Ref. Ares(2019)4125332 - 28/06/2019

iSQAPER
Interactive Soil Quality Assessment

Internal report on performance of promising land management practices to populate recommendations of SQAPP

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Deliverable: 6.1
Deliverable type: Report
Issue date: June 2019
Project partner: University of Évora

www.iSQAPER-project.eu

UNIVERSIDADE DE ÉVORA

DOCUMENT SUMMARY	
Project Information	
Project Title	Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience
Project Acronym	iSQAPER
Call identifier	The EU Framework Programme for Research and Innovation Horizon 2020: SFS-4-2014 Soil quality and function
Grant agreement no:	635750
Starting date	1-5-2015
End date	30-4-2020
Project duration	60 months
Web site address	www.isqaper-project.eu
Project coordination	Wageningen University
EU project representative & coordinator	Prof. Dr. C.J. Ritsema
Project Scientific Coordination	Dr. L. Fleskens
EU project officer	Mrs. A. di Biasio
Milestone Information	
title	Internal report on performance of promising land management practices to populate recommendations of SQAPP
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Deliverable Number	D6.1
Work package	WP6
WP lead	UE
Report due date	April 2019
Report publish date	June 2019
Dissemination	Report
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Internal report on performance of promising land management practices to populate recommendations of SQAPP

Project: iSQAPER | Work Package 6

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1. Abstract

This report concerns the performance of promising innovative agricultural practices concerning soil quality and overall sustainability of crop production, on selected and representative sites across pedoclimatic zones of Europe and China, in the scope of project iSQAPER (Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience).

Promising soil quality improving agricultural management practices (AMP), classified according to WOCAT's AMP groups, and respective controls, were selected following a paired-site approach at 132 different locations, across 8 pedoclimatic zones (6 in Europe and 2 in China) under different farming systems (arable, permanent and pastures) and covering different soil types. In 2016, the soils at the AMP fields and respective Control fields (with the conventional management practice) were then assessed for their soil quality status using a Visual Soil

Assessment (VSA) method, comprising 8 VSA indicators[1], and performing the measurement of 4 soil properties, on a total of 264 fields (132 AMP + 132 Control). In 2018, from the original 132 AMP-Control pairs identified and evaluated in 2016, 20 pairs of AMP-Control (40 fields) were selected to perform an extended VSA protocol, comprising 10 VSA indicators, and to measure 13 soil physical, chemical and biological properties, to check the correlations between VSA indicators and measured soil properties.

Correlations between VSA indicators and selected measured physical/ chemical/ biological properties were performed using Spearman's rank-order correlations. Ranking of measured properties was performed following 2 procedures: a) ranking of each property following their values, in an ordinal level of measurement (except for those properties where this ranking procedure would not make sense (e.g. *pH*)); b) ranking each property in 3 levels (also an ordinal level of measurement), with the same thresholds as used for SQAPP and, for those properties with no thresholds defined in SQAPP, we used appropriate ranking (see materials and methods). Correlations using the second ranking procedure, although producing different results, don't differ much in terms of strength of correlation, direction or significance for most soil properties and VSA indicators, and are discussed in the text.

Not taking into account the pedoclimatic zones effects, major correlations show the following:

The observed VSA indicators and the measured properties allowed for the calculation of 32 correlations in 2016 and 111 in 2018. Of the 32 correlations calculated with the dataset of 2016 between VSA indicators and measured properties, 14 are very weak (not statistically significant) or non-existing, and the remaining 18 correlations are weak to moderate and statistically significant. In the dataset of 2018, a higher number of correlations was calculated between VSA indicators and measured properties (111 correlations), but most (86 correlations) were not statistically significant. Measured properties with statistically significant correlations with VSA indicators in the data of 2016 were: *pH* (with 6 statistically significant correlations with VSA indicators out of 8 correlations), *infiltration rate* (with 5 out of 8), *organic matter* (OM) (with 4 out of 8) and LOC (with 3 out of 8). For the data of 2018, statistically significant correlations of measured soil properties with VSA indicators were: *total nitrogen* (N_{tot}) (with 7 out of 10), *number of macrofauna groups* (with 6 out of 10), *soil organic carbon* (SOC) (with 5 out of 10), *microorganism C* (with 2 out of 10), *bulk density* (2 out of 10), *available P* (P_{avail}), *exchangeable K* (K_{exc}) and *stone content* (all with 1 out of 10). Correlations with *texture* and particle size percentage are not included in the account above but are presented in the text and figures (data of 2018), because they require further analysis and more data (from the CSSs).

In the dataset of 2018, soil structure related VSA indicators (structure, porosity and stability) have moderate positive, statistically significant (α=0.05) correlations with SOC and *total N* (N_{tot}) and only VSA *structure* shows a moderate statistically significant correlation with *number of macrofauna groups*; in the data from 2016, correlation of VSA *structure* with OM is weak but statistically significant (r_s=0.24, n=106) and these VSA indicators (*structure*, *porosity* and *stability*) have no correlations with LOC (r_s<|0.10|, n=230), and they have weak/ moderate correlations with *pH* (moderate with VSA *porosity*), all statistically significant; only VSA

[1] **VSA indicator** is used to designate the visual observation of a soil property following a convenient protocol and scoring system.

structure and *porosity* have weak, statistically significant correlations with *infiltration rate*, while VSA *stability* has no correlation with *infiltration rate*.

VSA *subsoil compaction* (2018), has no correlation with calculated *susceptibility to compaction* (nor with *bulk density*) and these results, most probably, are due to protocol error (*bulk density* measured at a different depth than where subsoil compaction occurs). Other correlations exist and are discussed in the text.

Correlations between other VSA indicators and measured properties exist in both datasets (2016 and 2018) and are discussed in the text.

Of the 28 correlations calculated between VSA indicators of the 2016 campaign (n=264), only 6 were not statistically significant. The statistically significant correlations have coefficients varying between 0.14 (VSA *stability* with VSA *surface ponding*) and 0.42 (VSA *structure* with VSA *porosity*). The inexistence of correlation between VSA *stability* and VSA *structure*, and between VSA *stability* and VSA *tillage pan*, are probably the most unexpected results of this dataset. In the campaign of 2018 (n=40), 21 out of the 45 correlations calculated between VSA indicators were not statistically significant. The statistically significant correlations have coefficients varying between 0.36 (VSA *degree of clod development* x VSA *surface ponding*) and 0.78 (VSA *degree of clod development* x VSA *porosity*).

Correlations of AMP groups[2] with measured properties were only calculated with the dataset of 2016, and although some correlations were found, they are not statistically significant. Correlations of AMP groups with VSA indicators exist for some AMP groups/VSA indicators and allow to assess the impact of that particular category of management practices on soil quality. The main impact of the AMP groups in the campaign of 2016 on VSA indicators are structure related, mainly on porosity, but also on *structure* and *stability*. Only AMP groups *'no-till'* and '*leguminous crops'* have moderate positive, statistically significant, correlations with VSA *stability (slaking test)*, r_s=0.50 for both AMP groups. Only AMP *'no-till'* has a moderate positive, statistically significant correlation with VSA *susceptibility to erosion*. The AMP '*measures against compaction'* has only a weak positive, not statistically significant correlation with VSA *tillage pan*.

Pedoclimatic zone effects will be studied for Deliverable 6.2 (month 58 of the project).

2. Introduction

In the frame of iSQAPER (Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience), an interactive tool (SQAPP) was designed to allow onsite soil quality assessment and monitoring, providing management recommendations for improving soil quality. The complexity of this task, if based solely on measured chemical, physical and biological soil parameters, would require a trove of local information that is seldom available. Fortunately, a holistic approach to soil quality, accounting the visual perception (and the perception of other senses, like smell or touch) of signs empirically connected to soil quality, may provide the means to monitor effectively management/ land use change impact of the evolution of soil quality (functions).

[2] **AMP group** designates different, related, agricultural management practices that are classified based on the WOCAT approach (see Annex 1).

Several visual soil assessment methods exist and, depending on their goals, allow the observation of several soil properties (Bünemann et al. 2016). These methods, such as VESS, visual evaluation of soil structure (Guimarães et al. 2011), provides objective protocols and a scoring system that reduces the subjectiveness of the evaluation, allowing the use of semi-quantitative (ordinal scales) data treatment. The approach considered in the iSQAPER campaign of 2018 differs from that of 2016, using an extended number of VSA indicators observed, both consisting of a selection of VSA indicators from several other VSA approaches. Also, for both campaigns, an ordinal scale (poor (0), moderate (1), good (2)) was used to score soil quality for each VSA indicator, but no soil quality index that groups the VSA indicators objectively exists at the moment. Complementary measurements of soil physical, chemical and biological properties were made during both campaigns in order to establish the association between VSA indicators and measured properties.

This report aims to inform of the average impact of several innovative management practices, grouped under different categories, on soil quality assessed by means of VSA indicators and selected measured properties. The effect of different pedoclimatic zones on soil quality was not addressed in this report (it will be part of Deliverable 6.2).

3. Materials and Methods

3.1 Case Study Sites

The distribution of Case Study Sites (CSSs) covers 6 climatic zones in Europe and 2 in China (Table 1).

Table 1. CSSs *per* climatic zone in Europe and China.

Europe						China	
Atlantic	Mediterranean temperate	Mediterranean semi-arid	Southern Sub-Continental	Northern Sub-Continental	Boreal to Sub-Boreal	Central Asia Tropical Zone	Middle Temperate Zone
Netherlands (CSS1) France (CSS2)	Portugal (CSS3) Greece (CSS5)	Spain (CSS4)	Slovenia (CSS6) Hungary (CSS7)	Romania (CSS8) Poland (CSS9)	Estonia (CSS10)	Qiyang (CSS11) Suining (CSS12)	Gongzhuling (CSS14)

Definition of pedoclimatic zones

The major pedoclimatic zones were defined by Tóth *et al.* (2016). The climatic groups defined embody the soil processes that prevail at these climatic regions (Tóth *et al.*, 2016). A total of 8 climatic groups were defined in Europe (Figure 1): Boreal to Sub-Boreal (CZ1), Atlantic (CZ2), Sub-oceanic (CZ3) Northern sub-continental (CZ4), Mediterranean semi-arid (CZ5), Southern sub-continental, (CZ6), Mediterranean (temperate and sub-oceanic) (CZ7) and Temperate mountainous (CZ8). For China, a total of 10 climatic groups: Tropical zone; Southern Asia tropical zone; Central Asia tropical zone; Northern Asia tropical zone; Warm temperate zone; Plateau temperate zone; Plateau artic zone; Plateau sub-arctic zone; Middle temperate zone; Cold temperate zone.

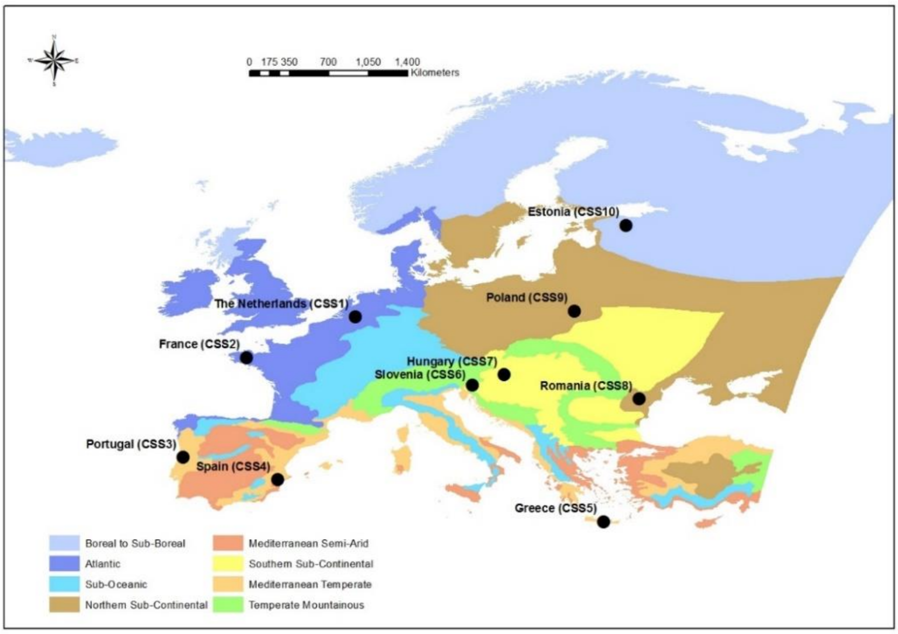


Figure 1. Climatic zones and location of Case Study Sites (CSSs) in Europe (adapted from Barão L. and Basch G., 2017).

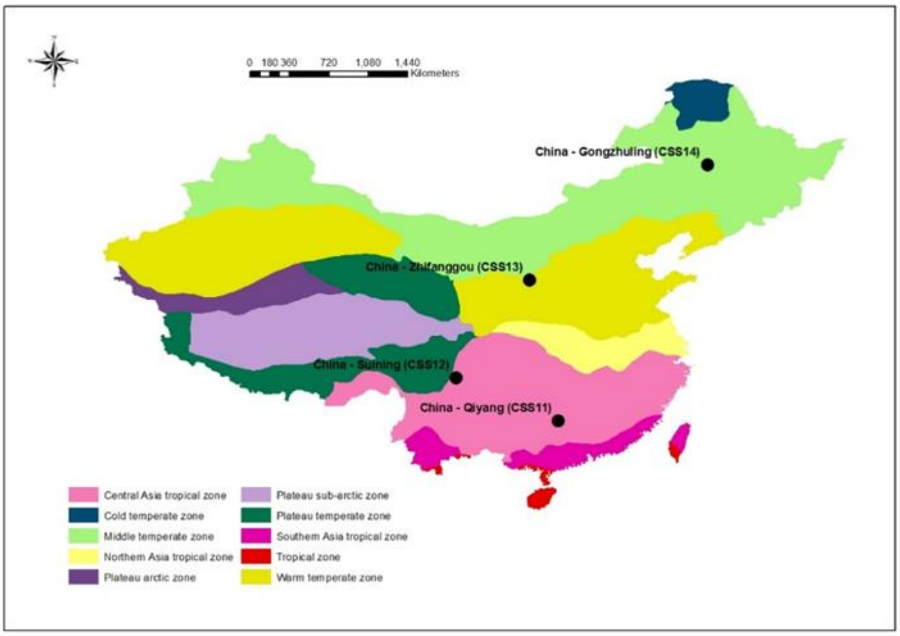


Figure 2. Climatic zones and location of Case Study Sites (CSSs) in China (adapted from Barão L. and Basch G., 2017). The CSS of Zhifanggou didn't present any AMP.

For the climatic zones defined for Europe and China, Reference Soil Groups (RSGs) were identified and each combination climatic zone/ RSG constitutes a pedoclimatic zone under that climate (Tóth *et al.*, 2016). For representativeness purposes, CSSs were advised to only consider AMPs in plots/ farms with soils that belong to the RSGs that occupy more than 10% of the territories (see Table 2).

Table 2. Representativeness (>10%) of RSGs *per* climatic zone.

	Europe						China	
	Atlantic	Mediterranean temperate	Mediterranean semi-arid	Southern Sub-Continental	Northern Sub-Continental	Boreal to Sub-Boreal	Central Asia Tropical Zone	Middle Temperate Zone
Podzol	16.7				10.3	41.6		
Albeluvisol				11.1	13.9	28.6		
Histosols						12.5		
Cambisols	27.1	47	39.5	11	11.4			
Luvisols	19.8		13.9	14.3	7			
Leptosols		24.5						
Regosols		10.1	21.3					
Chernozems				18	24.9			
Phaeozems				22.1				
All Others	36.4	18.4	25.3	23.5	32.5	17.3		

Shades of grey indicate the ranking of representativeness of the different soil categories

Identification of promising soil quality improving agricultural management practices

The farming systems of concern were defined by Kismányoky T. (2016). CSSs identified a total of 132 promising soil quality improving AMPs, implemented on farm fields or research plots, and, respectively, 132 contrasting control fields/plots where conventional practices are performed. Visual soil assessments of these 132 pairs AMP/control were performed in 2016.

