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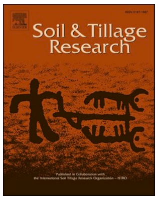

Manuring effects on visual soil quality indicators and soil organic matter content in different pedoclimatic zones in Europe and China

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ABSTRACT

A study was carried out to assess if the visual soil assessment method (VSA) would allow recognizing differences between soils receiving organic matter (OM) amendments and similar control soils, by the observation of visual soil quality indicators' score. 36 practices were identified across 8 pedoclimatic zones. These fields/plots were paired with nearby control fields/plots, without OM amendments, sharing similar farming features. A survey, comprising a VSA of the soil structure status, surface ponding, signs of erosion, earthworm counts and soil stability (slake test), complemented by measurements of soil organic matter (SOM) and permanganate oxidizable organic carbon (LOC) content, soil pH, penetration resistance and texture, on soils of both management system groups (OM addition and Control), was performed in 2016. Correlations of the visual soil quality indicators' score with SOM, LOC, other soil properties and climate variables and indices were calculated within each group; the correlations between soil properties, and between soil properties (SOM and LOC) and climate variables were also calculated. A statistically significantly higher proportion of soils of the OM group had a good score for "soil structure and consistency" and "soil porosity". These differences are not directly explained by non-inherent soil properties. No statistically significant Spearman's correlation coefficients were observed between "soil structure and consistency" and either soil properties or climate variables; concerning "soil porosity", distinct statistically significant correlations were observed between the two groups with different climate variables and indices. Correlations between the scores of the visual soil quality indicators and climate variables were found to follow the same directions of correlations of LOC content with the same climate variables, although the latter correlations were weak. Mean SOM and LOC content, were slightly higher in the OM group, although differences were not statistically significant. A high linear correlation between LOC (mg/g) and SOM (%) ($r = 0.65$, $n = 26$) exists

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within the Control group, but not within the OM group (r = 0.20 and n = 26). When the relationship of SOM and LOC content with visual soil quality indicators' score was studied, statistically significant correlations were only observed between SOM and "earthworm count" within the Control group ($r_s = 0.44$), and between LOC and "soil colour" within the OM group (r_s=-0.52). Both LOC content and LOC status (ranked as a function of LOC content and soil texture), had only **negative statistically significant correlations with visual soil quality indicators' score**, questioning their worth as *stand-alone* soil quality indicators.

1. Introduction

Soil organic matter (SOM) plays a major role in agricultural soils, as an integral part of nutrient cycling, improving soil aggregate stability through the formation of clay-humic complexes, and as a potential carbon sink in the frame of climate change mitigation. After a long time under a specific agricultural system and pedoclimatic conditions, SOM content will tend towards an equilibrium status that will only be disrupted if changes are introduced in the system (e.g. Li et al., 1997). Often, the SOM content equilibrium status under agricultural land use at a given location is rather low, negatively influencing the function and services soils provide (Gregorich et al., 1994), and changes in the management practices may be required to increase SOM levels (e.g. Balesdent et al., 2000). Several management strategies exist to enhance SOM content or to mitigate the negative impact of low SOM content. Such management practices rely on increasing biomass production, removing less biomass, adding biomass, or other practices that increase the rate of organic matter input or decrease SOM mineralization rate (Six et al., 2002; Bolinder et al., 2020). The net effect of these practices is somewhat unknown and may take an extended time until differences in SOM content can be measured, if at all (Li et al., 1997; Evanylo et al., 2008; Edmeades, 2003; Dick, 1983).

Traditionally manuring and other organic amendments were and still are the most common and straightforward action farmers employ to face the deterioration of the services soils provide, and that directly affect their agricultural systems' productivity, namely through nutrient depletion, loss of soil structure and soil loss through erosion (Edmeades, 2003; Liu et al., 2011). The rapid effect that OM amendments may have on soil functions is often conceptually associated with an increase in SOM. Although this association is true in the very short-term, the overall impact of OM amendments on SOM content is not clear due to "priming effects" - the increase of mineralization of stable soil organic carbon (SOM with a long turnover time), resulting from incorporation of fresh OM (e.g. Fontaine et al., 2007). Soil functions should be the focal point when managing SOM, but the direct measurement of SOM content evolution may not be the most adequate indicator to assess changes in soil functions and performance. Visual soil assessment schemes allow a quick hands-on approach to assessing soil functions' performance in-situ, which can be carried out by virtually everybody with little training required (e.g. van Leeuwen et al., 2018). The information gathered by visual soil assessment schemes focuses on soil properties such as structure, water movement in the soil, SOM change, aggregate stability, soil biology, the existence of soil pans, and so on, depending on the type of farming: arable, permanent crops, pastoral, etc. (e.g. Shepherd, 2000). The methodology consists of assessing visually or through other senses (smell, touch and hear) soil morphological attributes that are correlated, to a certain degree, with measurable soil parameters (e.g. Pulido Moncada et al., 2014). To these visual soil quality indicators are then assigned a score (a category), in a classification process that uses standards that are representative of each score such as the use of photographs, schematic pictures, measuring underlying variables and applying thresholds, and so on, to reduce subjectivity and enhance reproducibility (van Leeuwen et al., 2018). Other than in-farm soil monitoring, visual soil assessment schemes have been used in surveys and in monitoring programs (e.g. Newell-Price et al., 2013), and their use may prove very useful for modelling purposes to increase the predictive power of several soil properties (Lilly and Lin, 2004; Murphy et al., 2013; Pulido Moncada et al., 2014). Nevertheless, visual soil quality indicators are at best ordinal variables, which constrain the statistical analysis of their relationships (correlations) with measured soil properties, or any other variable.

The visual soil assessment scheme adopted in our survey was the New Zealand VSA method (Shepherd, 2000), complemented by other observations and measures. Prior studies, by other authors, showed that SOM content can be a statistically significant predictor of a soil's ranking score of the New Zealand VSA method (the sum of weighted scores of visual indicators) (e.g. Newell-Price et al., 2013), while in others, the relationship between VSA ranking score and SOM is, apparently, inexistent (e.g. Murphy et al., 2013). In common, these studies do not present the relationship between SOM and individual visual soil quality indicator scores. SOM comprehends a large number of organic compounds that differ in their complexity and properties that are often divided into different pools, depending on the ease of extraction. Research has been done to identify fractions of SOM that better correlate with different soil quality indicators (e.g. Bongiorno et al., 2019). Weil et al. (2003) proposed the use of a protocol for measuring permanganate oxidizable soil organic carbon (from now on designated by LOC, labile organic carbon), using a diluted solution (0.02 M $KMnO_4$), that was reported to correlate better than total soil organic carbon with biologically mediated soil properties, such as aggregation or microbial biomass, and to be a more sensitive indicator than protocols using high concentrations of permanganate when studying management effects. Subsequently, Des McGarry (n.d.) and Moody and Cong (2008) proposed threshold values based on LOC content and soil texture, to be used in the frame of visual soil assessment protocols, defining classes that purportedly are indicative of an LOC status positively correlated with soils' ability to function. The present study was focused on the relationships of each visual soil quality indicator with SOM and LOC content.

