Estimating the carbon sequestration potential of agricultural soil reforested with directly seeded native vegetation belts around Canberra, Southern Tablelands, NSW

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Abstract

Sowing native vegetation tree belts on agricultural soils using direct seeding is a technique that has been carried out by Greening Australia in the Australian Capital region for many years. It results in improved landscape biodiversity and habitat, provides shelter for pastures, crops and livestock and protects soil from erosion. Initial research identified a range of changes the vegetation belts make to the physical and chemical functions of soils including: an increase in the thickness of the surface litter and depth of the A_o horizon. This leads to a commensurate increase in total soil organic C; a reduction in bulk density; an increase in total nitrogen; and a decrease in pH and effective CEC. The study also used the Landscape Function Analysis method and found a significant improvement in the three functional indices: infiltration, nutrient cycling and stability. These findings are being investigated as part of a new study which aims to develop a model to estimate the C sequestration potential of agricultural soils in which vegetation belts have been established. Additionally, the chemical nature of the soil organic C in the vegetation belts will be compared with C from adjacent grassland soils to identify whether the trees are sequestering a more stable form of soil C than the grasslands. The soil biological and ecological characteristics are being analysed as part of the research.

Key Words

Soil organic carbon, SOC, reforestation, carbon sequestration

Introduction

Since the arrival of Europeans in Australia the landscape has undergone considerable change due to widespread clearing of native vegetation ecosystems to make way for agricultural activities. The removal of the native vegetation has contributed to substantial soil degradation and erosion across the landscape. In an effort to restore some landscape ecosystems, Greening Australian has established a number of native vegetation tree belts on agricultural land across the Southern Tablelands of New South Wales. The belts have a range of ecological benefits, including enhancement of landscape biodiversity and habitat and provision of shelter for pastures, crops and livestock. They can be a source of timber or fodder but importantly they protect soil from the erosive forces of wind and water and improve soil ecological function.

In 2008 an initial study was carried out on 36 native vegetation tree belts sown by Greening Australia using a direct seeding method during the period 1990 to 1996. The study identified changes to soil physical and chemical functions attributable to the presence of vegetation belts. This research was undertaken by comparing a range of soil function variables in the native vegetation belts with those on soil in the adjacent grassland/paddock. The grasslands were presumed to represent the condition of the soil prior to the sowing of the belts and consequently to give an indication of the extent and direction of the soil changes initiated by the belts. For each vegetation belt an analogue site was also selected to be a benchmark of the soil condition. The analogue sites were presumed to be the best representation available of the original soil condition in the grasslands prior to intervention by land clearing and subsequent agricultural activity, and consisted of laneways, travelling stock reserves or road verges.

Methods

A range of soil physical and chemical attributes were analysed. 36 sites were measured in Phase 1, and then a subset of six were studied in greater detail in Phase 2 (Table 1).

Table 1. Soil attributes studied during in 2008 during Phase 1 and Phase 2.

Attribute	Phase 1 (36 sites)	Phase 2 (6 sites)
Soil Landscape	✓	
Soil Profile (Northcote)		✓
Surface litter (t/ha)	✓	
A_O	✓	
SOC (Walkley & Black) for A1 horizon (phase 1) and B horizon (phase 2)	✓	✓
Bulk Density		✓
C Density (to 30cm)		✓
Biota abundance		✓
pH / EC (1:5 water)	✓	✓
Total N & P		✓
Extractable Anions		✓
Total Cations		✓
Exchangeable Cations		✓
Effective Cation Exchange Capacity		✓
Landscape function analysis	✓	

In Phase 1, 10 soil samples from the A_1 horizon to a depth of 5cm were collected from each of the 36 sites with 2 samples obtained from the grassland above and 2 from below the vegetation belt, 4 from within the vegetation belt (two from the tree-row and two from the inter-row), and two from the analogue site. The landscape function analysis (LFA) method (Ludwig and Tongway, 1995) was also used to record changes to landscape functionality.

Five samples of each of the A_1 and B horizons were obtained from the six phase 2 sites with one sample obtained from the grassland above and below the vegetation belt, 2 from within the vegetation belts (one from the tree-row and one from the inter-row) and one from the analogue site.

Results

There were 20 soil-landscape units indentified across the 36 sites. This variation may have influenced the distribution of the soil function results between sites, but no relationship could be identified, probably due to the low total number of study sites compared with the diverse range of soil landscape units. The research findings from Phase 1 indicated that compared to the adjoining grasslands, the tree belts had significantly ($P<.001$) greater amounts of surface litter, a more developed A_o horizon and a higher percent of total organic C.