Selection of "testing sites" for further assessing impact of AMPs on soil quality

The selection of testing sites for further assessing the impact of AMPs on soil quality followed the criteria below (adapted from Barão and Basch (2017)):

- 2 innovative AMPs were selected in each CSS area. Where only one soil type or one farming system was identified, only 1 AMP was selected;
- Selection always considered different innovative AMP's identified by each CSS, and in different farming systems;
- In case of multiple possible choices, selection favoured the most representative soil type for the CSS area (Table 2).
- Within the same climatic region, selection favoured contrasting innovative AMP's. This is relevant since some CSS's are located in the same climatic region.
- Selection of innovative AMP's in each particular CSS took into consideration the major soil threat identified for this very CSS and the innovative AMP relevant to that threat;
- In case the CSS had not identified any field/plot with innovative AMP's relevant to the most significant soil threat, the second most significant soil threat was considered (and its convenient innovative AMP's), and so on.
- Always, if possible, selection favoured combined AMP's linked to a higher number of soil threats directly impacting the CSS area.

3.2 Field work: Soil properties measurements and Visual Soil Assessment.

Soil quality assessment of innovative AMPs and controls took place in 2016 and 2018.

In the spring/summer 2016, all 132 innovative AMPs and respective control fields/plots were subjected to a visual soil assessment (VSA). VSA indicators observed at that time were 2 baseline indicators, as defined by Alaoui (2018), 6 soil indicators and measurement of 4 soil properties (Table 3). For further information on the protocols used to assess each VSA indicator, please consult Alaoui and Schwilch (2016).

Table 3. Visual soil assessment observed indicators (2016).

Type of indicators	Indicators
Baseline indicators	Surface Ponding (under cropping); Susceptibility to Wind and Water Erosion
Soil indicators	Soil structure and consistency; Soil porosity; Soil stability (Soil slaking test); Presence of a cultivation pan; Soil colour; Biodiversity (earthworm count); Infiltration rate (measured property); pH (measured property); Labile organic carbon (measured property) Organic matter (measured property)

In the mid-spring/summer 2018, a new VSA campaign, comprising more VSA soil indicators, and measurements of an extensive range soil properties were conducted by the CSSs on the fields under selected AMPs and respective controls (a total of 20 pairs of AMP/control). For more information on the Visual Soil Assessment (VSA) protocols please see Alaoui A. (2018), and for the measured physical, biological and chemical parameters, see Barão *et al.* (2018).

Briefly, and in what concerns this report, the following observations and measurements were performed and/or information gathered:

- Visual Soil Assessment (VSA) (see Table 4 for indicators observed/measured in the scope of the assessment)
- Data and parameters for water erosion modelling (RUSLE) (see Barão and Basch, 2017)
- Soil texture (clay/silt/sand)
- Stone content (%)
- Bulk density (t m^3)
- Microorganisms carbon content (g kg^{-1} soil)
- Number of different co-occurring soil macrofauna groups
- Organic matter (%)
- Total Nitrogen
- Available P (mg kg^{-1})
- Exchangeable K (mg kg^{-1})
- pH ($CaCl_2$)
- Electrical conductivity (dS m^{-1})

Table 4. Visual soil assessment observed indicators (2018).

Type of indicators	Indicators
Baseline indicators	Surface Ponding; Susceptibility to Wind and Water Erosion
Soil indicators	Soil structure and consistency; Soil porosity; Soil stability; Topsoil compaction [a)]; Subsoil compaction; Soil colour; Number & colour of soil mottles; Earthworm count; Degree of clod development; pH; Labile organic carbon

a) Excluded from the present study because of methodological reasons.

Topsoil compaction evaluation was performed on the fields by measuring the *infiltration rate* or measuring penetration resistance, scoring the results as poor, moderate or good (see Alaoui, 2018). Correlation studies are not presented because of the following methodological reason: this approach, and the interchangeability in the use of the two measurements (without clearly stating what was measured) renders the results meaningless.

3.3 Statistical analysis

Association between measured soil properties (physical, chemical and biological) and VSA score values, between VSA indicators score values, and between VSA score values of AMPs/Control, were tested by Spearman's rank-order correlation. To determine if the correlations were statistically significant, the respective t-values were calculated (for a significance level α=0.05), both in Excel (Microsoft Office Professional Plus 2013).

Ranking of measured soil properties was performed following 2 procedures: a) ranking in 3 levels (classification), by applying the same thresholds as used for SQAPP (for those properties with no thresholds defined we used appropriate ranking - see below); b) ranking each property by their values, in an ordinal level (except for *pH* and *texture*)).

For ranking thresholds adopted in the development of SQAPP, see Annex 3. Rankings for other variables, not covered or made explicit in SQAPP, are as follow:

Ranking of soil texture was performed based on FAO-UNESCO soil texture classes, see Table 5. Scoring from 1 to 5 was attributed, respectively, from "Coarse" to "Very fine".

Table 5. FAO soil texture classes (adapted from Jones et al. 2003).

Code	Class	Particle size grades
1	Coarse	Less than 18% clay and more than 65% sand
2	Medium	Less than 35% clay and more than 15% sand; more than 18% clay if the sand content exceeds 65%
3	Medium fine	Less than 35% clay and less than 15% sand
4	Fine	Between 35 and 60% clay
5	Very fine	More than 60% clay
9	Organic	
0	No texture	

Ranking of *stone content* was set by establishing the following criteria: less than 5% content of particles > 2mm (w/w), corresponds to a score of 2, from 5-10% to a score of 1, and >10% to a score of 0.

Ranking of macrofauna was based on the number of groups identified (0 to 14 groups). Alternatively, macrofauna was ranked based on: 0= no macrofauna groups present, 1=1 group, 2=2 or more groups.

Ranking of *microorganism C* was based on abundance (g/1x10^{-3} m^3): less than 0.318, 0.318 to 0.616 and higher than 0.616, corresponding to scores of 0, 1 and 2, respectively.

Ranking of *susceptibility to compaction* followed the classification proposed by Jones et al. (2003), where, depending on *texture* class and packing density, high susceptibility scored 2, moderate susceptibility scored 1 and low susceptibility scored 0.

4. Results

4.1 Correlation between VSA soil indicators and measured soil properties (2016)

The number of pairs AMP/control surveyed in 2016 was 132 (n=264). Because some CSSs didn't (or only partially) measured the proposed soil properties, the number of observations for those properties are lower.

Infiltration, pH and Labile Organic Carbon

The sample size for *infiltration rate* is n=264, for *pH* n=256 and for LOC n=230. VSA indicators, in broad terms, showed weak to low moderate positive correlations with *infiltration rate* and *pH*, and, for those VSA that showed a correlation with LOC, it was weak and negative. Detailed description below (also Figure 3).

VSA *structure* shows a weak, positive Spearman correlation with *pH* (r_s=0.16) and *infiltration rate* (r_s=0.21), both statistically significant for α=0.05 (Figure 3 top left). Correlation with LOC is non-existing (< |0.1|).

VSA *porosity* shows a moderate correlation with *pH* (r_s=0.31) and a weak correlation with *infiltration rate* (r_s=0.14), both statistically significant for α=0.05. Correlation with LOC is non-existing.

VSA *stability (slaking test)* shows a positive weak correlation with *pH* (r_s=0.21), statistically significant. Correlations with *infiltration rate* and LOC are non-existing.

VSA *tillage pan* shows a weak, positive Spearman correlation with *pH* (r_s=0.26) and *infiltration rate* (r_s=0.18), and a weak negative correlation with LOC (r_s=-0.15), all statistically significant.

VSA *soil colour* shows a moderate correlation with *pH* (r_s=0.33) and a weak negative correlation with LOC (r_s=-0.13), both statistically significant for α=0.05. Correlation with *infiltration rate* is non-existing.

VSA *biodiversity (earthworm count)* only shows a weak negative correlation with LOC (r_s=-0.24).

VSA *susceptibility to wind and water erosion* only shows a positive weak correlation with *infiltration rate* (r_s=0.19) and *pH* (r_s=0.12), but only the correlation with *infiltration rate* is statistically significant.

VSA *surface ponding* shows a moderate correlation with *pH* (r_s=0.30) and a weak correlation with *infiltration rate* (r_s=0.19), both statistically significant for α=0.05. Correlation with LOC is non-existing.

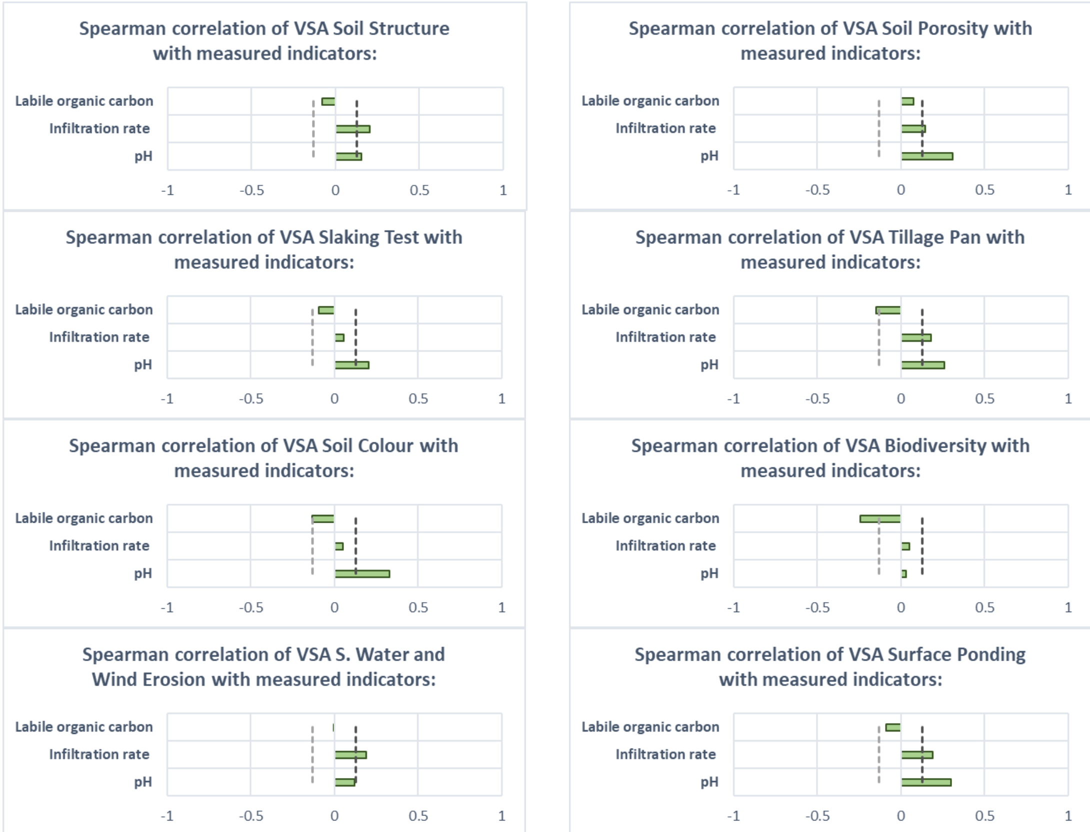


Figure 3. Spearman's correlations between VSA indicators with measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Organic matter

The sample size for Spearman's correlation studies is n=106, from 5 CSSs. VSA *tillage pan* has a negative weak correlation with OM (r_s=-0.15); VSA *biodiversity (earthworm count)* has a weak positive correlation (r_s=0.17); and both VSA baseline indicators show no correlation. The other VSA indicator have positive, statistically significant correlations with OM: weak correlation for VSA *structure* (r_s=0.24), and moderate correlations with *soil colour* (r_s=0.38), *stability* (r_s=0.40) and *porosity* (r_s=0.34) (see Figure 4).

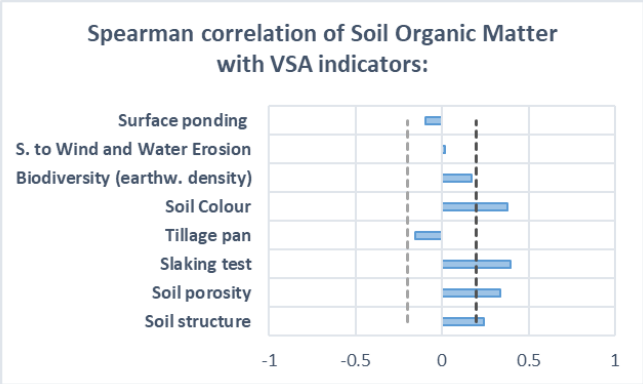


Figure 4. Spearman's correlations of VSA indicators with measured soil organic matter (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

4.2 Correlation between VSA soil indicators (2016)

The sample size of this study is n=264. For an overview of the results see Figure 5.

The correlations between <u>VSA *structure*</u> and other VSA indicators are positive and weak with 4 out of 7 VSA indicators, 3 statistically significant, and there's a moderate positive correlation with VSA *porosity* (r_s=0.42).

<u>VSA *porosity*</u> shows positive, statistically significant correlations with all other VSA indicators. Besides the above said moderate correlation with VSA structure, it also shows a moderate correlation with VSA *soil colour* (r_s=0.38).

<u>VSA *stability (slaking test)*</u> shows a positive and statistically significant correlation with 5 out of 7 VSA indicators, being the correlation with VSA *soil colour* moderate (r_s=0.37). Noteworthy is the lack of correlation with VSA *structure* and *tillage pan* (it will be discussed in the next section).

<u>VSA *tillage pan*</u> shows positive weak correlations, statistically significant, with 4 VSA indicators, the highest being with VSA *porosity* (r_s=0.28).

<u>VSA *soil colour*</u>, besides the already mentioned moderate correlation with VSA *porosity* and stability, shows weak, statistically significant correlations with all other VSA indicators.

<u>VSA *biodiversity (earthworm count)*</u> shows positive weak correlations, statistically significant, with 5 VSA indicators, the highest being with VSA *soil colour* (r_s=0.28). No correlation with VSA *tillage pan*, and not statistically significant with VSA *structure* (r_s=0.12).

<u>VSA baseline indicators</u>, both *surface ponding* and *susceptibility to erosion*, show only weak correlations with all other VSA indicators.

