Increasing the amounts of organic matter in agricultural soils as a means of climate change mitigation

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WISEST

Women in Scholarship, Engineering, Science, and Technology

Final Project
July 2020

Introduction

Ever since the industrial revolution, humans have continued to create an unbalance in our planet's natural equilibrium with our excessive production. As a result of this improved productivity, the world's population was able to grow at an exponential rate, creating a greater demand for resources. This meant an increase in food production, as well as an increase in land use to cultivate this food and to expand residential and commercial space. Natural forests were either burned or cut in order to accommodate for this growth, the land being repurposed for human consumption. The Amazon rainforest, for example, takes in approximately 2 billion tonnes of carbon dioxide per year (Nobre, 2020), around 5% of our global emissions, and yet we are still destroying its ecosystems to make room for grazing or croplands. Consequently, there has been a drop in the rate of photosynthesis, and thereby a decrease in the amount of carbon dioxide being taken from the atmosphere. The change brought about by this loss of natural ecosystems will be dramatic, and we may find ourselves struggling to adapt (Houghton, 1994).

Human industry is interfering with the carbon cycle's regulation of one of the most fundamental elements, and its impacts can be seen throughout almost every environment. Carbon plays a significant role in life on earth, but for the purposes of this paper we will be focusing on its role pertaining to soils. During its cycling, plants pull carbon out of the atmosphere in the form of carbon dioxide through a process called photosynthesis where it is then incorporated into their structure or used as an energy source. When a living thing dies, the leaves, roots, or branches fall to the ground as organic matter, and are then decomposed by microorganisms who respire this carbon back into the atmosphere. It is the organic matter that remains resistant to this decomposition or that becomes chemically bound to the soil that makes up the soil carbon pool. It should be noted that by holding approximately 2,500 Gt of carbon (Schwartz, 2014), the global soil carbon pool stores more than three times that of the atmospheric carbon pool (Gross & Harrison, 2019). Soil is not only an important reservoir for carbon, it depends on its presence. The soil organic matter is the primary indicator of soil health, as its role in water retention, soil biodiversity, fertility for plants, and erosion resistance (4 per 1000, 2018) allow for ecosystem growth and sustainability. The cycling of carbon through photosynthesis could be the most crucial aspect to maintaining ecosystem health, food production, and atmospheric balance. The problem is that the environmental systems that are responsible for maintaining life on earth have a limit, and by remaining steadfast in our outdated approaches we are exceeding these limits. This is why the 4 per 1000 project came into the picture.

The 4 per 1000 initiative ('4 per mille Soils for Food Security and Climate') was brought forth by French minister Stéphane Le Foll at the COP21 following the creation of the Paris Climate Agreement. The goal of this project was to increase soil organic matter by 0.4% (or 4/1000) each year in hopes of offsetting anthropomorphic emissions and improving food stability in order to stay under the Paris agreements threshold of a 2°C increase in the planet's temperature. Global warming is an international threat which requires a solution that can be implemented across the majority of the earth's landscape. This is why 4 per 1000 chose to make use of an often overlooked asset in climate change mitigation; soil. Through various management plans and land use models, agricultural soils can be used as a carbon sink rather than remain a source. The five principle practices described by the project being seen as capable of increasing soil organic matter (SOM) are; land restoration, conservation of natural ecosystems, covering bare soil, adding organic matter in the form of organic fertilizers, planting nitrogen fixing plants, and allowing water to pool at the foot of plants. (4 per 1000, 2018) That being said, there are treatments and landscapes that hold a higher capacity for carbon sequestration in their soils. The more depleted the land is, the higher its storage threshold, or its maximum level of carbon saturation (Minasny et al., 2017). Details like this will be further discussed, as well as an examination of the effects of several treatment types, with the goal of investigating if the methods described in the 4 per 1000 initiative can be used as short-term solutions to climate change. The treatments included in this paper have been chosen for their promising results, and because of the greater knowledge base and availability of papers as compared to other mechanisms described by the 4 per 1000's article. There are other promising solutions, but these four caused the greatest amount of interest for me personally.

Discussion

Agroforestry

In this section, the findings from multiple papers will be discussed, as well as some specific issues or downfalls that have been observed with this management system. For some background, agroforestry is a type of agricultural management that involves the incorporation of woody vegetation (i.e. trees or shrubs) into cropland or pastures (Shi et al., 2018), however for the purpose of this paper only data pertaining to agroforestry and cropland will be included.

