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1 **Carbon sequestration potential through conservation agriculture in Africa has been**
2 **largely overestimated**

3 *Comment on: “Meta-analysis on carbon sequestration through conservation agriculture in*
4 *Africa”*

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23 Soil organic carbon (SOC) sequestration depends on several factors, including land use, pedo-
24 climatic conditions, topographic position and the initial SOC stock (Post and Kwon, 2000;
25 Minasny et al., 2017). At the plot scale, a positive SOC balance is created by increasing the
26 input of organic matter to the soil to exceed the carbon (C) losses by mineralization, leaching
27 and erosion or by decreasing the rate of SOC decomposition. In Africa, agricultural soils are
28 generally known to have potential as a C sink due to previous SOC depletion (Vågen et al.,
29 2005; Swanepoel et al., 2016). Two widely promoted crop management practices to store C in
30 agricultural soils are conservation agriculture (CA) and agroforestry. Both practices can
31 increase SOC through increased C inputs from higher biomass productivity and reduced C
32 losses (through soil cover), leading to a net transfer of C from the atmosphere to the soil, thus
33 contributing to the mitigation of climate change (Smith et al., 2005, Powlson et al., 2011;
34 Griscom et al., 2017).

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

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

47 Gonzalez-Sanchez et al. (2019) evaluated datasets from a number of studies in Africa for their
48 estimations of annual per-area SOC sequestration rates with CA practiced in annual or woody
49 perennial cropping systems for four climatic zones (i.e. Mediterranean, Sahelian, Tropical and
50 Equatorial, see Figure 1 and Table 1 in their study). In their analysis, the total SOC
51 sequestration potential for Africa was then calculated from the climate-specific rates and from
52 estimated total land areas cultivated with annual and woody perennial crops in the different
53 countries (from FAOSTAT, <http://fao.org/faostat/en/#data>), considering the major climate(s)
54 in each country. Finally, they compared their estimate of sequestration potential with an
55 estimated current annual SOC sequestration based on present areas of cropland under CA. They
56 conclude that the total annual SOC sequestration potential through CA in Africa is about 93
57 times the current estimated figure.

58

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

60

61 First, in contrast with their claims, the reported annual per-area SOC sequestration rates under
62 CA in their study (see Table 1 in their paper) are high, ranging from 0.44 Mg C ha⁻¹ yr⁻¹
63 (Mediterranean climatic zone) to 1.56 Mg C ha⁻¹ yr⁻¹ (Equatorial climatic zone) for annual
64 crops, and from 0.12 Mg C ha⁻¹ yr⁻¹ (Sahelian climatic zone) to 1.29 Mg C ha⁻¹ yr⁻¹
65 (Mediterranean climatic zone) for woody perennial crops. The resulting average rates for the
66 whole of Africa are 0.92 and 0.70 Mg C ha⁻¹ yr⁻¹ for CA with annual and woody perennial
67 crops, respectively (recalculated from Table 3 and 4 in their study). Even though Gonzalez-
68 Sanchez et al. (2019) refer to their analysis as a meta-analysis, their reported figures do not
69 reveal any use of statistical tests, lacking any indicator of data variability and uncertainty of
70 their estimates. In fact, from their paper it is not clear which, and how many studies were used

71 for their estimates of annual per-area SOC sequestration rates. They simply list the publications
72 they referred to but do not cite any “supplementary information” that presents the data used to
73 derive their mean values.

74

75 We estimated average SOC sequestration rates for CA on croplands per climatic zone from
76 published studies used in a recent literature review (Corbeels et al., 2019). Our results for the
77 Tropical and Equatorial climate zones show rates that are 20-60% of those reported by
78 Gonzalez-Sanchez et al. (2019) and show high variability (Table 1). Since the review by
79 Corbeels et al. (2019) only referred to sub-Saharan Africa (excluding South Africa), the
80 Mediterranean region was not considered. No studies were found in Corbeels et al. (2019) for
81 the Sahelian climatic zone. The sequestration rate of 0.5 Mg C ha⁻¹ yr⁻¹ for annual crops in the
82 Sahelian region given by Gonzales-Sanchez et al (2029) seems extraordinarily high given the
83 strong water limitations to crop growth in this region. Average cereal yields in this region are
84 1000 kg ha⁻¹ or less (<http://fao.org/faostat/en/#data>). Assuming a harvest index of 0.35 and a
85 root:shoot ratio of 0.3 (corresponding to the 0–30 cm soil layer), this represents a potential
86 annual input of about 2700 kg dry matter ha⁻¹, corresponding to about 1200 kg C ha⁻¹. A
87 sequestration rate of 0.5 Mg C ha⁻¹ yr⁻¹ would mean that 42% of the C input is converted into
88 SOC, which is clearly not plausible. A recent study on SOC sequestration in tropical croplands
89 found that the conversion rate of C inputs to SOC was 8.2 ± 0.8% (Fujisaki et al., 2018). Smith
90 et al. (2008) estimated that the annual per-area sequestration rate for no-tillage and residue
91 management practices in warm-dry regions was about 0.10 Mg C ha⁻¹ yr⁻¹ with high uncertainty
92 (range between -0.21 and 0.40 Mg C ha⁻¹ yr⁻¹). Similar results were found for sub-Saharan
93 Africa in the meta-analysis of Powlson et al. (2016).

