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Original Research Paper

Whole Soil Sampling to Compare Carbon Sequestration Under Perennial Pastures of Western Australia

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ABSTRACT

Changing from annual to perennial pastures may be a key strategy for farmers to both adapt to, and help mitigate, climate. In this study organic carbon determined by Walkley and Black analysis of 'whole soil' samples (i.e., including roots) from annual and perennial pastures was used to determine the carbon stocks in the top 30 cm of soil. Samples were collected from old perennial pasture trial sites, and also from adjoining paired paddocks of annual and perennial pastures. Sequestration rates were calculated as the increase in carbon stocks of the perennials above the traditional annuals, averaged over the number of years since the perennials were sown. The results indicate that denser perennial pastures can sequester in the range of 5 to 10 t CO_2e /ha/year. We hypothesise that the flux rates from particulate organic matter to the humus pool currently used for annuals in RothC may be too low for perennial pastures. These results are particularly encouraging as (a) all but one of the sites was on coarse sandy soils, and (b) all of the years since the perennials were sown were below average rainfall.

INTRODUCTION

Australia has signed and ratified the Kyoto Protocol. This requires the Australian government to submit National Carbon Accounts to the United Nations Framework Convention on Climate Change (UNFCCC).

Under the Kyoto Protocol Australia must account for the emission of Green House Gasses (GHG) and for the sequestration of carbon dioxide (CO_2) for all sectors of the economy, including agriculture. The Kyoto Protocol allows for the sequestration of carbon in the vegetation and soils of 'crop land' and 'grass land' (i.e. pasture land). These sinks are referred to as Kyoto Protocol 'Article 3.4 sinks'. Article 3.4 sinks are optional in the first commitment period (2008-2012) but are mandatory in the 'second and subsequent commitment periods'. In addition, estimates of soil carbon stocks for 1990 are required for baseline accounting to UNFCCC.

As per IPCC (2006), constructing a greenhouse gas inventory for the land use category Grassland Remaining Grassland involves estimation of changes in carbon stocks from five carbon pools i.e., above-ground biomass, below-ground biomass, dead wood, litter and soil organic matter, as well as emissions of non-CO_2 gas.

The Australian government has decided to have a national Emissions Trading Scheme (Carbon pollution reduction scheme) as a central policy to achieve the Kyoto Protocol limit on net emissions. The Federal Government has commissioned two major reviews to assist in designing the Emissions Trading Scheme (ETS). These are the Deptt. of Climate Change's 'Green Paper' and the Garnaut Review team's reports. The final decisions on the national ETS design has been made by the Australian Government in late 2008.

The Green Paper and Garnaut Review, both recommend that agriculture should become a covered sector at some time in the future. However, they disagree on whether soil carbon should be allowed as offsets under the ETS. The inclusion of soil carbon is the most contentious and critical issue relating to agriculture inclusion in the ETS.

One of the reasons given in the Green Paper for not including soil carbon in the ETS was that there is limited potential for building up carbon in Australian soils. Unfortunately there is very little trial data on changes in soil carbon stocks for Western Australia (WA), and none on perennial grass pastures. However, some limited soil testing by farmers and researchers in the Northern Agriculture Region of WA has indicated substantial build up of carbon below perennial grass pastures. These results were indicating sequestration rates of 5 to 10 t CO_2e /ha/year. These rates are not consistent with soil carbon models such as RothC. RothC is an empirical model which has only been calibrated for annual crops and pastures in the eastern states of Australia (Skjemstad et al. 2004).

More detailed sampling was conducted in May and June 2008 to determine if the initial estimates of carbon sequestration in the soil were realistic. This involved sampling soils from old perennial pasture trial sites, and also of adjoining paired paddocks of farmers' annual and perennial pastures.

The sequestration rates of the perennials were calculated as the increase in organic carbon stocks in the top 30 cm of soil above that of the traditional annual pastures.

MATERIALS AND METHODS

There are two approaches for estimating changes in carbon pools (IPCC 2006).

