

# Soil organic carbon sequestration in north agriculture region, western Australia

## Abstract

Mingenew, Northern Agriculture Region, NAR of Western Australia was chosen to study the effect of annual pasture, perennial grasses (C4). The perennial grass pastures had SOC stocks, 1.6 Mingenew times that of the annual pastures. SOC pools were 1.90, 2.97 and 2.88% for annuals, perennials and tagasaste at the site. 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 Mingenew deep sandy duplex site and 1.2 times greater for perennial pasture deep-sand site, to a depth of 1.6m. Perennial grasses in this region generally produced more aboveground 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 hypothesize that the perennial grasses promote fungi such as mycorrhiza that convert a greater proportion of labile carbon to stable humus forms than under annual pastures.

**Keywords:** biomass, SOC, perennials, tagassasta, mingenew, NAR

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## Introduction

Southern Western Australia 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.<sup>1</sup> 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.<sup>2</sup>

It is known that perennial pastures can increase soil carbon more than annual pasture for example<sup>3</sup> estimated that the total carbon contribution for perennials was 2.7 times more than for annuals. The coarse sands of the Northern Agricultural Region (NAR) of Western Australia have very low levels of clay and silt (< 5% of each). It is widely believed that soils with such low levels of silt and clay cannot 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%.<sup>4</sup> However limited soil testing had indicated that soil carbon levels were increased under perennial grasses growing on these coarse sands in the NAR. 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.<sup>5</sup> Leaving crop residues as litter after harvest, increases soil organic carbon.<sup>6</sup> Litter reduces soil erosion by reducing runoff, and improves soil structure and fertility through the addition of organic matter.<sup>7</sup> Pasture land has the ability to store substantial pools of soil C and N. Pasture land contains about 10% of the world C pool.<sup>8</sup> In temperate regions cultivation when cropping may release as much as 40% of the C that has been stored in the previous pasture phase.<sup>8</sup> Also cultivation can narrow the soil carbon-to-nitrogen ratio (C:N)

favoring the release of soil N through N mineralization processes.<sup>10</sup> On the Canadian prairies there is often a 2 to 9 year sequence of perennial pastures between cereal crops.<sup>11</sup> This pasture phase can increase soil Carbon and enhance the yields of the following cereal crops. The crop residues after harvest go into the litter pool and subsequently a proportion is sequestered into the soil. Initial break down of the litter results in large losses of organic Carbon and annual cultivation for cropping exacerbates the loss.<sup>7</sup> The deep light texture soils of the Northern agricultural Region of Western Australia (WA) have very low water holding potential (30–40mm/m<sup>3</sup>).<sup>9,10</sup> On these coarse sand textures the shallow rooted annual crops and pasture cannot 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 ground water 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 sandy soils in the Northern Agricultural Region, NAR

## Methodology

### Sites descriptions

The site is located 37km west of Mingenew, WA (latitude is 29° 18' 57.350" S, 115° 08' 46.568" E). 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 rye-grass, Patterson's curse. 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 rye-grass and clover pastures.

### Rainfall

The cumulative rainfall between 20 June 2013 and 18

December 2014 was 350 mm for Mingenew. The cumulative rainfall for January 8 and 10 June 2012 was 180mm, giving a combined rainfall of 530mm. The summer months (November to February) normally have low rainfall. However there was significant rainfall during the period of December 2013 to February 2010 at both sites. During this period Mingenew had 20mm. This atypical summer rainfall events would have accelerated the nitrogen mineralization from soil organic matter. The long term average annual rainfall is 480 mm for Mingenew.

## Materials and methods

Monthly soil samples were collected at both the Mingenew. Four replicates 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, and 120-150cm). Samples were air dried and sieved (2mm) prior to chemical analysis. Soil samples were analyzed for Organic Carbon using the Walkley Black method.<sup>7,11</sup> Nitrate and ammonium were determined by (14). Bulk density was determined by collecting soil samples with a Bulk Density ring and drying at the 105 OC for 48 hours.