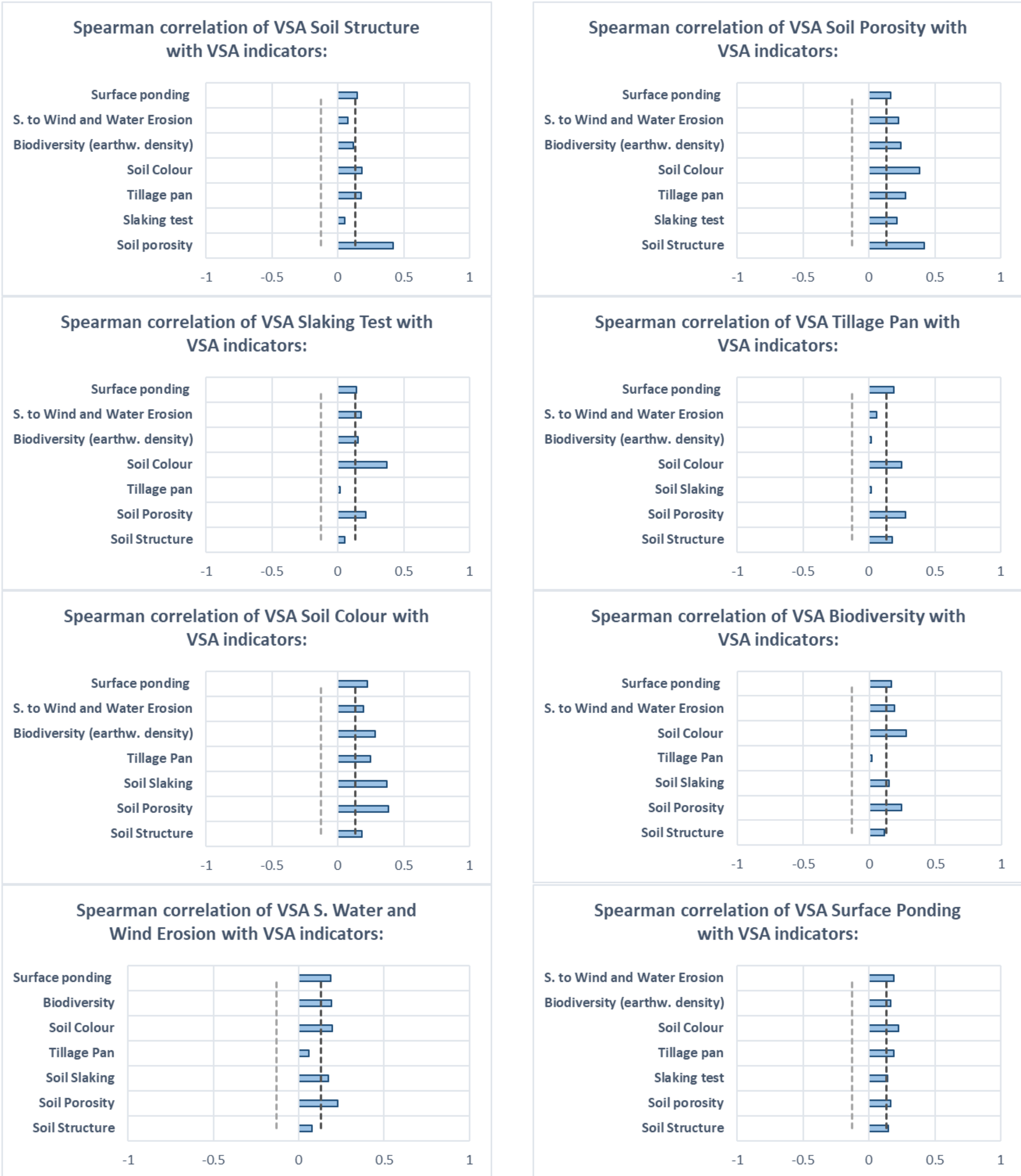


Figure 5. Spearman's correlations between VSA indicators (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

4.3 Correlation between VSA soil indicators and measured soil properties (2018)

The number of pairs AMP/control surveyed in 2018 was 20 (n=40). Because some soil properties were not measured by some CSSs, n for some properties is lower. Although presented in the text below, correlations with soil texture and particles (% of sand, silt and clay) are not further discussed in this Deliverable (it will be part of Deliverable 6.2).

<u>VSA *structure*</u> shows a positive and moderate Spearman's rank correlation coefficient with SOC, N_{tot} and *macrofauna*, respectively r_s=0.45, 0.42 and 0.48, and a negative correlation with sand content, all statistically significant for α=0.05. Bordering statistical significance, a moderate negative correlation with *stone content* can also be observed (Figure 6, blue bars). All other measured soil properties showed no correlations, or very weak, not statistically significant.

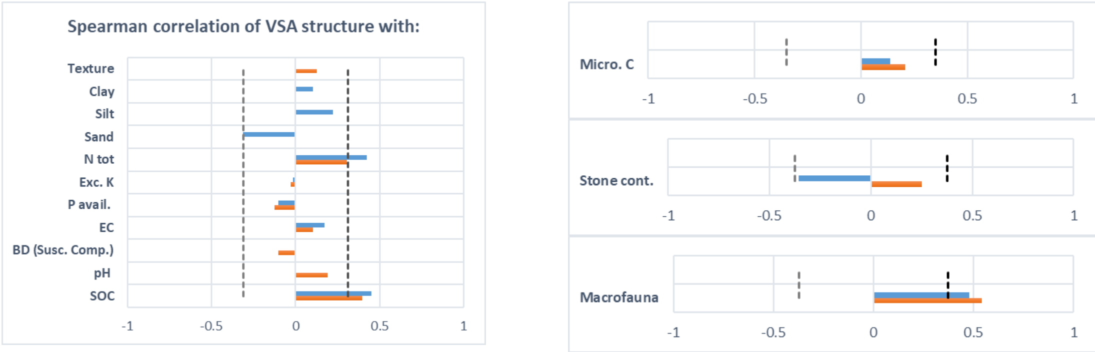


Figure 6. Spearman's correlations between VSA *structure* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Comparing the above correlations results with correlations using ranking after classification of measured properties (orange bars), coefficients drop for SOC (0.45 to 0.40), N_{tot} (0.42 to 0.30) and *stone content* (absolute coefficient, because of reverse ordering, from 0.36 to 0.25), but only N_{tot} changed (lost) statistical significance.

<u>VSA *porosity*</u> shows a positive moderate Spearman's rank correlation coefficient with SOC, N_{tot} and Silt, respectively r_s=0.37, 0.40 and 0.38, and a negative correlation with sand content (r_s=0.41), all statistically significant. *Macrofauna groups* and *microorganism C* also show a moderate positive correlation with porosity (see Figure 7, blue bars).

Figure 7. Spearman's correlations between VSA *porosity* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Differences with results of correlations using ranking after classification of the above soil properties are slight, except for N_{tot} (orange bars). However, for clay (data not depicted) there is an important difference between correlation coefficients, passing from r_s=-0.05 to -0.28 (it will not be discussed).

<u>VSA *stability* *(slaking)*</u> shows positive Spearman's rank correlation coefficients with N_{tot} and SOC, respectively r_s=0.36 and 0.34, statistically significant for α=0.05. And moderate/ weak correlations with *microorganism C* and *electrical conductivity* (EC).

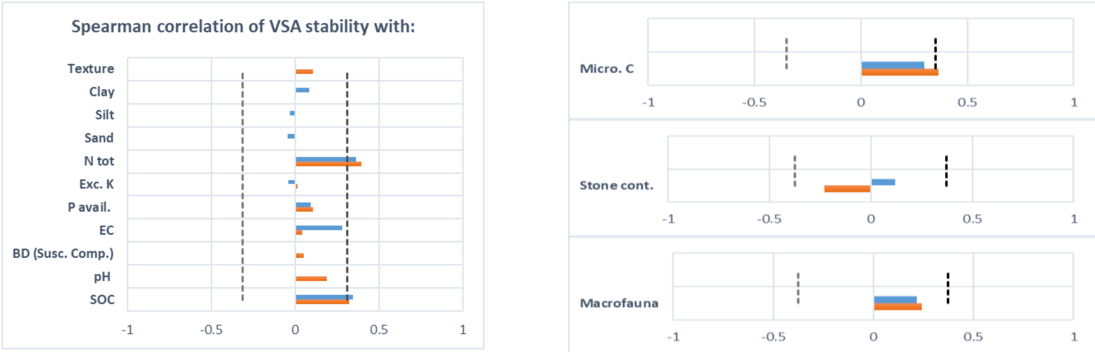


Figure 8. Spearman's correlations between VSA *stability* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Main differences with results of correlations using ranking after classification of soil properties are slight. There's also a decrease in correlation with EC from 0.28 to 0.04 that will be discussed in the next section.

VSA *subsoil compaction* *(formation of hardpans)* shows a positive Spearman's rank correlation coefficient with *microorganism C*, *number of macrofauna groups*, SOC, N_{tot}, *texture* (from coarse to medium fine textures), *silt* of respectively r_s=0.53, 0.41, 0.44, 0.37, 0.37 and 0.40, and a negative correlation with *sand* and *available P*, respectively r_s=-0.54 and -0.33, all statistically significant for α=0.05. The Spearman's correlation between *subsoil compaction* and *susceptibility to compaction* was weak and negative and almost none existing when using only *bulk density*.

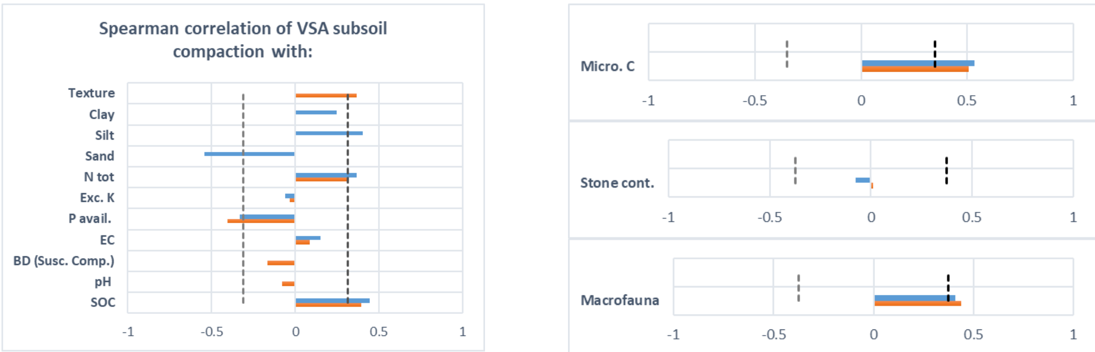


Figure 9. Spearman's correlations between VSA *subsoil compaction* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Using ranking after classification, we observe slight differences in the correlations although it only resulted in a change in statistical significance with N_{tot} (0.37 to 0.31).

VSA *number and colour of mottles* shows weak Spearman's correlations with all properties but *number of macrofauna groups*, where a moderate positive correlation exists, although not statistically significant.

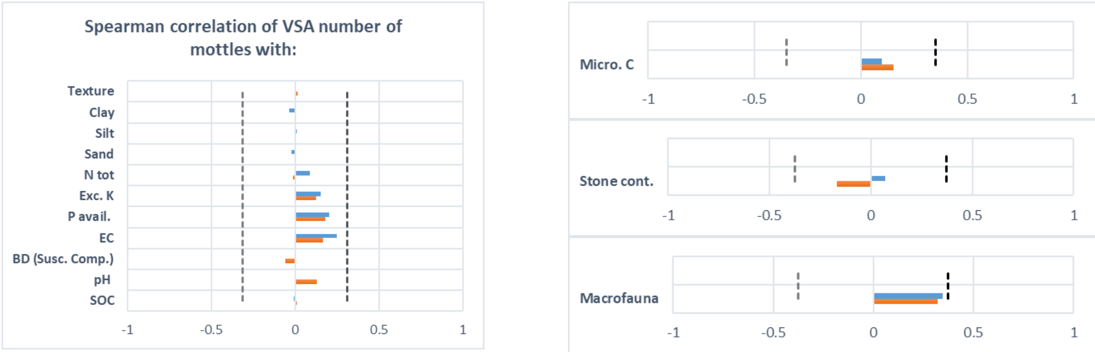


Figure 10. Spearman's correlations between VSA *number of mottles* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Differences in the correlations resulting from using ranking after classification, are minor and with no apparent relevance.

<u>VSA *earthworm count*</u> shows a positive, statistically significant, Spearman's correlation coefficient with soil's N_{tot}, *number of macrofauna groups* and *stone content*, respectively r_s=0.37, 0.47 and -0.42. Although the correlation with *susceptibility to compaction* was not statistically significant, a negative and statistically significant correlation was found with *bulk density* (r_s=-0.32) (not shown in Figure 11). Correlations with all other soil properties tested were weak.

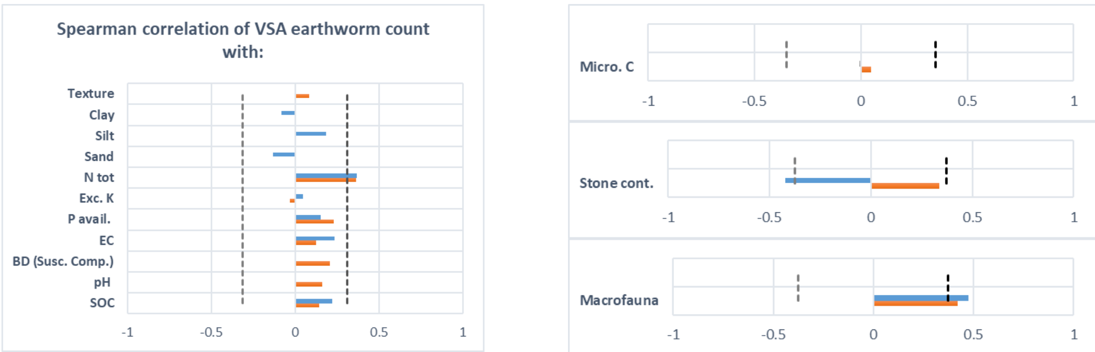


Figure 11. Spearman's correlations between VSA *earthworm count* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Differences in the correlations resulting from different ranking procedures are slight.

<u>VSA *degree of clod development*</u> shows positive Spearman's correlations with SOC, N_{tot} and *number of macrofauna groups*, respectively r_s=0.41, 0.42 and 0.54, statistically significant for α=0.05. All other correlations were weak and not statistically significant.

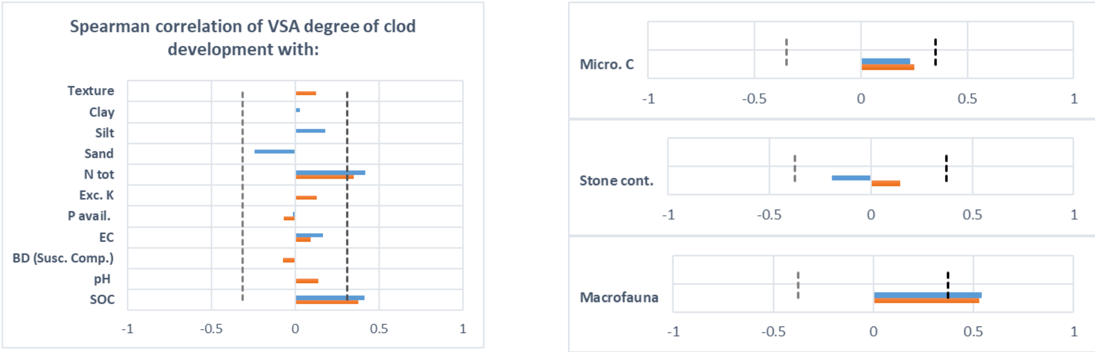


Figure 12. Spearman's correlations between VSA *degree of clod development* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Differences in the correlations resulting from different ranking procedure are slight.

<u>VSA *soil colour* </u>shows a positive moderate Spearman's correlations with *number of macrofauna groups*, *microorganism C* and exc. K, respectively r_s=0.44, 0.39 and -0.33, statistically significant. All other correlations are weak and not statistically significant.

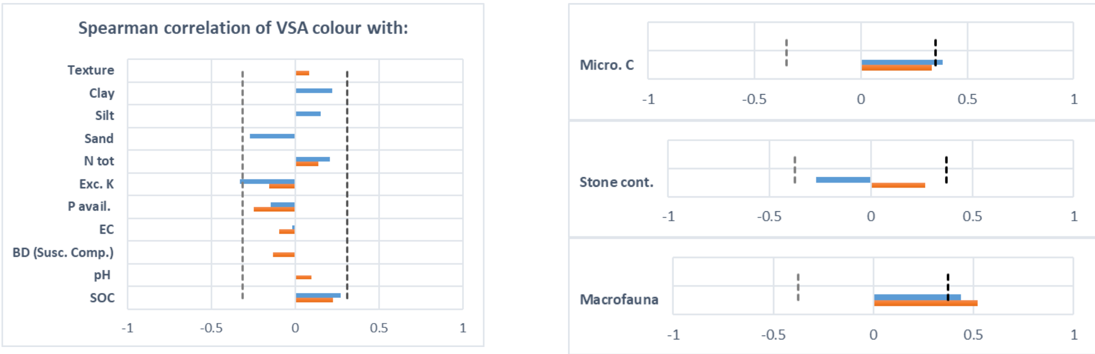


Figure 13. Spearman's correlations between VSA *soil colour* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Differences in the correlations resulting from different ranking are slight and/or not relevant.

