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CARBON SEQUESTRATION and PLANTATION:A Review

Chemistry

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ABSTRACT

When agricultural land is no longer used for cultivation and allowed to revert to natural vegetation soil organic carbon(SOC) can accumulate by different processes, that essentially reverse some of the effects responsible for soil organic carbon losses .We discuss the about soil organic matter dynamics that may result in enhanced soil carbon sequestration with changes in land-use and soil management. We review literature that reports changes in soil organic carbon after changes in land-use that favor carbon accumulation. This review provides a guide to SOC sequestration that is possible with management, and also indicates the relative importance of some of the factors that influence the rates of organic carbon sequestration The loss of soil organic carbon by conversion of natural vegetation to cultivated use is well known [18]. Various land-uses result in very rapid declines in soil organic matter [2] much of this loss in soil organic carbon can be attributed to reduced inputs of organic matter, increased decomposability of crop residues, and tillage effects that decrease the amount of physical protection to decomposition. A considerable part of the depleted SOC pool can be restored through conversion of marginal lands into restorative land uses, adoption of conservation tillage with cover crops and crop residue mulch, nutrient cycling including the use of compost and manure, and other systems of sustainable management of soil and water resource. The carbon sequestration benefit from reforestation can be determined by the difference in average carbon stock between the previous land use and the forest or plantation. We assemble some information concerning processes that regulate the amount and rate of change in SOC.

INTRODUCTION:

Carbon sequestration

Trees remove carbon dioxide from the atmosphere through the natural process of photosynthesis and store the carbon (C) in their leaves, branches, stems, bark and roots. Approximately half the dry weight of a tree's biomass is carbon. One tonne of C = 3.67 tonnes of 'carbon dioxide equivalent' (CO2-e) Trees in forests (including plantations), if well-stocked, typically sequester carbon at a maximum rate between about age 10 and age 20–30. As an indication, at age 30 years about 200 to 520 tonnes CO2-e are sequestered per ha in forests with productivity ranging from low to high [4]. After this age, if the trees are not harvested, the sequestration rate slows gradually until maturity at about 80 to 100+ years of age, and flattens out from then on as growth is balanced by decay. Reforesting cleared areas will create carbon sinks to counteract greenhouse gas emissions, and will assist in other aspects of environmental improvement such as salinity control and creation of wildlife habitat. [3] In terrestrial ecosystems the amount of carbon in soil is usually greater than the amount in living vegetation. [18] The loss of soil organic carbon by conversion of natural vegetation to cultivated use is well known. Various land-uses result in very rapid declines in soil organic matter [19] Much of this loss in soil organic carbon can be attributed to reduced inputs of organic matter, increased decomposability of crop residues, and tillage effects that decrease the amount of physical protection to decomposition. We assemble information concerning processes that regulate the amount and rate of change in SOC.

Estimating sequestration

The carbon sequestration benefit from reforestation is determined by the difference in average carbon stock between the previous land use and the forest or plantation. Generalised predictions of the sequestration rate of reforestation projects cannot be made, since growth (and sequestration) depends on local climate, soil factors and management. For forests managed for timber production on a long-term plant–harvest–replant cycle, the maximum C stock achieved will not be maintained. In such cases it is more useful to consider the average sequestration benefit of each hectare across multiple rotations (horizontal line in Fig. 1).[3]

Carbon dioxide equivalents (CO2-e)

Carbon dioxide equivalents (CO2-e) provide a universal standard of measurement against which the impacts of releasing (or avoiding the release of or actively sequestering) different greenhouse gases can be evaluated. Every greenhouse gas has a Global Warming Potential (GWP), a measurement of the impact that particular gas has on 'radiative forcing'; that is, the additional heat/energy which is retained in the Earth's atmosphere system through the addition of this gas to the atmosphere.

