Received: 24 November 2020 | Revised: 29 December 2022 | Accepted: 1 January 2023

DOI: 10.1111/sum.12879

RESEARCH ARTICLE

Soil Use and Management BRITISH SOCIETY OF SOIL SCIENCE WILEY

Soil organic carbon content and soil structure quality of clayey cropland soils: A large-scale study in the Swiss Jura region

Alice Johannes[1] | **Ophélie Sauzet**[2] | **Adrien Matter**[2] | **Pascal Boivin**[2]

[1]Soil Quality and Soil Use Group, Department of Natural Resources & Agriculture, Swiss Federal Research Station Agroscope, Zurich, Switzerland

[2]Soils and Substrates Group, University of Applied Science of Western Switzerland Hepia, Institute Land-Nature-Environment, Geneva, Switzerland

Correspondence
Ophélie Sauzet, Soils and Substrates Group, University of Applied Science of Western Switzerland Hepia, Institute Land-Nature-Environment, Geneva, Switzerland.
Email: ophelie.sauzet@hesge.ch

Funding information
Bundesamt für Umwelt, Grant/Award Number: 16-0104.PJ/BAFU-D-36173401/1312

Abstract

Soil organic carbon (SOC) fashions soil structure, which is a key factor of soil fertility. Existing SOC content recommendations are based on SOC:clay ratio thresholds of >1:10. However, the corresponding SOC content might be considered hard to reach in clayey soils, whose structure degradation risk is assumed to be high. Here, we analysed the SOC content and soil structure quality of soils under similar cropping practices with clay contents ranging from 16% to 52%. Five undisturbed soil cores (5–10 cm layer) were collected from 96 fields at 58 farms in the Swiss Jura region. We assessed the soil structure quality visually using the CoreVESS method. Gravimetric air content and water content, and bulk density at −100 hPa were also measured, and the soil structure degradation index was calculated. We found that the relationship between SOC and clay content held over the clay content range, suggesting that reaching an acceptable SOC:clay ratio is not limited by large clay contents. This suggests that the 1:10 SOC:clay ratio may remain useful for clayey soils. In contrast to what was expected, it is not more challenging to reach this ratio in clayey soils even if it implies reaching very large SOC contents. SOC content explained the considered physical properties better than clay content. From a soil management point of view, these findings suggest that the soil texture determines a potential SOC content, while the SOC:clay ratio is determined by farming practices regardless of the clay content.

KEYWORDS

agricultural management, SOC:clay ratio, soil organic matter, soil physical properties, soil structure quality

1 | INTRODUCTION

Soil structure is defined as the spatial arrangement of solid constituents and voids, formed by complex interactions between biological activity, climate and soil minerals, resulting in the aggregation and accumulation of biopores (Or et al., 2021). Good soil structure quality is essential for sustainable crop production (Lal, 1991).

Alice Johannes and Ophélie Sauzet contributed equally to this publication.

Many factors may influence soil structure quality, among which the importance of soil organic carbon (SOC) content is widely recognized (e.g. Emerson & Smith, 1970; Jastrow, 1996; Malamoud et al., 2009; Oades, 1984; see Kay, 1998 for a review). Because SOC is influenced by farming practices, reference values for SOC content are necessary to manage cropland soils. Dexter et al. (2008) introduced the concept of clay saturation by SOC as determining the soil physical properties, thus emphasizing the SOC:clay ratio as a key parameter for soil quality. The SOC:clay ratio of 1:10 was later-on shown as a threshold linked to acceptable structure and, therefore, as the reasonable minimum goal for sustainable soil management purposes (Johannes, Matter, et al., 2017; Prout et al., 2021). Though the soil structure can be immediately damaged by compaction despite a high SOC:clay ratio, these studies showed that the average observed field soil structure quality was linearly related to the SOC:clay ratio. The SOC:clay ratio recommendations published by Johannes, Matter, et al. (2017) were, therefore, considered as an index of soil structure vulnerability (Dupla et al., 2021) because the average soil structure quality observed in the field is the result of the soil's resistance and resilience to different stresses, which is the definition of vulnerability (Kay, 1998).