1. Stock change accounting or stock-difference method, involves measuring the carbon stocks in a parcel of land at one time and then monitoring changes over time. The changes in carbon stocks over time will be due to both, management practises and variations in seasonal conditions. This approach can be accurate, but can not separate out the affect of land management practises (i.e., anthropogenic emissions/sequestration) from that due to climate variability (non anthropogenic).

2. Rate change accounting or gain-loss method, is where carbon stocks are compared at one time on adjoining land (paddocks or trial plots) that has been under different land management practises. The carbon sequestered or emitted by an alternative land management method is determined as the change in carbon stocks compared to the traditional land management practise. This approach excludes climate variability, but can have uncertainties due to soil type variability between the paddocks or plots sampled. The yearly sequestration/emission rate is calculated as the carbon stock difference averaged over the years from when the alternative practise was first implemented on the site. This approach does not determine how sequestration rates may vary over time, and when or if soil carbon stocks have reached a new equilibrium.

The Project

This research has used the 'Rate change' approach for determining the changes in soil carbon stocks due to converting annual pastures to perennial pastures (and in one case from changing from continuous cropping to perennial pastures). Comparisons were made in soil carbon stocks between (1) plots in old established pasture trials and (2) paired sampling down a common fence line between farmers' paddocks with annuals and perennial grass pastures.

The sites were soil sampled using the principles outlined by McKenzie et al. (2000). Soil cores were taken with a mechanical corer to a depth of 30 cm. Ten cores were bulked for each sample site. For the paired paddock sampling there were 4 to 6 paired sites down a common fence line. Generally, for each of the pair, the cores were taken at 10 m distance from the common fence. At several sites there were trees planted down the fence line and the sampling sites were ~40 m from the fence, where there was no observable competition from the trees.

The ten cores for a site bulk sample were taken on a 20 m transects approximately parallel to the fence line. The exact coring site within these transects was effectively random as the driver of the vehicle could not see the corer mounted on the back of the vehicle. The transect was slightly offset from the direction of seeding the perennial pastures so that cores came from both within and between the rows of perennials. The perennials had originally been sown at row spacing of between 30 and 70 cm, and there had been limited spread of the perennial plants into the inter row. The sample sites coordinates were recorded using GPS.

The perennial pasture paddocks contained mixes of mostly Rhodes grass, Green panic and Signal grass. The proportion of each of these species varied between the paddocks sampled. Data were not collected on the density, composition and productivity of the perennial pastures.

The old pasture trial sites had been established to compare a range of different perennial pasture species with the traditional 'self regenerating' annual pasture. At all trial sites the control plots of annual pastures were soil sampled. Only the better perennial pastures species plots were sampled. Perennial pasture treatments were selected that had good plant establishment and persistence. Again, ten soil cores were collected to make one bulk sample per plot. The number of plot replicates varied between trial sites.

All of the perennial grasses were subtropical (C4) perennials. Several of the trial sites contained the perennial legumes *Lucerne, Siratro* and *Lotononis.*

Site Selection

The paired paddock sites were selected from a larger list of potential sites. Paddocks were inspected and many rejected as not being adequate for paired sampling. Sampling sites were selected to avoid other features that could potentially influence soil test results (e.g. head-lands, paddock trees, stock camps, etc.). Only those sites were selected where there was no observable difference in soil type on either side of the common fence. At some sites difference in soil type at depth became evident after the cores were collected. The results from these sites are not included.

At the Bain TTA/Burma paddock comparison site there was no observable difference in the soil cores collected. However, there may well have been a difference in the depth of white sand over clay below the sampling depth. This was also one of the sites with trees down the fence line resulting in the paired samples being taken much further apart (~80 m).

Soil Type and Control Treatment

All but one of the sites was located on sandy soils. This reflects the fact that to date perennial pastures have only been sown on soil types that farmers consider too poor or marginal for cropping in the Northern Agriculture Region of WA. The sands varied from white to pale yellow. All but one of the sites had been under volunteer annual pasture for a long period of time (20 years plus). The Carson paired site had better quality yellow sand, and the control paddock had been continuously cropped for 15 years using minimum tillage.