The main objectives of this work were to evaluate if the visual soil quality indicators of the New Zealand VSA method would allow assessing differences in the structure of soils receiving OM amendments and neighbouring similar soils, under similar agricultural systems, not receiving OM amendments. Also, the correlations between: a) visual soil quality indicators; b) visual soil quality indicators and SOM, LOC content, soil pH, soil penetration resistance, soil texture and climate variables; c) soil properties; and d) SOM, and LOC content, with climate variables, were calculated within each group to identify possible explanatory and/or underlying variables governing the magnitude of the visual soil quality indicators' score.

2. Materials and methods

A total number of 36 OM amendment practices, with a minimum of 5 years of continuous application, solely or in combination with other alternative agricultural management practices, were identified and selected across 8 different pedoclimatic zones[1] in Europe and China. These fields/plots receiving OM amendments were paired with nearby control fields/plots, without OM amendments, under the same farming

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[1] The pedoclimatic zones were defined as a combination of the climatic regions defined for Europe and China and Reference Soil Groups identified in these regions. The climatic groups defined embody the soil processes that prevail in these climatic regions (Tóth et al., 2016).

Table 1
Pedoclimatic zones, farming systems and OM amendment practices.

Country/ Case Study Site	Climatic Region	RSG	Site ID	Farming System	OM Amendment Details
Netherlands	Atlantic	Anthrosols	1.2	Arable. Irrigated land. Vegetable crops.	Combination of organic and mineral fertilizers.
Portugal	Mediterranean temperate	Fluvisols	3.3	Non irrigated arable land. Maize.	Dairy slurry.
	Mediterranean temperate	Fluvisols	3.4	Non irrigated arable land. Maize.	Dairy slurry.
Spain	Mediterranean semi-Arid	Cambisols	4.3	Arable. Irrigated land. Artichoke.	Manuring. Min-till. Permanent soil cover.
	Mediterranean temperate	Fluvisols	4.4	Permanent. Fruit trees.	Reduced till, located manure application and mulching.
	Mediterranean semi-Arid	Regosols	4.5	Permanent. Fruit trees. Pomegranate.	Min-till, manuring, permanent cover crop.
	Mediterranean semi-Arid	Regosols	4.6	Arable. Irrigated land. Melon.	Manuring, crop rotation and min-till.
	Mediterranean semi-Arid	Regosols	4.7	Permanent. Fruit trees. Lemon.	Manuring, pruning, permanent soil cover.
	Mediterranean temperate	Regosols	4.8	Arable. Irrigated land. Potatoes.	Manuring, alternating annual crops and controlled water supply.
	Mediterranean temperate	Regosols	4.9	Permanent. Olive trees.	Reduced tillage and compost application.
	Mediterranean semi-Arid	Cambisols	4.10	Arable. Irrigated land. Pepper.	Crop rotation, manuring.
	Mediterranean semi-Arid	Cambisols	4.12	Permanently irrigated land. Flowers, fruits and vegetables (pepper).	Crop rotation, manuring.
Slovenia	Southern sub-continental	Fluvisols	6.3	Non irrigated arable land. Cereals - vegetable - fodder legumes.	Organic farming with diverse rotation; dairy cow manure.
	Southern sub-continental	Fluvisols	6.4	Non irrigated arable land. Maize - sugar beet, cereals, vegetables.	Manuring (dairy cow and cattle manure, sugar beet in rotation).
	Southern sub-continental	Cambisols	6.9	Non irrigated arable land. Cereals - vegetable - fodder legumes.	Organic farming with diverse rotation; dairy cow manure.
	Southern sub-continental	Cambisols	6.10	Non irrigated arable land. Maize - sugar beet, cereals, vegetables.	Manuring (dairy cow and cattle manure, sugar beet in rotation).
Hungary	Southern sub-continental	Luvisols	7.2	Non irrigated arable land. Cereals, maize, oil crops.	Mineral fertilization and farmyard manure.
	Southern sub-continental	Cambisols	7.10	Non irrigated arable land. Cereals, maize, oil crops.	Farmyard manure and reduced tillage.
	Southern sub-continental	Cambisols	7.13	Non irrigated arable land. Cereals; maize, oil crops.	Crop rotation, farmyard manure. N mineral fertilization and no K and P. Crop residues retention.
	Southern sub-continental	Cambisols	7.14	Non irrigated arable land. Cereals, maize, oil crops.	Crop rotation, mineral fertilization and pig liquid manure.
Poland	Northern sub-continental	Podzols	9.1	Non irrigated arable land. Maize.	Residue retention / mulching.
	Northern sub-continental	Podzols	9.2	Non irrigated arable land. Cereals.	Residue retention / mulching.
	Southern sub-continental	Cambisols	9.12	Non irrigated arable land. Oil crops.	Residue retention / mulching.
	Southern sub-continental	Podzols	9.13	Non irrigated arable land. Cereals.	Residue retention/mulching - dairy sewage sludge.
	Northern sub-continental	Podzols	9.15	Non irrigated arable land. Oil crops.	Residue retention/mulching – digestate.
Estonia	Boreal to sub-boreal	Luvisols	10.1	Intensive, Grassland.	Grassland for cutting, manuring with slurry.
	Boreal to sub-boreal	Luvisols	10.3	Intensive, Grassland.	Permanent plant cover, grassland for cutting, manuring with slurry.
	Boreal to sub-boreal	Luvisols	10.4	Intensive, Cereals.	Manuring with slurry. Crop rotation
	Boreal to sub-boreal	Luvisols	10.5	Intensive, Grassland.	Permanent plant cover, grassland for cutting, manuring with slurry.
	Boreal to sub-boreal	Luvisols	10.6	Intensive, Cereals.	Manuring with slurry, crop rotation.
China Qiyang	Central subtropical	Regosols	11.1	Permanently irrigated land. Root crops.	Chemical fertilizer and organic fertilizer (plant rice with compound chemical fertilizer, pig manure and straw return).
	Central subtropical	Regosols	11.7	Permanently irrigated land. Root crops.	Chemical fertilizer and ash soil (hole application compound fertilizer and manure).
China Suining	Central subtropical	Anthrosols	12.3	Non irrigated arable land. Maize.	Chemical fertilizer and manuring.
	Central subtropical	Anthrosols	12.4	Permanently irrigated land. Cereals, oil crops.	Chemical fertilizer and manuring.
China Gongzhuling	Middle Temperate	Phaeozems	14.3	Permanently irrigated land. Maize.	Pig manure and chemical fertilizer.
	Middle Temperate	Chernozems	14.6	Permanently irrigated land. Maize.	Sheep manure and chemical fertilizer.

