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# Conservation Agriculture as Climate Change Mitigation

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## Abstract

Ethiopia's economy and ecological system are fragile and vulnerable to climate change. Conservation agriculture (CA), comprising minimum soil disturbance, retention of crop residues and crop diversification, is widely promoted for reducing soil degradation and improving agricultural sustainability. This review paper encompasses the role of conservation agriculture for climate change mitigation. Soil Organic Carbone (SOC) increases are reversible and the climate change benefit relies on the new management practice continuing indefinitely. To achieve long term climate change mitigation, the additional SOC must be in recalcitrant forms. As several studies indicate that the additional C accumulated under CA practices such as no-till is concentrated in particulate organic fractions or other forms considered 'labile' with only marginal increases in more recalcitrant form The important point is that simply because SOC benefits are demonstrated under experimental conditions, the large scale adoption of conservation agriculture (CA) in regions dominated by resource poor smallholder farmers may be extremely slow: its is therefore unwise to rely on adoption of CA as a major strategy for climate change mitigation. One kg additional $N_2O$ emitted per ha will offset 0.13 MG C per ha sequestered. In many cases CA practice will be functional only a small degree of climate change mitigation through soil carbon sequestration.

**Keywords:** Conservation Agriculture, Climate Change, Climate Change mitigation, N fertilizer

## 1. Introduction

### 1.1. Background and justification

Conservation agriculture (CA), comprising minimum soil disturbance, retention of crop residues and crop diversification, is widely promoted for reducing soil degradation and improving agricultural sustainability (Powlsonet al., 2015). A group of crop management practices termed "conservation agriculture" (CA) are widely promoted to increase crop yields, reduce soil degradation and develop systems that are more resilient to weather-induced stresses including those caused by climate variability and change (FAO, 2001; Kassam et al., 2009; Thierfelder and Wall, 2010; Jat et al., 2012). Although CA shows great promise in many agro-ecological environments, there is continuing vigorous debate about its practical feasibility under certain farmer circumstances, especially for smallholders in mixed crop/livestock systems in tropical regions, where there is competition for crop residues between their use as animal feed as opposed to soil retention (Giller et al., 2009, 2011; Valbuena et al., 2012).

The impact of climate change on agricultural productivity is severe in Sub Saharan Africa (Mohammed *et al.,* 2020). It is due to low adoption of key production technologies that enhance adaptation to climatic change and increase productivity.Future work need to consider also studying the effects of different climate change adaptation strategies(Mohammed *et al.,* 2020). It is thus against this scenario and statistics that, rural farmers have to consequently adopt farming practices that conserve fragile soils and improve its fertility for improving crop production in marginal rainfall regions.

Ethiopia's economy and ecological system are fragile and vulnerable to climate change (César and Ekbom, 2013). Food security is highly sensitive to climate risks and rainfall is one of the main climatic determinants of food production in Ethiopia. Rainfall is highly erratic and unreliable (Stroosnijder and Van Rheenen, 2001; Mesfin et al., 2009) in respect to mainly the delay in the onset and early cessation this intermittent long dry spell throughout the growing season has a tremendous influence crop production (Rockstrom, 2000; Abdelkdair and Richard, 2005) and it is the main risk contributing to food insecurity and overall vulnerability of households. The vulnerability to climate-related hazards and food insecurity is closely linked to land degradation, in which about 85% of the land surface in Ethiopia is considered susceptible to moderate or severe soil degradation and erosion. Moreover, the main reasons for dryland cropland degradation in Ethiopia include complete removal of crop residues at harvest, aftermath overgrazing of livestock, frequent tillage, drought and inefficient use of technologies and practices (Manado, 1997; Taddese, 2001). Farmers in the study areas plough their land 3-5 times for Sorghum and maize crops per season using traditional equipment 'Maresaha'. Repeated tillage accelerates SOM decomposition (Doran and Smith,1987) and water runoff and soil erosion (Derpsch et al., 1991), and other manifestations of physical, chemical and biological soil degradation (Benites, 2008; Kerte´ szet al., 2008), and it has been reported to be the main cause of land degradation in Ethiopia (Tefera, 2002). This review paper encompasses the role of conservation agriculture for climate change mitigation. So, the objective of this review paper was: (1) to asses soil carbon sequestration for climate change mitigation; (2) To overview soil organic carbon condition under conservation agriculture in the context of climate change mitigation; (3) To assess the adoption by farmers of practices leading to SOC increases and implications for climate change mitigation; (4) To review the Nitrogen management as a climate change mitigation.