The Metcalfe trial site was on a strong loamy soil. This would be considered as one of the best cropping soils in the region. The paddock was in annual pasture when the perennial pasture treatments were first sown, but the previous cropping history is unknown. For the first two years of the trial (2008 & 2010) the whole site was left as pasture treatments. In spring 2009 all the pasture treatments were spray topped with 1 L/ha glyphosate. In 2010 the whole site was 'pasture cropped'. This meant that in June 2009 the whole site was sprayed with 2 L/ha spray seed and then sown to wheat using a culti-trash disc seeder. In 2008 the management was again solely for pasture. So for the Metcalfe site the control treatment was two years annual pasture, one year wheat and the final 6 months was annual pasture.

The Gillam Q &Q and Badgingarra RS Q &Q trial sites were not grazed by stock. The plots were mown and the plant material removed from the plots. This would have decreased the soil carbon sequestration rates as the biomass input was artificially reduced. All other trial sites and paired paddocks were grazed by stock.

Sample Preparation

The first bulk samples were oven dried at 65°C for 48 hours. Unfortunately due to the gas crisis in WA the ovens were shut down and subsequent samples were only air dried in the lab at 22°C.

The bulked soils were vigorously mixed by hand. The bulk samples were then spread out on a tray and a sub sample collected using a spoon from ten points spread across the tray. Any large clumps of plant material (e.g., grass crowns) were avoided. The samples were mostly sand and none contained any clods or aggregates.

The samples were not sieved and, thus, contained plant roots. As the samples were not sieved prior to organic carbon analysis they would not meet the normal soil science definition of 'soil organic carbon'. Rather the results presented are in terms of total organic carbon within the top 30 cm of soil, or 'whole soil' analysis. McKenzie et al. (2000) suggested that sieving out the roots for measuring below ground plant carbon as being optional.

It is essential that any coarse fragments containing carbon, as either organic matter (roots, woody debris, fungal mats, or charcoal, etc.) or carbonate minerals (finely divided carbonate, carbonate segregations, calcrete, calcinite, limestone etc.) must be chemically analysed for their carbon concentration. There is a choice here to either separate each component for separate analyses or comminute all components into a single specimen (whole soil) McKenzie et al. (2000).

Root material (alive or dead) <50 mm diameter within soil samples should be treated as part of the soil organic matter. Separation of larger roots into separate components can be made at the specimen preparation stage as an optional procedure (McKenzie et al. 2000).

If the roots were to be sieved out and analysed separately they would still need to be included in the calculations of 'changes in carbon stocks' required under the IPCC 2006 'Best practise guidelines for national carbon accounts'. These Kyoto Protocol accounting rules also include changes in above-ground carbon stocks. However, it can be assumed that while there are changes in above-ground plant and litter stocks between seasons, that these average out over time in crops and pastures, and therefore, are not a significant sink or source. Similarly, the below ground roots would not vary much over time for continuous crops or annual pastures. However, when changing from an annual pasture to a permanent perennial pasture, there could be a sustained increase in roots below ground. This research did not determine that change in root carbon stocks versus 'soil carbon' stocks, and further work is needed in this area.

Sample Chemical Analysis

The soil sub samples were sent to the CSBP lab for analysis for organic carbon (%) using the Walkley and Black method (Walkley & Black 1934). CSBP were requested not to sieve out the roots prior to analysis.

Bulk Density

Pits were dug under the control annual pasture and some of the perennial pastures for determining bulk density. Bulk density samples were collected using a bulk density ring. The bulk density samples were oven dried at 65°C for 48 hours prior to weighing.

Bulk density samples were taken at 5, 15 and 25 cm depth down the profile and results averaged to give the 30 cm core average following the recommendations of McKenzie et al. (2000).

