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Original Research Paper

Soil Organic Carbon Sequestration Under Pastures in Arid region

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ABSTRACT

Two sites in Iraq were chosen to study the affect of annual pasture and perennial grasses (C4). The perennial grass pastures had SOC stocks, 1.6 (Baghdad) and 1.4 (Babylon) times that of the annual pastures. Soil Organic Carbon (SOC) pools were 1.90, 2.97 and 2.88% for annuals, perennials and tagasaste at Baghdad site. At Babylon the SOC pools were 2.7, 4.70, and 3.71% under annuals, perennials and tagasaste respectively. Estimated total C sequestration contribution to the resident soil organic C pool was 2.8 times greater for perennials and 2.7 times for tagasaste than annual pasture at the Baghdad deep sandy duplex site and 1.2 times greater for perennial pasture and 1.2 times greater for tagasaste than annual pasture at the Babylon deep-sand site. Both the sites were sampled to a depth of 1.6m. Perennial grasses in this region generally produced more above ground biomass than annual pastures. However, the differences in biomass input are unlikely to be large enough to explain the high rate of sequestration of these perennials. We hypothesise that the perennial grasses promote fungi such as mycorrhiza that convert a greater proportion of labile carbon to stable humic forms than under annual pastures.

INTRODUCTION

Iraq has a Mediterranean climate with cool wet winters and hot dry summers. Farming systems have evolved based on rotations of annual grain crops and annual legume based pastures (Grace et al. 1995). A recent innovation has been the development of subtropical perennial grass pastures. These C4 perennial grasses have proven to be productive and persistent on the poorer sands where annual crops and annual legumes have been marginal at best. Tagasaste is a very deep rooted perennial legume shrub that has also proven to be very successful on the poorest deep sands (Oldham et al. 1999).

It is known that perennial pastures can increase soil carbon more than annual pasture. For example, Baron et al. (2002) estimated that total carbon contribution for perennials was 2.7 timed more than for annuals. Iraq has very low levels of clay and silt (< 5% of each). It is widely believed that soils with such low levels of silt and clay can not build up soil carbon. Soil tests (0-10 cm) under annual crops and pastures on these sands generally show very low levels of organic carbon in the range of 0.4% to 0.6 % (Walkley & Black 1934). However, limited soil testing has indicated that soil carbon levels were increasing under perennial grasses growing on these coarse sands in Iraq. This study was designed to accurately measure and compare soil carbon under annual pasture, perennial grass pasture and a fodder shrub on coarse sands.

Grazing management, litter and manures, roots and soil characteristics all have a major impact on organic carbon stocks in the soil. Litter refers to all dead (standing and fallen) plant material above the soil surface (Naeth 1988). Leaving crop residues as litter after harvest, increases soil organic carbon (Lal et al. 2004). Litter reduces soil erosion by reducing runoff and improves soil structure and fertility through addition of organic matter (Naeth 1988).

Pasture land has the ability to store substantial pools of soil C and N. Pasture land contains about 10% of the world C pool (Parton et al. 1995). In temperate regions cultivation when cropping may release as much as 40% of the C that has been stored in the previous pasture phase (Burke et al. 1995). Also cultivation can narrow the soil carbon-to-nitrogen ratio (C: N) favouring the release of soil N through N mineralization processes (Wedin 1996).

In the Canadian prairies there is often a 2 to 9 year sequence of perennial pastures between cereal crops (Entz et al. 1995). This pasture phase can increase soil carbon and enhance the yields of the following cereal crops (Campbell et al. 1990, Entz et al. 1995). The crop residues after harvest go into the litter pool and subsequently a proportion is sequestered into the soil. Initial breakdown of the litter results in large losses of organic carbon and annual cultivation for cropping exacerbates the loss (Campbell et al. 1990).

The deep light texture soils of Iraq have very low water holding potential (30-40 mm/m^3). On these coarse sands texture the shallow rooted annual crops and pasture can not use all of the rainfall, which is concentrated in the winter months. Consequently, there is a high rate of recharge below the root zone of the annual crops and pastures. This high rate of recharge results in rising groundwater tables that eventually causes dry land salinity in lower parts of the landscape.

This paper reports on research comparing annual pastures, perennial C4 grass pastures and tagasaste at two sandy soils in the middle of Iraq.

