RC2

An overall relevant contribution on use of conservation agriculture practices to improve maize crop productivity and raise carbon stocks (and in turn fertility) in Zimbabwe. The study relies on two well-established field trials and standard yet well executed assessments were used to reveal how tillage, mulching and crop rotation in isolation or jointly influence SOC in these understudied systems. While the approach is overall robust – aside from limited attention to crop C inputs – at times the interpretation remains rather superficial. I have listed a number of comments below:

We thank the Reviewer for the overall positive comment that our study was well executed scientifically and can contribute to the body of knowledge on conservation agriculture. We are grateful for the insightful comments that have improved our manuscript. Questions or comments raised by the Reviewer have been answered below. Therefore, in black are the Reviewer's comments/questions and in blue are our responses. We also answered the detailed/minor comments below.

L103 & 108 One aspect of the hypotheses is best elaborated a bit more: while it is clear that crop residue retention and adoption of no-tillage are likely to improve SOC stocks, this is less obvious so for crop rotation. Crop rotation as such rather seems like a means to combat pests, but why should there necessarily be any beneficial effect onto SOC? Indirectly perhaps, via enhanced crop growth?

We agree with the reviewer's comments. Crop rotation is indeed crucial to reduce pests and diseases. The hypothesis is that the productivity of the crops is enhanced due to this reduction is biotic pressure, and therefore carbon inputs to the soil might be increased too. The second point is that this rotation introduces a nitrogen fixing crop, cowpea. We expect the following maize crop might benefit from this additional nitrogen to the soil. The third hypothesis is that crop diversification enhances soil biological processes via different root systems, and possibly enhanced microfauna diversity and/or abundance (e.g. mycorrhizae) that could improve aggregate stability and therefore physical protection of soil carbon. The last hypothesis is that high quality residues (from the legume crop) have been shown to be preferentially stabilized in the soil due to a higher carbon use efficiency of soil microbes (Cotrufo et al., 2013; Kopittke et al., 2018). We have now better explained this in the introduction.

L300 Why carry out statistical comparisons for each individual date? This does not provide an overall view on the treatment effects and complicates drawing conclusions.

Cumulative CO_2 emissions per treatment and per hectare are computed using a linear interpolation between daily CO_2 efflux. Using sampling dates as a fixed effect in the linear mixed effect model does not prevent us from comparing emissions per treatment, it just gives an additional information on periods of the CO_2 effluxes. Using daily emissions in statistical models is a common practice and allows a comparison based on measurements and not on interpolation, which we think is more accurate (Kravchenko and Robertson, 2015; Barthel et al., 2022;Shumba et al., 2023).

In the UFZ site, Fig 3 reveals a rather conspicuous treatment effect of including a rotation 90cm depth (and to a lesser extent at 60cm as well). Perhaps relevant to discuss as well, even though these trends were apparently not (yet) significant. Maybe the introduction of peas particularly led to deeper root proliferation and derived C-inputs at depth… perhaps the authors could try using contrasts in the ANOVA to pool the three 'rotation' treatments vs. the other treatments and demonstrate such effect?

We concur with the observations by the Reviewer. However, there is a block effect at UZF (blocks 3 and 4) on SOC concentration in the deep soil layers as shown in Figure R1 below. We decided not to exclude the "outliers" since we thought it was a block effect rather than a treatment effect; all treatments are affected. As a result, there are no significant differences in SOC concentration between treatments in the deep soil layers. If we exclude the "outliers" in deep soil layers the graph for SOC concentration is as shown in Figure R2. All raw data of this paper can be freely accessed on the CIRAD database and linked to this paper (https://doi.org/10.18167/DVN1/VPOCHN). We have included the link to the raw data in the materials and methods section (Section 2) and in the Data analysis sub-section (Section 2.8).

We have now also added these Figures R1 and R2 in supplementary materials and discussed implications in the discussion. At this stage we have excluded the addition of error bars on Fig 3 as the graphs will be too congested.