## Evapotranspiration

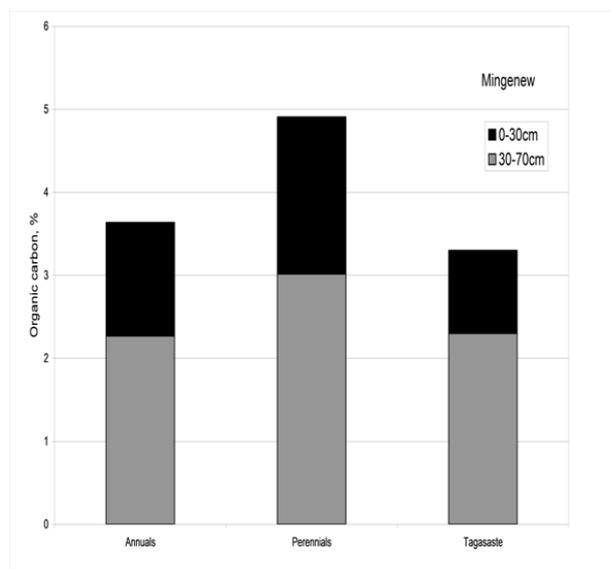
Daily evapotranspiration (Eta) was calculated based on the empirical equation of.<sup>12</sup> The cumulative evapotranspiration in Mingenew was 220mm for the annuals, 210mm for the perennials and 188 mm tagasaste. The monthly rates of Et are between 64 to 230mm for annuals, and from 59 to 210mm for perennials and tagasaste at Mingenew.

## Results

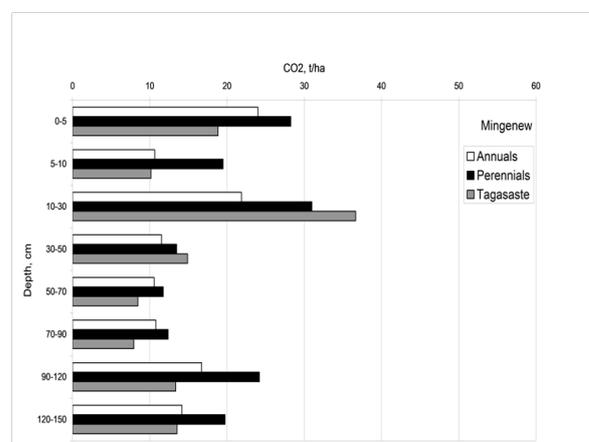
### Soil Organic Carbon

The perennial pastures had higher levels of organic carbon stocks than the annual pasture in both surface 0-30 cm and subsurface 30-70cm depths (Figure 1). The perennial pastures had an extra 2.3 t/ha of organic carbon in the top 70cm 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 40cm (Figure 1). There was a spike in CO<sub>2</sub> eq stocks in the 10-30cm depth (Figure 2), probably due to a layer of higher clay content. This 10-30cm layer had the highest CO<sub>2</sub> eq stocks for the perennial grasses and the tagasaste, and almost the highest for the annual pastures. The perennial grass had the highest CO<sub>2</sub> eq stocks for the whole 0 to 150cm depth. Tagasaste had more CO<sub>2</sub> eq stocks than the annual pasture in the 10 to 50cm depth interval, but not at other depths. The net difference between tagasaste and annual pastures for the whole profile was small/insignificant. The Intergovernmental Panel on Climate Change (IPCC)<sup>13</sup> sets out the accounting methods for determining green house gas emissions and sequestration for the Kyoto Protocols. The IPCC 2006<sup>13</sup> 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 practices 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. The perennial grass sequestered carbon

at all depths when compared to the traditional annual pasture (Figure 4). The biggest increase in soil carbon was in the 0 to 30cm and 90 to 150cm 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. Figure 5 Carbon dioxide sequestration rate (CO<sub>2</sub> eq t/ha/year) for the whole soil profile to 1.5m soil carbon stocks down to 150 cm increases under perennial grass pastures at both mundane. While the increase in carbon stocks under tagasaste was greater than under the perennial grasses. But as the tagasaste had been established for a much longer time than the perennial grasses the annualized sequestration rate of the tagasaste was lower. However the tagasaste data is only for the soil carbon and does not include carbon stored in the woody stems and woody roots of the tagasaste (Figures 4-5).



