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Short communication

Carbon sequestration potential through conservation agriculture in Africa has been largely overestimated
Comment on: "Meta-analysis on carbon sequestration through conservation agriculture in Africa"

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Soil organic carbon (SOC) sequestration depends on several factors, including land use, pedo-climatic conditions, topographic position and the initial SOC stock (Post and Kwon, 2000; Minasny et al., 2017). At the plot scale, a positive SOC balance is created by increasing the input of organic matter to the soil to exceed the carbon (C) losses by mineralization, leaching and erosion or by decreasing the rate of SOC decomposition. In Africa, agricultural soils are generally known to have potential as a C sink due to previous SOC depletion (Vågen et al., 2005; Swanepoel et al., 2016). Two widely promoted crop management practices to store C in agricultural soils are conservation agriculture (CA) and agroforestry. Both practices can increase SOC through increased C inputs from higher biomass productivity and reduced C losses (through soil cover and reduced soil tillage), leading to a net transfer of C from the atmosphere to the soil, thus contributing to the mitigation of climate change (Smith et al., 2005; Powlson et al., 2011; Griscom et al., 2017).

In their recent study published in Soil and Tillage Research: "Meta-analysis on carbon sequestration through conservation agriculture in Africa", Gonzalez-Sanchez et al. (2019) conclude that the practice of CA in Africa can effectively contribute to mitigating global warming through SOC sequestration. Gonzalez-Sanchez et al. (2019) claim that the SOC sequestration potential through CA for the African continent is 143 Tg C yr^{-1} on 160 Mha cropland (including woody perennial crops) which corresponds to about 0.90 Mg C ha^{-1} yr^{-1}.

Good estimates of the SOC sequestration potential with CA are certainly of great interest to policymakers at various levels of government in Africa regarding the nations' commitments to reduce greenhouse gas emissions by 2020. As a result, greater investments in research and innovations for the development and scaling of CA practices may be decided. However, we argue that the mitigation calculations and interpretations by Gonzalez-Sanchez et al. (2019) are flawed and biased.

Gonzalez-Sanchez et al. (2019) evaluated datasets from a number of studies in Africa for their estimations of annual per-area SOC sequestration rates with CA practiced in annual or woody perennial cropping systems for four climatic zones (i.e. Mediterranean, Sahelian, Tropical and Equatorial, see Fig. 1 and Table 1 in their study). In their analysis, the total SOC sequestration potential for Africa was then calculated from the climate-specific rates and from estimated total land areas cultivated with annual and woody perennial crops in the different countries (from FAOSTAT, http://fao.org/faostat/en/#data), considering the major climate(s) in each country. Finally, they compared

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their estimate of sequestration potential with an estimated current annual SOC sequestration based on present areas of cropland under CA. They conclude that the total annual SOC sequestration potential through CA in Africa is about 93 times the current estimated figure.

Here, we challenge the excessively optimistic results of their study.

First, in contrast with their claims, the reported annual per-area SOC sequestration rates under CA in their study (see Table 1 in their paper) are high, ranging from 0.44 Mg C ha^{-1} yr^{-1} (Mediterranean climatic zone) to 1.56 Mg C ha^{-1} yr^{-1} (Equatorial climatic zone) for annual crops, and from 0.12 Mg C ha^{-1} yr^{-1} (Sahelian climatic zone) to 1.29 Mg C ha^{-1} yr^{-1} (Mediterranean climatic zone) for woody perennial crops. The resulting average rates for the whole of Africa are 0.92 and 0.70 Mg C ha^{-1} yr^{-1} for CA with annual and woody perennial crops, respectively (recalculated from Table 3 and 4 in their study). Even though Gonzalez-Sanchez et al. (2019) refer to their analysis as a meta-analysis, their reported figures do not reveal any use of statistical tests, lacking any indicator of data variability and uncertainty of their estimates. In fact, from their paper it is not clear which, and how many studies were used for their estimates of annual per-area SOC sequestration rates. They simply list the publications they referred to but do not cite any "supplementary information" that presents the data used to derive their mean values.