The clay saturation concept was also used to determine the SOC sequestration potential (Chen et al., 2019). Both the structure vulnerability index and carbon saturation concept raise the question of the possibility to reach a targeted SOC:clay ratio with large clay contents. The minimum of 1:10 for acceptable structure vulnerability was determined in Switzerland on soils with clay content up to 35% (Johannes, Matter, et al., 2017). SOC content was shown to be well-correlated with clay content (Arrouays et al., 2006; Dexter et al., 2008; Hassink, 1997). However, soils with high clay content are considered harder to 'work' (Peltre et al., 2015; Schroeder, 1968) as soil workability highly depends on soil moisture and texture (Dexter & Bird, 2001; Obour et al., 2019; Paul et al., 2020). There is, therefore, a higher risk to damage the structure when working soils with heavy clay content. Moreover, reaching an acceptable SOC:clay ratio with large clay content requires storing very large amounts of SOC, which is often considered out of reach by farmers. As a matter of fact, Prout et al. (2021) reported the lowest SOC:clay ratios in heavy clay Pelosols among a variety of different soil types.

The issues related to soil workability and the large amounts of SOC required to meet the 1:10 SOC:clay recommendation are particularities of soils with large clay content. Our aim was to assess whether high clay contents may limit soil structure quality and SOC content. We pursued two specific objectives: (1) determine whether the SOC:clay ratio was decreased with increasing clay content (2) analyse whether soil structure quality was affected by increasing clay contents. Additionally, we also determined the importance of clay and SOC content in explaining physical properties.

2 | MATERIAL AND METHODS

2.1 | Study area

The sampled soils were located in the Swiss Jura region and belonged to the Cambisol reference soil group (Eutric, Calcaric, Pseudogleyed or Luvic) (Food and Agriculture Organization, 2014). The observed soils developed on limestone, molasses or loess deposits. All the samples came from cropped fields. We avoided recent tillage and sampled 96 fields in spring 2019 from 58 farms in the frame of 'Terres Vivantes', a cropland soil structure restoration project supported by the Swiss Federal Office for Agriculture. Information on the farm characteristics and cropping practices was collected through a survey and the following indicators were gathered as proposed by Büchi et al. (2019) (Table 1): used agricultural area for arable crops, permanent grassland and fallow (UAA), number of different crops cultivated, livestock unit, livestock units/UAA, crop diversity including temporary meadows/UAA (%) and mean duration of temporary meadows, soil disturbance and protection (i.e. number of tillage and stubble operations), quantity and type of manure applied during the past 10 years (m^3/ha), number of slurry amendments during the past 10 years. This information was gathered at farm scale ($n = 43$) and field scale ($n = 39$) (Table 1) to describe the associated cropping practices.

2.2 | Sampling and laboratory analysis

In each field, composite samples made of 20 aliquots were collected with a gouge auger in the 0–20 cm topsoil layer after the removal of the surface residues. Composite samples were sieved to 2 mm and dried at 40°C, prior to the texture (traditional pipette method, Gee and Bauder (1986)) and SOC analysis following Walkley and Black (1934). According to these data, the average clay content of the soils was 32 ± 9.4 (%, w/w) while the mean SOC content was 2.55 ± 0.94 (%, w/w) (Table 2).

Five undisturbed 5.6 cm diameter soil cores of approximately 150 cm^3 were collected at a depth of 5–10 cm in each field, which corresponds to 465 analysed samples after discarding the samples showing defects such as large coarse fraction or damaged structure at sampling or during transportation (Table 2). Undisturbed samples were collected with a custom-made sampler, allowing retrieval of

TABLE 1 List of 15 cropping practices used to describe the cropping systems of a ten-year crop rotation, with Pearson correlation coefficients between clay content and cropping practice and associated *p*-values

Description	Scale	Mean	cor	*p*
Mean duration of temporary meadows	Farm	4	−0.017	.87
Number of different crops cultivated	Farm	5	0.036	.72
Livestock unit	Farm	60	−0.091	.38
Quantity of solid amendments/UAA (m^3/ha)	Farm	8.5	0.050	.63
Quantity of liquid amendments/UAA (m^3/ha)	Farm	16.7	0.232	.02
Livestock unit/UAA - a value of 1 corresponds to 1 dairy cow per hectare	Farm	1	−0.034	.75
Utilized agricultural area used for arable crops, permanent grassland and fallow (ares)	Farm	5942	−0.064	.54
Area used for arable crops and temporary meadows/UAA (%)	Farm	65	−0.121	.31
Area used for permanent grassland (ares)	Farm	2111	0.094	.43
Number of years with temporary meadows during the past ten years	Field	4	0.078	.61
Number of different crops during the past ten years	Field	4	−0.051	.74
Number of organic amendments (solid or liquid) during the past ten years	Field	7.7	0.193	.20
Quantity of manure applied during the past ten years (m^3/ha)	Field	74	0.180	.27
Number of slurry amendments during the past ten years	Field	4.4	0.042	.79
Number of tillage and stubble operations during the past ten years	Field	12.8	−0.151	.34