MATERIALS AND METHODS

Sites description: The Baghdad site is located 100 km south of Baghdad (latitude is 33°N). The morphological description of the soil profile is a yellow/brown loose and deep sandy duplex with an upper convex. The surface layer is strongly water repellent. The trial sampling sites were in adjoining paddocks of perennial grass and volunteer annual pasture. The volunteer pasture consisted of wild radish, annual ryegrass, Patterson's curse and double gee. The perennial grass paddock was sown in 2010. The perennial grasses mostly grow during the warmer spring, summer and autumn months. In winter they remain dormant. During winter and spring the volunteer annual pasture species can germinate and grow at similar rates to that of pure stands of seasonally sown ryegrass and clover pastures.

Babylon site is located 8 km east of Babylon (latitude of 34°N). The site has a deep soil of loose, weathered gneiss. The surface is dark yellowish brown sand with a sharp delineated cultivation traffic pan boundary at 10 cm. The surface layer is strongly water repellent. The perennial pasture is a mix of Lucerne and Rhodes grass sown in 2007. The adjoining paddock had an annual pasture consisting of capeweed, erodium and some burr medic. Both the perennial and annual pasture paddocks have been grazed periodically with cattle from November 2010. The paddocks containing the sample sites are located upslope from the bore supplying water to the town of Babylon.

Monthly soil samples were collected at both the Baghdad and New Babylon sites. Four replicate samples were taken from each pasture type. Soil samples were collected down to 150 cm depth in nine increments (0-5, 5-10, 10-20, 20-50, 50-70, 70-90, 90-120, 120-150 cm).

Samples were air dried and sieved (2 mm) prior to chemical analysis. Soil samples were analysed for organic carbon using the methods of Walkley & Black (1934) and Jackson (1958). Nitrate and ammonium were determined by Searle (1984). Bulk density was determined by collecting soil samples with a Bulk Density ring and drying at 105°C for 48 hours.

RESULTS

Soil organic carbon (SOC): The perennial pastures had higher levels of organic carbon stocks than the annual pasture in both surface 0-30 cm and subsurface 30-70 cm depths (Fig. 1). The perennial pastures have an extra 2.3 t/ha of organic carbon in the top 70 cm above that under annual pastures. There was no significant difference in the distribution of carbon between the annuals and perennials when comparing the top soil compared to the next 40 cm (Fig. 1).

At Baghdad there was a spike in CO_2 eq stocks in the 10-30 cm depth (Fig. 2), probably due to a layer of higher clay content. This 10-30 cm layer had the highest CO_2 eq stocks for the perennial grasses and the tagasaste, and almost the highest for the annual pastures. The perennial grass had the highest CO_2 eq stocks for the whole 0 to 150 cm depth. Tagasaste had more CO_2 eq stocks than the annual pasture in the 10 to 50 cm depth interval, but not at other depths. The net difference between tagasaste and annual pastures for the whole profile was small/insignificant.

At Babylon the soil carbon dioxide equivalent (CO2 eq t/ha) stocks declined down the profile. The perennial grass had the highest levels of carbon stocks at all depths down the profile to 150 cm (Fig. 3). The annual pasture and tagasaste had similar CO_2 eq stocks down to 70 cm, but annual pastures had less CO_2 eq in the 70 to 150 cm depths (Fig. 3).

The Intergovernmental Panel on Climate Change (IPCC) sets out the accounting methods for determining green house gas missions and sequestration for the Kyoto Protocol. The IPCC 2006 has two methods for calculating sequestration in grassland. The stock difference method measures changes in carbon stocks over time on a given parcel of land. The gain-loss method compares carbon stocks under new management practises with that under the traditional land use.

Annual pastures are the traditional practice in Western Australia. Tagasaste and perennial grass pastures are an emerging alternative. The sequestration/emissions of these new perennial pastures can be calculated as an increase or reduction in carbon stocks compared to the traditional annual pasture.

At Baghdad the perennial grass sequestered carbon at all depths when compared to the traditional annual pasture (Fig. 4). The biggest increase in soil carbon was in the 0 to 30cm and 90 to 150 cm depths. The soil carbon profile appears to be reflecting the soil physical properties especially the particle size distribution (soil texture) at this site i.e., sand/gravel /clayey sand. This seems to indicate a positive relationship between perennial grasses and their ability to sequester carbon at higher rates in sandy soils. With tagasaste there was a sequestration in the 10-60 cm layer, but not at other depths. This resulted in almost no net change for the entire profile.