The four main grouping types in this practice are homegardens, alley croppings, silvopastures, and windbreaks (Shi et al., 2018). Of these groups, it has been found that homegardens, on average, have been the most successful in deep soil carbon sequestration (Shi et al. 2018; Hombegowda et al., 2016), perhaps due to their increased tree density. Since the decline in the amount of carbon (C) sequestration overwhelmingly follows the sequence of forest, agroforestry, plantations, arable crops (Nair et al., 2009a), it is assumed that homegardens resemblance to a natural forest brings with it its C storage promoting characteristics (i.e. shade cover, biodiversity, large tree content, increased litter). Homegardens as well as certain coffee plantations have even been found to replenish their soil organic carbon levels to that of a natural forest in that area (Hombegowda et al., 2016).

Throughout all of the findings, agroforestry as a whole was deemed to be a better alternative to traditional cropland in regards to carbon capture, with a 19% C stock increase in agroforestry (homegarden, alley cropping, silvopasture, and windbreaks) when compared to the cropland controls (Shi et al., 2018). It should be noted that the effectiveness of this practice depends on many variables, especially during the initial stages of its implementation. If one is converting natural forest to an agroforestry system, a 50-61% loss of carbon stock can be expected (Hombegowda et al., 2016), so the added organic carbon from the agroforestry system will simply be returning the lost carbon from the deforestation instead of capturing excess carbon dioxide from anthropogenic sources, and as a result, will not fulfill its intended purpose for the 4p1000 initiative.

The tree's species and age also have an impact on a system's C storage capacity (Zaro et al., 2020). This becomes evident when comparing C storage under the topsoil layer (30-100cm) in coffee systems, which stored 26% of its carbon in the subsoil, to homegarden, mango, and coconut systems, which stored 58%, 50%, and 59% respectively in their subsoils (Hombegowda et al., 2016). So while agroforestry has potential as a climate change mitigation strategy there is still a lot of research that needs to be done (Lorenz & Lal, 2014) in order to understand the best ways of implementing and maintaining this complex system. There are other known mechanisms that have been found to offer similar benefits as agroforestry, and the details of their results will be described in a similar manner as agroforestry was here.

No-till/Reduced till, Residue Incorporation, and Cover Crop

The discussion of these three treatment types have been combined into one section, as the majority of the experiments used in this review have chosen to apply them together in the same field. Let it be known that there are a few examples where the specific treatment has been applied without the others, or has been used in conjunction with only one of the remaining treatments. For some context, no-till agriculture is a method in which the soil is not disturbed before planting, as it would be with conventional ploughing/tilling. Residue incorporation often goes hand in hand with no-till practices, as it allows for the litter/old crops to remain on the soil surface, and hopefully get incorporated into the soil profile as organic matter. Cover crops are planted with the purpose of soil coverage, as the name indicates. This helps protect against the erosion of bare soils due to environmental factors, as well as acting as litter for residue incorporation.

In most of these studies, residue incorporation proved to be the largest contributor of organic matter at different depths (Angers et al., 1997), with a no-till (NT) accompaniment being found to increase C levels at the surface (0-30cm) layer (D'Haene et al., 2009; Angers et al., 1997), and a conventional tilling (CT) accompaniment contributing a considerable amount of organic matter in the subsurface layer (30-60cm) (Angers et al., 1997). This difference can most likely be attributed to the deep incorporation provided by the discs and ploughs in CT, which are able to move the residues further down than residues remaining on the soil surface in NT would be able to reach naturally at the same pace.

There were, however, cases where NT practices were found to greatly increase organic carbon stocks in the subsurface level. A good point for this finding is that by allowing the old crop/cover crop to remain on the surface, one is promoting deep root development (Piva et al., 2012), and is adding a form of protection against environmental conditions which slows the rate of organic matter's decomposition, thereby reducing carbon dioxide emissions (Powlson et al., 2016). The type of plant root also has a big impact on the amount of C stored (Boddey et al., 2010; Veloso et al., 2018). Legume plants, for example, have nitrogen fixing roots which help improve root growth of the adjacent crops (Boddey et al., 2010). The increase in root growth in lower depths and their subsequent contribution to the soil carbon pool upon death is a big factor in cover crops success in deep C sequestration as compared to organic amendments (Katterer et al., 2011). So while it may seem that NT is not effective enough, we must look deeper to truly understand its potential when combined with treatments such as cover crops and residue incorporation.