We estimated average SOC sequestration rates for CA on croplands per climatic zone from published studies used in a recent literature review (Corbeels et al., 2019). Our results for the Tropical and Equatorial climate zones show rates that are 20–60% of those reported by Gonzalez-Sanchez et al. (2019) and show high variability (Table 1). Since the review by Corbeels et al. (2019) only referred to sub-Saharan Africa (excluding South Africa), the Mediterranean region was not considered. No studies were found in Corbeels et al. (2019) for the Sahelian climatic zone. The sequestration rate of 0.5 Mg C ha^{-1} yr^{-1} for annual crops in the Sahelian region given by Gonzales-Sanchez et al (2029) seems, however, extraordinarily high given the strong water limitations to crop growth in this region. Average cereal yields in this region are 1000 kg ha^{-1} or less (http://fao.org/faostat/en/#data). Assuming a harvest index of 0.35 and a root:shoot ratio of 0.3 (corresponding to the 0–30 cm soil layer), this represents a potential annual input of about 2700 kg dry matter ha^{-1}, corresponding to about 1200 kg C ha^{-1}. A sequestration rate of 0.5 Mg C ha^{-1} yr^{-1} would mean that 42% of the C input is converted into SOC, which is clearly not plausible. A recent study on SOC sequestration in tropical croplands found that the conversion rate of C inputs to SOC was 8.2 ± 0.8% (Fujisaki et al., 2018). Smith et al. (2008) estimated that the annual per-area sequestration rate for no-tillage and residue management practices in warm-dry regions was about 0.10 Mg C ha^{-1} yr^{-1} with high uncertainty (range between −0.21 and 0.40 Mg C ha^{-1} yr^{-1}). Similar results were found for sub-Saharan Africa in the meta-analysis of Powlson et al. (2016).

Second, Gonzalez-Sanchez et al. (2019) estimated the cropland area in 2016 based on FAOSTAT. This area include land that has recently been converted from native forest or savannah. Given the relatively high original SOC stocks under forest or savannah land, converting this land into agriculture will induce SOC losses irrespective of the type of agricultural management practices employed (Sommer et al., 2018). For example, negative SOC sequestration rates (−0.17 to −0.55 Mg C ha^{-1} yr^{-1}) were reported in experiments in Nigeria where CA was installed following recent clearing of native vegetation (Lal, 1998; Agbede, 2008). Thus, new croplands should have been excluded from the calculations of the SOC sequestration potential. Based on data provided by FAOSTAT, the increase of cropland area over the last ten years in Africa is estimated at about 15 to 20%.

Besides, Gonzalez-Sanchez et al. (2019) included in their calculations the land area on which (most type of) woody perennial crops were cultivated in 2016. This land was considered as land where CA could be practiced, labelled in their study as "CA in woody crops due to ground cover". However, it seems that the annual per-area SOC sequestration rates (Table 1 in their study) were estimated from studies on agroforestry systems. In these studies, the control plot is a treeless agricultural plot having the same tillage practice as the agroforestry plot. Therefore, the SOC sequestration rates are due to the presence of trees and are not linked to CA practices. In agroforestry systems, the soil can be tilled and is not necessarily covered by a mulch of crop residues, and tree crops can be grown in crop monoculture, as this was the case in many of the cited papers. Therefore, these rates cannot be used for woody perennial cropping systems practiced under CA. To have an estimation of the effect of CA in woody perennial cropping systems, we would need treatments in agroforestry with CA and with conventional tillage, which was not the case in the publications cited by the authors. Moreover, we found that the SOC sequestration rates were highly dependent on the type of agroforestry system (Cardinael et al., 2018; Corbeels et al., 2019). It is therefore not correct to group them in a single category as proposed by Gonzalez-Sanchez et al. (2019).

Third, Gonzalez-Sanchez et al. (2019) did not address the adoption rate of CA by farmers, supposing that all estimated cropland area (including woody perennial crops) in 2016 is easily and immediately converted to CA. This is misleading. As stated in their study, adoption of CA in 2016 covered an estimated 1.5 Mha of land, or 1.1% of the total land area of annual crops. A realistically achievable mitigation potential must also consider the socio-economic realities of farmers (Smith et al., 2005). This consideration is crucial; it has been extensively discussed elsewhere (e.g. Giller et al., 2011) but was totally ignored by Gonzalez-Sanchez et al. (2019). Smallholder farmers in Africa often face significant technical, infrastructural or socio-economic barriers to the adoption of CA (Andersson and D'Souza, 2014; Corbeels et al., 2014). Therefore, it is not realistic to rely on immediate adoption of CA over millions of hectares as a major strategy to mitigate climate change (Powlson et al., 2016).