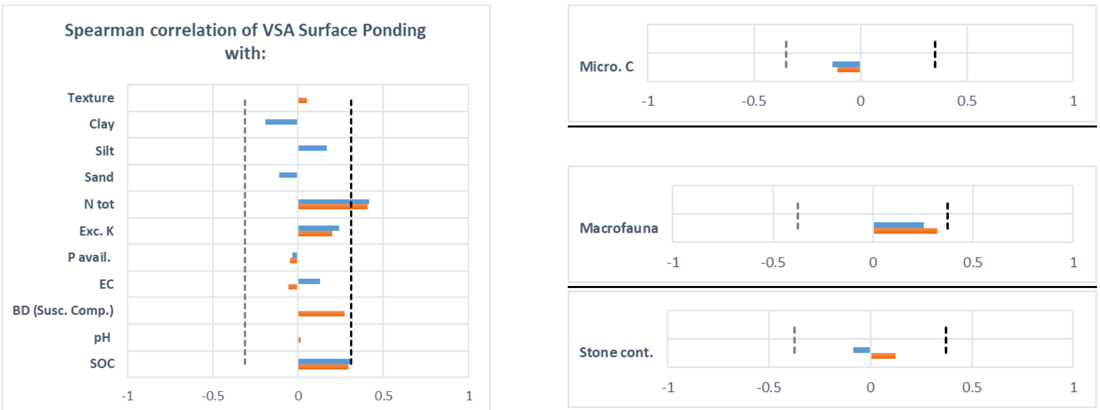


Figure 14. Spearman's correlations between VSA *surface ponding* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

VSA <u>*surface ponding*</u> shows a positive Spearman's correlation with N_{tot}, r_s=0.42, statistically significant for α=0.05 (Figure 14). It also depicts weak/moderate positive correlations with SOC and *susceptibility to compaction*, not statistically significant, and a moderate negative correlation with *bulk density* r_s=-0.32 (data not shown in Figure 14), statistically significant for α=0.05.

Differences in the correlations resulting from different ranking are slight and/or not relevant.

VSA <u>*wind and water erosion*</u> only shows a positive moderate Spearman's correlation with *number of macrofauna groups*, r_s=0.43, statistically significant for α=0.05. Correlations with *stone content*, exc. K and *sand* are weak/moderate and not statistically significant.

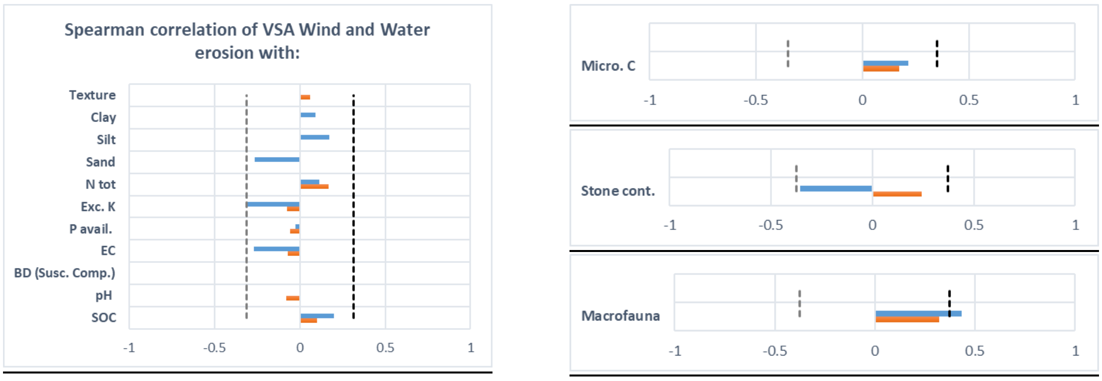


Figure 15. Spearman's correlations between VSA *erosion* and several measured parameters. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent. Blue: measured properties ranking according ordinal scale; Orange: measured properties ranking after classification. The right side of the figure shows *microorganism C*, *stone content* and *macrofauna* for ease of reading (different critical t-values for those variables).

Differences in the correlations resulting from different ranking are slight and/or not relevant.

4.4 Correlation between VSA soil indicators (2018)

VSA <u>*structure*</u> shows a positive, strong Spearman's correlation with VSA *porosity* and VSA *degree of clod development*, respectively r_s=0.72 and 0.68; moderate, statistically significant correlations are observed with VSA *colour*, VSA *subsoil compaction* and VSA *erosion*, of respectively r_s=0.52, 0.48 and 0.42 (Figure 16). The weak correlation with VSA *stability* (slaking), r_s=0.28, is discussed in the next section.

VSA <u>*porosity*</u>, besides the above said positive strong correlation with VSA *structure*, also shows a positive strong correlation with VSA *degree of clod development*, r_s=0.78, and, as expected by the nature of the observations, with VSA *subsoil compaction*, r_s=0.69. Moderate, statistically significant correlations are observed with VSA *susc. erosion*, *colour, stability* and *surface ponding*. The lack of correlation with VSA *earthworm count* is discussed in the next section.

With exception of earthworm count, <u>VSA degree of clod development</u> shows a statistically significant Spearman correlation with all other VSA indicators and, besides the strong correlation with VSA *porosity* and *structure*, it also shows a relatively high correlation with VSA *subsoil compaction* (r_s=0.66).

VSA <u>*stability*</u>, besides the above mentioned moderate correlation with VSA *porosity*, it also shows moderate, statistically significant correlations with VSA *degree of clod development*, *subsoil compaction*, *susceptibility to erosion* and *earthworm count*, respectively r_s=0.51, 0.49, and 0.40 for the last two.

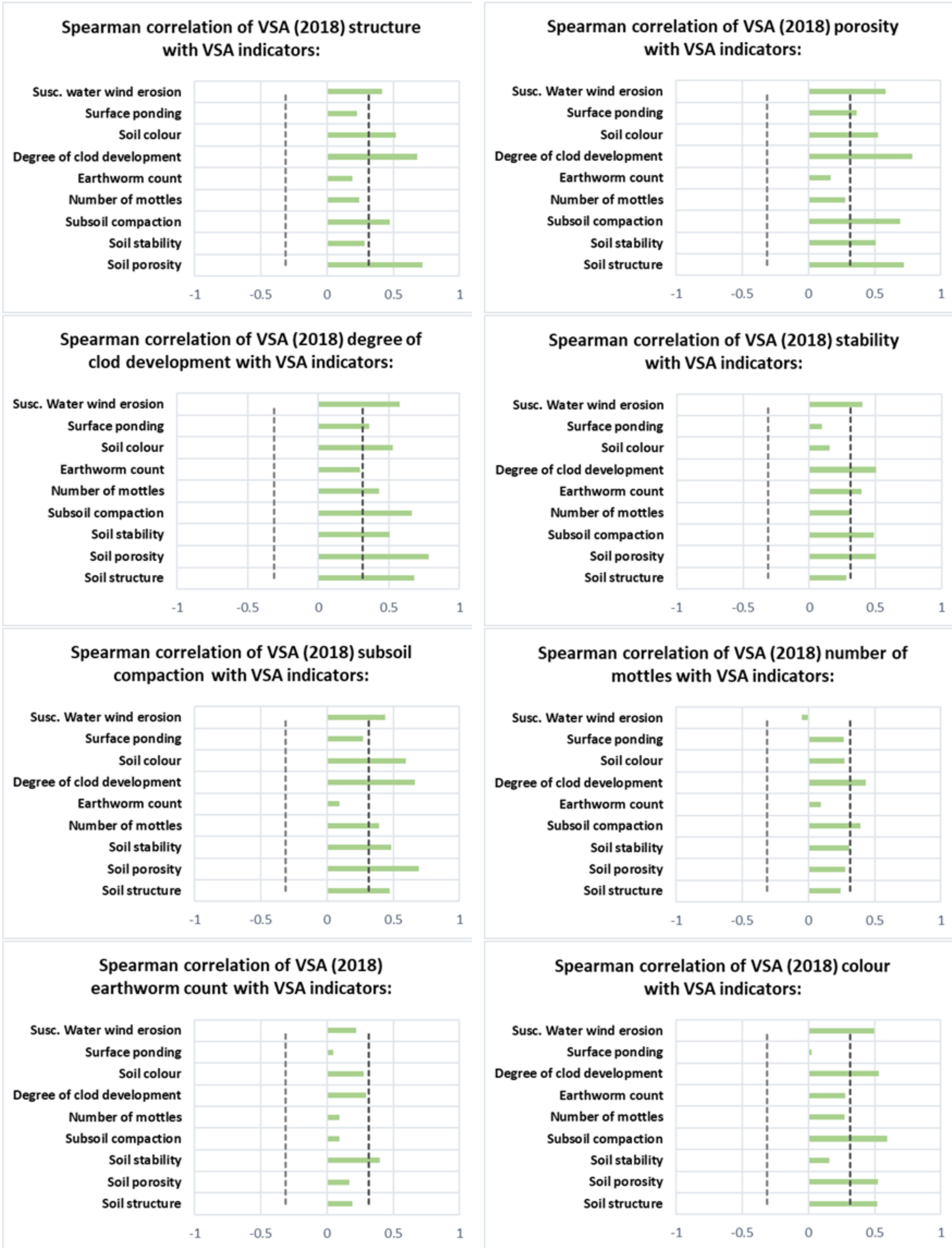


Figure 16. Spearman's correlations between VSA soil indicators and with VSA baseline indicators. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

<u>VSA *subsoil compaction*</u> shows, besides the already mentioned relatively high correlation with VSA *porosity* and *degree of clod development*, moderate positive correlations with all other VSA indicators with exception of VSA *earthworm count* (non-existing correlation) and *surface ponding* (r_s=0.27).

VSA *number and colour of mottles* shows positive, moderate correlations, statistically significant, with VSA *degree of clod development* and *subsoil compaction*, respectively r_s=0.43 and 0.39. Correlation with VSA *stability* borders statistical significance (r_s=0.31).

VSA *earthworm count* shows a positive, moderate correlation, statistically significant, only with VSA *stability (slaking test)* r_s=0.40. All other correlations are either weak or non-existing.

VSA *soil colour* shows positive, moderate correlations, statistically significant, with VSA *structure*, *porosity*, *subsoil compaction*, *degree of clod development* and *susceptibility to wind and water erosion*. Correlations with the rest of VSA indicators are either weak or non-existing.

VSA *surface ponding* shows a moderate, positive and statistically significant correlation with VSA *porosity* and *degree of clod development*, r_s=0.36 for both VSA indicators. Correlations with other VSA indicators are weak or non-existing.

VSA *susceptibility to wind and water erosion* shows moderate positive correlations with most VSA indicators, exceptions are: weak correlation VSA *earthworm count*; non-existing correlations with *surface ponding* and *number of mottles*.

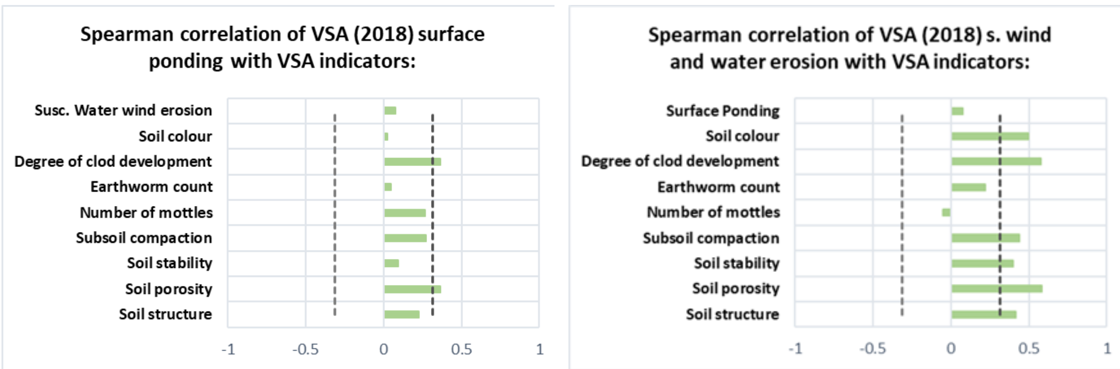


Figure 17. Spearman's correlations between VSA baseline indicators and with other VSA indicators. Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

4.5 Correlation between AMP groups and VSA soil indicators and measured soil properties (2016)

No-till

12 agricultural management practices were classified as *'no-till'* (n=24, 12 AMPs + 12 controls). Spearman correlation analysis show that *'no-till'* has positive correlations with all VSA indicators (that is, there is an increase of VSA score under *'no-till'*), strong with VSA *structure* (r_s=0.77) and moderate with VSA *porosity* (0.53), *stability (slaking test)* (0.50) and *susceptibility to wind and water erosion* (0.47), these 4 statistically significant for α=0.05. No correlation was observed with measured parameters.

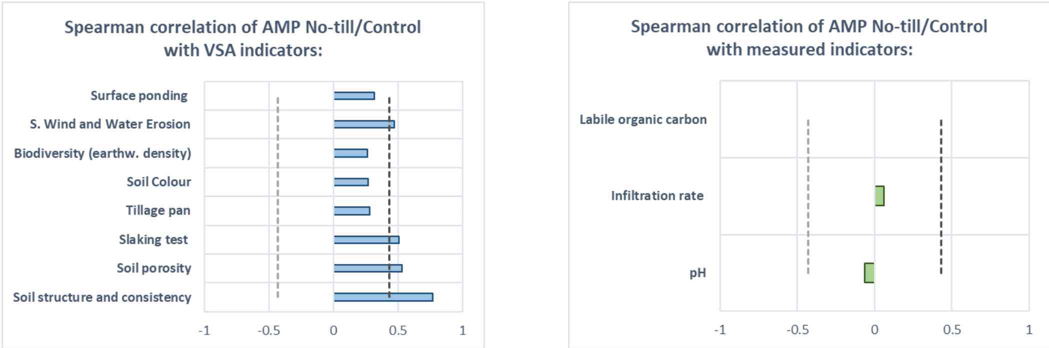


Figure 18. Spearman's correlations between *'no-till'*/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Minimum tillage

29 practices were classified as minimum tillage (n=58, 29 AMPs + 29 controls). No statistically significant correlation was found with any VSA indicator or property measured. Correlation with VSA *soil colour*, a weak positive correlation, was the only one bordering statistical significance. These results are discussed in the next section, and are most probably due to the broad sense that is given to the definition of minimum tillage (meaning that almost everything can be classified as such).

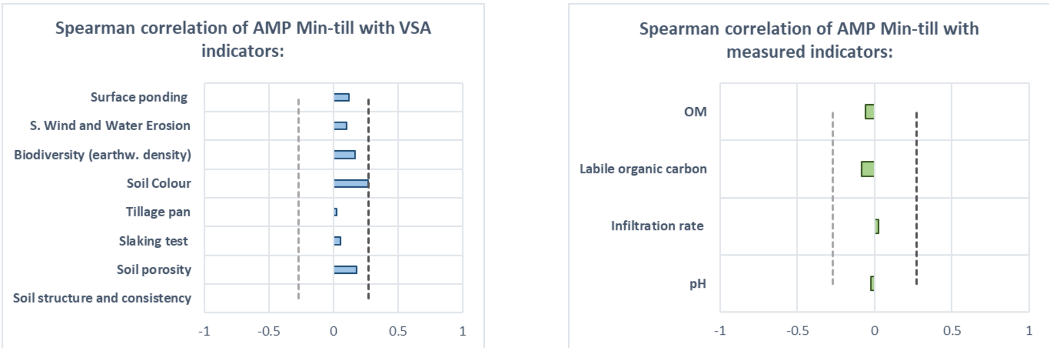


Figure 19. Spearman's correlations between Minimum tillage/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Permanent soil cover / Removing less vegetation cover

11 management practices were classified as permanent soil cover (n=22, 11 AMPs + 11 controls). Only the correlation with VSA *porosity* (r_s=0.49) was statistically significant. These results are discussed in the next section, and are close to the results obtained for AMP '*residue maintenance/mulching*' (see below).