There are some notable issues when applying these treatment types that are worth a closer look at in future studies looking at their impacts on climate mitigation. First of all, the implementation of cover crops in a system requires the farmer to purchase and apply a greater amount of weed and pest controlling chemicals. Not only does this increase costs, it requires a greater production of products (i.e. herbicides, pesticides, fertilizers) who's manufacturing adds to global emissions, and who's transportation creates the same counterproductive effect as well. Another noted concern is the increased decomposition of residue when combined with no-till agriculture. Since the organic matter is left on the surface, it is left exposed to its environment, where the heat from the sun, or the increased oxygen exposure will speed up the decomposition process (Powlson et al., 2016), thereby contributing to emissions and limiting the viable organic matter that can be stored in the soil. Lastly, no-till when applied as the sole treatment seems to serve more as a beneficial method for keeping previously sequestered carbon in the soil, as opposed to a means of increasing the storage of atmospheric carbon dioxide. The effects of no-till, cover crops, and/or residue incorporation seem to promote carbon sequestration at the highest degree when combined with one another (Kumar et al., 2019; Powlson et al., 2016), but there remains some uncertainty in their effectiveness in certain areas and management styles.

Conclusion

Each treatment type discussed offers a unique method to help with the mitigation of greenhouse gases, carbon in this case, that is released from or that is stored in agricultural fields. When compared to adjacent cropland, agroforestry was found to have been overall more successful in C sequestration, homegardens being the most effective out of the four varieties. Based on these findings, I believe that agroforestry should be considered when talking of potential short-term climate change solutions. A few more added benefits would be an increase in biodiversity, and the increased photosynthesis from the trees. There are of course variables that need to be taken into account in each separate location this strategy is being considered for application. If a natural forest is being destroyed, and is then replaced by agroforestry, the results will likely trend towards a net loss of carbon from the soil (Hombegowda et al., 2016). A drawback of this system could be that the length of time it takes a tree to mature to its most efficient age (Shi et al. 2018) for C sequestration, could fall behind the target of 0.4%/year that the 4 per 1000 initiative has deemed necessary to offset anthropogenic emissions.

The second topic discussed also proved to have many benefits to its implementation. Cover crops in general help the quality of soil thanks to their offered protection from erosion, and added residue on the soil surface as litter, as well as added organic matter as roots in subsurface layers. When coupled with no-till, all of these sources of added carbon can be achieved due to a decrease in soil disturbance from the elimination of plowing. In regards to whether or not these practices are feasible for 0.4% of C storage, I would say yes, but only if used together. For an example of the drawbacks of a single treatment method, no-till when applied alone was found to only affect the first 30cm of soil (Angers et al., 1997), which is not optimal for continued storage we are looking for in this review. It is only when the added organic matter from the cover crops and residual plant litter is involved that there is a significant increase in deep soil carbon stocks. So for the no-till, cover crop, residue incorporation studies, the overwhelming consensus is that these practices when combined promote C sequestration, or at the very least, keep already stored carbon in the soil (D’Haene et al., 2009).

Lastly we will discuss some possible downfalls of these methods. A common issue across all observed papers was the fickle nature of the location types. Different areas require different management types (Powlson et al., 2016), meaning that an in depth analysis of the soil type, climate, prior land use, as well as many other factors would need to be done prior to implementation. This process would take time and resources that would slow down progression towards meeting the 4 per 1000’s goal, and therefore would not be as useful a solution against climate change. Another possible area of concern would be the economic factors accompanying the conversion and maintenance of the different systems. All treatments studied required more labour for planting, applying more fertilizers and pesticides, and spending more money on gas. It can be assumed that farmers or landowners would be reluctant to increase their spending without some added profit from improved yields or subsidies. No-till agriculture’s lower labour needs was the only form of management that reduced spending.

All things considered, I believe that the public should consider looking into these practices when searching for climate change solutions. Any one of these on their own would not rise to meet the 0.4% of stored organic matter, but the complimentary effects they provide when practiced together could be enough to get us there. More research on this topic should be conducted in every variety of environment in order to make future administration more feasible, and to hopefully increase the public’s knowledge of these possible strategies to increase organic matter in agricultural soils as a means to mitigate climate change and enhance soil quality and sustainability.

Acknowledgements

I would like to express my sincere gratitude for all who made this project possible for me. To WISEST for giving me this amazing opportunity to experience and appreciate the world of research. To Bridget and Deb, for their unwavering support and encouragement throughout this month, all of us student researchers could not have made it through without your guidance, and of course, your pre-PD chats. To Mattise Rensburg for her support and help proofreading. To Mr. Cole Gross for introducing me to the incredible field of soil science, I'm sorry I couldn't be in the lab sifting samples with you. To Dr. Edward Bork for the short, but entertaining conversation on agriculture, and sustainability. And finally, thank you to my fellow SRP teammates who's kindness and friendship made this program an experience one that I will never forget.

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