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Interactive comment on "Proximal sensing for soil carbon accounting" *by* Jacqueline R. England and Raphael Armando Viscarra Rossel

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We thank the reviewer for the constructive comments on our submission. We have addressed all of the comments made. Our responses, indicating the revisions that we made, are preceded by 'Authors response:'.

Anonymous Referee #1: This review paper is prepared on the basis of 132 well selected original papers covering the current state of proximal sensing for soil organic C accounting methods. The problems described in the article are topical and worth putting forward analysts who are dealing with management practices to sequester soil organic C.

Authors response: We did our best to select the most relevant information to include

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in our manuscript, and certainly, we also agree that the subject matter is currently relevant. Thank you.

Anonymous Referee #1: Before making a decision concerning publication of the article some remarks given below should be considered. Some parts of this review are too general or even "empty", and they do not inform the reader about the range of possibilities (techniques) that can be used for the purpose such as OC analysis and its limitation.

Authors response: We disagree that the review is ‘too general’, in fact, we think quite the opposite: the manuscript relates specifically to proximal soil sensing for soil carbon accounting. It is for this reason that, for example, we did not review ‘on-the-go’ sensor systems, which are useful for agronomic applications – see below. We also disagree with the comment about not informing readers of the range of techniques. As far as we know, we covered all of the currently known (supported by peer-reviewed literature), potential and ‘emerging’ sensing techniques for measuring soil organic C concentrations, bulk density and gravel, and we critically review their advantages and limitations, with particular regard to their accuracy, cost, practicality and safety.

Anonymous Referee #1: The paragraph 4.1.2 (vis-NIR and mid-infrared spectroscopy), authors should mention the mobile (on-the-Go) field vis–NIR sensors which are available today (Shibusawa et al., 2001; Mouazen et al., 2005; Christy, 2008) and provide high-resolution sampling with the results obtained in some studies.

Authors response: Our review concerns only sensing technologies that can be used for soil C accounting. The primary application of mobile (on-the-go) sensors is for soil property mapping. These systems are insufficient for soil organic C accounting because: (i) they do not provide a consistent measurement depth, (ii) measurements are often only made within the 0–20 cm layer, which is shallower than the recommended minimum depth of measurement for soil C accounting, (iii) although such systems can measure soil organic C concentration, they do not measure C stocks. Certainly, on-the-

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go systems, like those mentioned by the reviewer, could be used to derive maps of soil organic C, which could be used to inform the soil sampling design and the estimation of the stocks. We noted this at the start of section 4 in our revision.

Anonymous Referee #1: It should also be pointed out in which cases the respective literature provides a comparison of a lab method with respective field techniques on the same samples or not. Without the comprehensive information on the potentially promising field methods, a researcher intending to develop them towards practical applicability is not provided with realistic information expected by a review.

Authors response: The reviewed literature on the comparisons is in relation to conventional laboratory methods. For instance, the literature on the sensing of soil organic C concentrations reports comparisons to the dry combustion method, those for bulk density sensing are in relation to the volumetric ring method on the same samples for AGA transmission and CT, and on paired samples for AGA backscatter. The reported comparisons for the estimation of gravel content were also in relation to the conventional methods (drying, sieving, grinding and weighing). This is now better emphasised in our revision of section 4, and in the captions of Table 2 and Table 4.

Anonymous Referee #1: The paragraph 4.1.3 (Laser Induced Breakdown Spectroscopy (LIBS)) in my opinion is the worst part. The authors must refer to LIBS as an emerging method for estimating soil OC, with a comment how this approach can be useful for soil analysis. Papers: Bricklemyer, R.S., Brown, D.J., Barefield, J.E., Clegg, S.M., 2011. Intact Soil Core Total, Inorganic, and Organic Carbon Measurement Using Laser-Induced Breakdown Spectroscopy. Soil Sci. Soc. Am. J. 75, 1006-1018; da Silva, R.M., Milori, D.M.B.P., Ferreira, E.C., Ferreira, E.J., Krug, F.J., Martin Neto, L., 2008. Total carbon measurement in whole tropical soil sample. Spectrochim. Acta Part B At. Spectrosc. 63, 1221–1224; Senesi, G.S., Senesi, N., 2016. Laser-induced breakdown spectroscopy (LIBS) to measure quantitatively soil carbon with emphasis on soil organic carbon. A review. Anal. Chim. Acta 938, 7–17, can be used as a source of the methodology description as well as trends in this field.

Authors response: We revised section 4.1.3 LIBS, and included the suggested references, thank you. However, we prefer to remain impartial and only report the current state in our understanding. A lot of the testing with LIBS has been and is being done in the laboratory. Few studies report the development of systems for soil analysis by proximal sensing (i.e. in the field). The Bricklemyer et al. paper is one of the few, but we note that they report poor estimates of organic C (r2=0.22). From our review of the literature, we conclude that there are significant limitations that need to be overcome before LIBS may be considered as an 'emerging technology' for proximal soil organic C sensing (i.e. sensing in the field, not in the laboratory). The limitations are: samples preparation is involved and time-consuming; sample representativeness needs to be carefully considered because only a tiny amount of soil is ablated, we only have very limited understanding of how LIBS performs under field conditions with soil that has variable water content, particle sizes, etc., and to estimate organic C, LIBS spectra need to be calibrated. We have emphasised and clarified these points in our revision of section 4.13 and in the Final remarks.

Anonymous Referee #1: Table 4 would be the central point regarding the soil C accounting in this manuscript, however, the results reported in this table are not clear. It should mention the range of exact analytes, and sample preparation applied along with the references of these studies.

Authors response: We have revised Table 4 to include a more informative caption describing the exact comparisons made and footnotes for the actual references used.

Anonymous Referee #1: The conclusion is much too long. Concluding remarks should clearly be stressed that the development of the field techniques towards practical applicability still have to follow and the literature provides rather proof-of-concepts-studies so far.

Authors response: We revised our 'Final remarks' so that they now focus on the key messages. Although some of the technologies are, as the referee suggests, at the proof-of-concept stage, our review indicates that currently, there are sensors that can be used for cost-efficient soil organic C accounting.

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