RSG- Reference Soil Group.

systems, sharing similar soils and topography. A survey, comprising a visual soil assessment (New Zealand VSA method (Shepherd, 2000)) of the soil structure status, surface water ponding, signs of soil erosion, and earthworm counts, complemented by measurements of SOM and LOC content, soil pH, soil texture (soil separates), soil penetration resistance, and soil stability (slake test) of both management systems groups (OM addition and Control) was performed in 2016. A summary of the "study sites’" description and the survey and laboratory analysis, is given below. For more details on the methodology used in the selection of these fields/plots, please refer to Barão et al. (2019).

Table 2
Visual soil quality indicators and references.

Visual indicator	Reference	Brief Description	Ranking
Soil structure and consistency	Shepherd (2000)	Based on a soil volume (0.2 m edge cube)/ clods shattering from waist height and aggregate size distribution. Assessment (comparison) with reference photographs.	Indicator status: 0= poor; 1=moderate; 2=good.
Soil porosity	Shepherd (2000)	Based on visual observation of a spade slice of soil or clod inspection for macropores. Assessment (comparison) with reference photographs.	Indicator status: 0= poor; 1=moderate; 2=good.
Soil stability (slake test)	Tongway and Hindley (1995)	An adaptation of the procedure proposed by Tongway and Hindley. Three soil aggregates masses are immersed in the water atop of a mesh with 1 cm openings. Time to collapse and percentage of slumping material is observed. Reference photographs.	Indicator status: 0= poor; 1=moderate; 2=good.
Soil colour	Shepherd (2000)	Comparison of the colour of cultivated soil with the colour of undisturbed soil (e.g. from a nearby fence or other structure). Reference photographs.	Indicator status: 0= poor; 1=moderate; 2=good.
Presence of cultivation pan	Shepherd (2000)	Based on visual observation of the face of the hole dug to extract the initial cube, comparison between the lower and upper part of the topsoil profile. Assessment (comparison) with reference photographs.	Indicator status: 0= poor; 1=moderate; 2=good.
Earthworm count	Shepherd (2000)	The number of earthworms found in a 5 min search in the volume of soil used for *Soil structure and consistency*.	Indicator status: 0= poor (count<4); 1=moderate (4 < count<8); 2=good (count>8).
Surface ponding (under cropping)	Shepherd (2000)	Based on the time ponded water took to infiltrate after a heavy rainfall or wet period in winter.	Indicator status: 0= poor (ponding for more than 3 days); 1=moderate (ponding up to 3 days); 2=good (no evidence of ponding after 1 day).
Susceptibility to wind and water erosion	Shepherd (2000)	Observed signs of erosion: rills, sedimentation in water streams and drains, differences in topsoil depths between crests and bottom of slopes, size of dust plumes during cultivation, etc.	Indicator status: 0= poor; 1=moderate; 2=good. For further details refer to the citation.

2.1. *Study sites description*

At each site, a nearby field/plot, with the same crop, farming system and landscape features, not receiving any OM amendment was selected as a control (Table 1). All sites were georeferenced.

2.2. *Visual soil assessment*

A description of the visual soil quality indicators used in this study is provided in Table 2. For further information on the protocols used to assess each visual soil quality indicator, consult the references in Table 2.

2.3. *Soil properties and ranking*

Soil samples were collected and quantitative analysis of soil texture and total soil organic carbon (SOC) content were performed in the laboratory, following the protocols in use at each location (Table 3). SOC values were converted to organic matter (SOM), using the conversion equation SOM (%) = 1.72 x SOC (%). Measurements of soil pH (in water) were performed with a soil: water ratio 1:1 (McLean et al., 1982). Penetration resistance was measured with Eijkelkamp penetrologgers. LOC content was measured with a diluted solution 0.02 M of $KMnO_4$ (for details refer to Weil et al., 2003, adapted by Alaoui and Schwilch, 2016).

For classification of soil status of each soil property and respective thresholds, see Table 4. Spearman's correlation coefficients of SOM and LOC with other variables were performed with **both** SOM and LOC classified according to the **thresholds of** Table 4 (identified as SOM status and LOC status), and by the ordinal **ranking of individual values** (without prior classification).

2.4. *Climate variables and indices*

Local climate variables and indices for the georeferenced locations of paired fields/plots were calculated with the software "Local Climate Estimator" (New Loc_Clim), which uses the dataset FAOCLIM 2 (worldwide agroclimatic data), that uses monthly data from ca. 30,000 terrestrial stations, and long term averages (1961–1990) (FAO, 2005). Although the use of long-term averages from the period between 1961 and 1990 can be subject of debate, we used **mean annual values** and there was no evidence of major changes in local long-term averages of most climate variables that would prompt the rejection of these series (1961–1990) as representative of the local climate. The following climate variables and indices were selected: i) mean annual temperature (°C); ii) mean annual precipitation (mm); iii) mean annual potential evapotranspiration (mm); iv) aridity index (dimensionless); v) precipitation deficit (mm); vi) net primary production potential (NPP), temperature and precipitation limited (g (DM) m^{-2} yr^{-1}).

2.5. *Statistical analysis*

The associations (correlations) between ordinal variables and other variables were assessed by the Spearman rank-order correlation coefficient, which indicates how well an association between two variables can be described by a monotonic function. Thus, the associations between visual indicators' score, between measured soil properties and visual indicators' score, and between visual indicators' score and climate variables and indices, were assessed by Spearman's correlation. Associations between measured soil properties, and between measured soil properties and climate variables and indices were assessed with Pearson's correlation coefficients, which is a measure of the linear correlation between the variables. The t-values of the correlation coefficients were calculated to determine their statistical significance. The chosen significance level, for both correlation coefficients, was $\alpha = 0.05$. In the next sections, we defined no-correlations for $r < =|0.10|$, weak correlations for $|0.10| < r <= |0.3|$, moderate correlations for $|0.3| < r$

Table 3
Soil texture and soil organic carbon measurement methods used at each study site.