Note: 'Scale' indicates whether the indicator is computed at farm scale (2019) or at field scale.

the soil cores for matric potential equilibration (sandbox), physical analyses and visual evaluation of structure quality. The samples were kept at 4°C before analysis. They were equilibrated at −100 hPa matric potential in a sandbox and weighted to determine their gravimetric water content at −100 hPa. Their volume was measured using the plastic bag method (Boivin et al., 1990) and used to determine gravimetric air content at −100 hPa. This parameter is of particular interest because it is associated with limit values addressing soil structure quality and compaction diagnosis (Johannes et al., 2019). After volume measurement, the samples were scored for their structure quality using CoreVESS as described in Johannes, Weisskopf, et al. (2017). Similar to the VESS spade test (Ball et al., 2017; Guimarães et al., 2011), the CoreVESS method gives scores of structure quality (Sq) ranging from 1 to 5 (with half points), based on observation of aggregate shape and porosity and breaking difficulty. Sq3 is the limit between good (<3) and degraded (>3) structures. Finally, the samples were oven-dried at 105°C until equilibrium, weighed and sieved to 2 mm to determine the <2 mm fraction weight. The weight and volume of the coarse fraction (>2 mm) were measured and removed from the sample volume and weight, to calculate the physical properties of the <2 mm fraction, namely gravimetric water content at −100 hPa ($W_{-100\,hPa}$), bulk density at −100 hPa (ρ_b), gravimetric air content at −100 hPa ($A_{-100\,hPa}$). ρ_b at −100 hPa was calculated as the mass of oven-dried soil divided by the volume at −100 hPa. $A_{-100\,hPa}$ was calculated as $A_{-100\ hPa} = V_{-100\ hPa} - W_{-100\ hPa} - 1/\rho_S$, with ρ_S the particle density (2.65 $cm^3\ g^{-1}$) and $V_{-100\,hPa}$ the specific volume at −100 hPa.

$A_{-100\,hPa}$ and $W_{-100\,hPa}$ correspond to the >15 and <15 µm pores in equivalent radius, respectively, according to Jurin-Laplace's law. Therefore we sometimes refer to $A_{-100\ hPa}$ as the 'coarse porosity'. Additionally, soil structure quality classes were defined for $A_{-100\ hPa}$ using threshold values developed by Johannes et al. (2019).

2.3 | Statistical analysis

The relationships between the clay content and the main characteristics of cropping practices at the field and farm level (Table 1) were analysed using the Pearson correlation coefficient and associated p-values.

To analyse the relationships between the SOC:clay ratio, SOC content and clay content, linear regressions were fitted using the linear model 'lm' of the R software (version 3.6.3). The linearity was tested using LOWESS (LOcally WEighted Scatter-plot Smoother) (Cleveland, 1979).

To analyse the impact of clay content on structure quality, linear regressions between clay and ρ_b, $A_{-100\ hPa}$ and CoreVESS scores were fitted using the linear model 'lm'. As clay and SOC are highly correlated, the relative contribution of clay and SOC to explain the physical properties was tested using the 'relaimpo' package (type lmg) (Groemping, 2006) whose metrics assess the relative

TABLE 2 Summary of the dataset with data of the plots (composite sample) and of the samples

	Plots (n = 96)			**Samples (n = 465)**			
	Clay	**SOC**	**SOC:Clay ratio**	**ρ_b**	**$W_{-100\,hPa}$**	**$A_{-100\,hPa}$**	**CoreVESS Sq scores**
	(%)	**(%)**	**(−)**	**$g\,cm^{-3}$**	**$g\,g^{-1}$**	**$cm^3\,g^{-1}$**	**(−)**
Mean	32.0	2.5	1:12.5	1.24	0.359	0.081	3.08
Median	30.8	2.4	1:13.8	1.26	0.336	0.073	3.00
SD	9.4	0.94	0.017	0.13	0.080	0.041	0.76
Min.	16.4	1.1	1:18.5	0.79	0.137	0.012	1.00
Max.	51.5	6.6	1:7.25	1.56	0.778	0.320	5.00

Abbreviations: A—gravimetric air content; n—number of observations; SD—standard deviation; SOC—soil organic carbon; ρ_b—bulk density; W—gravimetric water content.