94

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

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

99 n denotes the number of studies

100 Soil depth considered varies between 5 and 60 cm

101

102

103 Second, Gonzalez-Sanchez et al. (2019) estimated the cropland area in 2016 based on
 104 FAOSTAT. This area include land that has recently been converted from native forest or
 105 savannah. Given the relatively high original SOC stocks under forest or savannah land,
 106 converting this land into agriculture will induce SOC losses irrespective of the type of
 107 agricultural management practices employed (Sommer et al., 2018). For example, negative
 108 SOC sequestration rates (-0.17 to $-0.55 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) were reported in experiments in Nigeria
 109 where CA was installed following recent clearing of native vegetation (Lal, 1998; Agbede,
 110 2008). Thus, new croplands should have been excluded from the calculations of the SOC
 111 sequestration potential. Based on data provided by FAOSTAT, the increase of cropland area
 112 over the last ten years in Africa is estimated at about 15 to 20%.

113 Besides, Gonzalez-Sanchez et al. (2019) included in their calculations the land area on which
 114 (most type of) woody perennial crops were cultivated in 2016. This land was considered as
 115 land where CA could be practiced, labelled in their study as “CA in woody crops due to ground
 116 cover”. However, it seems that the annual per-area SOC sequestration rates (Table 1 in their
 117 study) were estimated from studies on agroforestry systems. In these studies, the control plot

118 is a treeless agricultural plot having the same tillage practice as the agroforestry plot. Therefore,
119 the SOC sequestration rates are due to the presence of trees and are not linked to CA practices.
120 In agroforestry systems, the soil can be tilled and is not necessarily covered by a mulch of crop
121 residues, and tree crops can be grown in crop monoculture, as this was the case in many of the
122 cited papers. Therefore, these rates cannot be used for woody perennial cropping systems
123 practiced under CA. To have an estimation of the effect of CA in woody perennial cropping
124 systems, we would need treatments in agroforestry with CA and with conventional tillage,
125 which was not the case in the publications cited by the authors. Moreover, we found that the
126 SOC sequestration rates were highly dependent on the type of agroforestry system (Cardinael
127 et al., 2018, Corbeels et al., 2019). It is therefore not correct to group them in a single category
128 as proposed by Gonzalez-Sanchez et al. (2019).

129

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

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

155

156 Finally, Gonzalez-Sanchez et al. (2019) compared their estimated SOC sequestration potential
157 (i.e. 143 Tg C yr⁻¹) with an estimated (current) SOC sequestration based on the present cropland
158 area under CA (i.e. 1.5 Tg C yr⁻¹). This is not correct. A baseline including other best crop
159 management practices that increase C input to the soil, such as fertilization, irrigation,
160 improved crop rotations, and agroforestry, should be used. It has been estimated that 7 to 15
161 Tg C yr⁻¹ can be sequestered on croplands in Africa, assuming 20% of the croplands are
162 subjected to improved management (Batjes, 2004).

163 For the reasons given in our analysis, we believe that Gonzalez-Sanchez et al. (2019) grossly
164 overestimated the total SOC sequestration potential through the practice of CA in Africa.

165 Roughly, as a first approximation we estimate the potential at 10.8 Tg C yr⁻¹ assuming an
166 average per-area rate of 0.45 Mg C ha⁻¹ yr⁻¹ and that 20% of the current soil C-depleted (annual)
167 croplands (estimated at 120 Mha) are cultivated with CA. It is, however, important to note that
168 SOC stocks do not increase forever, and that annual sequestration rates decline as the soil
169 approaches a new equilibrium, which can take from 20 to +50 years depending on climate and
170 soil type. Hence, rates cannot be extrapolated indefinitely (Paustian et al., 1997; Powlson et al.,
171 2011, 2014). Lastly, it should also be mentioned that nitrous oxide (N₂O) emissions could be
172 enhanced in CA and, more generally, in practices with addition of organic amendments
173 (Charles et al., 2017; Lugato et al., 2018; Mei et al., 2018), partially offsetting the climate
174 benefits due to increased SOC storage.

175 It remains critical that we determine rates of SOC sequestration through improved agricultural
176 practices, and the role they can play in helping to meet short- to medium-term reduction targets
177 of greenhouse gas emission. It would, however, be appropriate for Gonzalez-Sanchez et al.
178 (2019) to reflect on a more conservative assessment of the mitigation potential through CA in
179 Africa. The presentation of implausible potentials leads to unrealistic expectations of climate
180 change mitigation with improved agricultural management. There is a danger that presenting
181 unrealistically high numbers of climate change mitigation potential through agricultural
182 practices could have a negative impact on the necessary actions to reduce CO₂ emissions from
183 fossil fuel combustion.

184 On the other hand, even if CA has limited value for climate change mitigation, the practice of
185 CA – through crop residue mulching and crop diversification- is expected to enhance the
186 resilience of cropping systems to climate change (Rusinamhodzi et al., 2011; Steward et al.,
187 2018). This may bring livelihood benefits to farmers, especially in regions with increased risk
188 of drought stress. Thus, it is more reasonable for policymakers and investors to plan promotion
189 of CA for reasons of climate resilience benefits than for climate change mitigation.

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