	Soil texture analysis	Reference	Soil organic carbon	Reference
The Netherlands	Interaction with radiation (near-infrared spectrometry)		Loss on ignition (NEN5754 protocol)	NEN (1992)
Portugal	Sieving and sedimentation (pipette method)	Robinson (1922)	Oxidation at 600 °C and quantified through the infrared analyzer (LecoSC-144 DR)	LECO SC-144DR (2004)
Spain	Sieving and sedimentation (hydrometer method)	Gee and Bauder (1986)	Walkley-Black chromic acid wet oxidation method	Nelson and Sommers (1982)
Slovenia	Sieving and sedimentation (pipette method)	ISO 11277	Dry combustion (elementary analysis)	ISO 10694
Hungary	Sieving and sedimentation (pipette method)		Wet combustion with sulfuric acid by Tjurin method	Vorobyova (1998)
Romania	Sieving and sedimentation (pipette method)		Walkley-Black chromic acid wet oxidation method, modified by Gogoasa	
Poland	Interaction with radiation (laser diffraction)		Wet combustion method	Jankauskas et al. (2006)
Estonia	Sieving and sedimentation (pipette method)	ISO 11277	Wet combustion with sulfuric acid by Tjurin method	Vorobyova (1998)
China Qiyang	Sieving and sedimentation	Gee and Bauder (1986)	Walkley-Black chromic acid wet oxidation method	Walkley and Black (1934)
China Suining	Sieving and sedimentation	Gee and Bauder (1986)	Walkley-Black chromic acid wet oxidation method	Walkley and Black (1934)
China Gongzhuling	Interaction with radiation (laser diffraction)	Gee and Bauder (1986)	Walkley-Black chromic acid wet oxidation method	Walkley and Black (1934)

Table 4
Classification of soil properties and thresholds (scores).

		Poor (0)	Moderate (1)	Good (2)	Reference
SOC* (%)		0–1	1–2	>2	SQAPP** thresholds
LOC (mg/g)	In Sand	<0.5	0.5–1	>1	Alaoui and Schwilch (2016)
	In Sandy loam	<0.7	0.7–1.4	>1.4	
	In Loam	<0.9	0.9–1.8	>1.8	
	In Clay-loam/Clay	<1.2	1.2–2	>2	
pH		<5.5 or >8.	5.5–6.5 or 7.5–8	6.5–7.5	SQAPP thresholds
PR*** (MPa)		>3	2–3	<2	SQAPP thresholds

* SOC = Total soil organic carbon.
** Soil Quality Mobile App (SQAPP) developed in the frame of iSQAPER (section References).
*** PR = Penetration resistance.

$<=|0.7|$, and strong correlations for $r > |0.7|$.

To test if the arithmetic means of measured soil properties were equal for the fields/plots of the OM and Control groups, we performed Welch's unequal variances two-tailed t-tests, for a level of significance $\alpha = 0.05$.

To test the differences between expected and observed frequencies of the categories of the ordinal variables of the OM and Control groups, we used the maximum likelihood ratio Chi-square test, for a level of significance $\alpha = 0.05$. Where an insufficient number of observations of a particular category appeared, this category was combined with another category to meet the criteria to use the test (for example, observations with score "poor" were combined with observations with score "moderate" for that particular soil visual indicator, producing a single combined category); this was the case for all but *Soil stability*. The strength of the effect was calculated with Cramér's V test.

All calculations were performed using Excel (Microsoft Office 2016).

3. Results and discussion

3.1. Effect of OM amendments on VSA indicators

Grouping the scores of the visual soil quality indicators into an OM group and a Control group, the OM group had higher proportions of Good scores than the equivalent proportions of the Control group, and the differences were statistically significant for the following indicators: "soil structure and consistency" and "soil porosity" (Table 5).

The **lack** of correlation (Spearman's) between both "soil structure and consistency" and "soil porosity" with other visual indicators, all weak or inexistent (Table 6), **suggests** that these other visual indicators measure, to a certain extent, the **magnitude of different underlying variables or interactions**. Thus, the information they provide is not redundant, i.e. they complement the information given by "soil structure and consistency" and "soil porosity". Within the OM group, only the correlation between "soil colour" and "soil stability" was statistically

Table 5
Differences in the visual soil quality indicators' scores, for soils with OM amendment and respective controls (maximum likelihood ratio Chi-square test ($\alpha = 0.05$)).

	OM group			Control group					
	Good n (%)	Moderate n (%)	Poor n (%)	Good n (%)	Moderate n (%)	Poor n (%)	G	p-value	Cramer's V
Str	20 (55.6)	16 (44.4)		7 (19.4)	29 (80.6)		10.34	**0.00***	**0.38**
Por	22 (61.1)	14 (38.9)		8 (22.2)	28 (77.8)		11.55	**0.00***	**0.40**
Sta	15 (41.7)	15 (41.7)	6 (16.6)	8 (22.2)	23 (63.9)	5 (13.9)	3.95	0.14 (ns)	0.23
Pan	18 (50.0)	18 (50.0)		11 (30.6)	25 (69.4)		2.85	0.09 (ns)	0.20
Col	15 (41.7)	21 (58.3)		13 (36.1)	23 (63.9)		0.23	0.63 (ns)	0.06
Ear		22 (61.1)	14 (38.9)		16 (44.4)	20 (55.6)	2.02	0.16 (ns)	0.17
Ero	30 (83.3)	6 (16.7)		28 (77.8)	8 (22.2)		0.36	0.55 (ns)	0.07
Pon	27 (75.0)	9 (25.0)		25 (69.4)	11 (30.6)		0.28	0.60 (ns)	0.06

* Statistically significant ($\alpha \leq 0.05$); (ns) Not statistically significant ($\alpha \leq 0.05$). Str: *Soil structure*; Por: *Soil porosity*; Sta: *Soil stability* (Slake Test); Pan: *Presence of a tillage pan*; Col: *Soil colour*; Ear: *Earthworm count*; Ero: *Susceptibility to wind and water erosion*; Pon: *Surface ponding*.

Table 6
Spearman's correlation coefficients between VSA indicators. Effect of OM amendment and comparison to control. Numbers in bold are statistically significant (α = 0.05, n = 36 (for *Surface ponding* n = 32)).