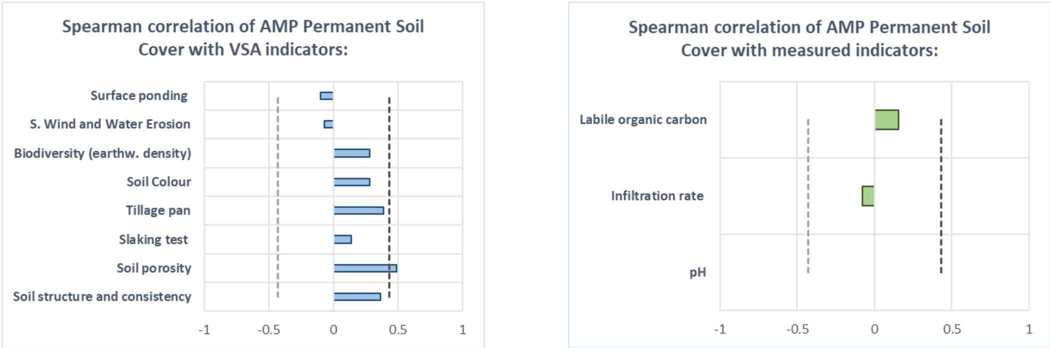


Figure 20. Spearman's correlations between Soil cover/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Leguminous crop

The introduction of leguminous crops in crop rotations counts 11 proposed innovative management practices (n=22, 11 AMPs + 11 controls). Spearman correlation was moderate, positive and statistically significant with VSA *structure* (r_s=0.50), *porosity* (r_s=0.46) and *stability* (r_s=0.50).

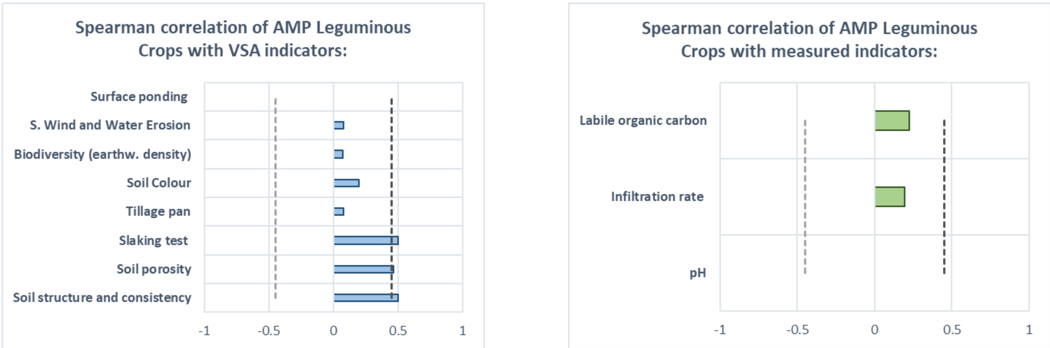


Figure 21. Spearman's correlations between Leguminous/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Manuring/Composting

The inventory registers 34 management practices under AMP '*manuring/composting'* (n=68, 34 AMPs + 34 controls). The Spearman's correlation with VSA indicators and measured properties is only statistically significant with VSA *porosity* (r_s=0.46) and *structure* (r_s=0.37). Manuring has no correlation with measured soil organic matter (r_s=0.00 and n=34) and only a weak correlation with LOC (r_s=0.16 and n=62).

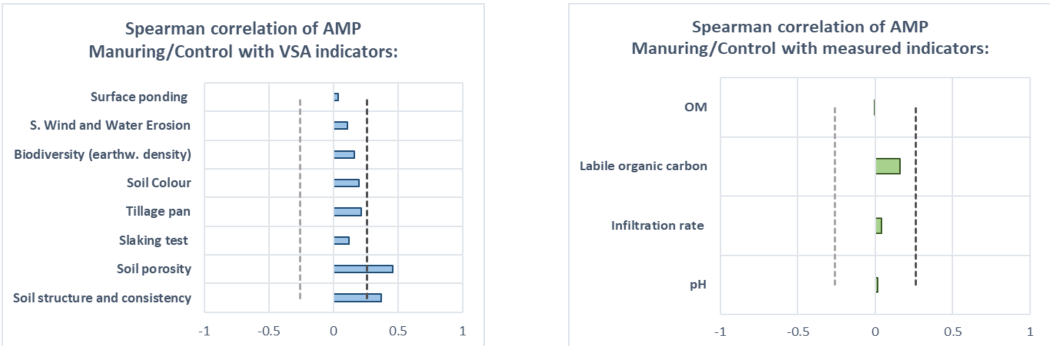


Figure 22. Spearman's correlations between Manuring/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Residue maintenance / Mulching

22 management practices were classified under this AMP (n=44, 22 AMPs + 22 controls). As for AMP '*permanent soil cover*', only correlation with VSA *porosity* was statistically significant, a positive moderate correlation (r_s=0.37), underlining the positive effect soil cover on VSA *porosity* despite the differences that can be expected both from an agro-ecologic point of view but also on the management practices themselves (33 innovative management practices, 11 +22).

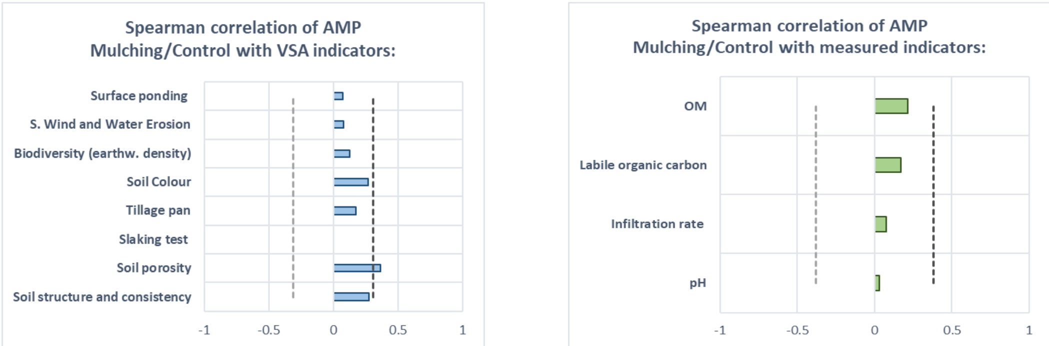


Figure 23. Spearman's correlations between Mulching/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Crop rotation

Under AMP '*crop rotation*' there's 30 innovative management practices (n=60, 30 AMPs + 30 controls). All correlations with VSA indicators were weak or non-existing, and only statistically significant with soil porosity (r_s=0.27).

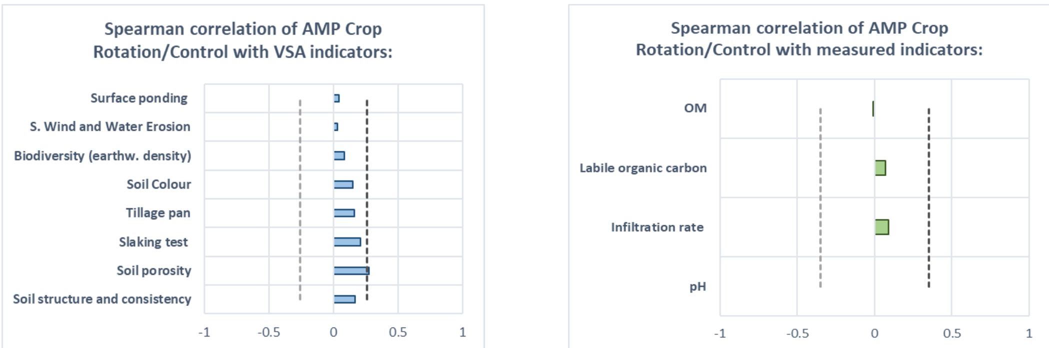


Figure 24. Spearman's correlations between Crop rotation/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Measures against compaction

This AMP group counts 12 innovative practices (n=24, 12 AMPs + 12 controls). Only correlation with VSA *structure* is moderate (r_s=0.36). Correlations with other VSA indicators and measured soil properties are either weak or non-existing. Correlation with VSA *tillage pan* is weak, r_s=0.18. All correlations are not statistically significant.

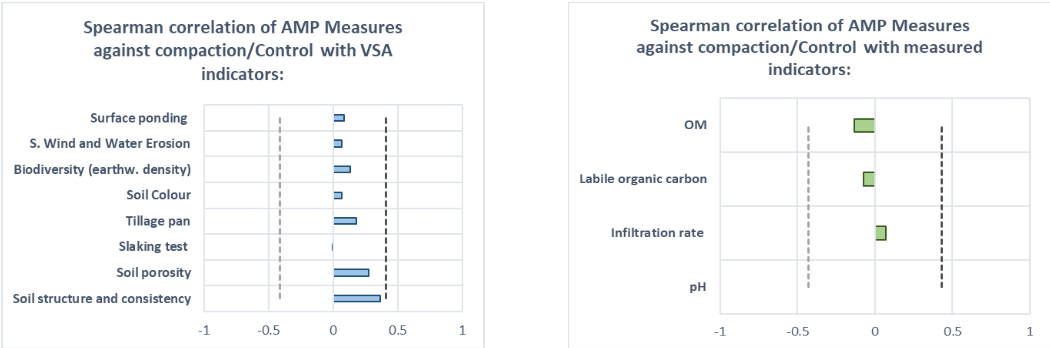


Figure 25. Spearman's correlations between '*Measures against compaction*'/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Integrated Pest Management (inc. Organic Agriculture)

13 management practices fall under this AMP group (n=26, 13 AMPs + 13 controls). Positive, moderate and statistically significant correlations are observed with VSA *porosity* (r_s=0.51) and *structure* (r_s=0.45), all other correlations are either weak or non-existing.

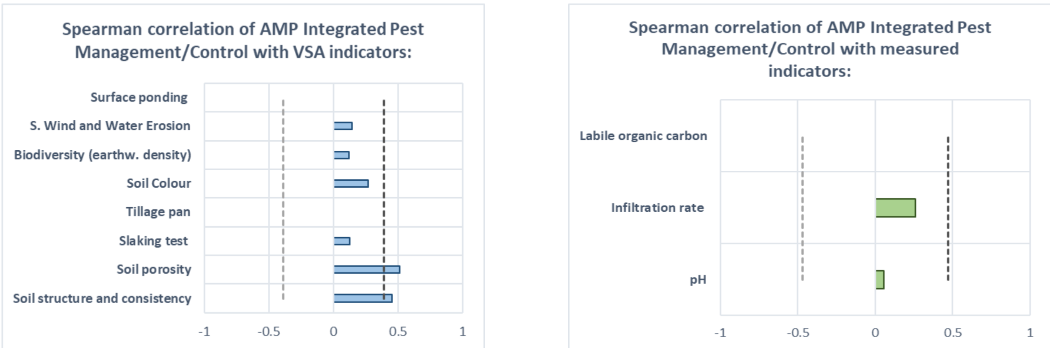


Figure 26. Spearman's correlations between IPM/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Irrigation Management

Only 7 management practices are identified under this AMP group (n=14, 7 AMPs + 7 controls). Although correlations with 4 VSA indicators and 1 measured property are moderate, the small sample (high critical t-value) causes that only correlation with VSA *structure* is statistically significant.

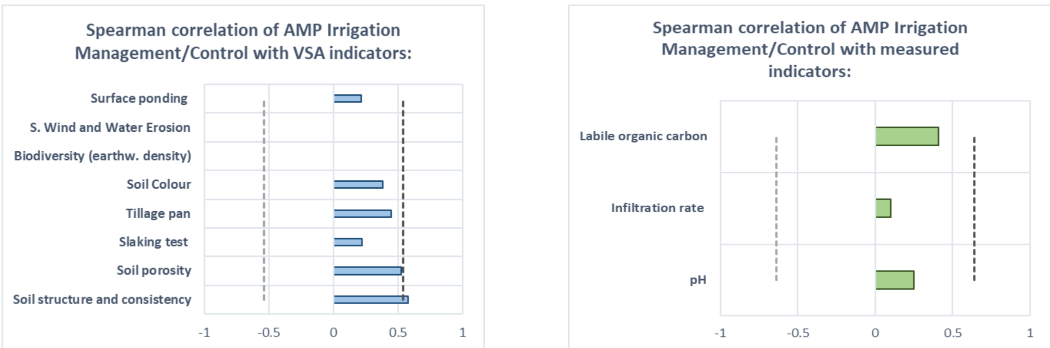
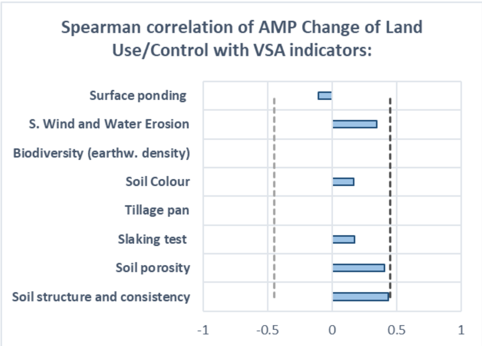


Figure 27. Spearman's correlations between Irrigation management/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Change of Land Use/Intensity level

10 management practices fall under this AMP group (n=20, 10 AMPs + 10 controls). Although no correlations with VSA indicators or measured soil properties were statistically significant, moderate positive correlations were observed with VSA *structure*, *porosity* and *susceptibility to wind and water erosion*, and with measured soil properties *infiltration rate* and LOC (negative). All other correlations were either weak or non-existing.



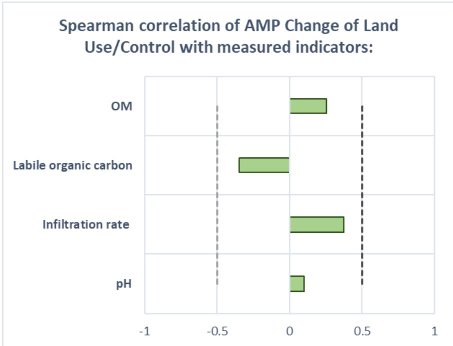


Figure 28. Spearman's correlations between Change of land use/control with VSA indicators and measured soil properties (2016). Dashed vertical lines show the 95% confidence interval, indicating that within these dashed lines variables must be considered independent.

Other AMP groups

For the remaining AMP groups, the number of innovative management practices identified (size of the sample) was very low, so we refrain from reproducing the analysis results, except for those classified under *Green manure* (n=12, 6 AMP fields + 6 control), where the Spearman correlation with VSA *soil colour* (r_s=0.60) was statistically significant.

Lack of statistical significance, was observed for the management practices classified under *Cover crops* (n=10, 5 AMP fields + 5 control), *Cross-slope measure* (n=6, 3 AMP fields + 3 control), *Water diversion and drainage* (n=4, 2 AMP fields + 2 control), *Major change in timing of activities* (n=4, 2 AMP fields + 2 control) and *Area closure/rotational grazing* (n=4, 2 AMP fields + 2 control). No innovative management practice was identified under *Layout change according to natural and human environment/needs*.

4.6 Measured impact of innovative AMPs to address soil threats (2018)

Individual results (pairs of AMP/control) at a specific agro-climatic condition, cannot be used to infer results elsewhere. Figure 29 depicts the impact of different AMPs on soil threats. For details of the AMP groups, see Annex 2.