At Babylon in the deep sand perennial grasses again sequestered more carbon at all depths (Fig. 4). The effect of

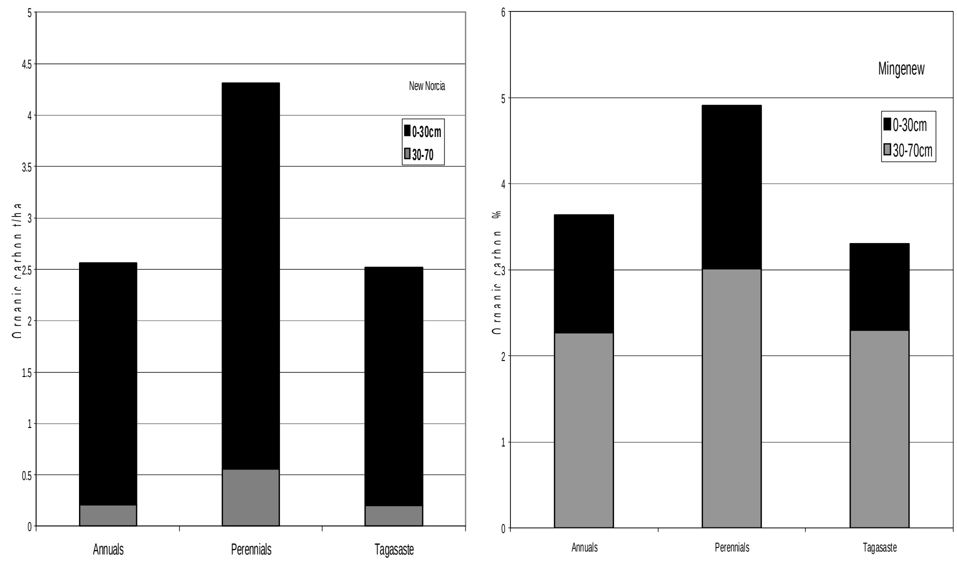

Fig. 1: Organic carbon stocks of annual, perennial and tagasaste pasture in the surface and subsurface soil samples at New Norcia and Mingenew sites.

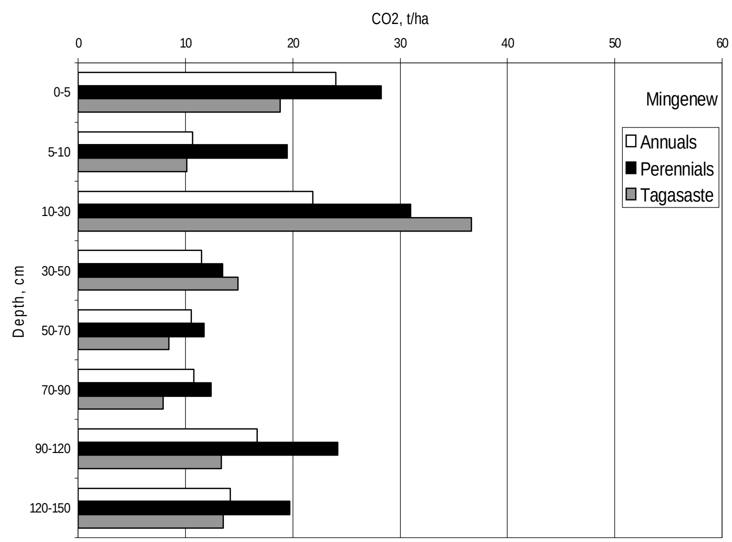

Fig. 2: Quantity of CO_2 eq under annuals, perennials and tagasaste pastures at New Norcia site.

the tagasaste was small compared to the annual pasture and variable down the profile.

Carbon dioxide sequestration rate (CO_2 eq t/ha/year) for eight depth increments down to 1.5 m at Babylon site based on soil carbon stock difference of perennial grasses and tagasaste pastures above the annual pasture control are given in Fig. 4. Carbon dioxide sequestration rate (CO_2 eq t/ha/year) for the whole soil profile to 1.5 m at Baghdad soil carbon stocks down to 150 cm increases under perennial grass pastures at both sites (Fig. 5). The increase in carbon stocks under tagasaste was greater than under the perennial grasses. But as the tagasaste have been established for a much longer time than the perennial grasses, the annualised sequestration rate of the tagasaste was lower. However, the tagasaste data are only for the soil carbon and do not include carbon stored in the woody stems and woody roots of the tagasaste (Figs. 4-5).