	OM group								Control group						
	Str	Por	Sta	Pan	Col	Ear	Ero	Pon	Str	Por	Sta	Pan	Col	Ear	Ero
Por	−0.27	–	–	–	–	–	–	–	0.29	–	–	–	–	–	–
Sta	0.14	0.17	–	–	–	–	–	–	−0.09	0.14	–	–	–	–	–
Pan	0.13	0.31	−0.11	–	–	–	–	–	0.12	0.25	−0.03	–	–	–	–
Col	0.11	0.21	**0.47**	0.13	–	–	–	–	0.04	0.30	**0.43**	**0.47**	–	–	–
Ear	−0.06	0.07	0.07	−0.09	0.03	–	–	–	0.15	0.19	0.25	−0.10	0.08	–	–
Ero	−0.11	−0.05	0.08	−0.04	0.08	0.07	–	–	0.13	0.15	**0.49**	0.18	**0.42**	0.32	–
Pon	0.23	0.02	0.20	0.07	0.23	0.09	0.01	–	0.00	0.06	0.08	0.31	**0.36**	0.26	**0.36**

Str: *Soil structure*; Por: *Soil porosity*; Sta: *Soil stability* (Slake Test); Pan: Presence of a tillage pan; Col: *Soil colour*; Ear: *Earthworm count*; Ero: *Susceptibility to wind and water erosion*; Pon: *Surface ponding.*

Table 7
Soil property value intervals, their arithmetic means and hypothesis testing that the means are equal, for soils with OM amendment and controls (Welch's *t*-test (α = 0.05)).

	OM group				Control group				
	Mean	n	s^2	Interval	Mean	n	s^2	Interval	p-value
SOM (%)	2.13	26	1.15	[0.55, 5.10]	1.87	26	1.11	[0.50, 5.19]	0.38 (ns)
LOC (mg/g)	2.09	35	5.59	[0.29, 7.76]	2.01	35	6.30	[0.17, 8.88]	0.89 (ns)
pH $[H^+]$	5.9	36	7.89 x 10^{-12}	[4.83, 8.70]	5.8	36	7.59×10^{-12}	[4.95, 8.70]	0.77 (ns)
PR (MPa)	2.34	29	1.15	[0.62, 4.96]	2.20	29	0.90	[0.53, 4.25]	0.60 (ns)

s^2= Variance of the sample; (ns) Not significant. pH, mean (presented as a log of $[H^+]$) and variance calculated for H^+ concentration (moles/liter). PR, penetration resistance (MPa).

Table 8
Pearson's correlation coefficients between measured soil properties within the OM and Control group (left side of the table). Spearman's correlation coefficients between ranked measured soil properties within the OM and Control group (right side of the table). Numbers in bold are statistically significant (α = 0.05).

	Linear association (Pearson correlation)							Monotonic association (Spearman rank correlation)							
	OM group			Control group				OM group				Control group			
	pH	PR	LOC	pH	PR	LOC	SOM	pH	PR	LOC	SOM	pH	PR	LOC	SOM
PR	0.27	–	–	0.29	–	–	–	0.23	–	–	–	0.18	–	–	–
LOC	0.17	−0.21	–	0.13	0.05	–	–	**−0.50**	0.09	–	–	−0.23	0.17	–	–
SOM	−0.04	0.05	0.20	−0.03	−0.07	**0.65**	–	0.09	0.10	**0.38**	–	0.04	0.22	**0.49**	–

For linear associations: pH (Status); PR: penetration resistance (MPa); SOM: soil organic matter (%); LOC: labile organic carbon (mg/g). For Spearman's rank correlation: ranking according to the thresholds, section 2.3. For LOC, soil texture is accounted for in the ranking procedure.

significant (r_s = 0.47), all other correlations were either weak or non-existing. Within the Control group, "soil colour" had statistically significant, moderate positive correlations with "soil stability", "the presence of a tillage pan", "susceptibility to wind and water erosion" and "surface ponding" (r_s = 0.43, 0.47, 0.42 and 0.36, respectively); other statistically significant, moderate positive correlations existed between "soil stability" and "susceptibility to wind and water erosion" and between "surface ponding" and "susceptibility to wind and water erosion", r_s = 0.49 and 0.36, respectively. The interpretation of these correlations is problematic because these visual soil indicators are either multi-attributes, and the inexistence of a weighting factor for each attribute leads to a relatively high degree of subjectivity (e.g. "susceptibility to wind and water erosion"), or they are measuring the magnitude of very different underlying variables and or interactions at each location of inherent soil properties and climate, but also of soil management (e.g. "surface ponding" and "tillage pan").

3.2. Effect of OM amendment on soil properties. Correlations of soil properties with visual soil quality indicators

If the analysis of the results focused only on the arithmetic mean values of measured soil properties, no statistically significant differences

Table 9
Pearson's correlation coefficients between measured properties and soil texture classes for soils with OM amendment and comparison with the Control group. Spearman's correlation coefficients between measured properties and soil texture classes for soils with OM amendment and comparison with Control group. Numbers in bold are statistically significant (α = 0.05).

Linear association (Pearson correlation)							Monotonic association (Spearman rank correlation)							
OM group				Control group			OM group				Control group			
	PR	LOC	SOM	PR	LOC	SOM	pH	PR	LOC	SOM	pH	PR	LOC	SOM
Sand	0.11	0.22	−0.08	0.08	0.16	−0.12	0.10	0.12	0.01	0.05	0.08	−0.04	−0.25	−0.14
Silt	−0.11	**−0.41**	−0.09	−0.18	**−0.38**	−0.20	−0.06	−0.17	−0.24	−0.29	0.02	0.01	−0.19	−0.15
Clay	−0.01	0.35	0.31	0.14	0.31	**0.53**	−0.19	0.20	**0.38**	0.27	−0.12	0.03	**0.67**	**0.43**

For linear associations: PR: penetration resistance (MPa); SOM: soil organic matter (%); LOC: labile organic carbon (mg/g). For Spearman's rank correlation: ranking according to the thresholds, section 2.3. For LOC, soil texture is accounted for in the ranking procedure.

Table 10

Spearman’s correlation coefficients between measured properties and VSA indicators for soils with OM amendment and control. Statistically significant for numbers in bold (α = 0.05, n = 24 to 36). Status next to LOC and SOM indicates ranking according to the thresholds described in section 2.3 (Table 4); for LOC status, soil texture is accounted for in the ranking procedure.