The GWP of a given gas describes its effect on climate change relative to a similar amount of carbon dioxide. As the base unit, carbon dioxide is 1.0. This allows the greenhouse gases regulated under the Kyoto Protocol to be converted to the common unit of CO2-e. [1]

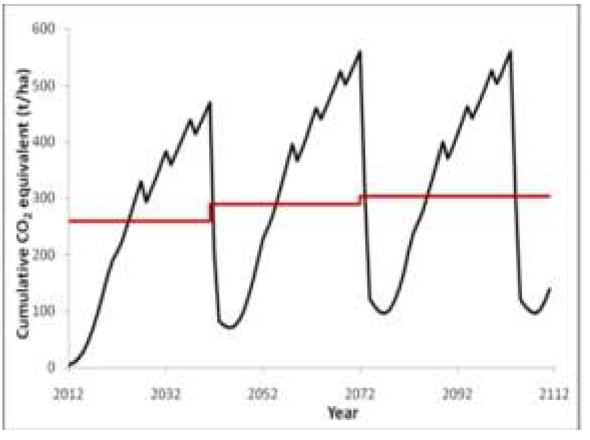

Figure 1. Rotational replant and harvest carbon storage.

The red line shows the average carbon stock from each timber rotation.

Source: Commonwealth Department of Climate Change

Carbon Sequestration Predictor

Industry & Investment NSW has produced a simple-to-use model, the Carbon Sequestration Predictor (CSP) Version 3.1. This gives predictions of changes in carbon stocks in plants and soil over two time intervals: 10 years and 100 years . It is designed for use in areas of NSW with <800 mm rainfall per year .[5] The CSP assists landholders in determining the amount of carbon that is sequestered under different land-use change scenarios. For example, the graph below shows the total amount of carbon, including soil carbon that is sequestered when **annual pasture** is converted to an **environmental planting** (800 trees/hectare), on chromosol soil with a mean annual rainfall of 500 mm. [3]

Soil Potential for Carbon Accumulation

The amount of organic carbon stored in soil results from the net balance between the rate of soil organic carbon inputs and rate of mineralization in each of the organic carbon pools . Schlesinger (1990)[6] compiled data on long-term rates of soil organic carbon accumulation in Holocene age soils. He found a slow rate of carbon increase in soil even after thousands of years. This long-term increase represents accumulations of passive soil organic carbon fractions, which include charcoal and resistant compounds physically protected in organomineral complexes.Schlesinger (1990)[6] documented long-term rates of carbon storage from 0.2 g C m^{-2} y^{-1} in some polar deserts to greater than 10 g C m^{-2} y^{-1} in some forest ecosystems, with an average rate of 2.4 g C m^{-2} y^{-1} over all ecosystems.

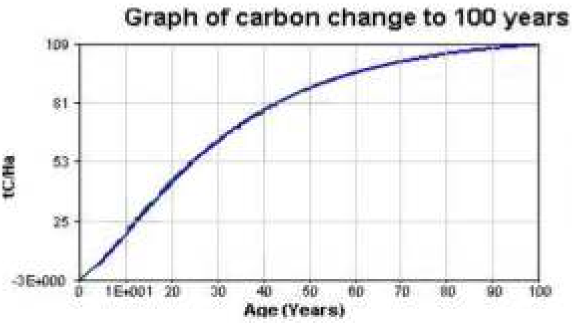

Figure 2.Example graphical output from CSP from: www.dpi.nsw.gov.au/forests/info/csp.

Schlesinger (1990)[6] indicates that faster rates of change over short time periods are possible as a result of changes in environmental conditions.

When natural vegetation is converted to cultivated crops, rapid declines in soil organic matter are partly due to a lower fraction of non-soluble material in the more readily decomposed crop residues. Tillage, in addition to mixing and stirring of soil, breaks up aggregates and exposes organo-mineral surfaces otherwise inaccessible to decomposers.