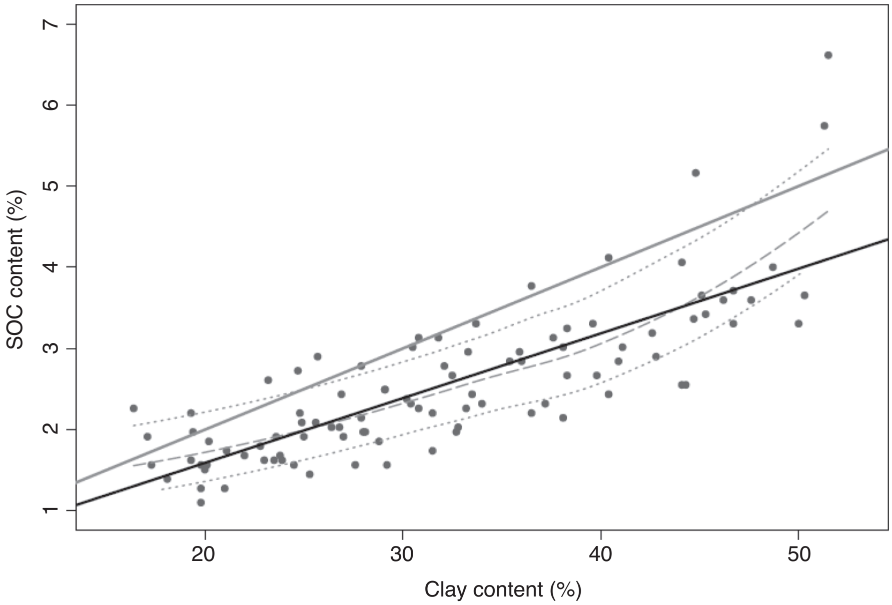

FIGURE 1 Linear model and 'lowess' nonparametric local regressions between soil organic carbon (SOC) and clay content; black solid line: linear regression line; light grey dashed line: lowess smooth curve (polynomial degree 2); light grey dotted lines: 95% confidence interval; grey solid line: 1:10 SOC:clay ratio; the parameters of the regression equations are given in Table 3.

importance of the factor in linear models providing a decomposition of the model explained variance into non-negative contributions. Kruskal-Wallis rank sum tests (based on plot scale means for soil structure quality classes and on plot scale medians for CoreVESS classes) were used to test the significance of the difference of average clay contents between soil structure quality classes identified by the $A_{-100\,hPa}$ thresholds of Johannes et al. (2019) and between the soil structure quality classes identified by CoreVESS (classes determined to half points).

3 | RESULTS

3.1 | Clay content and agricultural practices

All farms had quite similar cropping systems, namely a mix of permanent pasture associated with livestock and conventionally tilled soils. The rotations were also very similar (wheat, corn, rapeseed and barley with three years of temporary meadows). The soil clay content of the 96 fields ranged from 16% to 52%, and there was no correlation between the clay content and the cropping systems described in Table 1 at farm level (p-value > .05) except for the amount of liquid amendments applied on the agricultural area with significant Pearson correlations of 0.232 (Table 1). The cropping practices at the field scale showed no relationship with clay content. For instance, the number of tillage and stubble operations was not significantly correlated with clay content (cor = −0.151; p-value = .34).

3.2 | Clay content and soil organic carbon content

The SOC content ranged from 1.1% to 6.6%. The SOC:clay ratio was 1:12.5 on average (Table 2), which is below the

1:10 recommendation. According to linear and LOWESS model results (Figure 1 and Table 3), the relationship between clay content and SOC was linear (R^2 =0.64), on the whole clay content range. In other words, with similar cropping practices, the SOC content of these soils increased proportionally to the clay content on the full clay content range. Accordingly, there was no significant relationship between SOC:clay and clay (Figure 2; *p*-value: .40). Therefore, the soil structure vulnerability, represented by the SOC:clay ratio, was independent from clay content.

3.3 | Clay content of different soil structure quality classes according to CoreVESS and $A_{-100\ hPa}$

The mean CoreVESS score was 3, i.e, between a good and a poor structure quality (Table 2). The linear model results show that there was no relation between CoreVESS and clay content (Figure 4 and Table 3). According to the Kruskal-Wallis rank sum test, the clay content and the SOC content of the CoreVESS classes were not significantly different (*p*-value = .08 and .54, respectively). Figure 5 depicts $A_{-100\ hPa}$ as a function of $W_{-100\ hPa}$, along with the different soil structure quality threshold values for $A_{-100\ hPa}$ proposed by Johannes et al. (2019). Though slightly decreasing from indicative to remediation threshold, the clay content of the different classes was not significantly different (*p*-value = .089) (Table 4) according to the Kruskal-Wallis rank sum test.