The LFA results demonstrated an improved infiltration, stability and nutrient cycling capability for the soils within the vegetation belts when compared with the adjacent grassland/paddock and that the infiltration capacity within the vegetation belts had exceeded that of the analogue sites. Landscape Function Analysis also indicated an improved soil function down slope of the vegetation belts compared with upslope. Sites in which some livestock grazing had occurred within the tree belt had a higher TOC value indicating a beneficial outcome in terms of nutrient cycling. It is probable that excreta from stock and trampling breaks down the surface litter and thereby hastens the decomposition process.
Phase 2 results indicated that there were no significant differences in total N and total P between the belts and adjacent grassland/paddock. However, N values tended to be higher within the vegetation belts; this is thought to be caused by the symbiotic fixation of N due to the presence of the native leguminous *Acacia* spp. trees in the vegetation belts, and P values were lower in the belts, probably due to the extraction of P by the trees. The pH was marginally lower within the vegetation belts, but this trend was not significant.

Discussion

Agricultural soils have the capacity to lose or gain C depending upon management practices used. For example, when organic matter is removed from the system such as when land is converted from forest to agriculture there can be a reduction in SOC by up to 50% (Lal 2005). However, improved land management practices such as reduced tillage have been shown to increase SOC (Six *et al.* 1998). Inputs of organic matter from plant material contribute to an increase in C stock in soils, as does an increase in clay content, although climatic conditions such as moisture and temperature can influence the rate of decomposition and subsequent loss of SOC (Jastrow *et al.* 2007). Forest soils gain a large proportion of their organic matter and SOC from tree litter; therefore it is beneficial to soil function to establish trees in agricultural soil to increase the SOC stock (Read 2008), although other studies have found that in some cases this can take many years depending on the level of soil disturbance during establishment (Turner 2005).

Both native and plantation forests and including those used for agroforestry store C in both the above ground biomass and contribute C to the SOC pool. For C accounting purposes, reforestation is determined by the Australian Government (CPRS White Paper 2009) as meeting the Kyoto Protocol when the trees have been established by humans on land that was clear of forest on 31 / 12 / 1989. The trees must be determined to have the potential to grow to a height of at least two metres, have a crown cover of at least 20% and be grown on areas larger than 0.2ha. The vegetation belts sown by Greening Australia, fulfil the definition of reforestation under the terms of the Kyoto Protocol and potentially are an important contributor to the SOC pool.

Measuring above ground living biomass is commonly used as a surrogate for calculating the C content in forest communities. Each ecosystem has a unique biomass concentration and therefore measurements of the above-ground biomass which can include both overstorey and understorey biomass and standing woody debris can be used for estimating C in forest ecosystems, and fallen debris, surface litter, root systems and SOC are measured to determine forest SOC stocks (Snowdon *et al.* 2002).

In this follow-up study, measurements of the above ground biomass of direct seeded native vegetation belts will be correlated with soil classification and SOC density results and will be used to develop a model for predicting the potential of certain soil types as found across the Southern Tablelands of NSW to sequester C. Organic matter has many roles (e.g., water retention, physical, chemical and biological properties of soil), but it is also integral to the process of developing and stabilising soil aggregates. The stabilisation process involves protecting SOM from mineralisation by microorganisms. Physical protection of SOM is achieved by encapsulating SOM within aggregates, and micro aggregates (<250 μm) provide greater protection than (macro aggregates >250 μm) (Goebel *et al.* 2009).

Macro aggregates are more sensitive to cultivation and land use change than micro aggregates but can be stabilised by the presence of carbohydrate rich root or plant debris being occluded within the aggregates (Six *et al.* 1998). The LFA results from the preliminary study show that for the stability index soil from the vegetation belt has improved compared with that analysed from the grassland soil. To determine whether there is a link between the improved soil stability index and aggregate stability the physical nature of aggregates in soils in the vegetation belts will be compared with those from the grasslands to determine whether sufficient time has elapsed to allow micro aggregate development and if so also determine the extent the aggregates are contributing stable C to the soil pool.

Polysaccharides such as cellulose, hemi-cellulose, chitin and peptidoglycan can be found in fresh plant and microbial tissues in soil particles > 20μm. Decomposition of the labile components result in a reduction in particle size and an increase of more recalcitrant materials such as lignin and alkyl structures from the 2-20μm size (Baldock *et al.* 2000). The follow-up study will analyse the chemical structure of the SOC from both the vegetation belts and grasslands to determine whether the nature of the SOC is changing and becoming more stable.

Conclusion

Overall, the results of the preliminary research project provide evidence that the vegetation belts can induce an improvement to a range of soil function variables. However, over time as the tree growth declines there is evidence that surface litter and TOC also may decline. These trends are being investigated in a larger 3 year follow-up study where the changes to SOC are being examined more closely to investigate whether it is possible to predict the amount of increase in SOC that can be attributed to the establishment of the tree belts and whether soil type or tree species mix has any influence on the extent of change. This will be done by comparing tree biomass with SOC density to 30cm depth at approximately 100 sites across the Southern Tablelands of NSW, and then comparing these results with biomass and SOC density results from adjoining grasslands.

Other important objectives of the follow-up study are to determine whether there has been sufficient time since the establishment of the vegetation belts for aggregates to stabilise and provide greater physical protection for the organic matter within the vegetation belts compared with the grasslands and whether the chemical nature of the SOC is changing to increase the concentration of stable C.

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