# Report on SQAPP Assessment as a tool to monitor soil quality improvement.

## Part 2. Soil threats, Soil Quality Index and recommendations for SQAPP

Project: iSQAPER | Work Package 6 | Task 6.3

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**Working Paper**


## Abstract

For each soil, SQAPP estimates accurately classified the level of threat (Low, Moderate, High), on average, in 53% of soil threats. The percentage of soil threats' classes correctly identified using SQAPP estimates, per soil, varied between 14 and 83%. A soil quality index based on the soil threat classes (sum of the individual threats' classes according to their level and attributing a value of 0, 0.5 or 1, for respectively high, moderate or low), yielded on average 0.75 (or 75%) using measured and SQAPP estimated values. This convergence is only apparent and the individual soil indexes (measured vs. estimated) may be quite disparate. A recommendation system based on threat level classes estimated using SQAPP values will produce 10% gross errors (classifying low as high and vice versa).

Soil erosion estimates (SQAPP) accuracy can be increased if SQAPP users are allowed or asked to fill landscape features and land use. The use of SOM and texture estimates (SQAPP) and user inputs on landscape features and land use allowed to properly classify soil erosion threat in 40 out of 41 fields. When using SQAPP estimates without users input, estimates dropped to 24 out of 41 fields.

Microorganisms C estimates (SQAPP) agreement with measured microorganisms' C can also be improved, although with little change concerning the correlation coefficient, which may result in a much higher accuracy of the soil biodiversity threat classification, through an indirect estimation (modelled from SOM soil content).

We also propose to model soil N total estimates from SOM content, as it increases the correlation coefficient between measured and estimated from r=-0.07 to r=0.69, and a much better agreement.

Other approaches can be tested to increase SQAPP accuracy for some soil properties, e.g. bulk density, but they are time consuming and the results are not assured.

## Introduction

In this report we discuss the accuracy of soil properties and soil threats classification based on soil properties estimates of the Soil Quality App (SQAPP) and the correlation and agreement with the soil properties and soil threats classification using measured physical, chemical and biological soil properties, for the same location. The final goal is to assess if SQAPP can be used to monitor soil quality improvement, and the adequacy of the recommendation system.

## Materials and Methods

In the scope of the iSQAPER project, WP6, task 6.1, innovative agricultural management practices (AMPs) were first chosen at 14 case study sites (Barão and Basch, 2017) for evaluation and demonstration purposes. A final set of 24 georeferenced pairs of AMPs and control fields was defined (see Annex 1), at 13 CSSs, and the CSSs were asked to collect the data needed to assess threats and soil quality status by answering a questionnaire and measure soil physical, chemical and biological properties (see Annex 2). Of the 13 CSSs, only 11 complied with the deadline set to provide a filled questionnaire. The questionnaire from The Netherlands is semi-filled and there is no reply from Hungary.

The data from SQAPP was compiled with the beta version released in June 2018 (compilation occurred from June to November 2018) (see Table 1).

Table 1. Origin of the data used in the correlation studies.

| | NL | SQ | FR | SQ | PT | SQ | SP | SQ | GR | SQ | SI | SQ | RO | SQ | PL | SQ | EE | SQ | CN-11 | SQ | CN-12 | SQ | CN-14 | SQ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clay | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Silt | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Sand | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Bulk Density | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Coarse Fragments | | x | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| SOC | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| pH | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Electrical Conductivity | | x | x | x | x | x | x | a | x | x | x | x | x | x | x | x | x | x | x | a | x | x | x | x |
| Exc. K | x | x | x | X | x | x | x | a | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| P (Olsen) | x | a | x | x | x | | x | a | x | a | x | x | x | x | x | a | x | x | x | a | x | x | x | x |
| Total N | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Microbial Biomass | | x | | x | | x | x | a | x | a | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Fauna groups | | x | | x | x | x | x | x | x | a | x | x | x | x | | x | x | x | | x | | x | | x |

Grey- no data provided by the CSS; Blue- no data registered in SQAPP; a data available in SQAPP only at 1 location.