3.4 | Effect of clay content, SOC content and their relative importance on soil physical properties

Figure 3a shows that ρ_b decreased linearly with clay content (R^2 =0.42) (Table 3). Adding SOC as a second explanatory variable to the linear model allowed to increase the R^2 from 0.42 to 0.53 (Table 5). ρ_b decreased with increasing SOC and increasing clay content. The soil organic carbon content explained 60% of the model variance while clay content explained 40% with a significant effect of clay.

The air content at −100 hPa ($A_{-100\ hPa}$) increased with increasing clay content (R^2 = 0.07) (Figure 3b and Table 3). Adding SOC as the second variable to the linear model increased the R^2 from 0.07 to 0.13 (Table 5). More than 70% of the model variance was explained by SOC and 30% by clay, whose effect was not significant.

The water content at −100 hPa ($W_{-100\ hPa}$) increased with increasing clay content (R^2 =0.40) (Figure 3c and Table 3). Adding SOC as the second variable to the linear model increased the R^2 from 0.40 to 0.52 (Table 5). More than 60% of the model variance was explained by SOC and 40% by clay, with a significant effect of clay. Table 5 presents linear regression parameters without interaction terms. ρ_b and $A_{-100\ hPa}$ had no significant interaction term. In the case of $W_{-100\ hPa}$, the interaction term was significant but represented only 3% of the relative importance for the following equation: $W_{-100\ hPa}$ =0.277–0.0007 clay +0.0040 SOC + 0.0011 (clay * SOC) with R^2 =0.54.

4 | DISCUSSION

4.1 | Agricultural practices and clay content

Because farmers consider that soils with high clay contents are more difficult to 'work', there was a possibility that cropping practices might change with soil texture. This was not the case in our study. Except for slightly larger liquid manure application, clayey soils were not managed differently than less clayey soils. This observation accords with the findings of Büchi et al. (2019) who found no significant difference in cropping systems for 60 fields of the Swiss plateau ranging from 10% to 40% clay content. Similar results regarding the relationship between clay content and agricultural practices were obtained at Swiss level by Gubler et al. (2019). Therefore, we conclude that the observed soil properties in this study can be compared without the indirect effect of changing cropping practices with clay content.

TABLE 3 Parameters of the linear regressions of soil organic carbon content (SOC), bulk density (ρ_b), gravimetric air content at −100 hPa ($A_{-100\ hPa}$), gravimetric water content at −100 hPa ($W_{-100\ hPa}$) and CoreVESS visual scores as a function of clay content

Soil property	Equation	Multiple R^2	Adjusted R^2	*p*-value
SOC	−0.004 + 0.0798 * Clay	0.639	0.635	< 0.001
ρ_b	1.524 – 0.0090 * Clay	0.421	0.420	< 0.001
$A_{-100\ hPa}$	0.043 + 0.0012 * Clay	0.073	0.071	<0.001
$W_{-100\ hPa}$	0.186 + 0.0055 * Clay	0.402	0.401	< 0.001
CoreVESS	2.987 + 0.0028 * Clay	0.001	0.001	0.462

Note: Clay and SOC were determined on composite samples. Physical properties were determined on five undisturbed samples per field.

4.2 | The SOC:clay ratio in clayey soils

The SOC:clay ratio of 1:10 is commonly used in Switzerland as an objective for SOC management by farmers. Using this ratio implicitly assumes a linearity in the relationship between the two properties. Although many studies (e.g. Arrouays et al., 2006; Dexter et al., 2008; Hassink, 1997; Hassink & Whitmore, 1997; King et al., 2020) reported a linear relation between clay content and SOC, the linearity at high clay content was not discussed. In this study, the relationship between clay and SOC remained linear up to 52% clay content. In accordance with Prout et al. (2021), this finding supports that the soil structure vulnerability index with the SOC:clay threshold values provided by Johannes, Matter, et al. (2017) can be used as targets for soil quality management and SOC sequestration potential evaluation for soils with large clay content. Reaching the corresponding SOC contents can be considered as very demanding or even unattainable in cropped clayey soils. Despite this difficulty, this large-scale on-farm study did not reveal decreasing SOC:clay ratios for soils with increasing clay content. There was enough organic material fed to the soil to reach the same SOC:clay ratio on the whole clay content range, which may be related to the role of clay in SOC protection. This finding, however, applies to SOC:clay ratios below the 1:10 threshold including for soils at the lower end of the clay content range. Its relevance for more SOC-saturated soils should be further assessed.