**Figure 1** Organic carbon stocks of annual, perennial and tagasaste pasture in the surface and subsurface soil samples at Mingenew site.



**Figure 2** Quantity of CO<sub>2</sub> eq under annuals, perennials and tagasaste pastures at Mingenew site.

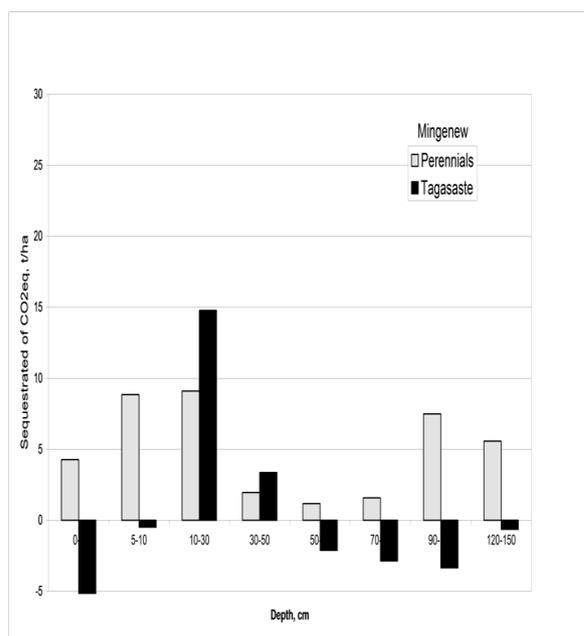


Figure 3 Quantity of CO<sub>2</sub>eq under annuals, perennials and tagasaste pastures at Mingenev site.

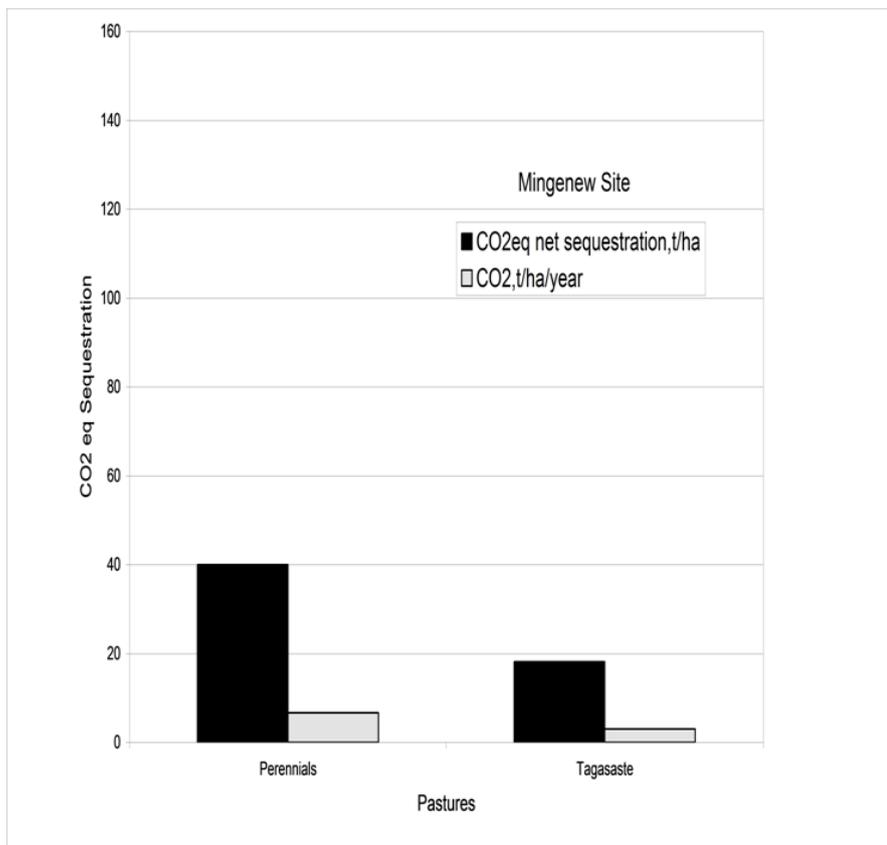
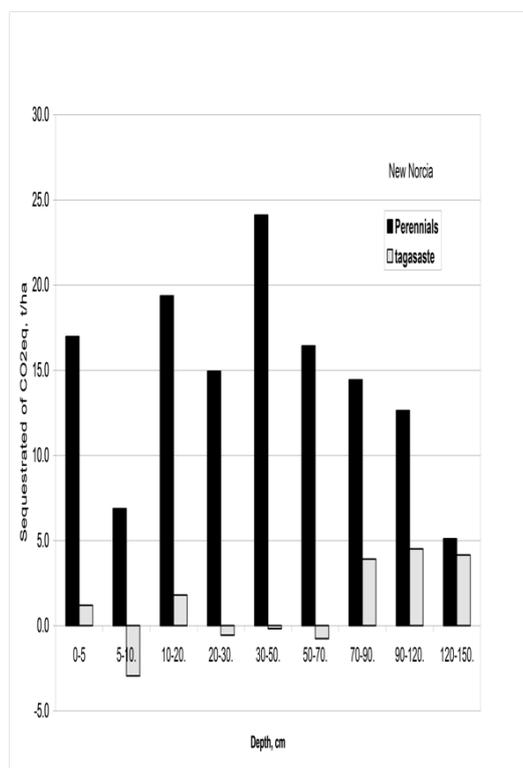