## 2.Conservation agriculture as Climate change mitigation

### 2.1. Soil carbon sequestration for Climate change mitigation

As indicated by different scholars, examples; Batjes, (2014); Scharlemann*et al*., (2015), the concept of sequestering organic carbon in soil to mitigate climate change arises because past land clearances caused a major decline in the global SOC stock and released CO2 to the atmosphere. so, in principle, there is potential to reverse this trend (Smith *et al*., 2008). SOC stocks are significant at the global scale, recently estimated at some 1500 Pg C to a depth of 1 m (Batjes, 2014; Scharlemann*et al*., 2015), about twice the amount in atmospheric CO2 and three times that in global vegetation. However, there are well known general limitations to the approach (Freibauer *et al*., 2004; Janzen, 2006; Powlson*et al*., 2011a; Stockmann *et al*., 2013; Sommer and Bossio, 2014).

According to Dimassi*et al*. (2013), the capacity for SOC accumulation is finite. Carbon content moves towards a new equilibrium value then increases no further. SOC increases are reversible and the climate change benefit relies on the new management practice continuing indefinitely. To deliver long-term climate change mitigation the additional SOC must be in recalcitrant forms. Several studies indicate that the additional C accumulated under CA practices such as no-till is concentrated in particulate organic fractions or other pools considered 'labile', with only marginal increases in more recalcitrant pools (Wander *et al*., 1998; Machado et al., 2003; Chivenge et al., 2007; Bhattacharyya *et al*., 2011, 2012; Tivet *et al*., 2013; O'Rouke*et al*., 2015). The largest amounts of SOC sequestration are obtained by taking agricultural land out of production and returning it to native grassland or forest but this change in land use conflicts with meeting food security goals (Smith et al.,2008).

In addition, reliably monitoring relatively small changes in Soil Organic Carbon (SOC) in agricultural soils following a management change is challenging due to a combination of soil variability and slow rates of change (Smith, 2004; Batjes and van Wesemael, 2015). This is exacerbated in many tropical regions due to a lack of monitoring networks or long-term experiments to complement site-based measurements (Batjes and van Wesemael, 2015). On the positive side, a soil C sequestration strategy can, in principle, start immediately, is not dependent on development of new technologies and will normally improve soil quality and contribute to a range of ecosystem services (Verhulst et al., 2010; Powlson*et al*., 2011b, 2014; Palm *et al*., 2013; Lal, 2015). Even small increases in labile SOC fractions can have positive effects on a range of soil physical properties, and thus potentially improve the resilience of soils to stress and contribute to climate change adaptation (Watts *et al*., 2006; Powlson*et al*., 2011b; Thierfelder and Wall, 2012; Thierfelder et al., 2013a; Chakraborty et al., 2014).

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## 2.2. Soil organic carbon increase under conservation agriculture in the context of climate change mitigation.

Many conservations practice (CA) practices including zero tillage increase the concentration of soil organic Carbone (SOC) in the surface layers of soil, which is beneficial for soil quality, but it does not necessarily follow that SOC stock is increased which is necessary for climate change mitigation.According to Mohammed (2022) the mean SOC stocks were higher among the vegetation communities in Norther than in the Southern aspects of Bale Mountain. CA contributes for vegetation community increment.Furthermore, it is incorrect to assume that every management practice leading to an increase in SOC stock mitigates climate change: interpretation has to take account of the processes leading to the SOC increase and whether or not there is a net transfer of C from atmosphere to soil compared to conventional practice (Powlson et al., 2011a; Stockmann et al., 2013; Sommer and Bossio, 2014). In the context of CA, certain types of crop diversification undoubtedly deliver an increased transfer of C from atmosphere to soil through a greater input of photosynthate. This is true for legume inter-crops grown between rows of maize, as promoted in regions of SSA where rainfall is sufficient to support growth of the extra crop without compromising yield of the main crop (Sakala et al., 2000; Myaka et al., 2006; Thierfelder et al., 2013c) or where an additional crop is grown in the period between other crops where the soil would otherwise be fallow (double or relay cropping; Ghosh et al., 2012; Mupangwa and Thierfelder, 2014). It is also possible that replacing one of the crops in an existing system with another could increase C inputs to soil: this depends on the root biomass of the replacement crop and the proportion of its above-ground biomass returned to soil compared to the conventional system. It also depends on the decomposability of the input from the replacement crop as influenced by its chemical composition (Vanlauwe et al., 2005. In addition to increasing soil C stock and concentration, diversification can deliver benefits to the farmer through the economic value of the additional crop, though there are often significant barriers to overcome regarding availability of seed, additional labour requirements and the establishment of local markets for new crops (Thierfelder et al., 2012, 2013c). In principle, zero tillage can lead to genuine C sequestration and climate change mitigation if it slows the rate of decomposition of existing SOC or promotes stabilization of incoming organic C (Powlson et al., 2011a; Stockmann et al., 2013), but the impact on SOC is often a matter of depth redistribution rather than net accumulation, at least in the short to medium term (Baker et al., 2007; Angers and Eriksen-Hamel, 2008; Govaerts et al., 2009; Luo et al., 2010; Virto et al., 2012; Powlson et al., 2014).