For the 8 soil threats considered (Erosion, Compaction, Salinization, SOM decline, Acidification, Nutrient Depletion, Contamination and Biodiversity Depletion), the soil properties and materials and methods used for their measurement (assessment), please see iSQAPER report on Milestone 6.2 (Identification of parameter/indicator set for testing and evaluating the impact on soil quality and crop production parameters).

For the soil threat ‘Contamination’, CSSs were asked to provide data on the pesticides used (pesticide active substance and rate per ha, for the last 3 years) and, in case they expected heavy metal contamination, soil analysis covering 6 heavy metals. Regarding pesticides, only Estonia provided both the active substance and rate applied for the last 3 years. Because SQAPP does not cover the pesticide part, we will focus only in heavy metals in soil.

Threshold for the classification of each soil threat can be found in Annex 3

*Statistical analysis*

Association between measured soil properties (physical, chemical and biological) and estimated values by the Soil Quality App (SQAPP) were tested by Pearson correlation coefficient and, to determine if the association between measured and estimated were statistically significant, the respective t values were calculated, both with Excel (Microsoft Office Professional Plus 2013). The standard error of the estimate was calculated.

# Results

**Soil Threats**

*Erosion*

The use of the soil properties estimated by SQAPP (texture and SOC) to calculate soil erosion (RUSLE), and using measured (observed) parameters for all other inputs (landscape features, land use, management, soil structure), allowed to properly classify soil erosion threat in 40 out of 41 fields (see Figure 1, top), at 12 CSS.

Unfortunately, there is no available data on soil erosion for China in SQAPP. The comparison between the results from soil erosion estimated by SQAPP (with no user input) and by SQAPP plus measured/observed parameters (9 CSSs), show a lower agreement on the classification of soil erosion threat (see figure 1, bottom). The correlation between the soil erosion estimates solely generated by SQAPP and by SQAPP plus measured/observed parameters by the CSS, is very low (r=-0.05), and thus, soil erosion classification agreement is due to chance.

The correlation between soil erosion values based on *SQAPP (soil texture and SOM) + CSS (landscape features, land use, management and soil structure)* and *Measured solely* (all data from the CSS) is very high (r=0.98), which highlights the known importance of landscape features, land use and management on soil erosion (see Figure 2). This results will be discussed in Section 4.