Calculation of Sequestration Rates

The sequestration rates of the perennials were calculated as the increase in organic carbon stocks compared to the annual pasture controls. Organic carbon stocks were calculated from the organic carbon content (% on dry weight basis) multiplied by the soil weight in the top 30 cm (i.e., Bulk density t/m^3 × 0.3m × 10,000 m^3/ha). Organic carbon stocks were converted to carbon dioxide equivalents (CO_2e) by multiplying by 44/12. The yearly sequestration rate was calculated based on the increase in carbon stocks under the perennials divided by the years since the perennials were sown.

The sites were spread over 400 km and there is considerable variation in rainfall between sites. The sequestration rates between sites were compared on the basis of actual rainfall at each site since the perennials were sown (i.e., sequestered CO_2e t/ha/mm rainfall).

Statistical Analysis

The carbon stocks (CO_2e t/ha) of each individual perennial pasture species was compared to the carbon stocks of the annual pasture control using the Student '*t*' test. A '*t*' test was also used to compare the carbon stocks of the annual pasture paddock with the perennial pasture paddock at each paired paddock site.

RESULTS

The results support the hypothesis that perennial pastures can sequester carbon below the surface (0-30 cm) at rates of 5 to 10 t CO_2e /ha/year. The actual rates varied between sites and between perennial species. At all trial sites, except for Gillam's, at least certain perennial species exceeded 5 t CO_2e/ha/year. The sequestration rate at Gillam's would be artificially low as the above ground biomass was removed by mowing.

These carbon sequestration results are particularly encouraging as (a) all but one of the sites was on coarse sandy soils, and (b) all of the years since the perennials were sown were below average rainfall.

In general, the perennial trial plots had higher sequestration rates than the farmer paddocks. This may be due to the trials being sown at much higher seeding rates than farmers' paddocks in the first instance. The trial plots were sown at 5 to 10 kg/ha seed while farmers usually sow between 1 and 3 kg/ha seed in commercial paddocks. This means that generally the trial plots get to 'mature stand density' sooner than farmer paddocks.

In the paired paddock comparisons, three of the sites exceeded 5 t CO_2e /ha/year, and two were over 10 t CO_2e/ha/year. The perennial paddock at Forsyth, Dongara had a lower sequestration rate (3.7 t CO_2e ha/year), but this site has always had only a moderate perennial pasture density and suffered from drought in 2006 and 2007. The perennial paddock at Carson's, Binnu also only achieved a more modest sequestration rate (3.9 t CO_2e /ha/year). This is still a remarkable result given that this Binnu farm had suffered from two years of extreme drought in 2006 and 2007 (< 150 mm of rainfall in both the years). The extreme drought of 2006 caused complete failure of the annual crops and pasture. On the Carson farm the perennial grass pastures were able to carry 4 to 6 Dry Sheep Equivalents/ha for the year while preventing erosion (Wiley & Grima 2007).

There was not a consistent ranking between trial sites of perennial species in terms of sequestration rates. This probably reflects the fact that productivity of the perennials varied between sites. Unfortunately biomass production data were not available to determine if this was the key factor.

The sequestration rates of the perennial pastures did not relate closely to the rainfall received since the perennials were established. However, 20 to 30 kg/ha CO_2e sequestered per millimetre of rainfall seems achievable.

DISCUSSION

These results suggest that even on sandy soils perennial pastures can sequester significant quantities of CO_2 from the atmosphere. These soil sequestration rates are far in excess of the likely emissions of methane from grazing stock (0.5-1.5 t CO_2e/ha/year), meaning that paddocks of perennial pastures are likely to be net sinks of green house gasses. Perennial pastures could potentially contribute to a massive reduction in agriculture's net emissions. Allowing soil carbon sequestration in the national ETS would provide the incentive for a significant increase in the planting of perennial pastures by farmers.

The sequestration rates measured in this work are not consistent with the RothC model. The sequestration rates in this research are also in excess of those reported for pastures in a major review of the published literature in Australia by Valzano et al. (2005).