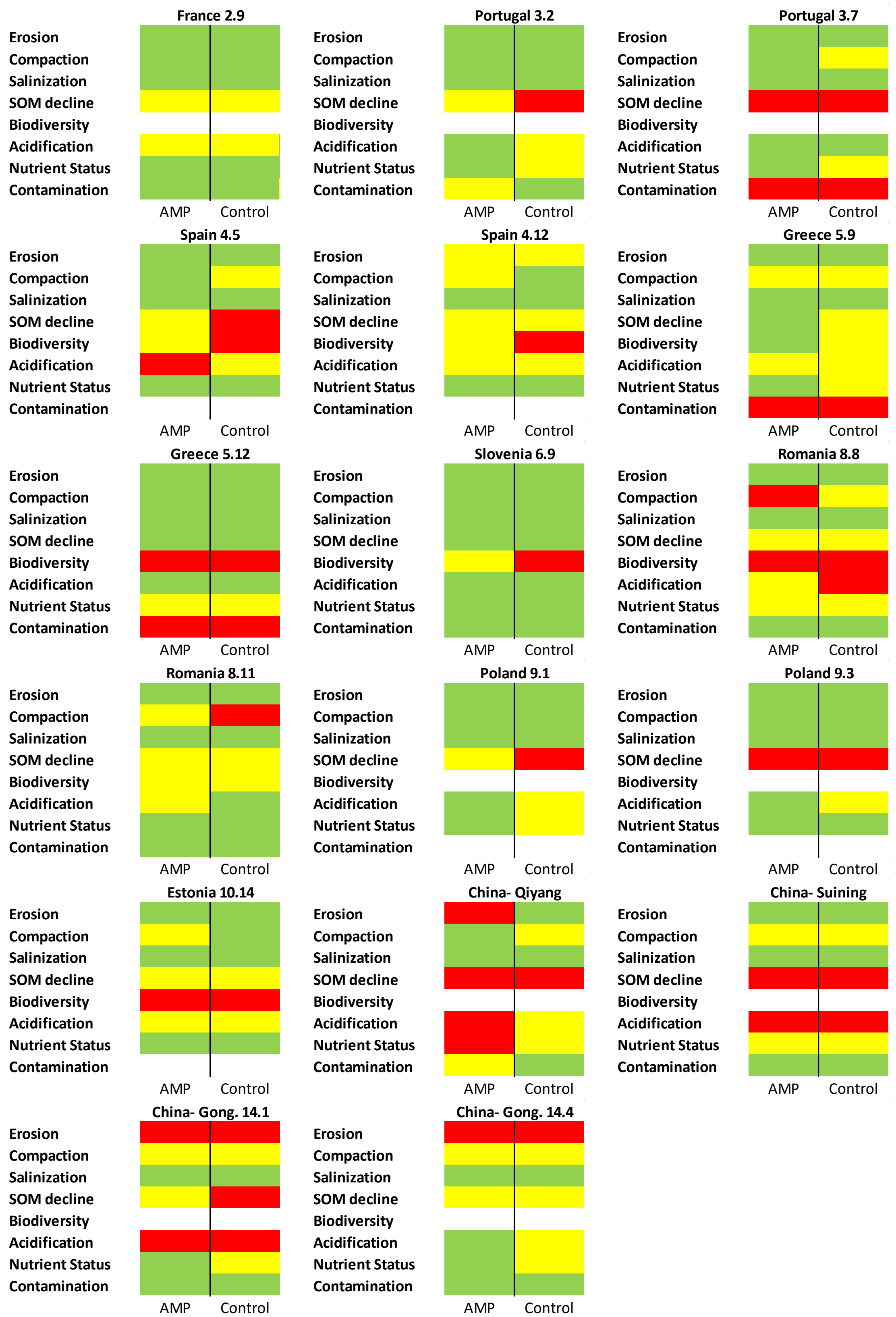


Figure 29. Soil Quality classification based on the soil threats and thresholds adopted for SQAPP (see Annex 3). White cells indicated that data was not sufficient to perform the calculation. Red cells indicate poor condition, yellow indicates moderate condition and green good condition. Where the length of the fields was not provided for the calculation of erosion, a length of 100 m was assumed. Rainfall erosivity factor and biodiversity potential were read on low resolution maps and may not represent local conditions. The respective AMP groups are referred to in Annex 2. The numbers of each CSS identify the respective pair of AMP/Control.

5. Discussion

Correlations of VSA indicators and measured properties

The sample size of the field campaign of 2016 is bigger than the one in 2018, n=264 vs. n=40. Also, a larger set of VSA indicators was assessed in 2018 albeit covering all VSA indicators assessed in 2016.

In relation to measured soil properties, raw data for soil properties systematically measured at the 2016 campaign (*pH*, *infiltration rate*, and LOC) is not available at the moment, but about to being compiled. Only organic matter (OM) from 2016 (n=106, from 5 CSSs) is available. Measured properties in the campaign of 2018 compose a different set of data and, with exception of OM, cannot be directly compared. Correlations with *number of macrofauna groups* are discussed separately, at the end of the end of this section (p. 32).

Statistically significant correlations of VSA indicators with OM, in 2016, are weak with VSA *structure* (r_s=0.24), and moderate with *soil colour* (r_s=0.38), *stability* (r_s=0.40) and *porosity* (r_s=0.34). These correlations are not very dissimilar from those obtained in 2018, with a lower N (40) and greater pedoclimatic zones coverage (11 CSSs), respectively r_s=0.45, 0.27 (not statistically significant), 0.34 and 0.37.

From the campaign of 2016 (n=264), VSA soil structure have a positive moderate Spearman's correlation with *porosity* (r_s=0.42), and no correlation with *stability* (r_s=0.05), while *porosity* has a weak correlation with *stability* (r_s=0.21). Roughly the same pattern exists in the data from the campaign of 2018 (n=40), although the strength of the association is much higher (respectively, 0.72, 0.28 (not statistically significant) and 0.51). Further analysis of the correlations between these and other VSA indicators, and with measured soil properties (including *texture*), may throw some light on the properties and relations governing these correlations or the lack of (part of Deliverable 6.2).

VSA *tillage pan*, *subsoil compaction* in the campaign of 2018, shows a weak and negative correlation with OM in 2016 campaign (r_s=-0.15) and a moderate positive correlation in 2018 (r_s=0.44). The differences in the correlation coefficients reflects the differences in the data sets (size and pedoclimatic distribution) and the question of representability of the sample may arise. Subsoil compaction is the result of direct load applied to the soil beyond the shear stresses it can resist (its bearing capacity), thus management related. The soil bearing capacity varies and it is a function of soil texture, water content, aggregate stability, among others that may have more or less importance depending on local context. Soil compaction is commonly associated with loads applied through traffic of tractors and machinery, intensive grazing, and aggravated by soil disruption through tillage. A compacted soil presents loss of porosity with the rearrangement of the soil particles (with decrease of natural aggregates) and the formation of more or less continuous masses of hard soil of higher *bulk density* than the original soil. In 2016, VSA *tillage pan* correlated positively, and statistically significant, with VSA *porosity*, r_s=0.28 (n=264), and this correlation is in fact the highest correlation of *tillage pan* with other VSA indicators. This correlation is much higher in the data from 2018, r_s=0.69, and again it is the highest correlation of *subsoil compaction* with other VSA indicators. From the data of 2018, neither VSA *subsoil compaction* nor VSA *porosity* are explained by *susceptibility to compaction* (the correlations with these two VSA indicators are respectively r_s=-0.17 and 0.01). The lack of correlation with *susceptibility to compaction* may be due to the methodological approach: sampling for *bulk density* was performed at 15 cm depth while *porosity* was assessed to a depth of 20 cm and *subsoil compaction* to a depth of 50 cm (by looking for evidence of hardpans); meaning that the model (*susceptibility to compaction*) may be well appropriate to describe compaction and loss of porosity but we failed to measure it at the appropriate depths. Correlation of *subsoil compaction* with *bulk density* is inexistent (r_s=0.04). Other statistically significant correlations exist between VSA *tillage pan (subsoil compaction)* with other VSA indicators and measured soil properties (namely with *microorganism C* content in the dataset of 2018), in both years (2016 and 2018), but given the mechanisms of subsoil compaction, any interpretation would be pure speculation.

The moderate correlation of OM with VSA *soil colour* in 2016 (r_s=0.38, n=106 from 5 CSSs) support the claim of VSA *soil colour* as a good indicator of OM soil status. However, a weak and negative, but statistically significant correlation of VSA *soil colour* with LOC (r_s=-0.13, n=230 from 13 CSSs) exists, meaning a weak trend for better VSA soil colour score where LOC is depleted. Nevertheless, we suspect that LOC status classification may have played an important role and masked a hypothetical stronger correlation (that can be sorted out if CSSs give access to LOC raw data). For the 2018 campaign, VSA *soil colour* shows only a weak correlation with OM (r_s=0.27), not statistically significant, an even lower correlation with N_{tot} (r_s=0.21), moderate statistically significant correlation with *microorganism C* (r_s=0.39), and moderate, negative, statistically significant correlation with exc. K (r_s=-0.33). The correlation with exc. K may be a statistical artefact, due to a low sample size and the positive correlation usually observed of exc. K with soil bacteria counts (e.g. Higashida and Takao, 1986). On the other hand, the correlation with *microorganism C* remains open, waiting for further correlation analysis of soil colour with LOC. Another circumstantial observation linking *microorganism C* abundance and soil colour lies on the moderate positive correlation between VSA *soil colour* and measured *pH* in the campaign of 2016 (r_s=0.33, n=256), the highest correlation between VSA indicators and *pH*; *pH* is known for the marked effect on soil microorganisms' communities, especially bacteria, both in terms of diversity and abundance (Rousk et al. 2010). If we analyse the correlations of VSA *soil colour* with other VSA indicators from the campaign of 2016 (n=264), there are moderate correlations with VSA *porosity* and *stability*, respectively r_s=0.38 and 0.37, while correlations with other VSA indicators are all weak, although statistically significant, and again, these VSA indicators, *porosity* and *stability*, show relatively high correlations with *pH* (r_s=0.31 and 0.21, respectively), meaning that factors (soil properties) governing soil colour may, to some extent, govern aggregate stability in water and porosity (part of Deliverable 6.2).

VSA *biodiversity (earthworm count)* correlation with OM in the campaign of 2016 is weak (r_s=0.17) and not statistically significant. A similar correlation of VSA earthworm count with OM was observed in 2018 (r_s=0.22) but, for the related soil property N_{tot}, the correlation between the two is moderate and statistically significant rs=0.37. This is interesting because the equivalent correlation with SOC (considering SOC= SOM x 0.58), is very weak (r_s=0.22), despite the strong linear relationship between N_{tot} and SOM, r=0.98 for n=45 (12 CSSs) and statistically significant for α=0.001 (Teixeira and Basch, 2019). If we consider the correlations between earthworm count and SOC, and between earthworm count and N_{tot}, performed after classification of SOC and N_{tot} according to SQAPP thresholds, we have respectively r_s= 0.14 and 0.37. When we compare pairs of N_{tot} and SOC ranks we observe differences in 9 out of 40 pairs, and in all occasions a higher N_{tot} rank, meaning that the C/N ratio was lower for those pairs; the remaining 31 pairs had equal scores. We also found that the number of earthworms is positively associated to a measurable lower C/N ratio. This raises the question whether it is the earthworms that cause a lower C/N ratio or whether earthworms prefer soils with lower organic matter C/N ratios? The correlation between VSA *earthworm count* with LOC in 2016, although weak (r_s=-0.24) is statistically significant, meaning that higher earthworm count VSA scores are associated with poorer LOC status (to be further analysed). Another interesting finding, in the 2018 campaign, is the inexistence of a correlation between VSA *earthworm count* and *microorganism C* (r_s=-0.01) and the moderate correlation with VSA *stability* (r_s=0.40), the only statistical significant correlation of VSA *earthworms* with other VSA indicators, backing the for long established fact that earthworm casts are stable aggregates (e.g. Shipitalo and Protz, 1989). This correlation (*earthworm count* with *slaking*) was also observed in 2016 and, although much weaker (r_s=0.15), it was statistically significant; *texture* may play a substantial role in the mechanisms (to be further assessed).

In the dataset of 2018, VSA *earthworm count* shows negative moderate correlations with *stone content* and *bulk density* (not *susceptibility to compaction*, with r_s=0.21), respectively r_s=-0.42 and -0.32, both statistically significant, meaning that earthworms thrive better where there's less mechanical impediments.

VSA *number and color of soil mottles* was only assessed in the 2018 campaign. Correlations between VSA *soil mottles* scores and measured properties were not statistically significant for any measured soil property, and all correlations are weak with the exception of a moderate correlation with macrofauna (r_s=0.34). Correlations between VSA *soil mottles* and other VSA indicators were only statistically significant with VSA *subsoil compaction* (r_s=0.39) and *degree of clod development* (r_s=0.43). The correlation with *subsoil compaction* is expected due to the reduction of soil aeration and waterlogging associated to compaction but another cause may be a high water table (poor drainage), and thus only a moderate correlation. The correlations with degree of clod development and subsoil compaction should be further investigated (part of Deliverable 6.2), see next paragraph.

As for VSA *mottles*, VSA *degree of clod development* was only assessed in 2018. The only correlations of VSA *degree of clod development* with measured properties that are statistically significant are with OM (SOC) r_s=0.41 and with related N_{tot}, r_s=0.42. With exception of the correlation with VSA *earthworm count*, that was weak and not statistically significant, correlations with other VSA indicators, are all moderate/strong, ranging from 0.36 with VSA *surface ponding* to 0.78 with VSA *porosity*. The correlation of VSA *degree of clod development* with *subsoil compaction* in the data from 2018 campaign is r_s=0.66. The important correlations with most VSA indicators make this VSA indicator very important for a quick soil assessment, and especially by the fact that it may constitute a good visual indicator (surface indicator) of subsoil compaction, especially because of the generalized believe that compaction leaves no telltale signs on the soil surface. Tilled surfaces of compacted soils will show broken pieces of the masses of hard soil, of higher *bulk density* than the original soil that may persist for longer on the soil surface after rainfall (higher rainfall accumulation until smoothing the surface).

Baseline indicator *surface ponding* shows in the data from 2016 (n=240), a positive, weak but statistically significant correlation with all other VSA indicators. In the data from 2018 (n=40), correlations are weak or inexistent with most VSA indicators with the exception of *porosity* and *degree of clod development*, where a moderate and statistically significant correlation exists, both r_s=0.36. Correlations with measured properties in the data from 2016, are moderate with soil *pH* (r_s=0.30) and weak with *infiltration rate* (r_s=0.19); and very weak (non-existing) with OM and LOC. In the data of 2018, with the exception of N_{tot} (r_s=0.42), correlations with all other measured properties were either weak or non-existing. An interesting finding is the relatively high correlation with VSA *susceptibility to compaction*, r_s=0.27, not statistically significant, and even higher correlation with *bulk density* r_s=-0.32, statistically significant, meaning better VSA scores are higher where *bulk density* is lower. These results reflect the known effect of the measured properties but are puzzling in relation to OM, very weak correlation in 2016 and moderate in 2018, but lower than N_{tot} (to be further investigated in Deliverable 6.2); otherwise a better porosity leads to higher soil infiltration capacity; soils with a lower *bulk density* (less compacted) preserve higher porosity and pore continuity and thus higher soil infiltration capacity.