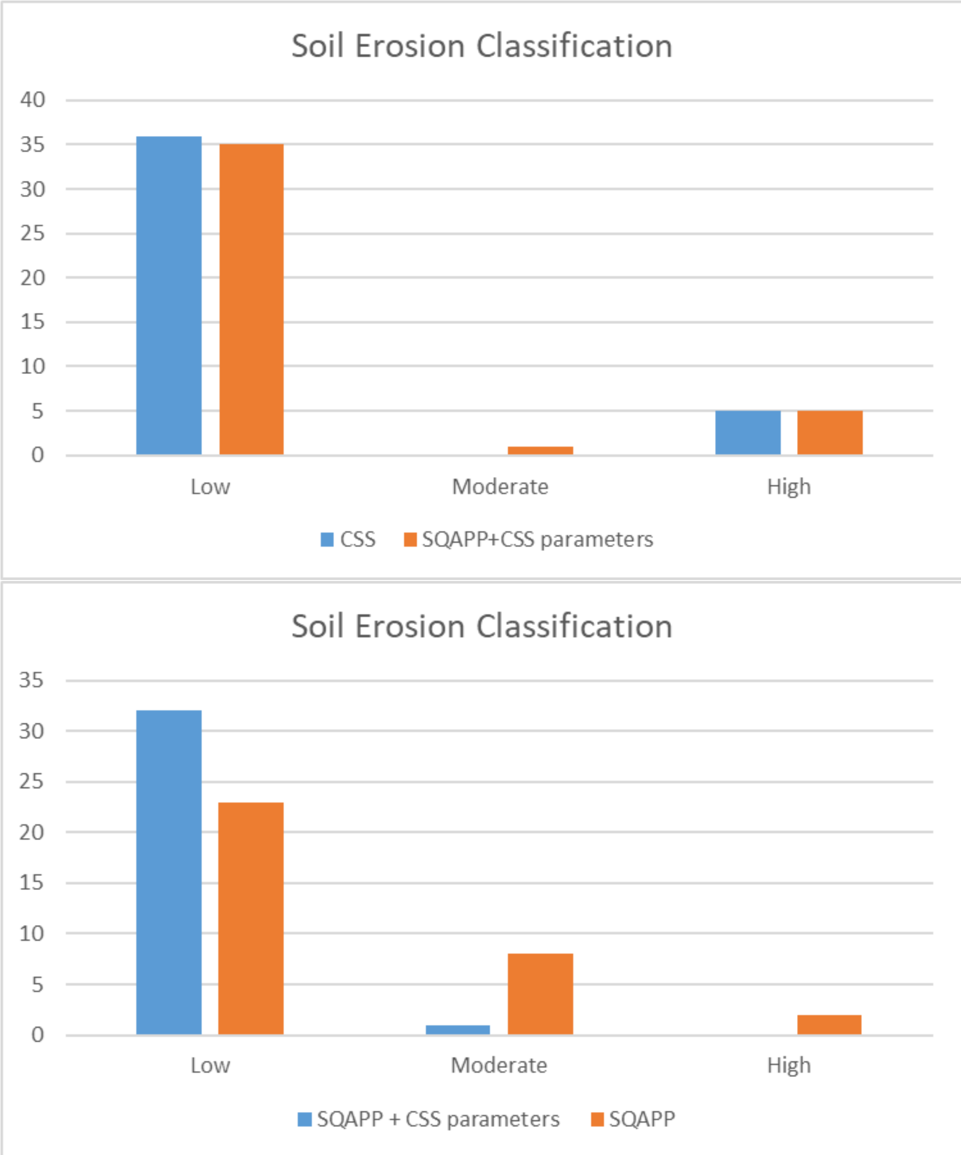



Figure 1. Top, soil erosion classification using CSS's data and SQAPP (soil texture and SOM) + CSS (landscape features, land use, management and soil structure) (**y- axis: number of fields**); bottom, soil erosion classification using SQAPP (soil texture and SOM) + CSS (landscape features, land use, management and soil structure) and SQAPP solely ) (**y- axis: number of fields**).

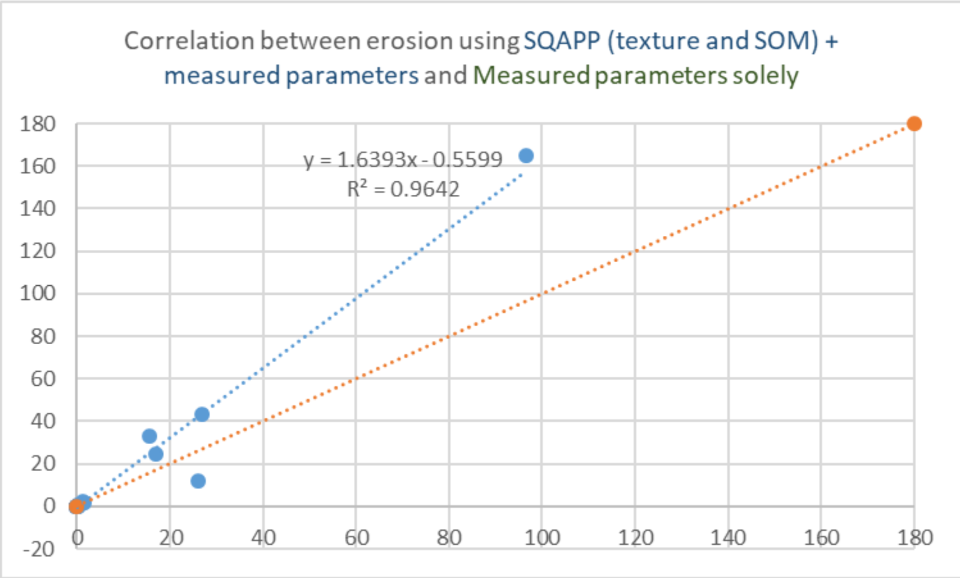



Figure 2. Correlation between soil erosion values (ton/ha/year) based on SQAPP (soil texture and SOM) + CSS (landscape features, land use, management and soil structure) and measured parameters solely (r=0.98 and $R^2$=0.96). Blue: regression line. Orange: equality line.