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LF-OC and some organomineral SOC. Losses of SOC of as much as 50% in surface soils (20 cm) have been observed after cultivation for 30 to 50 years. Reductions average around 30% of the original amount in the top 100-cm. The large and relatively rapid changes in SOC with cultivation indicates that there is considerable potential to enhance the rate of carbon sequestration in soil with management activities that reverse the effects of cultivation

on SOC pools. The refilling of depleted fast turnover LC-OC pools and the active portions of the organomineral pools may result in much higher rates of SOC storage than the slow accumulation of passive soil carbon documented by Schlesinger (1990). Although the time period for high accumulation rates may be relatively short, years or decades, these accumulation rates are of significance for current soil sustainability and carbon management issues.mineral SOC. Losses of SOC of as much as 50% in surface soils (20 cm) have been observed after cultivation for 30 to 50 years. Reductions average around 30% of the original amount in the top 100-cm. The large and relatively rapid changes in SOC with cultivation indicates that there is considerable potential to enhance the rate of carbon sequestration in soil with management activities that reverse the effects of cultivation

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Forest establishment after agricultural use

Rates of SOC change under aggrading forest range from small losses under cool temperate-zone pine dominated natural succession to an increase of 300 g C in a subtropical wet forest plantation. In two sites large SOC losses were observed when subsequent organic carbon inputs during the early stages of forest growth were not large enough to replenish the decomposition losses. An average accumulation rate of soil carbon, including these two sites, is 33.8 g C m^{-2} y^{-1} This is quite similar to the 30 g C m^{-2} y^{-1} estimated by Schlesinger (1990)[6] as the rate of SOC accumulation in 40- to 50-year-old soils. There is a tendency for rates of SOC accumulation to increase from temperate regions to subtropical regions . We infer from this trend that major factors determining the rate of accumulation are amounts of organic matter inputs which increase with temperature and moisture.

Bredja (1997)[7] studied a subtropical thorn steppe system, where the vegetation was shifted from a grazed grassland to an ungrazed woodland. Growth of woody plants resulted in a decrease in SOC, despite the fact that woody plants produced a greater amount of more recalcitrant material. Woody plants may be less effective than perennial grasses in some environments at storing carbon in soil. Woody plants deposit a larger fraction of total inputs than both grasses and pastures on the surface where decomposition conditions are generally more favorable. This may be the case in this study since a site in a grass opening without woody shrubs showed a SOC increase when grazing was eliminated

Another example that indicates the significance of vertical placement of new carbon inputs is demonstrated in a wet tropical forest life zone where sugar cane fields were converted to fast-growing eucalyptus trees (Bashkin and Binkley 1998).[8] After 10 to 13 years, soil carbon increased under eucalyptus by 1150 g C m^{-2} in the top 10 cm of soil, but decreased by 1010 g C m^{-2} in the 10 to 55 cm layer. By examining changes in C concentrations Bashkin and Binkley (1998)[8] were able to confirm that input rates of eucalyptus carbon into this deeper layer were small compared to previous sugar cane inputs.

There is considerable variation in accumulation rates of SOC that results from many factors and are not consistent among the studies. In addition to the differences in the quantity, quality and placement of organic carbon inputs mentioned above, there are differences in the degree that labile soil organic carbon pools, particularly the LF-OC pools, were depleted by cultivation prior to abandonment or land-use conversion. The rate of decomposition is usually well represented as a first order process where the amount of decomposition per unit time depends on the amount of material subject to decomposition times the rate constant for the environmental conditions and type of material. The amount of material in each decomposition class at the initial time in each study depends on the previous management history, which is generally unknown. As a result, initial decomposition rates may be low (SOC pools relatively depleted) or high (SOC pools large) relative to those that can be maintained if SOC pools were in equilibrium with current input rates of organic matter. When considering management activity to sequester carbon in soil, knowledge of site history such as cultivation duration is important. In two sites large SOC losses were observed. In both cases, the prior period of agricultural use or a bare fallow was short - only one year (Sanchez et al. 1985Gholz HL, Fisher RF (1982) [9][10]. In these cases, the short period of disturbance did not deplete the rapid turnover pools before forest planting.