The studies in temperate region showed that the impact of cereal straw incorporation on SOC content to be small and often non-significant, even when continued for up to 25 years (Powlson et al., 2011b). The rate of residue decomposition, and hence SOC accumulation, is more sensitive to environmental conditions (temperature, moisture) for surface-applied residues, as in CA, than for those that are incorporated (Helgason et al., 2014). Smaller SOC increases are expected in tropical regions compared to temperate due to more rapid decomposition under higher mean temperatures. Whether or not SOC increases produced by residue retention constitute climate change mitigation depends on the alternate fate of the residues under conventional practice. If the alternative is burning in the field, as is often the case in rice wheat systems in the western IGP, then any retention of residue-derived C in soil in a CA treatment, however small, is C that would otherwise have been emitted to the atmosphere during burning: in this situation the SOC increase represents genuine climate change mitigation. Residue-derived C not respired during digestion by the animal will be converted into manure and in most situations, certainly in SSA, manure is applied to soil by farmers because it is a valuable source of crop nutrients and of organic matter for improving soil properties. There will be some gaseous loss of manure C to the atmosphere as CO2 or methane, the amounts depending on numerous factors especially the period of manure storage and whether or not it is composted. But at least part of the original residue-derived C would have been returned to soil in manure under conventional practice, though often to a different field. Consequently, it is incorrect to treat the whole of the SOC increase from residue retention under CA as climate change mitigation. Because of the diverse range of situations in the two regions it is not possible to make a realistic estimate of the proportion of residue-derived C that would be returned under conventional practice, and hence the appropriate amount to discount SOC increases from direct residue return under CA. A significant quantity of animal manure (which includes residue-derived C) is dried and then burned as fuel for cooking or domestic heating, leading to complete loss of its C to the atmosphere. In these situations, it is reasonable to regard SOC increases from direct return of crop residues as retention of C that would otherwise have been emitted to the atmosphere and thus genuine climate change mitigation. Provision of alternative domestic energy sources in rural areas would be an influential policy to promote residue retention in the field with benefits for both climate change mitigation and soil quality (Helgason et al., 2014).

### 2.3.Adoption by farmers of practices leading to SOC increases andimplications for climate change mitigation

Even where genuine increases in SOC from CA can be demonstrated in experiments, and where they can correctly be interpreted as delivering climate change mitigation through soil C sequestration, there are often significant technical, infrastructural, social or policy barriers to the adoption of the new practices by smallholder farmers in regions such as SSA. This topic has been discussed in detail elsewhere (Gowing and Palmer, 2008; Govaerts*et al*., 2009; Giller *et al*., 2011; Thierfelder *et al*., 2012; Andersson and D'souza, 2013; Thierfelder *et al*., 2014; Corbeels et al., 2014; Mason *et al*., 2015) and there are some examples of these barriers being overcome (Thierfelder et al., 2014; Tittonell*et al*., 2012). The important point is that simply because SOC benefits are demonstrated under experimental conditions, the large-scale adoption of CA in regions dominated by resource-poor smallholder farmers may be extremely slow: it is therefore unwise to rely on adoption of CA as a major strategy to mitigate climate change.