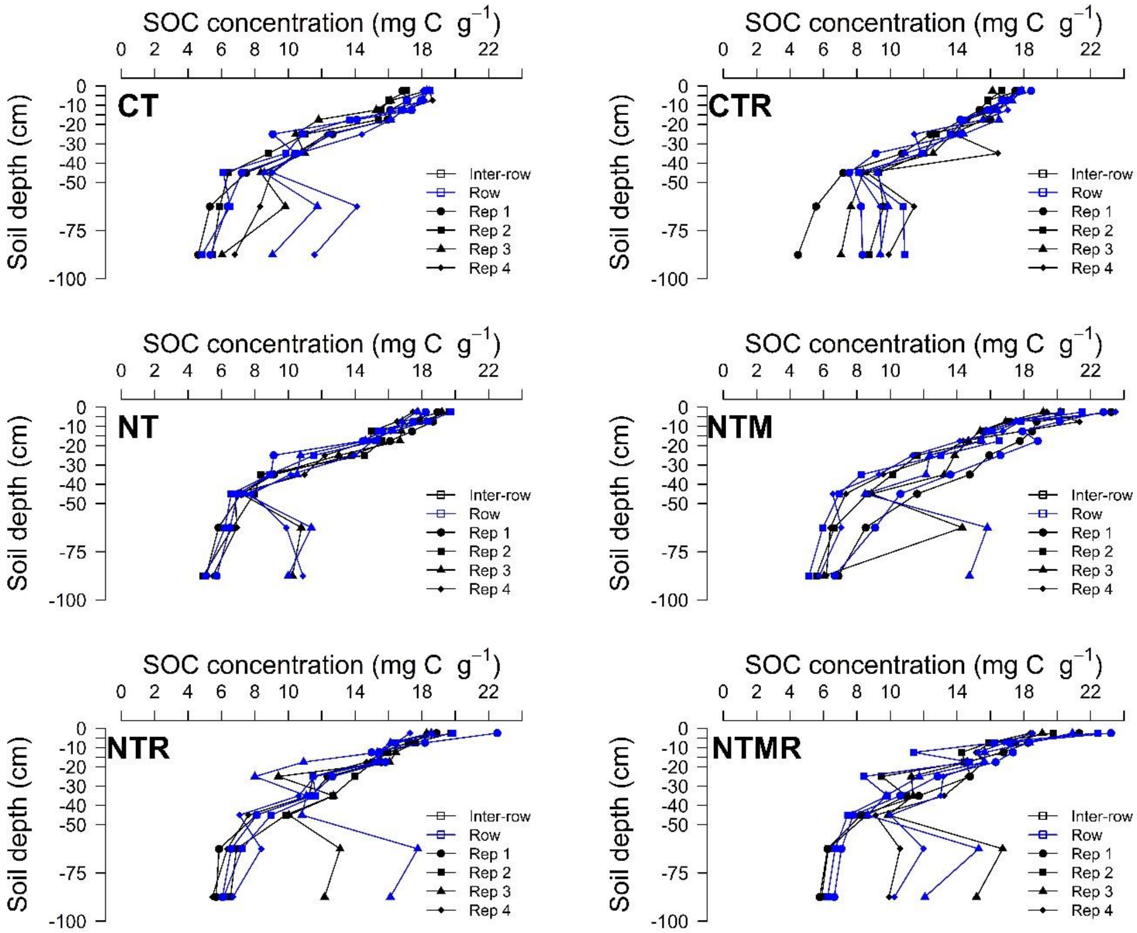

Figure R1: SOC concentration for the 100 cm soil profile for each treatment and replicate (block) showing "outliers" mainly in the 3rd and 4th replicates (blocks) at UZF.