*Compaction*

Compaction was calculated based on soil vulnerability to compaction (Jones et al., 2003), and soil status concerning compaction on the inverse of the vulnerability (i.e. high vulnerability corresponds to good status and vice versa). Soil properties involved in the calculation of soil vulnerability to compaction were bulk density (BD), clay content (%) and other texture components used to classify texture (texture classes of FAO).

Data of 11 CSSs, corresponding to 41 fields were used. Agreement between SQAPP and measured on the classification of the soil compaction status occurred at 21 fields (see Figure 3). Compaction status predicted by SQAPP is clearly biased, classifying most soils at a moderate compaction status.

The correlation between measured values of the packing density (see Jones et al., 2003) and estimated values based on SQAPP is very low (r=0.18) and not significant ($\alpha$=0.05). The agreement on soil compaction classification (21 fields out of 41) is due to chance.

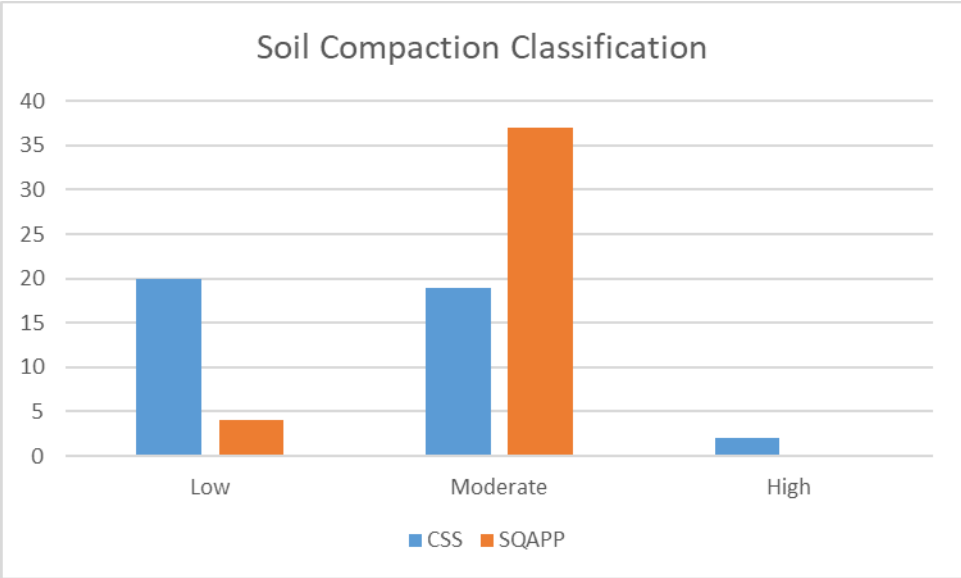


Figure 3. Soil compaction classification, measured (CSS) and predicted by SQAPP. (**y- axis: number of fields**)

*Salinization*

Data of 10 CSSs, corresponding to 36 fields were used. Agreement between SQAPP and measured values on the classification of the level of threat regarding soil salinization occurred at 33 fields (see Figure 4). Still, the correlation between measured values of the electric conductivity (dS/m) and estimated values based on SQAPP is very low (r=-0.17) and not significant (α=0.05). The agreement on the classification (33 fields out of 36) is due to chance.

