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Afforestation to Increase Soil Organic Carbon

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INTRODUCTION

Importance of Soil Carbon Sequestration

Soil has the ability to store up to three times the amount of carbon than the atmosphere, making it one of the most important potential carbon sinks in the world (Minasny et al., 2017). Soil organic carbon (SOC) sequestration is the process of atmospheric CO_2 being absorbed and converted to soil carbon where it can be stored for long periods of time (Minasny et al., 2017). For this reason, an increased storage of soil carbon could have the ability to mitigate greenhouse gas emissions (Minasny et al., 2017).

4 Per 1000 Initiative

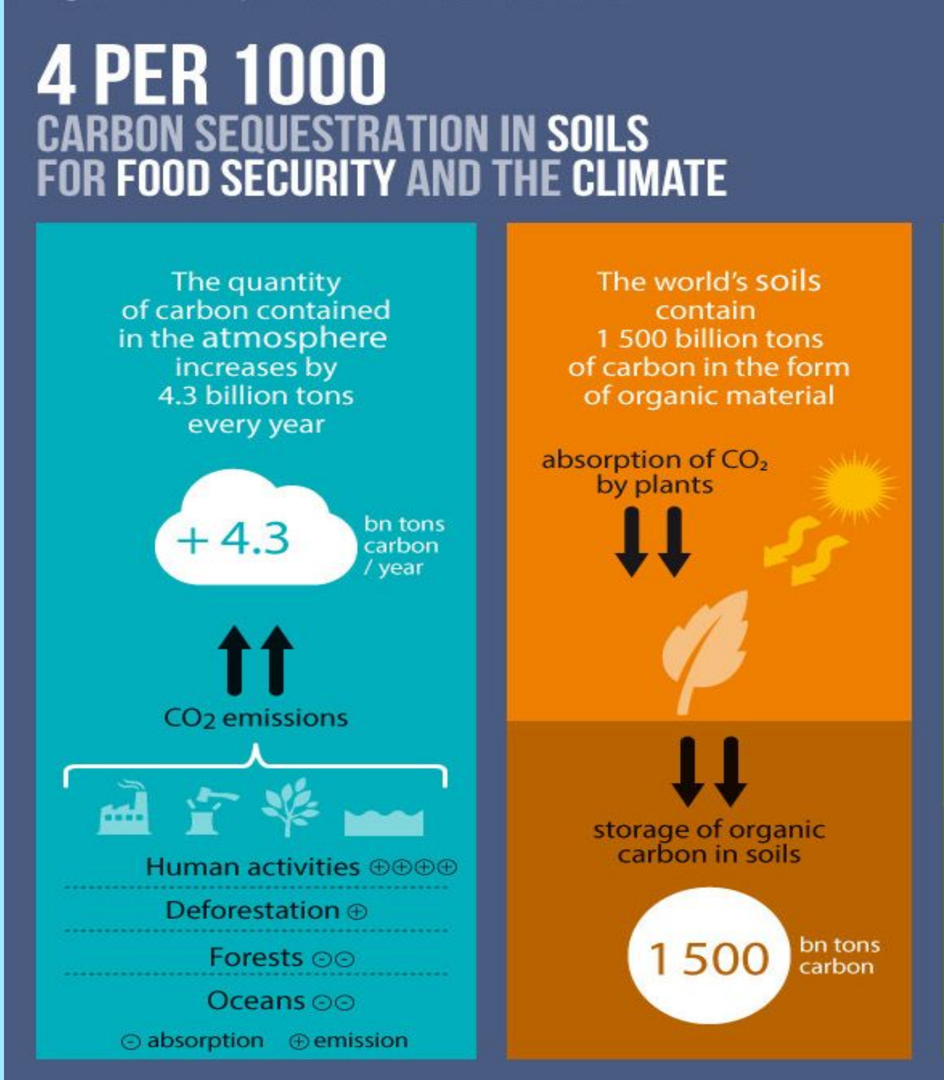
The 4 per 1000 initiative was created on December 1st, 2015; it emphasizes the importance of increasing organic carbon storage in the soil and the positive effects that would come as a result (4p1000, 2018). The 4 per 1000 website states:

“An annual growth rate of 0.4% in the soil carbon stocks, or 4‰ per year, in the first 30-40 cm of soil, would significantly reduce the CO_2 concentration in the atmosphere related to human activities.”

There are many different practices that currently exist to increase soil organic carbon such as agroecology, agroforestry, and conservation agriculture (4p1000, 2018). Afforestation is a technique included in these practices and could even be a solution to the 4 per 1000 initiative.

“CARBON SEQUESTRATION IN SOILS FOR FOOD SECURITY AND THE CLIMATE”

(4P1000, 2018)



Afforestation

Afforestation can be described as the “conversion of treeless land not previously forested into a plantation” (Laganière et al., 2009); this specific land use change could be a valid method for increasing the amount of organic carbon in the soil (Laganière et al., 2009).