Baseline VSA *susceptibility to water and wind erosion* in the data of 2016 (n=256) shows a positive, weak but statistically significant correlation with all other VSA indicators with exception of VSA *structure* and *tillage pan*, with which there are no correlations. Differently from 2016, data in 2018 (n=40) shows moderate positive correlations, statistically significant, with *structure* and *subsoil compaction*, no correlations with VSA *mottles* (only measured in 2018) and *surface ponding*, and only a weak and not statistically significant correlation with VSA *earthworm count* (r_s=0.22). Correlation with measured properties in the data of 2016 is only statistically significant with *infiltration rate* (r_s=0.19). In the data from 2018, only the correlation with *stone content* is moderate (r_s=-0.35), and not statistically significant.

pH in the campaign of 2016 (n=256), showed weak to moderate positive correlations, statistically significant with most VSA indicators, varying from r_s=0.12, with VSA *susceptibility to erosion*, to r_s=0.33 with VSA *soil colour*, the exception being with VSA *biodiversity (earthworm count)* where no correlation exists. Although the results from 2016 cannot be directly compared with the results from 2018, due to different protocol (*pH* measured in $CaCl_2$) and thresholds used for *pH* classification, weak correlations, not statistically significant, are observed for some VSA indicators namely VSA *structure* and *stability (slaking)*, both with a r_s=0.19.

Infiltration rate in the campaign of 2016 (n=264) showed only weak correlations with some VSA indicators, although statistically significant, varying from r_s=0.14, with VSA *porosity*, to r_s=0.21 with VSA *structure*. The lack of correlation with VSA *stability (slaking)* and VSA *biodiversity (earthworm count)*, is noteworthy because: 1) it allows to question the claim of a universal effect of earthworm count on water infiltration; 2) it allows to question the use of VSA *stability (slaking)*, irrespectively of soil properties, namely its *texture*, and the matric water potential at the time of the VSA assessment, as an indicator of status regarding water infiltration.

LOC in the campaign of 2016 (n=230) showed only weak and negative correlations with VSA *tillage pan* (r_s=-0.15), *soil colour* (r_s=-0.13) and *biodiversity (earthworm count)* (r_s=-0.24), already discussed above. No correlations were found with the rest of VSA indicators.

Measured soil chemical properties, *exchangeable K* and *available P*, with 2 exceptions, show only weak (or inexistence of) correlations with VSA indicators. Exc. K shows only a moderate, negative and statistically significant correlation with VSA *soil colour* (r_s=-0.33). *Available P* shows a negative, moderate but statistically significant correlation with VSA *subsoil compaction* (r_s=-0.33). This correlation of VSA *subsoil compaction* with *available P* may be explained by waterlogging that occurs where soil is compacted (lower VSA score), with the transformation of ferric phosphates to more soluble forms of ferrous phosphates, and thus a higher content of *available P* (e.g. Patrick and Mahapatra, 1968). Correlation between exc. K and VSA *soil colour* requires further analysis.

Electric conductivity (EC) was measured only in 2018 (n=40). Correlations of EC with VSA indicators are weak or inexistent. EC values at the 40 locations were all below 2 dS m^{-1} (value considered the upper threshold for good condition: below this value salinity is not a threat). The highest, not significant correlation coefficient (r_s=0.28) was found between EC and VSA *stability (slaking test)*, but disappears when ranking is performed after EC classification. Nevertheless, it shows a potential positive correlation with stability in the EC interval of the 2018 data.

Texture and particle size proportion (of sand, silt and clay) correlations with VSA indicators are not discussed because of the low sample size (n=40), range intervals, and the opposite/ contradictory results from an equally low sample (n=56, from Estonia, Romania and The Netherlands (3)) from 2016 campaign. An extended and meaningful study can be performed if the CSSs forward the raw data from the 264 sites.

Number of macrofauna groups was measured only in 2018 (n=28) and the correlation results with VSA indicators show that it may become a good, non-specific, overall indicator of soil quality status, especially if local indexes, based on local macrofauna, easily recognizable, can be developed, to lower the level of expertise needed that the present protocol requires. Moderate positive correlations, statistically significant, exist for several VSA indicators, including VSA *earthworm count* – in comparison, VSA *earthworm count* has a statistical significant correlation only with VSA *stability*. The small sample size restrains us from further analysis.

Correlations between AMP groups and VSA indicators (2016)

A major constraint of these correlation analyses is related with the selection of the management practices and the inherent problem that arises for upscaling the results. The innovative practices were identified by the CSSs based on the perceived potential success of those practices at their locations. Thus, this analysis is biased and reflects the contrast found between innovative (known successful practices) and traditional practices.

Another aspect of these analyses, that must be taken into account, is the fact that AMP groups that are defined in precise terms have better correlations (a higher correlation strength) with VSA indicators than those ill-defined. This doesn't mean that particular management practices may not have a much better impact on soil quality than other management practices belonging to the same AMP group.

Soil tillage related AMP groups are the perfect example of definition issues that may arise from a too broad definition. *'No-till'*, the absence of tillage, allows for little interpretation, and the identified management practices show a positive correlation (weak, moderate and strong) with all VSA indicators, while '*min-till'*, defined in a way that allows to include an endless number of practices, only has weak correlations with VSA indicators and only one is statistically significant (VSA *soil colour*, r_s=0.27). *'No-till'* correlations are moderate to strong, statistically significant, with VSA indicators related to soil structure (*structure* (r_s=0.77) , *porosity* (r_s=0.53) and *stability* (r_s=0.50)) and *susceptibility to erosion* (r_s=0.47), which is in line with known features of these cropping systems, and weak correlations with all other VSA indicators. No correlation exists with measured properties (*pH*, *infiltration rate* and LOC). The lack of correlation with measured properties (plus OM) is also observed with AMP '*min-till'*.

AMPs '*Permanent soil cover / Removing less vegetation cover*' and '*Residue maintenance / Mulching*', both show only a positive moderate, statistically significant correlation with VSA *porosity*, respectively r_s=0.49 and 0.37. Concerning measured properties, both AMP groups also show a similar, not significant weak correlation with LOC (AMP '*mulching*' also showed a weak correlation with OM, not assessed for AMP '*permanent soil cover*' because of insufficient data). Overall, AMP '*Permanent soil cover / Removing less vegetation cover*' show better correlations than AMP '*Residue maintenance / Mulching*' but, as discussed above, this is of little meaning.

AMP '*manuring/composting*' only shows positive moderate, statistically significant correlations with VSA *structure* and *porosity* (r_s=0.37 and 0.46) and only weak correlations with the rest of VSA indicators. Of the measured properties, only the correlation of the AMP with LOC exists, although weak and not statistically significant (r_s=0.16). The lack of correlation with OM content (r_s=0.00) should be stressed. The mechanisms behind the improvement of structure related indicators are not directly and solely connected to OM content but an OM amendment effect can be observed.

AMP '*leguminous crops*' show positive moderate correlations, statistically significant, with structure related VSA indicators (*structure* (r_s=0.50), *porosity* (r_s=0.46) and *stability* (r_s=0.50)), weak with *soil colour* and non- existing with other VSA indicators. Together with AMP *'no-till'*, they are the only AMP groups having a positive moderate impact on VSA *stability*. Correlations with measured properties are weak with *infiltration rate* and LOC (r_s=0.20 and 0.22). These results are in line with what is known and expected from the use of leguminous crops on soil properties.

AMP '*crop rotation*' only has weak correlations with most of the VSA indicators (r_s<|0.30|), and statistically significant only with VSA *porosity* (r_s=0.27). The data shows no correlation of the AMP group with measured properties. AMP '*crop rotation*', in our analysis, apparently has an impact on soil quality similar to permanent soil cover or mulching, but its recognized impacts on cropping systems exceed the soil properties measured and characteristics observed (weed control, prevention of pest and diseases, etc.).

AMP '*measures against compaction*' shows moderate positive correlation with VSA *structure* (r_s=0.36) and weak with VSA *porosity* (r_s=0.28), both not statistically significant. Correlation with VSA *tillage pan* is weak (r_s=0.18) and very weak or non-existing with the rest of VSA indicators and measured soil properties. The lacking (weak) correlation with tillage pan stresses the need to effectively prevent subsoil compaction, to avoid loads above the soil bearing capacity, because remediation practices to reverse the compacted status of a soil (e.g. by deep ripping), without changes in land use and with only minor changes in farming system, will probably fail, and regenerative practices often involve the change of land use and a natural rebuilding of the soil. When recommending an AMP to prevent or mitigate the effects of compaction, pore continuity may be a much better indicator than *bulk density* or soil penetration resistance (Ball and Robertson 1994). For arable and permanent crops, *'no-till'* confers higher resistance to compactive loads because of the network of dead roots capable to avoid major soil fabric rearrangement, and the increase of organic matter harnessing higher aggregate stability and strength.

AMP '*integrated pest management (inc. organic farming)*' shows moderate positive and statistically significant correlations with VSA *structure* and *porosity*, r_s=0.45 and 0.51, and a concordant correlation with *infiltration rate* r_s=0.26, although not statistically significant.

Correlation with VSA *stability* is weak. Further analysis is needed to interpret this data, including the application of organic matter to soils of AMPs and controls (not clear), green manuring, etc.

AMP '*irrigation management'* has a moderate positive and statistically significant correlation with VSA *structure* (r_s=0.58). Other correlations with other VSA indicators and measured properties are weak and moderate, but not statistically significant (small sample size). The results are in line with what would be expected from management practices that increase biomass production and create the soil moisture conditions for fauna and microorganisms to thrive.

AMP '*change of land use practices / intensity level'* encompasses a huge variety of management practices and, as said above, this results in low coherence. Correlations with VSA indicators are not statistically significant, and only correlation with VSA *structure* and *porosity* borders significance (r_s=0.44 and 0.41). With exception of the correlation with VSA *susceptibility to erosion*, all other correlations with VSA indicators are either weak or non-existing. Correlations with measured properties are weak, and not statistically significant, with *infiltration rate* (r_s=0.37) and LOC (r_s=-0.35). One can speculate that the negative correlation with LOC accompanied by a positive correlation with OM (r_s=0.25), means that change of land use and/or decrease in the intensity level drives the system to a new OM equilibrium and that reflects on soil structure and porosity.

The other AMP groups of the 2016 campaign have insufficient data for a meaningful statistical analysis, and little information can directly be extracted from the data.

The assessment made in 2018, based on measured physical, chemical and biological soil properties, and a set of different management practices, cannot be the subject of any meaningful statistical analysis regarding any specific AMP group due to the lack of sufficient data.

6. Recommendations for SQAPP

Depending on how the information of the VSA and measured properties (both from 2016 and 2018) will be integrated in the recommendation system, recommendations will vary accordingly.

In general terms, the following applies:

OM has weak positive to moderate correlation with VSA *structure* (depending on the data set) and moderate positive correlations with VSA *porosity* and *stability* and *soil colour*.

pH has weak positive correlation with VSA *structure*, *porosity* (moderate correlation), *stability* and *tillage pan*.

pH has a moderate positive correlation with VSA *soil colour*.

Stone content and *bulk density* show a moderate negative correlation with VSA *earthworm count*. Decrease in earthworm abundance where mechanical impediments exists.

Bulk density shows a negative correlation with VSA *surface ponding*. *Susceptibility to compaction* also has a correlation with VSA *surface ponding* (slightly weaker).

There is a positive correlation between VSA *earthworm* and *aggregate stability* (weak/ moderate).

Based on the data available, earthworms may play a substantial role in the decrease of soils' OM C/N ratios.

VSA *structure*, *porosity* and *tillage pan* have weak positive correlations with *infiltration rate*. VSA *stability (slaking)* has no correlation with water infiltration.

VSA *structure* and VSA *tillage pan* have no correlation with aggregate stability/slaking (VSA *stability*).

VSA *number and colour of mottles* show no statistically significant correlations with measured soil properties (mottles must be checked in situ). Moderate positive correlations with VSA *degree of clod development* (and *subsoil compaction*), indicates that this VSA indicator (*degree of clod development)* can and should be used as a telltale for further soil profile examination.

In terms of AMP group recommendations, the following applies:

No statistically significant correlation exists between AMPs and measured properties (*pH*, *infiltration rate*, LOC and OM) in the data from 2016. Correlations are weak, with few exceptions (for these exceptions the sample size is small and thus with no statistical meaning).

AMP '*no-till*' correlations with VSA indicators are moderate to strong, statistically significant, with VSA indicators related to soil structure (VSA *structure*, *porosity* and *stability*) and VSA *susceptibility to erosion*, which is in line with known features of these cropping systems, and weak correlations with all other VSA indicators.

AMP '*min-till'* show only a weak positive, statistically significant correlation with VSA *soil colour*, and very weak or no correlation with other VSA indicators.

AMP groups that increase soil cover (AMPs number 3 and 8, see Annex 1) have moderate, positive and statistically significant correlations with VSA *porosity*. All other correlations with VSA indicators are either moderate but not statistically significant, weak or non-existing. These AMP groups show a weak positive correlation with LOC, but not statistically significant.

AMP '*leguminous crops'* correlations with VSA indicators are moderate positive, statistically significant, with VSA indicators related to soil structure (VSA *structure*, *porosity* and *stability*). Correlations with other VSA indicators are weak or inexistent. Correlations with measured properties are weak and positive with *infiltration rate* and LOC, but not statistically significant.

AMP '*manuring/composting*' has positive moderate correlations with VSA *structure* and *porosity*. Correlations with other VSA indicators are either weak (inc. with VSA *stability*) or non-existing. Manuring and composting have no effect on OM content (r_s=0.00), and only show a weak positive correlation with LOC, not statistically significant.

AMP '*crop rotation'* only has a weak positive, statistically significant correlation with VSA *porosity*. Other correlations with VSA indicators and measured properties are either weak, not statistically significant, or non-existing.

AMP '*measures against compaction'* has no statistically significant correlation with VSA indicators and measured soil properties. The higher correlations, moderate and weak, are structure related (VSA *structure* and *porosity*) but not statistically significant. Correlation with

VSA *tillage pan* is weak and not statistically significant, which stresses the need to prevent soils from becoming compacted.

AMP '*integrated pest management including organic farming'* has positive moderate, statistically significant correlations with VSA *structure* and *porosity*. Other correlations with VSA indicators and measured properties are either weak, not statistically significant, or non-existing.

AMP '*irrigation management'* has positive moderate, statistically significant correlation with VSA *structure*. Other moderate correlations with VSA indicators exist with VSA *porosity*, *tillage pan* and *soil colour*, but not statistically significant. Other correlations are either weak or non-existing.

AMP '*change of land use practices / intensity level'*, has a definition too broad to allow any correlation to rise amid all the noise generated by so different management practices.

7. Conclusion

VSA indicators and measured properties, in both campaigns (2016 and 2018), have correlations that are in good agreement with what is known of the relation between those soil properties and different observable (visual) soil characteristics, and no awkward correlations were observed. Several relations were uncovered and are presented in the next paragraphs.

From a first analysis, and despite the small sample size (n=40), VSA *degree of clod development* correlations with VSA *porosity*, *subsoil compaction* and *number and colour of mottles*, show that it may be used to signal probable subsoil compaction issues (that should be later checked in the soil profile).

Although the results are preliminary, LOC negative correlations with VSA *soil colour* and *earthworm count* (poor LOC content correlates with better soil colour and earthworm count) may be a good measured indicator of thriving microbial communities and earthworms (this results should be further analysed with LOC raw data from the CSSs).

Number of macrofauna groups correlation results with VSA indicators show that it may become a good, non-specific, overall indicator of soil quality status (moderate positive correlations, statistically significant, with several important VSA indicators, including VSA earthworm count – in comparison, VSA earthworm count, in 2018, has a statistical significant correlation only with VSA stability). Soil macrofauna indexes should be defined locally, to simplify and reduce the level of expertise needed.

VSA indicators can be used to characterize differences of soil quality regarding innovative management practices. The measured properties show different degrees of association with VSA indicators and, most probably, these VSA indicators are the expression of different concurring soil properties and mechanisms that need to be better understood.

8. Future work

A multivariate analysis will be conducted to examine main soil properties governing VSA indicators (part of Deliverable 6.2).

Needs for further studies/ analysis:

Failure to assess the effect of *bulk density*/ susceptibility on VSA subsoil compaction (protocol error). Eventually, CSSs could measure *bulk density* at adequate depth.

LOC raw data for future correlation studies and multivariate analysis.

pH raw data for future correlation studies and multivariate analysis.

