different types of crop treatments; cotton, cotton/ cereal and cotton/ legume which were compared for nutrient retention.

Site: The seven sites were compared against each other for a comprehensive understanding of location affecting nutrient ratios.

Dryland vs Irrigated: The sites were separated into their categories of either a dryland cropping system, or an irrigated site and the nutrient ratios were assessed.

The two methods of analysis were also evaluated to find any significant difference in the results produced. This was able to be done for the Nitrogen results which both the Leco and digestion methods were able to produce.

Site	Years	Treatments	Replications	No. samples
"Auscott-Warren",	1994	Continuous cotton	3	15
Warren, NSW	2001	Cotton-HF wheat		15
		Cotton-LF wheat		
		Cotton-Field pea		
		Long fallow cotton		
"Beechworth",	1995	Continuous cotton	3	18
Merah North, NSW	2002	Long fallow cotton		18
		Cotton-wheat		
		Cotton-faba		
		Cotton-Lablab		
		Cotton-Lablab/+Fert		
"Glen Arvon",	1993	Cotton-wheat/+F	4	16
Wee Waa, NSW	2001	Cotton-wheat/-F		16
		Cotton-pulse (grain incorporated)		
		Cotton-pulse (grain harvested)		
Field C1,	1993	Cont. cotton/conventional till	4	12
ACRI, Narrabri, NSW	1999	Cont. cotton/min till		12
	2009	Cotton-wheat/min till		12
Field D1,	2002	Cont. cotton	3	12

ACRI, Narrabri, NSW	2013	Cotton-vetch		12
		Cotton-wheat/+F		
		Cotton-wheat/+F-vetch		
"Prospect"	2000	Cont. cotton	3	15
Warra, Qld	2004	Cotton-sorghum		15
		Cotton-wheat		
		Cotton-chickpea-fallow-wheat		
		Cotton-fallow-wheat		
"Elsden Farms"	1998	Early cotton/2 m beds	1	9
Emerald, Qld		Early cotton/1 m beds	1	
		Wheat sprayed/early cotton/2m beds	3	
		Wheat harvested/late cotton/2m beds	1	
		Wheat harvested/late cotton/1m beds	1	
		Sorghum-cotton	2	
			Total Samples	197

Figure 2 – Treatments from years 1993 to 2013 at each sampling site.

5. Results:

Only the most outstanding results have been discussed in this report which originated from the comparison of the two methods of analysis (Digestion versus Leco) and the comparison of the dryland and irrigated sites for the effect of added Nitrogen and Phosphorus on the sequestration of Carbon.

The results from the two methods of analysis were comparable for soil N. However, the results given by the Leco were significantly higher than the digestion method. Mean values of N determined by the Leco was 0.057mg/kg and Digestion 0.033mg/kg ($t= -24.75$ $df=196$ $p<.0001$).

As the Leco is suggested to be more accurate than the Digestion method (Jimenez and Ladha 1993), where possible, the Leco results were used for the analysis. The difference between the Digestion and the Leco methods with respect to N was significant (<0.05) Whilst the Leco results were able to be used to overcome this issue for the Nitrogen results, the Digestion results for Phosphorus still had to be used in this analysis which could potentially be an under-representation of the actual Phosphorus ratios.

The sites were separated into their categories of either a dryland cropping system, or an irrigated site. Results (Table 1) indicate that the addition of Nitrogen to dryland cropping systems is not providing a beneficial response in increasing Carbon storage. This contrasts irrigated systems in which the addition of Nitrogen resulted in a significant increase to soil Carbon stores, when corrected for varied crop management strategies.

Statistical Analysis of Treatments under Dryland and Irrigated Cropping Systems

Nutrient	Treatment	N	Intercept	Slope	R^2	MSE
Nitrogen	**Irrigated**	158	0.14	10.4	0.53 **	0.010
	Dryland	39	0.68	3.23	0.066^{ns}	0.008
	ANOVA	**F**	**DF**	**P<**		
	Slopes	9.1	1,193	0.01*		
	Intercept	95.5	1,194	0.001***		
Nutrient	**Treatment**	**N**	**Intercept**	**Slope**	**R^2**	**MSE**
Nitrogen	**Irrigated CC**	54	0.10	11.49	0.48**	0.014
	Irrigated CW	58	0.18	9.76	0.64**	0.006
	Irrigated CL	46	-0.03	12.46	0.57**	0.007
	ANOVA	**F**	**DF**	**P<**		
	Slopes	0.98	2,152	0.379^{ns}		
	Intercept	5.36	2,154	0.005**		
Nutrient	**Treatment**	**N**	**Intercept**	**Slope**	**R^2**	**MSE**
Nitrogen	**Dry CC**	9	0.64	4.51	0.21^{ns}	0.005
	Dry CW	24	0.74	1.60	0.02^{ns}	0.005
	DRY CL	6	0.56	5.94	0.07^{ns}	0.025
	ANOVA	**F**	**DF**	**P<**		
	Slopes	0.33	2,33	0.724^{ns}		
	Intercept	0.55	2,35	0.580^{ns}		
Nutrient	**Treatment**	**N**	**Intercept**	**Slope**	**R^2**	**MSE**
Phosphorus	**Irrigated**	158	0.64	5.18	0.41**	0.012
	Dryland	39	0.82	5.81	0.09**	0.007
	ANOVA	**F**	**DF**	**P<**		
	Slopes	0.99	2,191	0.373^{ns}		
	Intercept	1.52	2,193	0.221^{ns}		
Nutrient	**Treatment**	**N**	**Intercept**	**Slope**	**R^2**	**MSE**
Phosphorus	**Dry CC**	9	0.64	4.51	0.37^{ns}	0.005