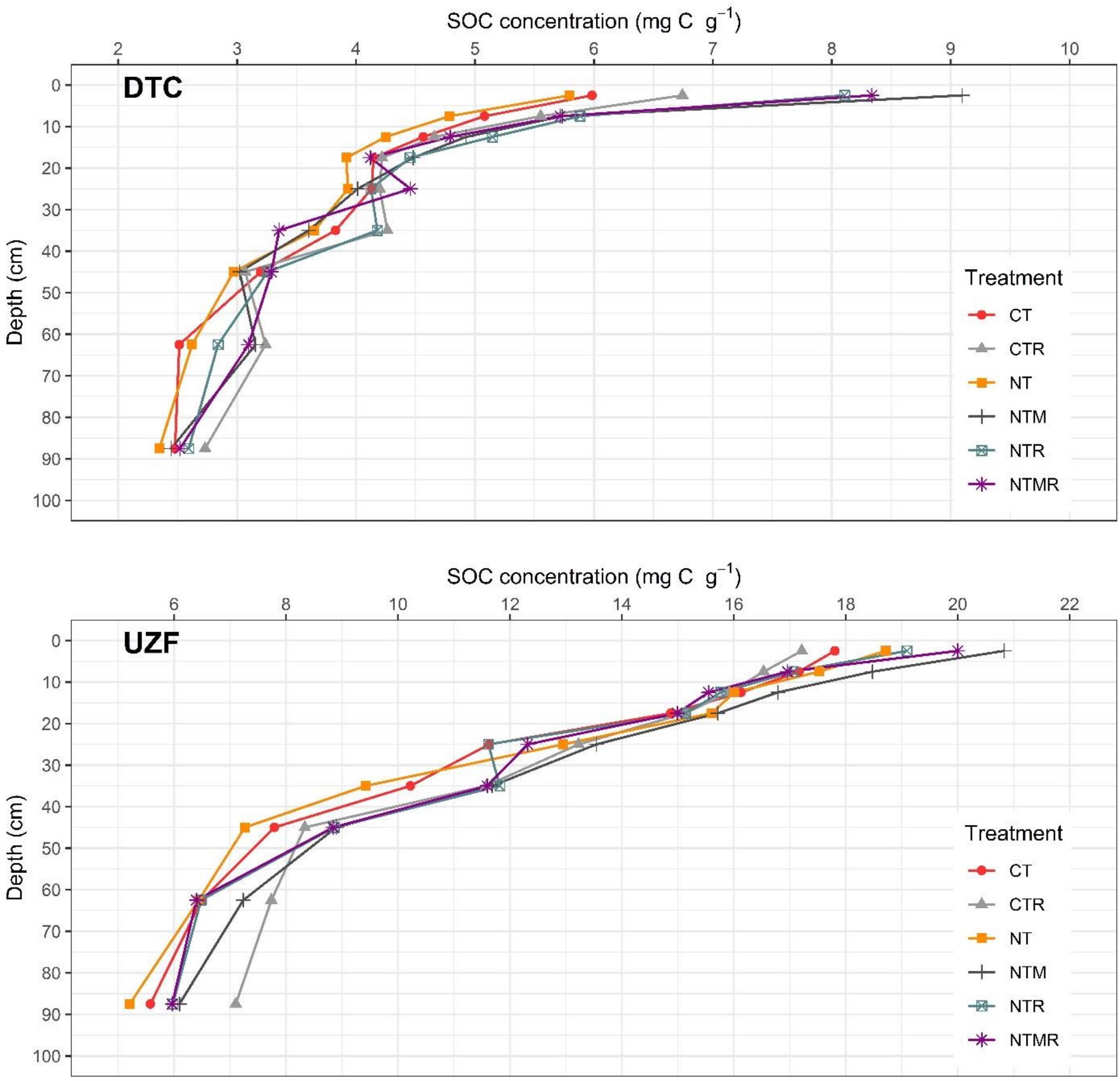

Figure R2: Mean SOC concentration for the 100 cm soil profile for each treatment excluding "outliers".