Need of OM values of all plots assessed in 2016 (if existing) for future correlation studies and multivariate analysis.

Need of soil *texture* and particle size distribution of all plots assessed in 2016 for further correlation studies and multivariate analysis.

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Annex 1. Agricultural Management Practice groups (AMP groups) description.

Agricultural Management Practices (AMP)			
N.	List / Identification	Description	Expected impacts / Ecological benefits
1	No-till	A system where crops are planted into the soil without primary tillage	Reduces decomposition of OM rates leading to its increase in soil, enhances cycling of nutrients, enhances soil structure and increases water infiltration. Improves soil biological life including disease and weed suppression.
2	Min-till	Tillage operation with • reduced tillage depth • strip tillage • mulch tillage or a combination thereof	Reduces decomposition of OM rates leading to its increase in soil, enhances cycling of nutrients, enhances soil structure and increases water infiltration. Improves soil biological life including disease and weed suppression.
3	Permanent soil cover / Removing less vegetation cover	Avoiding a bare or sparsely covered soil exposed to weather conditions (rain, wind, radiation, etc) by ensuring a permanent cover (at least 30% of the soil surface) throughout the year, e.g. through cutting less grass, leaving a volunteer crop or crop residues, etc. (see also cover crops and residue maintenance / mulching)	• Improves infiltration and retention of soil moisture resulting in less severe, less prolonged crop water stress and increases availability of plant nutrients. • Provides source of food and habitat for diverse soil life: created channels for air and water, biological tillage and substrate for biological activity through the recycling of organic matter and plant nutrients. • Increases humus formation. • Reduces the impact of rain drops on soil surface resulting in reduced crusting and surface sealing. • Reduces runoff and erosion. • Reduces wind erosion. • Increases soil regeneration. • Mitigates temperature variations on and in the soil. • Improves the conditions for the development of roots and seedling growth.
4	Cover crops	a. Cover cropping: planting close-growing crops (usually annual legumes), b. Relay cropping: specific form of mixed cropping / intercropping in which a second crop is planted into an established stand of a main crop. The second crop develops fully after the main crop is harvested. c. Better crop cover: selecting crops with higher ground cover, increasing plant density, etc.	a. Protects soil, between perennials or in the period between seasons for annual crops. N-fixation in case of leguminous crops. b. Continuously covered soil. Reduces the insect/mite pest populations because of the diversity of the crops grown. Reduces the plant diseases. Reduces hillside erosion and protected topsoil, especially the contour strip cropping. Attracts more beneficial insects, especially when flowering crops are included in the cropping system. c. Protects soil against the impacts of raindrops or wind and keeps soil shaded; and increases moisture content.
5	Leguminous crop	A leguminous crop is a plant in the family Fabaceae (or Leguminosae) that is grown agriculturally, primarily for their grain seed called pulse, for livestock forage and silage, and as soil-enhancing green manure. Well-known legumes include alfalfa, clover, peas, beans, lentils, lupins, mesquite, carob, soybeans, peanuts, and tamarind.	Provides soil with nitrogen and additional nitrogen from chemical fertilizers is not necessary. (See also cover crop and green manure)
6	Green manure / Integrated soil fertility management	Green manure is a crop grown to be incorporated into the ground, while the more general term 'integrated soil fertility management' refers to a mix of organic and inorganic materials, used with close attention to context-specific timing and placing of the inputs in order to maximize the agronomic efficiency.	Increases organic matter content, thereby improving fertility and reducing erodibility. In case of leguminous green manure, tilling it back into the soil allows exploiting the high levels of captured atmospheric nitrogen found in the roots.

7	Manuring(a) / composting(b)	a) Manure is organic matter, mostly derived from animal feces (except in the case of green manure, which can be used as organic fertilizer in agriculture). b) Compost is organic matter that has been decomposed and recycled as a fertilizer and soil amendment. Compost is a key ingredient in organic farming.	a) Contributes to the fertility of the soil by adding organic matter and nutrients, such as nitrogen, that are trapped by bacteria in the soil. b) Improves soil fertility through nutrient content and availability, soil structure and microbiological activity; impacts plant growth and health directly and indirectly.
8	Residue maintenance / Mulching	Maintaining crops residues or spreading of organic (or other) materials on the soil surface.	• Reduces sheet and rill erosion. • Reduces wind erosion. • Maintains or improves soil organic matter content. • Conserves soil moisture. • Provides food and escapes cover for wildlife.
9	Crop rotation(a) / Control or change of species composition(b)	a. Practice of alternating the annual crops grown on a specific field in a planned pattern or sequence in successive crop years so that crops of the same species or family are not grown repeatedly on the same field b. Diversify species in rotation systems or grasslands	a. Reduces risk of pest and weed infestations. Improves distribution of channels or biopores created by diverse roots (various forms, sizes and depths). Improved distribution of water and nutrients through the soil profile. Allows exploration for nutrients and water of diverse strata of the soil profile by roots of many different plant species resulting in a greater use of the available nutrients and water. Increases nitrogen fixation through certain plant-soil biota symbionts and improved balance of N/P/K from both organic and mineral sources. Increases humus formation. b. Introduces desired / new species, reduces invasive species, controls burning, residue burning.
10	Cross-slope measure	Structural measure along the contour to break slope lengths, such as terraces, bunds, grass strip, trashlines, contour tillage	Reduces surface runoff and erosion (increase infiltration capacity).
11	Measures against compaction	a) Breaking compacted soil: e.g. deep ripping, subsoiling (hard pans); Digging the soil up to twice as deep as normally. b) Growing deep rooted plants in the rotation such as: annual alfalfa, beet, sunflower, okra, flax, turnip. c) Controlled traffic farming: is a system which confines all machinery loads to the least possible area of permanent traffic lanes d) Soil compaction models (considering tire size, inflation pressure, weather and soil conditions) to predict allowable wheel load and soil compaction maps to show how soil compaction varies at different locations and depths across the field	a-b)Looses soil to improve drainage, infiltration, aeration and rooting characteristics, and brings nutrients up from deep below c-d) Minimizes soil damage and preserves soil function in terms of water infiltration, drainage and greenhouse gas mitigation, and (d) provides useful information for decision making process for site-specific applications such as variable deep tillage to benefit from increased timeliness (and reduced management costs)
12	Integrated pest and disease management incl. organic agriculture	Appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to reduce or minimize risks to human health and the environment.	Emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.
13	Water diversion and drainage	A graded channel with a supportive ridge or bank on the lower side. It is constructed across a slope to intercept surface runoff and convey it safely to an outlet or waterway	Reduces hazard towards adverse events (floods, storms,…), reduces soil waterlogging

14	Irrigation management	Controlled water supply and drainage: mixed rainfed – irrigated; full irrigation; drip irrigation	Improves water harvesting; increased soil moisture; reduces evaporation; improves excess water drainage; recharge of groundwater
15	Major change in timing of activities	Adaptation of the timing of land preparation, planting, cutting of vegetation according weather and climatic conditions, vegetation growth, etc.	Reduced soil compaction, soil loss, improved biomass, increased biomass, increased soil OM
16	Layout change according to natural and human environment/needs	eg exclusion of natural waterways and hazardous areas, separation of grazing types; increase of landscape diversity.	Reduces surface runoff and erosion, increases biomass, nutrients and soil OM, controls pests and diseases
17	Area closure / rotational grazing	Complete or temporal stop of use to support restoration	Improves vegetative cover, reduces intensity of use, and soil compaction and erosion.
18	Change of land use practices / intensity level	eg change from grazing to cutting (for stall feeding), from continuous cropping to managed fallow, from random (open access) to controlled access (grazing land), from herding to fencing, adjusting stocking rates.	Increases biomass, nutrient cycling, soil OM, improves soil cover, beneficial species (predators, earthworms, pollinators), biological pest / disease control, and increases / maintains habitat diversity. Reduces soil loss, soil crusting/sealing, soil compaction, and invasive alien species.
19	Plastic		

Annex 2. Selected 20 pairs AMP-Control, CSS, climatic region and georeferenced coordinates.

CSS	CLIMATIC REGION	PLOT Nº	GEOREFERENCED coordinates	FARMING SYSTEM	FARMING SYSTEM DETAIL	Description of the AMP/ Threats addressed	Years since adoption	SOIL GROUP	AMP Nº
France	Atlantic	2-2	48,002333° N 1,437944° E	Arable land Maize	No-till; maize/cereal rotation. Manuring.	Compaction/ Erosion	10	Cambisol	1; 9
		Control	48,072277° N 1,109666° E		Tilled; Maize monoculture. Manuring.				
		2-9	48,068388° N 1,141027° E	Pasture intensive	Permanent pasture/ Cows grazing	Compaction	100	Cambisol	18
		Control	48,06475° N 1,106083° E		Temporary pasture/ Cows grazing				
Portugal	Mediterranean temperate	3.2	40,237883° N 8,466333° W	Arable land Maize	Sludge application	OM depletion		Fluvisols	7
		Control	40,220333° N 8,48125° W		Tilled; Maize.				
		3.7	40,422117° N 8,485689° W	Permanent crops	Vineyards. Water diversion and drainage. Manuring.	OM depletion/ Compaction/ Nutrient depletion	12	Cambissols	13
		Control	40,422667° N 8,485667° W						
Spain	Mediterranean semi-arid	4.5	38,164218° N 0,712572° W	Permanent - crops	Pomegranate. Minimum tillage Residue maintenance Manuring	Salinization (soil sealing and increase OM)	7	Regosol	2; 3; 7
		Control	38,190709° N 0,687498° W		Pomegranate. Conventional management.				
		4.12	37,855917° N 0,830250° W	Arable permanently irrigated	Pepper. Crop rotation. Residue maintenance. Manuring.	OM depletion/ Compaction	12	Cambisol	9; 7
		Control	37,853980° N 0,831980° W		Pepper monoculture. Conventional management				
Greece	Mediterranean temperate	5.9	35,320803° N 25,236560° E	Permanent crops	Olives orchards. No-till.	Erosion/ OM depletion	13	Regosol	1
		Control	35,321462° N 25,236689° E		Oilve orchards. Tilled.				
		5.12	35,295923° N 24,907333° E	Pastures	Extensive pastures. Consists of schlerophyllous, annual natural vegetation	Erosion/ OM depletion	43	Cambisol	18
		Control	35,296190° N 24,907585° E		Intensive pastures (sowed)				
Slovenia	Southern sub-continental	6.9	46,093771° N 14,495881° E	Non irrigated arable land	Organic farming with diverse rotation (2018 Oat); manuring.	Compaction/ Sealing/ OM depletion	9	Cambisol	9; 7
		Control	46,093537° N 14,495542° E		Vegetable crops + cereal (2018 Barley)				
		6.12	46,124762° N 14,495882° E	Pastures	Grazing.(previously Maize)	Compaction/ Sealing/ Biodiversity	17	Cambisol	18
		Control	46,124491° N 14,497139° E		Grass cutting (2-3 times per year)				
Romania	Northern sub-continental	8.8	45,229629° N 27,579469° E	Non irrigated arable land	Sunflower. Irrigation management.	OM depletion/ Others (droughts)		Chernozems	14
		Control	45,197142° N 27,580508° E		Sunflower. Rainfed.				
		8.11	45,284859° N 27,850021° E	Pastures extensive	Controlled access to pasture.	OM depletion/ Salinization		Chernozems	18
		Control	45,304876° N 27,835111° E		Free access to pasture.				
Poland	Northern sub-continental	9.1	51,993824° N 22,550696° E	Non irrigated arable land	Maize. Application of "used" mushroom substrate.	OM depletion	22	Podzols	7
		Control	51,996773° N 22,547874° E		Cereals. Conventional management.				
		9.3	51,313861° N 22,450944° E	Permanent crops	Hops. Organic farming. No OM amendments.	OM depletion	10	Cambisols	12
		Control	51,302610° N 22,422940° E		Hops. Conventional management.				
Estonia	Boreal to sub-boreal	10.12	58,99181° N 24,871640° E	Grassland; conventional; intensive	Grassland for silage. Permanent cover.	Compaction	8	Eutric Histosol	3
		Control	58,99232° N 24,874360° E	Non irrigated arable land;	Crop rotation (2018, Maize)				
		10.14	58,2844° N 26,491210° E	Non irrigated arable land	Crop rotation (2018, Wheat). No-till.	Compaction	7	loamy sand Stagnic Luvisol	1

CSS	CLIMATIC REGION	PLOT Nº	GEOREFERENCED coordinates	FARMING SYSTEM	FARMING SYSTEM DETAIL	Description of the AMP/ Threats addressed	Years since adoption	SOIL GROUP	AMP Nº
		Control	58,2861° N 26,493190° E		Crop rotation. Tilled (inversion)				
China - Qiyang	Central Asia tropical	11.4	26,761111° N 111,865278° E	Permanent crops	Orange. Green manure; Manuring & composting and Irrigation management	OM depletion	6	Acrisols	7;14
		Control	26,758333° N 111,871390° E	Permanent crops	Orange. No fertilizer.				
China - Suining	Central Asia tropical	12.1	30,613067° N 105,022033° E	Arable land	Maize-Wheat rotation. Manuring.	OM depletion/ Erosion		Plaggic Anthrosols (Eutric)	9
		Control	30,613067° N 105,022033° E		Rice-rape rotation. Manuring.				
China - Gongzhuling	Middle Temperate	14.1	43,6125° N 124,794440° E	Arable land	Maize. Residue maintenance/ Mulching.	OM depletion	4	Phaeozems	8
		Control	43,6125° N 124,794440° E		Maize. Residue removal.				
		14.4	45,258333° N 124,896389° E	Irrigated arable land	Maize. Residue maintenance/Mulching and Irrigation management (drip irrigation)	OM depletion	4	Chernozem	8; 14
		Control	45,262778° N 124,875560° E		Tilled and flood irrigation.				

Annex 3. Thresholds for soil quality assessment (adapted from SQAPP).

SOIL THREAT and indicator		THRESHOLDS				
Soil erosion by water						
Soil loss (t/ha/year)			0-2	2-10	>10	
Vulnerability (class)			low	medium	high	
Soil erosion by wind						
Soil loss (t/ha/year)			0-0.5	0.5-3	>3	
Vulnerability (class)			low	medium	high	
Soil compaction						
Natural susceptibility			low	medium	high	
Soil salinisation						
Electrical conductivity (dS/m)			0-2	2-4	>4	
Soil organic matter decline						
Soil organic carbon content (%)			0-1	1-2	>2	
Soil nutrient depletion						
Exchangeable K (cmol/kg)			0-0.2	0.2-0.3	>0.3	
Available P (Olsen method) (mg/kg)	--> see note		0-20	20-40	>40	
Total N (g/kg)			0-1	1-2	>2	
Soil acidification						
Soil pH		<5.5	5.5-6.5	6.5-7.5	7.5-8	>8
Soil contamination						
Arsenic (mg/kg)			0-37.5	37.5-50	>50	
Cadmium (mg/kg)			0-2.25	2.25-3	>3	
Chromium (mg/kg)			0-300	300-400	>400	
Copper (mg/kg)	pH <5.5		0-60	60-80	>80	
	pH 5.5-6.0		0-75	75-100	>100	
	pH 6.0-7.0		0-101.3	101.3-135	>135	
	ph >7.0		0-135	135-200	>200	
Lead (mg/kg)			0-225	225-300	>300	
Mercury (mg/kg)			0-0.75	0.75-1	>1	
Nickel (mg/kg)	pH <5.5		0-37.5	37.5-50	>50	
	pH 5.5-6.0		0-45	45-60	>60	
	pH 6.0-7.0		0-56.25	56.25-75	>75	
	ph >7.0		0-82.5	82.5-110	>110	
Zinc (mg/kg)			0-150	150-200	>200	
Soil biodiversity						
Soil biodiversity index			low	medium	high	