	OM group									Control group								
	pH	PR	LOC status	LOC	SOM status	SOM	Sand	Silt	Clay	pH	PR	LOC status	LOC	SOM status	SOM	Sand	Silt	Clay
Str	0.22	0.12	−0.18	0.01	−0.08	−0.05	−0.09	−0.01	0.07	0.15	0.06	0.20	0.14	−0.03	−0.06	0.21	−0.23	0.01
Por	0.25	−0.22	−0.15	0.13	0. 30	0.23	0.20	−0.19	−0.05	0.31	0.22	0.12	0.14	0.39	0.28	0.09	−0.05	−0.03
Sta	0.30	0.27	−0.18	−0.17	−0.03	0.06	−0.06	0.14	−0.34	0.28	0.07	**−0.33**	0.06	−0.28	−0.27	0.10	0.00	−0.21
Pan	**0.41**	0.19	**−0.38**	−0.22	−0.14	−0.24	0.16	−0.05	**−0.36**	0.22	0.05	−0.06	0.07	0.13	0.29	−0.31	**0.39**	−0.15
Col	**0.37**	0.26	**−0.33**	**−0.52**	0.01	0.06	−0.02	0.21	**−0.58**	**0.44**	0.17	**−0.43**	−0.18	−0.03	−0.08	0.15	0.11	**−0.60**
Ear	0.13	−0.23	−0.09	0.22	−0.14	−0.06	−0.18	0.23	0.10	0.20	−0.13	0.02	0.33	**0.41**	**0.44**	−0.23	0.22	0.08
Ero	0.24	−0.04	0.16	0.12	0.13	0.16	−0.08	−0.06	0.09	**0.41**	0.07	−0.21	0.16	−0.21	−0.15	−0.04	0.15	−0.22
Pon	**0.46**	−0.01	**−0.36**	−0.15	−0.10	0.02	−0.08	0.22	−0.33	0.30	0.00	**−0.45**	−0.11	−0.30	−0.20	−0.08	**0.40**	**−0.53**

pH; PR: penetration resistance; SOM status: soil organic matter; LOC status: labile organic carbon (ranking according to the thresholds, section 2.3). Str: *Soil structure and consistency*; Por: *Soil Porosity*; Sta: *Soil Stability* (Slake Test); Pan: Presence of a Tillage Pan; Col: *Soil colour*; Ear: *Earthworm Count*; Ero: *Susceptibility to wind and water erosion*; Pon: *Surface ponding.*

would be observed between the soils of the two groups (Table 7). A higher SOM and LOC content, when comparing OM fields with the respective Control, was only observed in 61.5 % and 54.3 % of pairs, respectively, and, more unexpectedly, 62.1 % showed a higher penetration resistance, and only 10 out of 36 (27.8 %) a higher pH status, 24 showed similar pH status and only 2 soils of the Control group had a higher pH status.

Pearson’s correlation coefficients between these soil properties (Table 8) were not statistically significant with the exception, within the Control group, of the correlation between **LOC (mg/g) and SOM (%), which was moderate/strong and positive (r = 0.65 and n = 26)**. Weil et al. (2003) observed a similar correlation coefficient between total organic C and LOC (r = 0.69, n = 18). The fact that OM amendments reduced the linearity of the correlation between LOC and SOM **allows us to speculate** that the paths and/or the rate of decomposition of the organic matter added to the soil may alter the relationship between LOC and SOM compared with a soil not receiving OM amendments. In fact, soil amendments with manures have been found to favour diversity and dominance of copiotrophic bacteria, able to grow on organic substrates and to use different carbon sources, whereas in mineral fertilized soils lower diversity and dominance of oligotrophic bacteria have been observed (van der Bom et al., 2018).

In terms of soil separates, Pearson’s correlation coefficients of LOC with silt were moderate, negative and statistically significant within both groups (Table 9); whereas they were moderate, positive, although not statistically significant, with clay. The negative correlations of LOC (mg/g) with silt (%) means that LOC content decreases with an increasing proportion of the silt fraction which may be the result of more aerobic soil conditions favouring the preponderance of aerobic microbes. The dominance of aerobic microbes in the soil fractions larger than clay (>2 μm) was observed by Sessitsch et al. (2001). Contrastingly, SOM content correlations were much weaker/non-existing with silt, within both groups; the correlation of SOM with clay was higher and statistically significant only within the Control group (r = 0.53). A linear positive statistically significant correlation between SOM and clay, **within the Control group**, suggests that SOM decomposition is less pronounced when clay content increases, probably due to different microbial distribution on and within aggregates (e.g. Chenu et al., 2001).

The ranking procedure used for LOC status distorts any analysis involving soil texture and will be discussed later (in Section 3.4). Correlations with SOM were less affected by ranking, within both groups (right side of Table 9).

Spearman’s correlation coefficients of visual soil quality indicators’ scores with SOM were not statistically significant, they were either weak/moderate or non-existent within both groups, except the correlation with “earthworm count” within the Control group (Table 10). Where no OM amendment is practised, “earthworm count” may be a good indicator of SOM content, and vice-versa. The lack of correlation within the OM group, suggests that earthworm abundance can be profoundly modified by OM amendments, as a result of a food source input (e.g. Leroy et al., 2007), and not from a direct SOM change. Classifying before ranking SOM did not alter the correlations’ direction and strength to any significant degree.

LOC had a moderate, negative correlation with “soil colour” within the OM group, not paralleled within the Control group (r_s=-0.52 and -0.18, respectively). Correlations of LOC status with visual soil quality indicators, when statistically significant, were negative, within both groups, and will be discussed in section 3.4.

Another aspect, common to both OM and Control groups, was the relationship between “soil colour” and “soil stability” (slake test), r_s = 0.47 and 0.43 within the OM and Control groups, respectively (Table 6); these visual soil quality indicators may well be measuring the magnitude of the same or **related underlying variables or interactions**. Numerous studies support the assumption that “soil colour” is measuring the magnitude of SOM change when under cropping (by comparing it with undisturbed soil), (e.g. Franzmeier, 1988). “Soil

Table 11

Pearson's correlation coefficients between measured SOM (%) and LOC (mg/g) (and the ratios of SOM and LOC) and 6 climate variables and indices (calculated for the georeferenced locations, see Section 2.4), for OM and Control groups. Spearman's correlation coefficients (4 columns, right side of the table). Numbers in bold are statistically significant ($\alpha = 0.05$, $n = 26$ and 35 for SOM and LOC, respectively). Status next to LOC and SOM indicates ranking according to the thresholds described in section 2.3 (Table 4); for LOC status, soil texture is accounted for in the ranking procedure.