In approximately half the studies that have multiple measurement intervals there is a large difference between the maximum and average accumulation (or loss) rate. This indicates a slowing in accumulation rate as new steady state amounts of SOC are established and decomposition rates more closely match input rates. Some of these may be artifacts that arise from spatial heterogeneity and insufficient sampling. Additional errors arise with studies of chronosequences and paired plots.

Permanent grassland establishment

Substantial gains in SOC are also possible with conversion of cropland to grassland, particularly with management for high grass productivity [1] SOC is likely to increase when cultivated soil is planted with permanent grasses. Conversion of woody vegetation to grasses may also affect SOC storage. Replacement of native tropical savanna with productive, deep-rooting exotic grasses (Fisher et al. 1994)[11] can also result in significant SOC increases for several years (800 to 1300 g C m^{-2} y^{-1} over the first 3 to 6 years). When forest is cleared for pasture establishment, considerable aboveground carbon in vegetation is lost, but it is not necessary that there be declines in SOC. At least for tropical moist and wet forest life zones, it is also possible for SOC to increase when native mature forest is cleared and converted to pasture. In a study by Neil et al. (1997)[12]eleven of fourteen pasture conversion sites studied in Brazil showed increases in soil carbon. All sites in pasture for at least 10 years showed increases, with rates as high as 74.0 g C m^{-2} y^{-1} over 20 years. Two out of three sites studied in Costa Rica found declines in SOC when native forest was cleared for pasture (Veldkamp 1994).[13] Tropical dry forestshowed decreases in SOC when converted to pasture (Trumbore etal. 1995)[14]

Disscussion:

There are many factors and processes that determine the direction and rate of change in SOC content when vegetation and soil management practices are changed. Few that may be important for increasing

SOC storage include

(1) increasing the input rates of organic matter,
(2) changing the decomposability of organic matter inputs that increase LF-OC in particular,
(3) placing organic matter deeper in the soil either directly by increasing belowground inputs
or indirectly by enhancing surface mixing by soil organisms, and
(4) Enhancing physical protection through either intra-aggregate or organomineral complexes.

Conditions favoring these processes generally occur when soils are converted from cultivated use to permanent perennial vegetation. Variation in the rates of SOC change due to the differences in the influences of one or more of these factors even with data collected from similar studies is observed.[18] While there is not enough data currently available to precisely determine the amount of carbon accumulating in any large region or even some particular plot of land, we have enough information to infer the order of magnitude of the soil carbon sequestration rate. We can use this information to investigate some aspects of soil carbon fluxes in the present global carbon cycle. Various investigations have inferred indirectly from atmospheric CO_2 measurements that the terrestrial ecosystems of the Northern Hemisphere have been taking up and storing carbon in both vegetation and soil at a rate of 1 to 2 Pg C y^{-1} (1 Pg = 10^{15}g) over the past several decades (Tans et al. 1989, [16], Fan et al. 1998).[15] Applying the average rate of SOC accumulation to this entire area, the present rate of SOC sequestration would be .05 Pg C y^{-1}Only a small fraction of the inferred northern hemisphere terrestrial sink can be explained in terms of SOC accumulations in aggrading forests of the U.S. King et al. (1990)[17] indicate that 154 x 10 ha (120 x 10 > > ha in China and India alone) were reforested or afforested in the Northern Hemisphere in the 1980's.

Assuming that all this land was all afforested and not just replanted after a harvest and that this rate continued through the 1990's then the rate of SOC accumulation would potentially be 0.11 Pg C y^{-1} . While not insignificant, this rate is a very small fraction of the estimated rateof carbon sequestration in the Northern Hemisphere. If 1 to 2 Pg C y^{-1} are currently accumulating in aggrading forests then nearly all of this C would be increases in biomass and surface litter, not SOC. Tree plantings for carbon sequestration do not need to be of particular kinds or to be done on any particular type of site. Plantings carried out for wood production or salinity control on eligible land could 'double' as carbon sinks under the proposed CPRS[3] Because there are requirements for carbon plantations to remain viable and grow well over a long timeframe, careful attention to establishment and care of the growing plantation are vital.

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