Questions remain as to how these perennial pastures can achieve such high sequestration rates, and as to how RothC must be modified to account for this.

We hypothesise that the high sequestration rates under the perennials is partly due to changes in soil biology. It is known that mycorrhiza can produce enzymes that increase the rate of conversion of labile carbon in the soil to more stable humic forms (Kerek et al. 2002, Findlay 2008, Jastrow et al. 2007). In a purely annual plant based system the mycorrhiza population would die back in summer when there are no live plants. Under an evergreen perennial system the mycorrhiza populations and biological activity would be maintained year round. This increase in mycorrhiza activity could account for a much greater proportion of fresh plant matter ending up in the stable humic pools. If so it would require that the flux rate between the particulate organic matter pool and the humus pool in the RothC model be increased (Skjemstad 2004). Further research is required to

Table 1: Whole soil organic carbon and carbon sequestration rates in the top 30 cm of soil under volunteer annual pasture and perennial pasture species plots at established trial sites in the Northern Agriculture Region of Western Australia.

District	Soil type	Pasture type	Org. C %	Bulk Density	C t/ha	CO2e t/ha	Signifi-cance level	CO2e t/ha above annuals	Years since perennials sown	Seques-tration CO2e t/ha/year above annuals	Average rainfall since perennials sown	CO2e kg/ha per mm rain
Northampton	White sand	Annual	0.53	1.38	22.0	81		~	2.75	~	~	~
		Rhodes	0.64	1.38	26.6	97	**	17	2.75	6.1	310	20
		Green panic	0.64	1.38	26.5	97	**	17	2.75	6.1	310	20
		Kikuyu	0.70	1.38	29.0	106	***	26	2.75	9.4	310	30
		Lotononis*	0.82	1.38	33.9	125	***	44	2.75	16.0	310	52
Northampton	Yellow sand	Annual	0.47	1.48	20.9	77		~	2.75	~	~	
		Rhodes	0.58	1.47	25.6	94	**	17	2.75	6.3	310	20
		Lucerne	0.56	1.47	24.7	91	**	14	2.75	5.1	310	16
Irwin	White sand	Annual	0.47	1.28	17.9	66		~	3.75	~	~	~
		Rhodes	0.48	1.43	20.6	76	**	10	3.75	2.7	400	7
		Green panic	0.52	1.43	22.3	82	***	16	3.75	4.4	400	11
		Signal grass	0.52	1.43	22.5	82	***	17	3.75	4.5	400	11
Greenough	Loam	Annual	0.79	1.47	34.7	127		~	2.75	~	~	~
		Rhodes	0.93	1.47	40.8	150	**	22	2.75	8.1	315	26
		Green panic	0.77	1.47	34.0	125	ns	-3	2.75	-1.0	315	-3
		Kikuyu	0.84	1.47	37.0	136	*	8	2.75	3.1	315	10
		Lucerne	0.96	1.47	42.1	155	***	27	2.75	9.9	315	31
		Siratro	0.91	1.47	40.1	147	**	20	2.75	7.2	315	23
		Bambatsi panic	0.91	1.47	40.1	147	**	20	2.75	7.2	315	23
		Couch	0.83	1.47	36.4	134	*	6	2.75	2.2	315	7
Badgingarra	Duplex	Annual	0.44	1.42	21.0	77		~	4.75	~	~	~
		Rhodes	0.59	1.37	28.2	103	**	26	4.75	5.6	448	12
		Green panic	0.45	1.37	21.6	79	*	2	4.75	0.5	448	1
		Kikuyu	0.75	1.37	36.2	133	**	56	4.75	11.7	448	26

Significance level = '*t*' test comparing of the individual perennial pastures treatments with the annual pasture control for CO2e t/ha. *p = 5%, **p = 2.5%, ***p = 1%

accurately define the flux rates for perennial pastures in the RothC model.