	Linear association (Pearson correlation)								Monotonic association (Spearman correlation)			
	OM group			Control group			Ratios between groups		OM group		Control group	
	LOC	SOM	SOM/LOC	LOC	SOM	SOM/LOC	SOM /SOMctr	LOC/LOCctr	LOC status	SOM Status	LOC Status	SOM status
T mean	−0.28	0.11	0.18	−0.32	0.12	0.19	−0.16	0.07	**0.38**	0.01	**0.41**	0.05
P mean	0.16	0.18	**−0.43**	0.13	0.39	−0.39	−0.11	0.09	−0.11	0.20	−0.20	0.34
PET mean	−0.30	0.10	0.28	−0.27	0.10	0.23	−0.17	−0.19	**0.47**	0.04	**0.67**	0.05
AI	0.19	0.09	**−0.47**	0.15	0.24	**−0.43**	−0.04	0.12	−0.18	0.17	**−0.38**	0.29
P deficit	−0.27	0.06	**0.45**	−0.22	−0.19	0.39	−0.03	0.12	0.16	−0.21	0.32	−0.33
NPP Lim	0.27	0.16	**−0.42**	0.21	0.36	−0.37	−0.09	0.18	−0.01	0.21	−0.13	0.35

T mean = mean annual temperature (°C); P mean = mean annual precipitation (mm); PET mean = mean potential evapotranspiration (mm); AI = Aridity index = P annual mean/PET annual mean, dimensionless (UNEP, 1992); NPP = net primary production potential, NPP Lim = limiting value, NPP temperature or NPP precipitation (g (DM) m^{-2} yr^{-1}). Ranking according to the thresholds, section 2.3).

stability" status is also closely related to soil's OM content (e.g. Greenland et al., 1975). In the present study, **the lack of correlations** (weak or none) of both, "soil colour" and "soil stability" with SOM (Table 10), is an indication that these visual indicators were not assessing the magnitude of SOM content but **the effect of one or more interactions** of SOM with other soil properties, or climatic and biological variables. However, within the OM group, the correlation of "soil colour" with LOC content (r_s=-0.52) **suggests** the exact opposite, i.e., lower LOC content was closely associated with higher scoring (possibly related to higher microbial activity). Methodologically, "soil colour" scoring is performed by comparison of the soil under cropping with undisturbed soil collected nearby that provides a benchmark (Shepherd, 2000). In the present study, the observations of "soil stability" (slake test) were performed only on soils under cropping. Undisturbed soil aggregates' stability may be higher than soil aggregates' stability under cropping (e.g. Robinson and Page, 1951). Assessing the change in "soil stability" of undisturbed and "under cropping" aggregates (i.e. performing a differential observation, following the same reasoning used for "soil colour") could help to unveil how these two soil quality indicators are correlated ("soil colour" and "soil stability") and what underlying variables they might be assessing.

Of all visual indicators only "soil colour" has a moderate, positive and statistically significant correlation with soil pH, common in both groups. These positive correlations, of similar strength, between soil pH and "soil colour", within OM and Control group, **allow us to hypothesize** that microbial activity, especially bacterial growth, which varies markedly in soil pH values ranging from acidic to alkaline (e.g. Rousk et al., 2010), may have an important role in "soil colour" scoring.

In both groups, penetration resistance showed only weak or no correlations with visual soil quality indicators.

Within the OM group, soil separates sand and silt showed only weak or no correlations with visual soil quality indicators, while clay showed moderate, negative, statistically significant correlations with "soil colour" and "the presence of a tillage pan". Within the Control group silt content was positively correlated with "surface ponding" and "the presence of a tillage pan", and clay was negatively correlated with "soil colour" and "surface ponding". It is important to point out the negative correlation between "soil colour" and clay, within both groups (r_s=-0.58 and -0.60, for OM and Control groups respectively). The relationship of a **lower "soil colour" score** with increasing clay content, co-exists with the observed Pearson's correlation coefficients between clay and SOM content ($r = 0.53$ and 0.31, for Control and OM groups, respectively, and only statistically significant within the control group); if "soil colour" measures the magnitude of SOM content change (between soil "under cropping" and undisturbed soil), it would mean that in soils with higher clay content, a **higher SOM content change** for the soil "under cropping" would occur. However, a greater difference in SOM of soils with higher clay content, when comparing soils under cultivation and not tilled (e.g. grasslands), does not seem to be the case in other studies (e.g. Burke et al., 1989). Thus, if "soil colour" contrast scores are lower with increasing clay content, and if SOM content increases with clay content, one must question if "soil colour" really measures the magnitude of SOM content change between undisturbed and cultivated soil. Alternatively, if "soil colour" measures the magnitude of microbial activity change, both relationships would be explained, less microbial activity due to higher clay contents (e.g. Chenu et al., 2001) and, concomitantly, a tendency for higher SOM content with higher clay content, enhanced by the occlusion of SOM (e.g. Kölbl and Kögel-Knabner, 2004).

3.3. Climate effect on SOM and LOC content. Correlations with VSA indicators

The climate effect on soil LOC and SOM content, and different ratios of these two soil properties, were studied taking into account different variables and calculated indices (Table 11).

Correlation coefficients of LOC and Ratio SOM/LOC with climate variables and indices were very similar (both in strength and direction) between the two groups. Within the Control group, although not statistically significant, SOM's correlation coefficients with mean annual precipitation (Pmean), aridity index (AI), precipitation deficit, and net primary production limiting value (NPP Lim) were much higher than the equivalent correlation coefficients within the OM group. SOM/LOC ratio had the highest of Pearson's correlation coefficients with most climate variables and indices. By contrast, LOC correlations with climate variables and indices were weak/moderate. Ratios $\mathbf{SOM_{OM}/SOM_{Control}}$ and $\mathbf{LOC_{OM}/LOC_{Control}}$ showed no-correlation or only very weak correlations with the selected climate variables and indices.

Spearman's correlation coefficients of ranked LOC (**LOC status**) with climate variables and indices **showed the opposite direction** when compared to Pearson's correlation coefficients of LOC content with these climate variables and indices, within both groups (Table 11). Ranking SOM did not alter significantly the strength or direction of the correlations when compared to Pearson's correlation coefficients, within both groups.