The discussion section requires improvement:

Thank you for the comment and we have tackled the respective comments below.

The second half of 4.1 does not make much of a connection with own observations (L476-483) – it is not clear what message the authors wanted to bring here.

We thank the Reviewer for the insightful comment and we have rephrased the section to read as follows:

"SOC mineralization is relatively low in the subsoil due to lack of oxygen and physical protection of SOC (aggregate protected C) (Rumpel et al., 2012; Sanaullah et al., 2016; Shumba et al., 2020; Button et al., 2022). Nevertheless, belowground OC inputs are concentrated in the top 30 cm hence the recommendation for crop varieties with deep rooting systems in the pursuit of increasing subsoil OC inputs through root mortality and exudates."

However, in the section referenced (Section 4.1), we were discussing the implications of our study findings as well as suggesting alternative ways of increasing subsoil SOC. The main message we were putting across is the importance of sub-soils in SOC storage as well as stressing whole soil profile sampling in SOC monitoring studies.

Section 4.2 is lengthy - Perhaps this section could benefit from further subdivision into subparts that deal with the various treatment aspects (tillage, mulching, crop rotation).

We agree with the Reviewer's comments and we have subdivided section 4.2 accordingly into three sub-sections which dealt with the different treatment aspects in our study. Sub-section 4.2.1, 4.2.2 and 4.2.3 dealt with mulching, tillage and maize-cowpea rotation aspects, respectively. Some editorials and references were also added to improve the section.

4.2 lacks a clear calculation of conversion efficiency of C-inputs into SOC. There have been ample studies on removal or incorporation of maize residues (in light of research into the value of root vs. shoot C inputs) – such studies have generally revealed that aboveground biomass C inputs are far less effective in sustaining SOC – and this body of literature should be used to complement the discussion here. Even though much of the C-inputs are just derived from yield data, it would still be relevant to see some estimates of the efficiency by which these C-inputs formed or sustained SOC.

Thank you for the suggestion to calculate conversion efficiency of C-inputs into SOC. We tried to calculate this efficiency in the 0-30 cm depth for some treatments only. It was indeed not possible to calculate it for treatments with lower SOC stocks than the reference, or for treatments having higher SOC stocks but with less C-inputs than the reference (for example NTR at DTC). Here is the result:

Treatments	DTC	UZF
NTM vs CT	0.34	0.46
NTM vs NT	0.45	0.27
NTMR vs CT	0.75	0.17
NTMR vs NT	0.98	

Some of these rates are unrealistic, especially the rates of NTMR at DTC. This is due to the high uncertainty linked to the estimation of C inputs to the soil, but also to the low number of replicates (4) for SOC stocks. Another explanation could be that most additional SOC might be in the form of labile particulate organic matter < 2mm, i.e decomposing plant materials accumulating in the soil, but not really stabilized carbon. While the calculation of the conversion efficiency of C-inputs into SOC could have been of interest, we believe they are too uncertain to show them. We have therefore decided not to include them in the manuscript.

We also took cognisant of the comments raised by the Reviewer on aboveground- vs belowground biomass in sustaining SOC. We have discussed the essence of belowground biomass to SOC storage in Section 4.2 (sub-section 4.2.1) and giving relevant literature (Hirte et al., 2021, 2018; Jones et al., 2009; Villarino et al., 2021) in support of the discussion.

The discussion lacks considerations on the potential mechanisms through which the inclusion of peas in the crop rotation might influence maize C inputs. With a legume introduced there may well be more N-available for the maize crop – not trivial given the very low doses of mineral N-supplied. If so, we may expect this to hold an effect on the soil C balance not only through an overall stimulation of maize productivity (and that is currently not clearly explained in the current discussion) but possibly also by effects onto the maize rooting pattern. These aspects should at least be commented upon, especially in light of the rather conspicuous difference in SOC at 75 or 90cm depth when a rotation is included (at least such would seem so from Fig 3, but unfortunately no comparison is given of the 75-100cm SOC stocks).