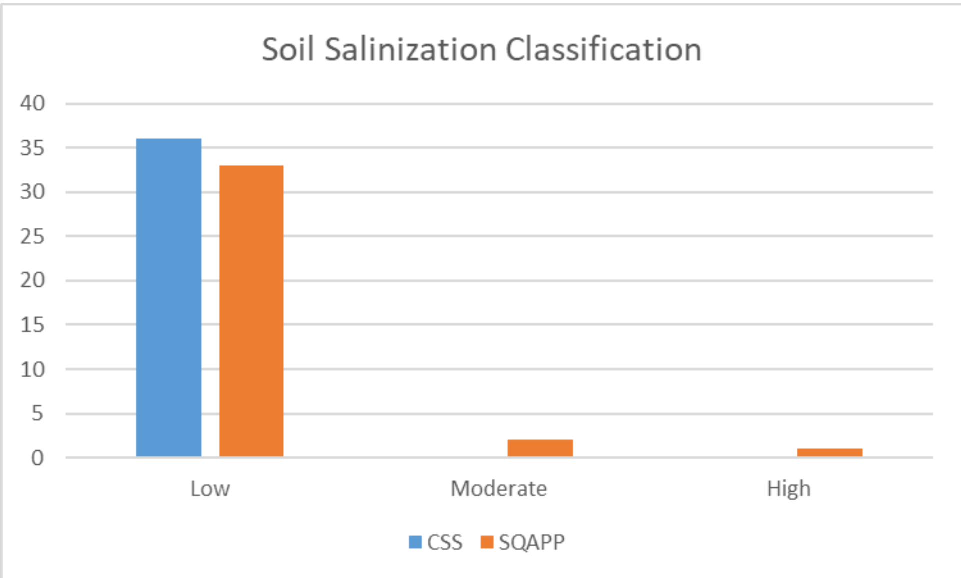


Figure 4. Soil salinization classification, measured (CSS) and predicted by SQAPP. (**y- axis: number of fields**)

*SOM stock*

Agreement on the classification of SOM content level (posed threat) between SQAPP and measured SOM content occurred for only 19 out of 45 fields (12 CSS), see Figure 5. The high

correlation between observed and measured SOM, r=0.71 for N=45 (a higher correlation than previously found, resulting from the inclusion of the values from Estonia and France), indicates that the classification results are not due to chance but to the low agreement between measured and estimated values, narrow range of the thresholds (for a comparably high standard error of the estimate=1.98%).

When the values of SOM are used with BD to calculate the SOM stock to a defined depth (0.2 m), the correlation between SOM stock with SQAPP estimated values and measured values is even higher, r=0.75 for N=41 (Figure 6).

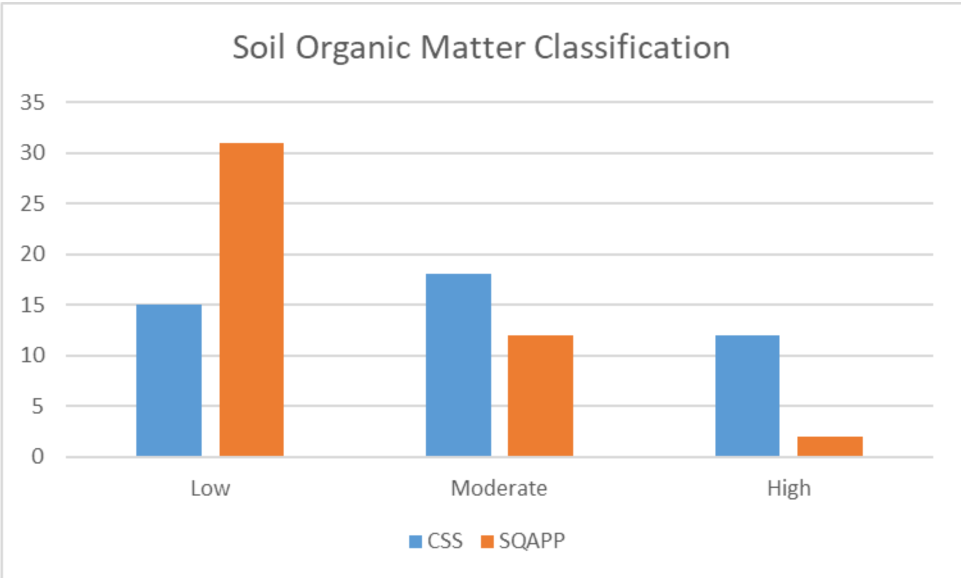



Figure 5. Soil Organic Matter classification (threat posed), measured (CSS) and predicted by SQAPP.