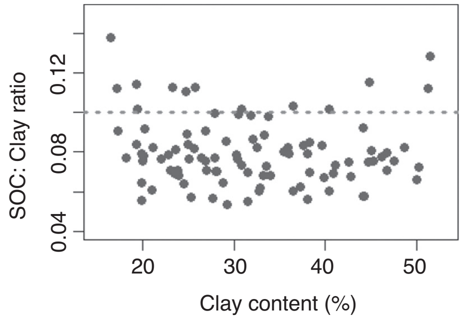

FIGURE 2 Soil organic carbon content to clay ratio (SOC:clay) as a function of clay content. The dotted grey line corresponds to a SOC:clay ratio recommendation of 1:10.

4.3 | Soil structure quality in clayey soils

Despite higher compaction risks related to tillage and trafficking in clayey soils considered harder to work, the CoreVESS scores remained similar over the whole clay content range (Figure 4). Similarly, the soil structure quality classes defined by the limit values of $A_{-100\ hPa}$ also remained independent from clay content (Figure 5, Table 4). The fact that CoreVESS and coarse porosity ($A_{-100\,hPa}$) behave similarly may not be surprising because coarse porosity and visual examinations are well-correlated (Johannes, Weisskopf, et al., 2017; Pulido Moncada et al., 2014). Indeed, visual examination methods focus on the observation of large visible pores and

TABLE 4 Mean clay content of samples (based on plot scale means) classified according to target, trigger and remediation limits of gravimetric air content at −100 hPa as defined in Johannes et al. (2019)

	Number of observations		Average clay cont.	Clay cont. Standard deviation
	(–)	(%)	(%)	(%)
Above Indicative threshold	53	11.4	32.3	9.5
From Investigation to Indicative threshold	201	43.2	33.9	9.4
From Remediation to Investigation threshold	138	29.7	30.8	8.9
Below Remediation threshold	73	15.7	27.1	8.0

TABLE 5 Relative importance of SOC and clay content in linear models for bulk density (ρ_b), gravimetric air content at −100 hPa ($A_{-100\,hPa}$) and gravimetric water content at −100 hPa ($W_{-100\,hPa}$) and their regression parameters

Soil physical property	Multiple R^2	Adjusted R^2	Relative importance of clay	Relative importance of SOC	Clay coefficient	SOC coefficient
ρ_b	0.537	0.535	40%	60%	−0.0027***	−0.0787***
$A_{-100\,hPa}$	0.130	0.126	28%	72%	−0.0002	0.0175***
$W_{-100\,hPa}$	0.521	0.519	40%	60%	0.0015***	0.0496***