DISCUSSION

In this study the perennial grasses consistently have twice as

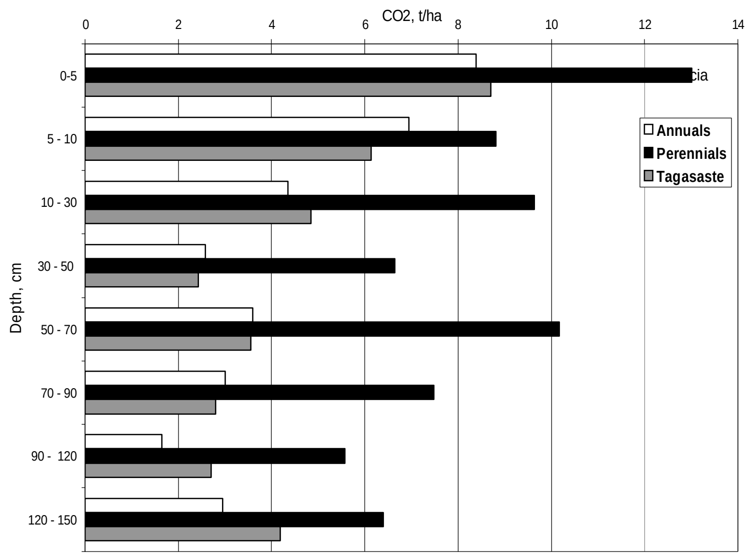

Fig. 3: Quantity of CO_2 eq under annuals, perennials and tagasaste pastures at New Norcia site.

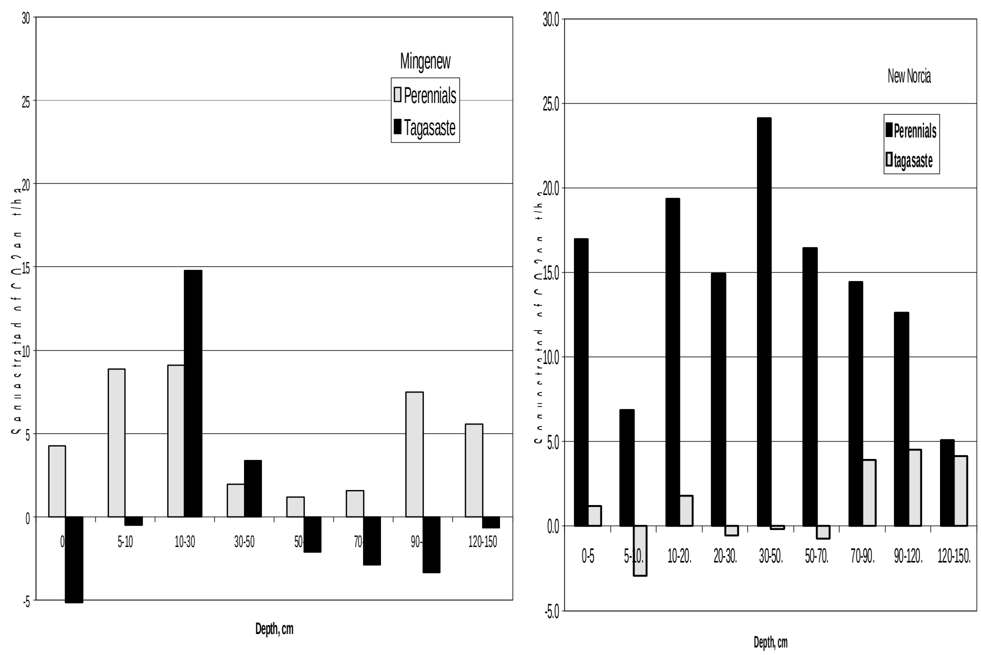

Fig. 4: Carbon dioxide sequestration rate (CO_2 eq t/ha/year) for eight depth increments down to 1.5 m at Mingenew site based on soil carbon stock difference of perennial grasses and tagasaste pastures above the annual pasture control.

much soil organic carbon as the annual pasture. Increase in soil organic carbon is often attributed to an increase in the input of biomass carbon into the soil. It is unlikely that the increase in soil organic carbon can be explained by the extra biomass input from the perennial pastures in this study. Measurements by Moore et al. (2008) at a site near the Baghdad trial found that the perennial grasses on average only produced an extra give the value % of above ground biomass.