Figure 4 Carbon dioxide sequestration rate (CO<sub>2</sub> eq t/ha/year) for eight depth increments down to 1.5 m at Mingenev site based on soil carbon stock difference of perennial grasses and tagasaste pastures above the annual pasture control.



**Figure 5** Carbon dioxide sequestration rate (CO<sub>2</sub> eq t/ha/year) for the whole soil profile to 1.5m at New Norcia site based on soil carbon stock difference of perennial grasses and tagasaste pastures above the annual pasture control.

## Discussion

In this study the perennial grasses consistently had twice as much soil organic carbon as the annual pasture. Increases in soil organic carbon are 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 was at a site near the Mingenew 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 toughest 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, and Willms<sup>11</sup> found that large root (>2 mm diameter) pool contained 3.2 times more carbon than in the SOC pool in the top 2 m of soil. In addition there was also a 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.<sup>7</sup> The turnover of perennial grass roots is more difficult to assess, as the management of the

pastures can influence the lifespan of the roots. Grazing, cutting, and fertilizer applications tend to shorten the average regeneration period.<sup>7</sup> 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<sub>2</sub> 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<sub>2</sub> 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 agricultures 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 Roth C model. (*com.*). 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.<sup>14</sup> Questions remain as to how these perennial pastures can achieve such high sequestration rates and as to how Roth C 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 Mycorrhizal 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 Mycorrhizal population would die back in summer when there are no live plants.

Under an evergreen perennial system the Mycorrhizal populations and biological activity would be maintained year round. This increase in Mycorrhizal 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 Roth C to be increased. Further research is required to accurately define the flux rates for perennial pastures in the Roth C 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 cannot 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 Roth C 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 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. 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 sand on the Forsyth property at Dongara. These results suggest that agricultural management practices could have a large effect on net emissions/sequestration from the soil. This has an implication for the National Carbon Accounts that Australia is required to supply to the UNFCCC. The IPCC<sup>13</sup> accounting rules require each country to estimate the 'uncertainties' in the accounts. The IPCC<sup>13</sup> guidelines describe 'Key Categories' that contribute the greatest uncertainties to the national accounts. I. e. IPCC 2006,<sup>13</sup> Chapter 4. "Methodological choice and identification of Key Categories"<sup>15</sup>

1. It is therefore 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.
2. Define "A key category is one that is prioritized 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 used, it includes both the source and sinks categories.

Given that there are 470million hectares under dry land 'agricultural' in Australia, and that these results and other research<sup>7</sup> 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 require Australia to commit substantial resources to improve the estimates of changes in soil carbon stocks on agricultural land.<sup>16-18</sup>

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## Conflict of interest

None

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