Fourth, we argue that the extrapolation of the per-area SOC sequestration rates over the whole of Africa using climatic zones is simplistic, ignoring important factors of SOC sequestration. Although a similarly simple approach is employed in the Tier 1 method of the Intergovernmental Panel on Climate Change (IPCC, 2006), it has clearly been shown in the broader literature that SOC sequestration depends to a large extent on soil properties (Feller and Beare, 1997; Torn et al., 1997). Countries in West Africa such as Mali, Burkina Faso or Niger are mainly characterized by sandy Arenosols and Lixisols, compared to e.g. Kenya, Tanzania or Ethiopia where largely Nitisols and Vertisols are present, that have a much more clayey texture. It is generally known that the SOC sequestration potential is considerably lower in sandy soils than in clayey soils (Chivenge et al., 2007). Yet in their analysis, the basic SOC sequestration rates used for e.g. Burkina Faso are the same (or higher) than of those for Ethiopia (Table 3 and 4). Digital soil maps for Africa are now available (http://soilgrids.org), which enables to include soil factors, such as soil texture, in SOC sequestration estimates, and could have been used by Gonzalez-Sanchez et al. (2019).

Finally, Gonzalez-Sanchez et al. (2019) compared their estimated SOC sequestration potential (i.e. 143 Tg C yr^{-1}) with an estimated (current) SOC sequestration based on the present cropland area under CA (i.e. 1.5 Tg C yr^{-1}). This is not correct. A baseline including other

Table 1
Soil carbon sequestration rates (Mg C ha^{-1} yr^{-1}, average and standard deviation) in annual cropping systems under CA per climate zone (data from Corbeels et al., 2019, values larger than 4 Mg C ha^{-1} yr^{-1} or smaller than −4 Mg C ha^{-1} yr^{-1} were considered as outliers and excluded).

Climatic zone	Soil carbon sequestration rate (Mg C ha^{-1} yr^{-1})
Sahel	No data
Tropical	0.58 ± 1.06 (n = 17)
Equatorial	0.32 ± 1.53 (n = 8)

n denotes the number of studies.
Soil depth considered varies between 5 and 60 cm.

best crop management practices that increase C input to the soil, such as fertilization, irrigation, improved crop rotations, and agroforestry, should be used. It has been estimated that 7–15 Tg C yr^{-1} can be sequestered on croplands in Africa, assuming 20% of the croplands are subjected to improved management (Batjes, 2004).

For the reasons given in our analysis, we believe that Gonzalez-Sanchez et al. (2019) grossly overestimated the total SOC sequestration potential through the practice of CA in Africa. Roughly, as a first approximation we estimate the potential at 10.8 Tg C yr^{-1} assuming an average per-area rate of 0.45 Mg C ha^{-1} yr^{-1} and that 20% of the current soil C-depleted (annual) croplands (estimated at 120 Mha) are cultivated with CA. Furthermore, it is important to note that SOC stocks do not increase forever, and that annual sequestration rates decline as the soil approaches a new equilibrium, which can take from 20 to +50 years depending on climate and soil type. Hence, rates cannot be extrapolated indefinitely (Paustian et al., 1997; Powlson et al., 2011, 2014). Lastly, it should also be mentioned that nitrous oxide (N_2O) emissions could be enhanced in CA and, more generally, in practices with addition of organic amendments (Charles et al., 2017; Lugato et al., 2018; Mei et al., 2018), partially offsetting the climate benefits due to increased SOC storage.

It remains critical that we determine rates of SOC sequestration through improved agricultural practices, and the role they can play in helping to meet short- to medium-term reduction targets of greenhouse gas emission. It would, however, be appropriate for Gonzalez-Sanchez et al. (2019) to reflect on a more conservative assessment of the mitigation potential through CA in Africa. The presentation of implausible potentials leads to unrealistic expectations of climate change mitigation with improved agricultural management. There is a danger that presenting unrealistically high numbers of climate change mitigation potential through agricultural practices could have a negative impact on the necessary actions to reduce CO_2 emissions from fossil fuel combustion.

On the other hand, even if CA has limited value for climate change mitigation, the practice of CA – through crop residue mulching and crop diversification- is expected to enhance the resilience of cropping systems to climate change (Rusinamhodzi et al., 2011; Steward et al., 2018). This may bring livelihood benefits to farmers, especially in regions with increased risk of drought stress. Thus, it is more reasonable for policymakers and investors to plan promotion of CA for reasons of climate resilience benefits than for climate change mitigation.

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