The soil organic matter under the tagasaste was distributed differently down the profile compared to the annual pasture. However, the total SOC pool for the profile was not greatly different from the annual pasture. This study did not measure the large woody roots of the tagasaste. A study by Dornaar & William (1992) found that large root (>2 mm diameter) pool contained 3.2 times more carbon than in SOC pool in the top 2 m of soil. In addition, there was also a

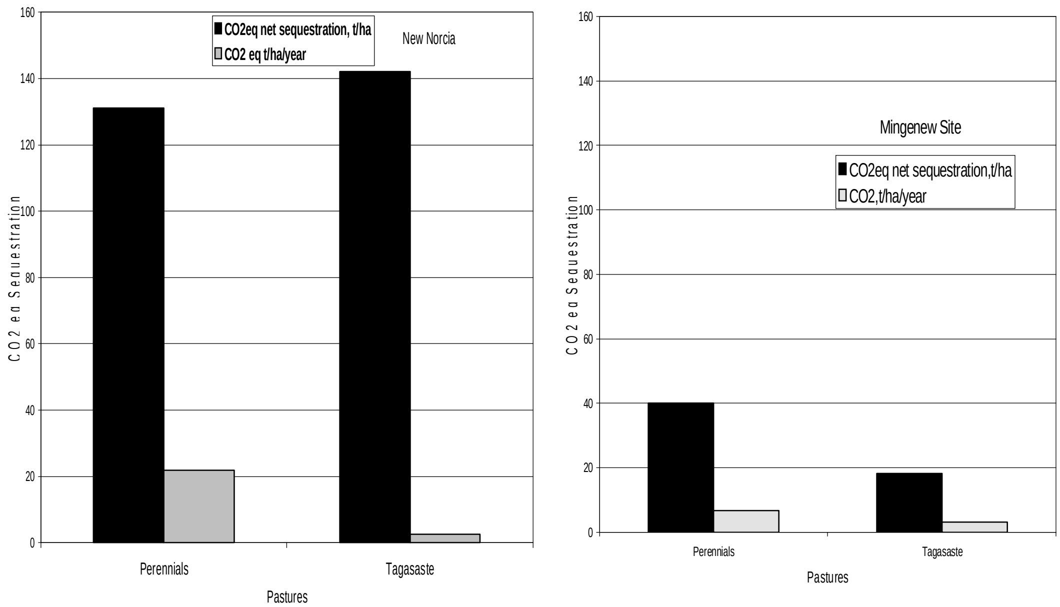

Fig. 5: Carbon dioxide sequestration rate (CO_2 eq t/ha/year) for the whole soil profile to 1.5 m at New Norcia site based on soil carbon stock difference of perennial grasses and tagasaste pastures above the annual pasture control

significant pool of carbon in the above ground trunk and limbs. To assess the sequestration potential of tagasaste it will be necessary to measure both the SOC and the large woody pools both above and below ground.

The additional soil organic carbon in this study is in part due to the perennial pastures having living roots year round, while the annual pasture roots die off in summer. The live roots were not measured directly in this study, but they contributed to soil organic carbon as roots regenerate regularly. Turnover of root material is an important consideration in determining the annual contribution of roots to the soil carbon pools. The life-span of roots may vary from as little as 4 to 6 weeks up to several years as in short grass prairies (Whitehead 1995). The turnover of perennial grass roots is more difficult to assess, as the management of the pastures can influence the life-span of the roots. Grazing, cutting, and fertilizer applications tend to shorten the average regeneration period (Whitehead 1995, Van Veen & Paul 1981).

The difference in soil organic carbon between annual and perennial pastures is more likely to be due to the difference in the decomposition of roots and above ground litter.

The results of this study 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_2 eq/ha/year) meaning that paddocks of perennial pastures are likely to be net sinks of greenhouse gasses. Perennial pastures could potentially contribute a massive reduction in agriculture 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 hypothesis that the high sequestration rates under the perennials is 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. In purely annual plant systems, the mycorrhiza population would die back in summer when there are no live plants. Under an evergreen perennial system the mycorrhiza population 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 to be increased. Further research is required to 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 practice are often erroneously assumed to be the carbon saturation level for a soil. A change in management practice will inevitably lead to a new equilibrium level in the soil. Using soil carbon models to define the maximum soil carbon levels is fraught with danger. These results suggest that agricultural management practice could have a large effect on net emissions/sequestration from the soil.

Given that there are 170 million hectares under dry land agricultural in region, and that these results and other research (Valzano 2005) show large variations in soil carbon stocks due to management, it is likely that soil carbon is the key category in the national accounts. The Kyoto Protocol would, therefore, requires Australia to commit substantial resources to improve the estimates of changes in soil carbon stocks on agricultural land.

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