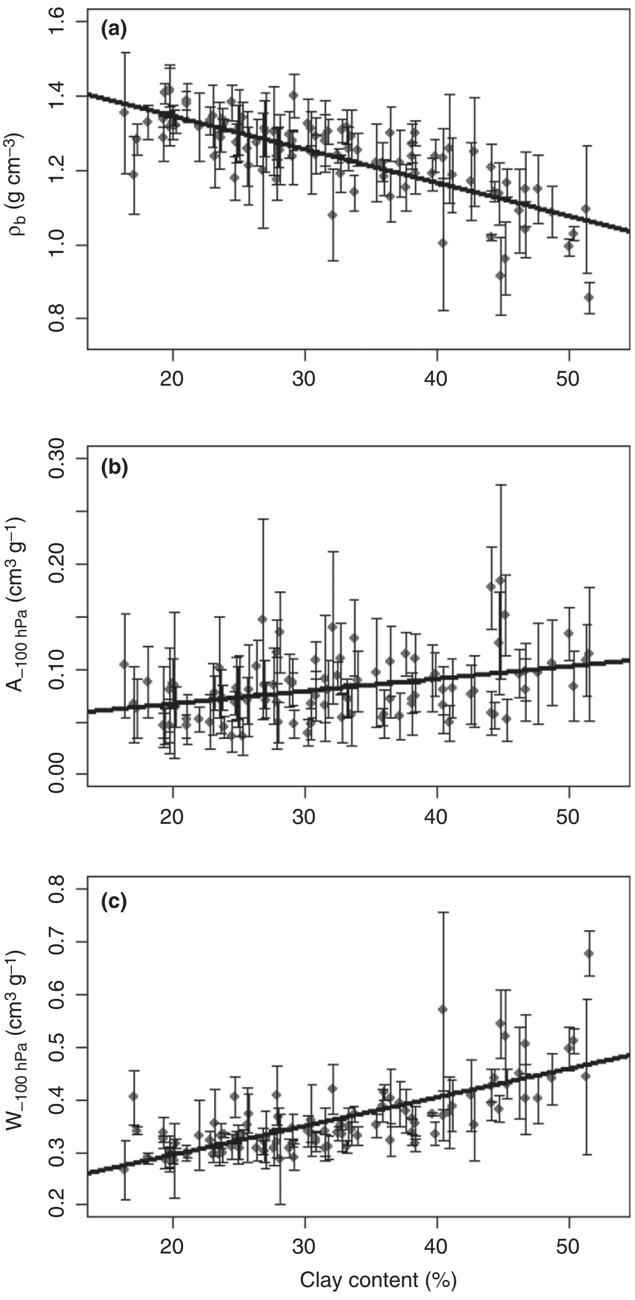

FIGURE 3 Linear regression between (a) bulk density at −100 hPa (ρ_b), (b) gravimetric air content ($A_{-100\,hPa}$), (c) gravimetric water content ($W_{-100\,hPa}$) and clay content; black solid line: linear regression line; the parameters of the regression equations are given in Table 4; Upper whiskers represent the mean plus one standard deviation and the lower whiskers represent the mean minus one standard deviation; dark grey dots: mean value of the field

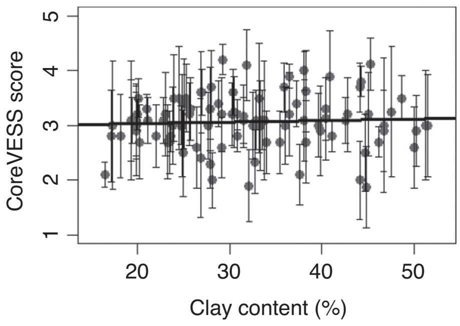

FIGURE 4 Linear regression between CoreVESS and clay content; black solid line: linear regression line; the parameters of the regression equation are given in Table 4; black whiskers: 2SD (whisker up = 1 ×SD and whisker down = 1 ×SD); dark grey dots: mean value of the field

therefore a large part of the score is determined by these large visible pores. Finally, both CoreVESS and $A_{-100\,hPa}$ showed the poorest R^2 (from 0.01 to 0.07) in the linear model explained by clay content (Table 3). The poor relation between clay content and soil structure quality (determined by both CoreVESS and $A_{-100\,hPa}$) may not be surprising, because although clay is an important soil structuring element, its direct influence on biological processes forming coarse porosity is limited.

4.4 | Effect of clay content, SOC content and their relative importance on soil physical properties

While structure quality indexes were independent from clay content, ρ_b decreased linearly with clay content and $W_{-100\,hPa}$ and $A_{-100\,hPa}$ increased linearly with clay content. Both clay content and SOC content are known to influence most physical properties (e.g. Rawls, 1983), including bulk density, porosity and water content. Many studies focused on the effect of clay content on physical properties (e.g. Keen and Raczkowski (1921)) or on the effect of SOC on physical properties (e.g. Benjamin et al. (2008); Boivin et al. (2009); de Dios Herrero et al. (2020); Heuscher et al. (2005); Johannes, Matter, et al. (2017)).

In this study, when considered alone, clay content had a significant effect on all studied physical properties ($W_{-100\,hPa}$, ρ_b and $A_{-100\,hPa}$) as expected. However, when both parameters (clay and SOC contents) were considered together in multiple regression, the effect of SOC content on physical properties was always significant, while the effect of clay remained significant only for $W_{-100\,hPa}$ and ρ_b, and not for $A_{-100\,hPa}$. Moreover, the effect of clay on $A_{-100\,hPa}$ became small and its coefficient had the opposite sign: $A_{-100\,hPa}$ is thus decreasing with increasing clay content when the effect of SOC content is accounted for by the model. The analyses about the relative importance of clay and SOC in these multiple regressions, systematically point out SOC as the most explanatory variable (Table 5).

These findings are in good agreement with previous literature reporting separately that (1) SOC content and