OBJECTIVES

Determine if afforestation is an effective method for increasing soil organic carbon

5 CLIMATE ZONES:

01

BOREAL

Long, cold winters and short, mild summers

02

SUBTROPICAL

Hot and humid summers, cold/mild winters

03

TEMPERATE CONTINENTAL

Hot summers and cold winters, 4 distinct seasons

04

TEMPERATE MARITIME

Hot, rainy summers and mild winters

05

TROPICAL

High temperatures year round and lots of precipitation

Boreal Climate

Pinno & Belanger (2008)	Wang et al. (2006)
Pinno & Belanger (2008) directed a field study in Saskatchewan, Canada that followed the afforestation of pasture to broadleaf and pine tree plantation. Underneath trees in the A horizons (0-20 cm) carbon pools decreased, and carbon increased in the B horizons (20-40 cm) (Pinno & Belanger, 2008). Carbon redistribution has a close relation with root production and quality, which is consistent with the results of this study (Pinno & Belanger, 2008).	In this study, Wang et al. (2006) observed changes in SOC during the conversion of cropland to broadleaf and pine forest in northeastern China. During the first 12 years of the project, soil carbon decreased and then gradually began accumulating in the 12-33 year time period (Wang et al., 2006). Overall, a net sequestration of carbon was recorded and appeared to be most notable in tree biomass (Wang et al., 2006).

Boreal Climate

Pinno & Belanger (2008)	Wang et al. (2006)
“**Ecosystem C gains in the forested plots were evident** when compared to pasture plots. Most of this gain was attributed to the standing biomass and to lesser extent to forest floor development.” (Pinno & Belanger, 2008)	“The initial (0–12 yr) decrease in soil carbon was an average **1.2% per year** among case studies, whereas the increase in soil carbon (12–33 yr) was **1.90% per year**.” (Wang et al., 2006)

Subtropical Climate

Markewitz et al. (2002)	Richter et al. (1999)
Markewitz et al. (2002) evaluated SOC sequestration following the afforestation of cropland into pine tree forest in this Georgia, USA study. For the duration of the 14 year investigation, there was no carbon accumulation in the soils of the afforested site (Markewitz et al., 2002). Although carbon did not increase in the soil, Markewitz et al. (2002) noted that carbon could still have been stored in above and belowground biomass. This study suggests that more time might be needed for there to an accumulation of carbon in afforested soils (Markewitz et al., 2002).	Richter et al. (1999) conducted a study focussing on the effects of converting cropland to pine forest in South Carolina, USA. Carbon only had a significant increase in the 0-7.5cm layer of the soil, and in depths from 35-60cm there was great decrease in carbon after 40 years (Richter et al., 1999). It was concluded that the forest had become a prominent carbon sink, however the majority of carbon accumulation occurred in tree biomass and the forest floor (Richter et al., 1999).

Subtropical Climate

Markewitz et al. (2002)	Richter et al. (1999)
"The average content of soil C in planted stands was about **16 Mg/ha less** than that in the never tilled soils" (Markewitz et al., 2002)	"Since 1957, the aggrading forest accumulated **3,925 g/m²** of new carbon in the soil profile." (Richter et al. 1999)

Temperate Continental Climate

Hansen (1993)	Morris et al. (2007)
A study was conducted in north central USA by Hansen (1993) where cropland was converted to broadleaf tree plantations. Initially, there was soil carbon loss predominantly in the 0-30 cm layer, but carbon sequestration increased with plantation age (Hansen, 1993). The most significant carbon increase was found in the 30-50 cm layer of soil due to tree root growth, and bulk density was also higher in this layer (Hansen, 1993). Hansen (1993) concluded that growing hybrid plantations on rotations of 6-12 years would greatly increase the storage of SOC.	In this study, the afforestation of pasture by coniferous and broadleaf trees in Michigan, USA resulted in a net carbon sequestration in the soil (Morris et al., 2007). Afforested broadleaf areas had higher soil carbon accumulation than the afforested coniferous areas (Morris et al., 2007). Morris et al. (2007) also suggest that an increase in calcium in afforested areas could improve SOC storage.

Temperate Continental Climate

Hansen (1993)	Morris et al. (2007)
"Soil carbon accretion rate beneath 12 to 18 year old poplar plantations exceeded that of adjacent agricultural crops by **1.63 +/- 0.16 Mg/ha/yr**." (Hansen, 1993)	"Planting agricultural soils to deciduous forests resulted in ecosystem C accumulations of **2.4Mg/ha/yr** and soil accumulations of **0.35 Mg/ha/yr**." (Morris et al., 2007)

Temperate Maritime Climate

Poulton et al. (2003)

Poulton et al. (2003) investigated the changes in soil carbon that occurred during the afforestation of old arable land to deciduous forest in Hertfordshire, UK. Over this 120 year period, it was concluded that afforested land has the capacity to accumulate large amounts of carbon in both soil and tree wood (Poulton et al., 2003). Nitrogen accumulation was determined to be the main limiting factor for carbon sequestration in regenerating forest (Poulton et al., 2003).