### 2.4. Nitrogen management as climate change mitigation strategy as compared to conservation agriculture.

To place the degree of climate change mitigation possible from CA into a wider context it is appropriate to compare with the potential from other agricultural approaches. Management of nitrogen (N) fertilizer is an obvious comparison because of its large greenhouse gas footprint (Brentrup and Pallière, 2008; Zhang *et al*., 2013; Cheng *et al*., 2015). There are numerous examples of relatively simple improvements in N fertilizer management either leading to decreased total applications whilst maintaining, or even increasing, crop yields or of changes in practice leading to increased N use efficiency such that a given rate of N produces increased yield (Khurana et al., 2008; Sapkota et al., 2014). These improvements in N management inevitably lead to decreased emissions of N2O or, even if total emission is not decreased, to a decrease in yield-scaled emissions (Bhatia *et al*., 2012; Chauhan et al., 2012). i.e., emission expressed per ton of grain (Linquist *et al*., 2012). As indicated by Davison, (2009), an emission saving equivalent to 0.16 Mg C ha1 yr1 if calculated using an emission factor of 2.5% for N fertilizer (i.e., 2.5% of applied N fertilizer released to the atmosphere as N2O-N through a combination of direct plus indirect emissions (Davidson, 2009). This is of the same order as GHG reductions possible from soil C sequestration. According to Smith et al. (2012), each 1 kg of N fertilizer is responsible for an emission of 11.7 kg CO2e, equivalent to a change of 3.2 kg SOC. The benefit from N management could be even greater as there is some evidence to indicate that emission factors could be as large as 4% of applied N (Smith *et al*., 2012). Even using the current IPCC default emission factor of 1.25% the GHG saving from reduced N fertilizer use is substantial and sustainable. Even relatively small changes in the timing of N applications, but with the same total dose, can deliver a significant decrease in N2O emission. The measured annual N2O emission decreased by 16%, equivalent to 0.04 Mg C ha1 (Bhatia et al., 2012). A key advantage of decreasing GHG emissions through N management is that unlike soil C sequestration the benefits are irreversible and can continue indefinitely. In addition, CA practices themselves can sometimes increase the efficiency of use of N fertilizer (Jat *et al*., 2012; Sapkota et al., 2014), thus providing a synergy between CA and N fertilizer management that contributes to decreased GHG emissions. There are however numerous barriers to increased inputs of fertilizers due to a range of cost and infrastructure issues (Montpellier Panel, 2014) so any conservation of nutrients through improved management such as retention of crops residues, or inputs of N through inclusion of legumes as an aspect of crop diversification, is highly beneficial for food security whether or not it contributes to climate change mitigation. Increased N inputs from any source will almost inevitably cause an increase in total N2O emission from agriculture in the SSA. This would appear to be a necessary cost of improving food security however, with the associated increased yields, yield-scaled emissions would be expected to decrease (Linquist et al., 2012).

### 2.5. Effect of reduced tillage on nitrous oxide emissions

In some circumstances zero tillage may lead to increased emission of N2O, but this is not universally observed (Van Kessel et al., 2013). There is currently a paucity of evidence on the impact of zero tillage or other aspects of CA on N2O emissions in the IGP or SSA regions. However, the issue is crucial for determining the potential for CA to mitigate climate change as even a small increase in N2O emission will offset a gain in SOC (Grandy et al., 2006). One kg additional N2O emitted per ha will offset 0.13 Mg C ha1 sequestered. In a situation with high rates of N fertilizer, a combination of no-till and straw retention led to a decrease in N2O emission but equal or increased crop yields compared to conventional tillage with straw removed (Huang et al., 2015). By contrast, a study in Madagascar with intercropped maize-soybean on a clay soil (Chapuis-Lardy et al., 2009) showed no difference in N2O emission between a direct seeded mulch based system and traditional hand ploughing with previous crop residues removed.

## 3. Conclusion and recommendation

As different literatures showed, globally CA contribute significant for food security, and shows a general trend for all of the practices constituting CA to cause some increase in SOC stock, implying some degree of climate change mitigation through soil C sequestration. The wide variability between sites and agricultural systems indicates that it is incorrect to assume that results from a specific location are necessarily transferable. Most of the published values are almost certainly inflated by 20–30% (Palm et al., 2013) due to the inappropriate soil sampling method used: equal soil depth rather than equal soil mas This is an important yet frequently overlooked point. Where a significant increase in SOC stock is measured it is essential to assess the specific management practice responsible in order to determine whether it represents a net additional transfer of C from atmosphere to land, and hence genuine climate change mitigation, rather than a spatial redistribution of organic C in soil. SOC increases caused by crop diversification will almost certainly constitute genuine mitigation; this third principle of CA, which is often overlooked, warrants further assessment, especially in view of the potential multiple benefits it can deliver. However, it must be recognized that adoption of this change, and other CA practices, face considerable practical barriers for resource-poor smallholder farmers in the regions we considered. Thus, it would be unwise to assume that CA can be a key strategy for climate change mitigation. Therefore, we can conclude that in many cases CA practices will deliver only a small degree of climate change mitigation through soil carbon sequestration.CA practices can reasonably be regarded as contributing to climate change adaptation and to sustainable intensification, whether or not they consistently deliver increased crop yields in every season. We suggest that CA should be promoted on these grounds, in addition to any more direct livelihood benefits to farmers that will vary between regions and economic situations. Any contribution to climate change mitigation should be regarded as a welcome additional benefit, not as a key policy driver for promoting the practices. From a policy perspective there is a risk that a narrow focus on soil C sequestration can lead to an exaggerated view of the opportunities for climate change mitigation through CA or related practices with too little attention given to other approaches that may have greater potential and be more easily achieved in practice. One such example is the management of N fertilizer, whether through its direct management or through ensuring an adequate supply of other nutrients.

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