In concurring with the Reviewer, we have included the nitrogen input through biological nitrogen fixation from cowpeas in stimulating productivity of the succeeding maize crop. We also included another potential SOC stabilization mechanism in the form of addition of high-quality cowpea residues (above-and belowground biomass) which have been shown to be preferentially stabilized in the soil due to a higher carbon use efficiency of soil microbes (Cotrufo et al., 2013; Kopittke et al., 2018).

In our case, we think the possible rotation effects in deep soil SOC stocks at UZF is an artefact due to a block effect as explained above with graphical illustrations (Figures R1 and R2). We have now also discussed that.

Towards the end of the discussion and in the conclusion clearly the specificity of the here established crop rotation needs to be stipulated. By no means could we simply extrapolate found results to other 'crop rotations' – with different crops and plant C-inputs.

We agree with the comment and we have improved the section where we discussed the issue of OC quality in terms of C:N ratio where there was alternate addition of low- (maize) and high- (cowpea) quality OC inputs in the cowpea-maize rotation treatment especially in sub-section 4.2.3. We also discussed the relevance of these rotation systems which had significant effects on SOC stocks under NT systems albeit under soils with higher clay content typical of UZF in our study.

L497: what about the whole idea that reduction of tillage would promote physical protection of OM inside microaggregates – should be commented on here as well.

The comment is acceptable and we have included the suggested idea in the discussion (section 4.2.2) with some references to support it. The part which was included the discussion now reads:

"Minimum soil disturbance through NT also physically protects SOC in microaggregates from exposure to oxidative losses (Shumba et al., 2020; Six et al., 2002; Dolan et al., 2006; Liang et al., 2020). However, NT without mulch is a nonentity compared to other combinations of CA principles for long-term sustainability in cropping systems (Nyamangara et al., 2013; Kodzwa et al., 2020; Mhlanga et al., 2021; Li et al., 2020; Bohoussou et al., 2022) and NT is only effective in increasing SOC stocks when it is associated with other CA principles, especially mulch. On the other hand, our study suggest that NT can achieve the same results of SOC storage as NTR and NTMR since they had similar SOC stocks at UZF. This can be explained by the low aboveground OC inputs in rotation treatments during the season when cowpeas were grown."

L510 SOC storage does not seem very site specific but rather rotation-specific + 'the differences in the response to SOC changes' makes little sense -> rephrase

We agree with the comment and we have deleted the sentence in pursuit of compressing the section.

L518 'the net SOC loss in CTR was due to seasonal exposure to oxidative losses (SOC mineralization) through disruption of soil macroaggregates by tillage' this makes little sense since these numbers are actually obtained by comparison with the CT treatment in which there is an equally intensive disruption of soil structure.

In this case we were referring to the UZF site (now indicated), for the comparison of CTR vs NTR there was significant differences in SOC accumulation / loss rates. At DTC, it was the mulching component that had significant effects on SOC accumulation / loss rates (Table 2). Below are the new phrases we used to elaborate our point.

“However, in our study, cowpea rotation benefits on SOC accumulation rates were not significant at DTC. Maize-cowpea rotation had no significant effects on maize yield (Shumba et al., 2023b; Mhlanga et al., 2021) which corresponded to low belowground biomass as well. Instead, maize stover mulching improved maize yields at DTC.”

L547 what about other SOC stabilization mechanisms?

We have added SOC adsorption to clay particles as another possible SOC stabilization mechanism.

4.4 as it is stands alone and really does not bring a clear message. It may be better to integrate this section into 4.2 (which then gets even lengthier and is therefore best split).

Thank you for the suggestion but we think this is a stand-alone section which deals with CO_2-C emissions. However, we have now further discussed that the conventional tillage using hand-hoes in our study was mere loosening of the top 15 cm and not full soil inversion done by animal- or tractor-drawn ploughs.

The conclusion section is fine.