The results reported are from sites that have been under perennial pastures for a relatively short period of time (maximum 6 years). These results can not be used to predict long term sequestration rates or the ultimate equilibrium level of the carbon pools under perennial pastures. Only time will tell. Models such as RothC can be used to predict soil carbon pools well into the future. However, if the flux rates used in these types of models are inaccurate then ultimate equilibrium levels predicted would also be significantly inaccurate.

The equilibrium levels of soil carbon predicted by models for a particular management practise are often erroneously assumed to be the carbon 'saturation' level for a soil. A change in management practise will inevitably lead to a new equilibrium level in the soil. Using soil carbon models to define the 'maximum' levels of soil carbon is fraught with danger.

The results reported here may underestimate the amount of carbon sequestered in the soil by perennials. Perennial pasture can be very deep rooted on these sands. Live perennial grass roots have been found 4.5 m below the surface of a deep sand on the Forsyth property at Dongara.

These results suggest that agricultural management practise could have a large effect on net emissions/sequestration from the soil. This has implication for the National Carbon Accounts that Australia is required to supply to the UNFCCC. The IPCC 2006 accounting rules require each country to estimate the 'uncertainties' in the accounts. The IPCC (2006) guidelines describe 'Key Categories' that contribute the greatest uncertainties to the national accounts.

As per IPCC (2006), It is good practice to identify those categories that have the greatest contribution to overall inventory uncertainty in order to make the most efficient use of available resources. IPCC (2006) also gives definition of 'Key Category' as: A key category is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory in terms of the absolute level, the trend, or the uncertainty in emissions and removals. Whenever the term key category is

Table 2: Whole soil organic carbon and carbon sequestration rates in the top 30 cm of soil of paired sampling between volunteer annual pasture paddocks and adjoining mixed perennial grass pasture paddocks on farms in the Northern Agriculture Region of Western Australia.

District	Trial/ Paddock	Soil type	Pasture type	Org. C %	Bulk Density	C t/ha	CO2e t/ha	Signifi-cance level	CO2e t/ha above annuals	Years since perennials sown	Seques-tration CO2e t/ha/year above annuals	Average rainfall since perennials sown	CO2e kg/ha per mm rain
New Norcia	Hasson Annual	White sand	Annual	0.41	1.60	19.7	72		~		~	~	
	Hasson Perennial		Perennial	0.66	1.60	31.5	116	**	43	4.00	10.8	446	24
Lancelin	Nested cell	White	Annual	0.80	1.57	37.7	138						
	Old trial	sand	Perennial	0.94	1.57	44.3	162	**	24	4.00	6.0	605	10 ~
Binnu	Crop paddock	Pale ~sand	Annual crop	0.56 ~	1.38 ~	23.2 ~	85						
	Ist Perennial		Perennial	0.69	1.37	28.2	104	*	18	4.75	3.9	286	14
Dongara	Hasson Annual	White sand	Annual	0.32	1.61	15.5	57		~		~	~	~
	Hasson Perennial		Perennial	0.45	1.61	21.6	79	***	22	6.00	3.7	420	9
Walkaway	Williams	White	Annual	0.59	1.5	26.3	97		~		~	~	~
	South	sand	Perennial	0.83	1.5	37.5	137	***	41	3.75	10.9	340	32
Walkaway	TTA	White	Annual	0.63	1.5	28.5	104		~		~	~	~
	Burma	sand	Perennial	0.60	1.5	26.9	99	ns	-6	3.75	-1.5	340	-5

'Whole soil' includes roots in the soil sample analysed.

Significance level = '*t*' test comparing of the perennial pastures paddocks with the annual pasture paddocks for CO2e t/ha. *p = 5%, **p = 2.5%, ***p = 1%

used, it includes both the source and sink categories.

Given that there are 470 million hectares under 'dry land agriculture' in Australia, and that these results and other research (Valzano 2004) show large variations in soil carbon stocks due to management, it is likely that soil carbon is the key category in Australia's national accounts. The Kyoto Protocol would, therefore, require Australia to commit substantial resources to improve the estimates of changes in soil carbon stocks on agricultural land.

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