DeGryze et al. (2004)

A study performed by DeGryze et al. (2004) consisted of the conversion of cropland to afforested broadleaf tree area in Michigan, USA. In the 0-50 cm layer of soil, the amount of carbon was unchanged between the cropland and afforested land (DeGryze et al., 2004). Alternatively, an increased level of soil carbon was found in the successional system (DeGryze et al., 2004). DeGryze et al. (2004) estimate that it may take up to 40 years for subsurface carbon stocks to increase in afforested areas.

Temperate Maritime Climate

Zerva & Mencuccini (2005)
This publication analyzed carbon stock changes after the afforestation of grassland through the use of coniferous trees in northeast England, UK (Zerva & Mencuccini, 2005). Zerva & Mencuccini (2005) found that there were significant changes in soil carbon amount, concentration, and density. It was recorded that carbon stocks dropped in the first rotation and then rose up to similar levels as the natural grassland during the second rotation (Zerva & Mencuccini, 2005).

Temperate Maritime Climate

Poulton et al. (2003)	DeGryze et al. (2004)	Zerva & Mencuccini (2005)
“The acidic site gained **2.00 t/ha/yr** (of carbon) over the 118-year period.” The calcareous site gained **3.39 t/ha/yr** over the 120-year period.” (Poulton et al., 2003)	“The successional system increased total soil C (0–50 cm) at a rate of **0.786 t/ha/yr**.” (DeGryze et al., 2004)	“The vertical distribution of carbon also changed, with proportionally **more carbon stored in the litter and inside the mineral layer** and less in the organic layer after afforestation and two rotations.” (Zerva & Mencuccini, 2005)

Tropical Climate

Bashkin & Binkley (1998)	Mendham et al. (2003)
Bashkin & Binkley (1998) studied differences in soil carbon content after the afforestation of cropland with eucalyptus trees in Hawaii, USA. In the 0-10 cm layer of soil there was an increase in carbon after at least 10 years, but almost the same amount of carbon was lost in the 10-55 cm layer resulting in a negligible net gain of SOC (Bashkin & Binkley, 1998). The decrease in carbon in the lower soil layer was most likely due to the land use change (Bashkin & Binkley, 1998).	In southwestern Australia, Mendham et al. (2003) conducted a study where pasture was converted into broadleaf tree plantation. 7-10 years after afforestation, there were no noticeable changes in soil carbon quantities (Mendham et al., 2003). Although there was no increase in SOC, there was still increases of carbon in course roots and surface litter of the plantation site (Mendham et al., 2003)

Tropical Climate

Bashkin & Binkley (1998)	Mendham et al. (2003)
"*Eucalyptus* increased total soil C in the 0–10 cm layer by **11.5 Mg/ha,** but that was offset by a loss of **10.1 Mg/ha** of cane-derived C from the 10–55 cm layer." (Bashkin & Binkley, 1998)	"Plantation soils had an average of **3.1 Mg/ha** more C in coarse roots than pasture, and significant quantities of C in surface litter." (Mendham et al., 2003)

Afforestation as a Solution to 4 Per 1000?

- May cause an increase in SOC, providing a short term solution to climate change (Hansen, 1993; Poulton et al., 2003; Morris et al., 2007)
- Can further reduce atmospheric Co2 through storage of carbon in tree biomass and the forest floor (Richter et al., 1999; Markewitz et al., 2002; Mendham et al., 2003; Wang et al., 2006)

YES

- Could possibly have no effect on SOC sequestration, or effects incomparable to natural forests (Bashkin & Binkley, 1998; Markewitz et al., 2003; Mendham et al., 2003; Degryze et al., 2004)
- May require a long amount of time for there be sequestration of carbon in the soil (Markewitz et al., 2002; DeGryze et al., 2004; Zerva & Mencuccini, 2005; Wang et al., 2006)

NO

CONCLUSION

Summary and Recommendations

Summary

- Afforestation has the potential to increase organic carbon in soils but the magnitude (and direction) in change in organic carbon is dependent on various factors, including species of tree used, climate, previous land use, soil type and initial organic carbon levels, and amount of time provided
- Afforested cropland soils were the most effective in gaining SOC when compared to pasture and grassland (Laganière et al., 2009)
- Broadleaf tree species have a higher potential to sequester soil carbon than coniferous trees (Laganière et al., 2009)
- In the Boreal climate zone, afforestation resulted in the smallest initial decreases of SOC in comparison to other climate zones (Laganière et al., 2009)

Recommendations

Afforestation has the potential to increase the sequestration of organic carbon in the soils and fulfill the goals of the 4 per 1000 initiative. The conversion of cropland into broadleaf tree forests may be the most effective practice of afforestation, allowing for the highest capacity of carbon to be stored in the soil (Laganière et al., 2009). Further research needs to be conducted on the effects of climate zone on afforestation and SOC storage.

Atmospheric CO_2, and ultimately greenhouse gases, can be reduced through SOC sequestration as well as carbon storage in the tree biomass and forest floor (Richter et al., 1999; Markewitz et al., 2002; Mendham et al., 2003; Wang et al., 2006). For this reason, afforestation can play an important role in achieving the goals set out by the 4 per 1000 initiative, as it can restore degraded agricultural soils in addition to possibly being a short term solution to climate change.

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