	Dry CW	24	0.74	1.61	0.26 ^{ns}	0.005
	Dry CL	6	0.56	5.94	0.35 ^{ns}	0.025
	ANOVA	**F**	**DF**	**P<**		
	Slopes	1.05	2,18	0.370 ^{ns}		
	Intercept	1.13	2,20	0.344 ^{ns}		
Nutrient	**Treatment**	**N**	**Intercept**	**Slope**	**R^2**	**MSE**
Phosphorus	**Irrigated CC**	51	0.62	5.93	0.43 ^{ns}	0.015
	Irrigated CW	56	0.63	5.40	0.35 ^{ns}	0.011
	Irrigated CL	46	0.61	5.68	0.48 ^{ns}	0.009
	ANOVA	**F**	**DF**	**P<**		
	Slopes	0.09	2,147	0.913^{ns}		
	Intercept	0.23	2,149	0.796 ^{ns}		

Table 1. Linear regression analysis of soil nitrogen, phosphorus and carbon concentrations from treatments under dryland and irrigated cotton cropping systems. A model of the form y = ax + b was fitted to the data where y was carbon concentration, x, the nitrogen or phosphorus, a, the slope and b, the intercept. R^2, regression coefficient; MSE, mean square error; DF, degrees of freedom; N, number of observations; CC, continuous cotton; CL, cotton-legume; CW, cotton-wheat; ns, non-significant; *, significant at the 95% level of probability; **, significant at the 99% level of probability; ***, significant at the 99.9% level of probability.

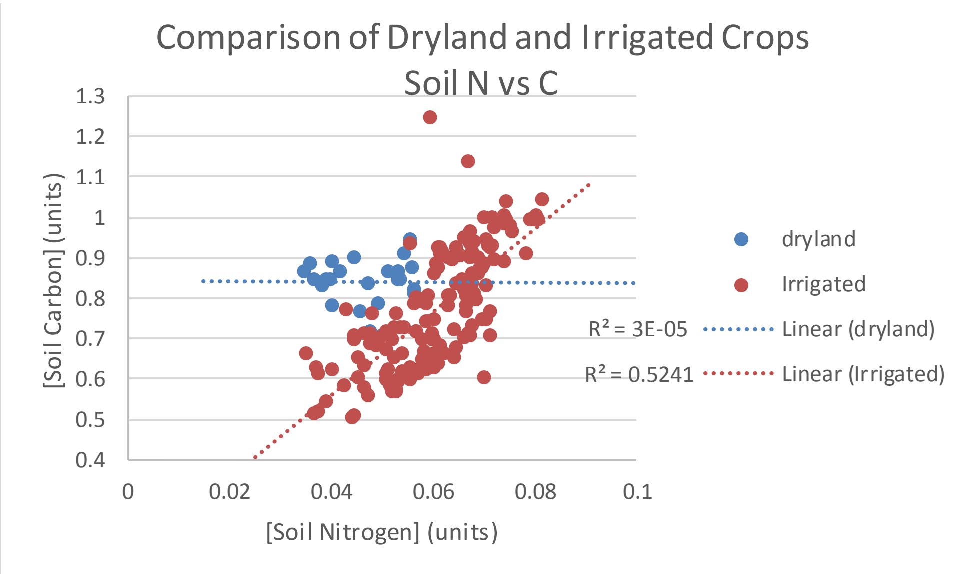

Figure 3. Comparison of the effects of Nitrogen on Carbon between dryland and irrigated plots.

6. Discussion and Conclusions:

Effects on the stoichiometric ratios of cotton cropping soils have been varied throughout the treatments over the plots. At this present time of analysis, the most obvious relationship that was found was between the dryland and irrigated plot soil Carbon storage due to Nitrogen addition. The addition of Nitrogen to dryland soils has been shown to have much less of an effect on soil Carbon storage levels than under an irrigated system. This discovery has the potential to alter recommended fertilizer addition ratios over cotton cropping systems.

7. Highlights:

The main objective of this research was to analyse dryland and irrigated cotton cropping sites for their stoichiometric ratios and if the different treatments were having an effect these ratios. Results indicate that the addition of Nitrogen to dryland cropping systems is not providing a beneficial response in increasing Carbon storage. This contrasts irrigated systems in which the addition of Nitrogen resulted in a significant increase to soil Carbon stores, when corrected for varied crop management strategies.

8. Future Research:

Increased efforts to enhance Carbon sequestration through the use of improved cropping practices that create a nutrient balance within the soil should be focussed on for the future of a resilient and sustainable crop management system. By adopting modernized scientifically supported farming methods, climate change mitigation and adaptation will prove beneficial in improved or at least sustained yields.

9. Presentations and Public Relations:

An application for this research to be presented in a three minute thesis format at the CRDC conference in August 2016 has been submitted to present the findings for potential application throughout the cotton industry. Applications for this research to be presented in poster format at the Soil Science Australia conference in December 2016 have also been submitted.

10. Reference List:

Australian Cotton Production Manual I CRDC, 2014. *Australian Cotton Production Manual* I CRDC. [ONLINE] Available at http://www.crdc.com.au/publications/australian-cotton-production-manual [Accessed 1 February 2016].

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