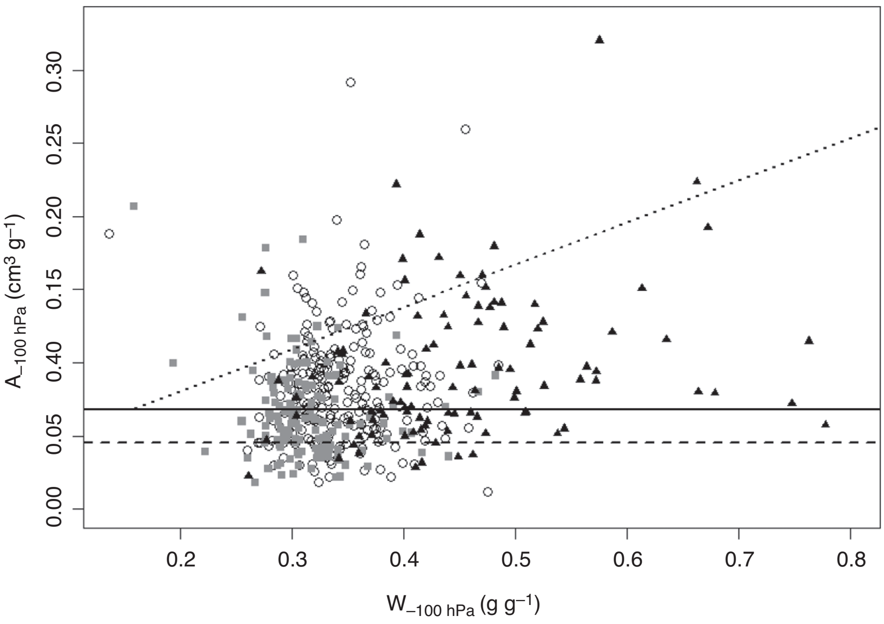

FIGURE 5 Classification of the samples according to the soil structure quality index (Johannes et al., 2019) and clay content categories. Clay content <25%: light grey squares, 25% ≤ Clay content ≥40%: dark grey circles, clay content >40%: black triangles; target value (dotted line), trigger limit (full line) and remediation threshold (dashed line)

soil physical properties tend to be proportional (linear relationships) (Dexter et al., 2008; Emerson & Smith, 1970; Jastrow, 1996; Kay, 1998; Malamoud et al., 2009; Oades, 1984), (2) SOC content and clay content tend to be correlated (Arrouays et al., 2006; Dexter et al., 2008; Hassink, 1997) and (3) structure quality is related to SOC:clay ratio thresholds (Johannes, Matter, et al., 2017; Prout et al., 2021). Our observations suggest a more comprehensive understanding of the processes explaining physical properties in cropped soils, namely that under comparable cropping practices clay content controls the SOC content, which in turn controls soil physical properties.

5 | CONCLUSIONS

This large-scale cropland study shows that despite higher soil degradation risks linked to harder workability in clayey soils, soil structure quality was not negatively affected by high clay contents for comparable cropping practices. Clay content had no influence on both CoreVESS visual evaluation of soil structure quality and the soil structure quality classes defined by $A_{-100\,hPa}$. Moreover, the relationship between SOC and clay was linear and therefore the SOC:clay ratio was constant over the clay content range from 16% to 52%, which suggests that the 1:10 SOC:clay ratio may be useful in clayey soils and that in contrast to what was expected, it is not more challenging to reach large SOC contents in clayey soils (up to 6.6% at the highest clay content in this study).

When considered alone, clay content had a significant effect on ρ_b., $A_{-100\,hPa}$ and $W_{-100\,hPa}$, but when considered together, the statistical analyses showed that SOC was a better explanatory variable than clay. The linear relation between SOC and clay suggests that clay content controls the SOC content, which in turn controls the soil physical properties, while the SOC:clay ratio is linked to the soil structure vulnerability. From a soil management point of view, our results suggest that the inherent soil texture determines a potential SOC content, but that it is in the hands of farmers to improve soil physical properties in their fields by managing SOC. Extending these conclusions to other agro-pedo climatic contexts and SOC:clay ranges should be considered.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support provided for the TERRES VIVANTES project by the Swiss Federal Office for Agriculture and Jura and Bern cantons and the support provided by the Swiss Federal Office of the Environment for project 'Zielwert Humus für tonreiche Böden' n°16-0104.PJ/BAFU-D-36173401/1312. We are grateful to the farmers involved and to the managers of Terres Vivantes project: Luc Scherrer and Amélie Fietier and all their colleagues from the Fondation Rurale Interjurassienne. The authors thank Saskia Leopizzi, Karine Gondret and Alessandro Milo for sampling, Marlies Sommer for laboratory measurements, Sol Conseil for providing soil clay and organic carbon content data and Nicole Chavaz-Cirilli for statistics. Open access funding provided by Haute Ecole Specialisee de la Suisse Occidentale.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Ophélie Sauzet https://orcid.org/0000-0002-9927-8963

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How to cite this article: Johannes, A., Sauzet, O., Matter, A., & Boivin, P. (2023). Soil organic carbon content and soil structure quality of clayey cropland soils: A large-scale study in the Swiss Jura region. *Soil Use and Management*, *39*, 707–716. https://doi.org/10.1111/sum.12879