Spearman's correlation coefficients between visual **soil quality indicators and climate variables and indices**, within each group, showed differences between the two groups (Table 12); with few exceptions, where no correlation was observed ($r_s<|0.10|$), the correlations **had the same directions observed for the correlations between LOC content and climate variables and indices.** When comparing the two groups, although **similar in terms of direction**, the correlations were very **distinct in terms of strength**: within the OM group, the correlation strength of "soil stability" with climate variables and indices was much higher than within the Control group while, on the other

Table 12
Spearman's correlation coefficients between VSA indicators and 6 climate variables and indices (calculated for the georeferenced locations). Effect of OM amendment and comparison to control. Numbers in bold are statistically significant ($\alpha = 0.05$, n = 36 (for *Surface ponding* n = 32)).

	OM group								Control group							
	Str	Por	Sta	Pan	Col	Ear	Ero	Pon	Str	Por	Sta	Pan	Col	Ear	Ero	Pon
T mean	−0.07	**−0.35**	−0.15	−0.12	−0.31	−0.26	−0.06	−0.33	−0.24	−0.11	−0.23	0.04	**−0.37**	−0.23	−0.28	**−0.41**
P mean	0.05	0.20	**0.58**	0.09	0.19	0.00	0.26	**0.35**	−0.06	**0.39**	**0.35**	**0.35**	**0.60**	0.13	**0.42**	0.31
PETmean	0.00	**−0.34**	**−0.55**	−0.08	**−0.53**	−0.23	−0.06	**−0.37**	−0.06	−0.13	**−0.34**	−0.08	**−0.56**	−0.24	−0.29	**−0.51**
AI	0.03	0.22	**0.66**	0.01	0.30	0.10	0.22	0.32	−0.05	0.30	**0.39**	0.22	**0.57**	0.27	**0.39**	**0.36**
P deficit	−0.07	−0.21	**−0.66**	0.00	−0.28	−0.12	−0.23	**−0.35**	0.04	−0.32	**−0.37**	−0.27	**−0.58**	−0.29	**−0.41**	**−0.40**
NPP Lim	0.05	0.22	**0.54**	0.06	0.10	−0.01	0.26	**0.36**	−0.10	**0.37**	**0.35**	0.32	**0.56**	0.10	**0.41**	0.29

Str: *Soil structure*; Por: *Soil porosity*; Sta: *Soil stability* (Slake Test); Pan: Presence of a tillage pan; Col: *Soil colour*; Ear: *Earthworm count*; Ero: *Susceptibility to wind and water erosion*; Pon: *Surface ponding*.

hand, within the Control group correlations of "soil colour" with climate variables and indices showed higher strength. These differences in the correlations' strength between the two groups **suggest** that the addition of OM alters the response of the underlying variable(s) of these visual soil quality indicators under different moisture regimes, but not so much concerning temperature regimes (mean annual temperature). Water was the main limitation in net primary production in 30 of the 36 sites studied. "Soil stability" scores were, apparently, associated with water **and** OM availability, and the relationships with climate variables were stronger within the OM group; thus, it can be **hypothesized** that "soil stability" is related to microbial activity, controlled by substrate availability and diffusion (Zak et al., 1999). Working with data from other paired fields (not related with OM amendments), we found Pearson's correlation coefficients between SOM and microbial biomass C of r = 0.81 (n = 14, only control fields) and correlation of microbial biomass C with climate variables and indices such as r = 0.62 with mean annual precipitation, 0.62 with aridity index, and 0.63 with net primary production (precipitation). Weak or no-correlations were observed with mean annual temperature (r=-0.04) and potential evapotranspiration (r=-0.13) (data not published). Concerning "soil colour", the relationships with water-related variables and indices were of higher strength within the Control group, and the same hypothesis can be raised. These differences between "soil stability" and "soil colour" correlations with climate variables, in response to OM amendment, may be partially explained by the fact that "soil colour" measures the magnitude of a **differential** assessment (the difference between the "soil colour" of undisturbed soil and soil under cropping), while "soil stability" measures the magnitude of slaking of soil aggregates under cropping.

For the correlations of "soil porosity" with climate variables, OM and Control groups showed distinctly different statistically significant correlations, although the differences were only in strength, not in direction. All other visual soil quality indicators, within both groups, had, with few exceptions, no correlations with climate variables and indices, or they were weak and not statistically significant.

3.4. LOC status vs. content

LOC status as defined by Des McGarry (n.d.), and used in this study, is based on soil LOC content and soil texture. If these thresholds related meaningfully with the visual soil quality indicators of the New Zealand VSA scheme (Shepherd, 2000), **a better LOC status would correspond to better visual soil quality indicators' score**. In the present study, the opposite was observed: all statistically significant Spearman's correlation coefficients between visual soil quality indicators' score and LOC status were negative. These differences in the correlations are not reconcilable.

LOC content may well be closely associated with crop performance (e.g. Culman et al., 2013) and soil quality. Our findings seem to support this assumption by the fact that correlations between visual soil quality indicators' score and climate variables follow the same directions of correlations of LOC content with the same climate variables. However, Spearman's correlation coefficients between LOC content and visual indicators' score were weak or non-existent, within both groups, except for the correlations of LOC with "soil colour" within the OM group, which was negative and moderate. This **suggests** that a higher "soil colour" score within the OM group corresponds to a state of lower LOC content, for example as a result of higher microbial activity. Other, not manuring-related paired field/control comparisons, showed a Pearson's correlation coefficient between microbial biomass C (g/kg) and SOM content that was positive, strong and statistically significant (r = 0.73, n = 28), while the Pearson's correlation coefficient between microbial biomass C (g/kg) and LOC (mg/g) was negative, weak and not statistically significant (r=-0.20, n = 26) (data not published). Thus, the use of LOC values (content or status), as a measure of soil quality may have an interest at a site-specific level, but it does not seem to hold any value as a universal indicator.

4. Conclusions

In conclusion, soil OM amendment had a statistically significant positive effect on visual soil quality indicator scores of “soil structure and consistency” and on “soil porosity”. These differences in the visual soil quality indicator scores between OM and Control groups cannot be attributed to differences in the measured content of SOM or LOC.

The high correlation between LOC (mg/g) and SOM (%) within the Control group suggests that LOC may be used, in the frame of field surveys, and where soils do not receive OM amendments, as a quick field assessed indicator of SOM content. Soil LOC status, defined based on LOC content and texture, did not correlate logically with either visual soil quality indicators score or with climate variables and indices, and thus its meaning and use, as a soil quality indicator, should be questioned.

Declaration of Competing Interest

The authors report no declarations of interest.

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