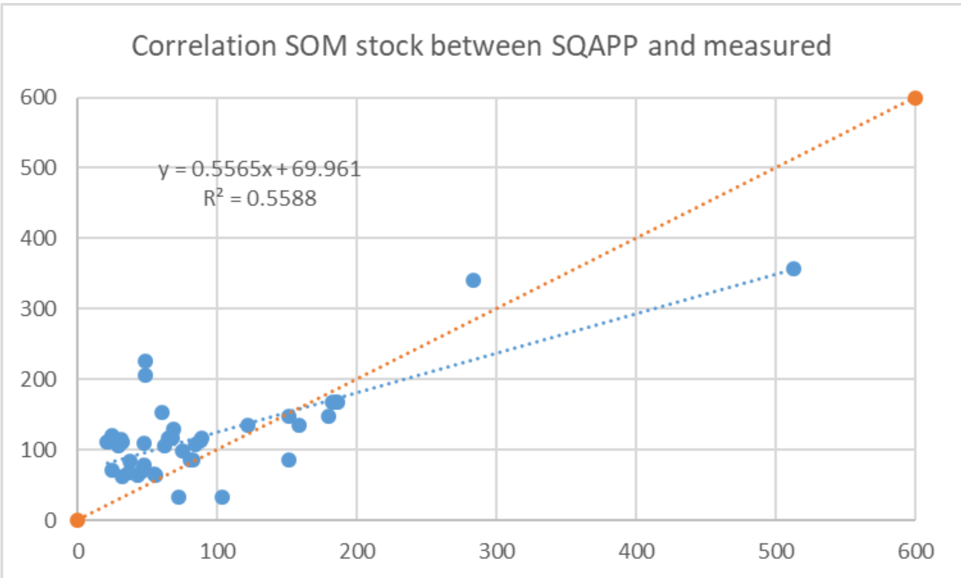



Figure 6. Correlation of Soil Organic Matter stock, to 0.2 m depth, between measured (CSS) and estimated using SQAPP values (x and y axis: Mg OM/ha). Blue: regression line. Orange: equality line.

*Biodiversity*

The soil biodiversity index was only calculated for 15 fields from 4 CSSs, due to lack of data in SQAPP or not, or only partially, provided by the CSSs. Agreement on the classification by SQAPP and measured was observed for 13 out of 15 fields (see Figure 7). Although the correlation is high, r=0.73 and N=15, statistically significant for α=0.01, agreement between estimated and measured values are low (Figure 8).

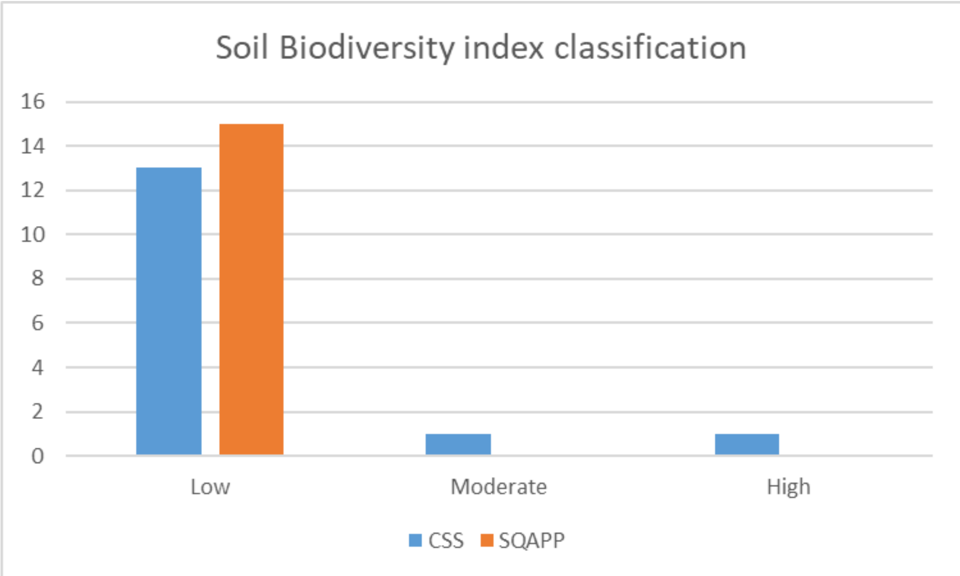



Figure 7. Soil biodiversity index classification (threat posed), measured (CSS) and predicted by SQAPP (**y- axis: number of fields**).

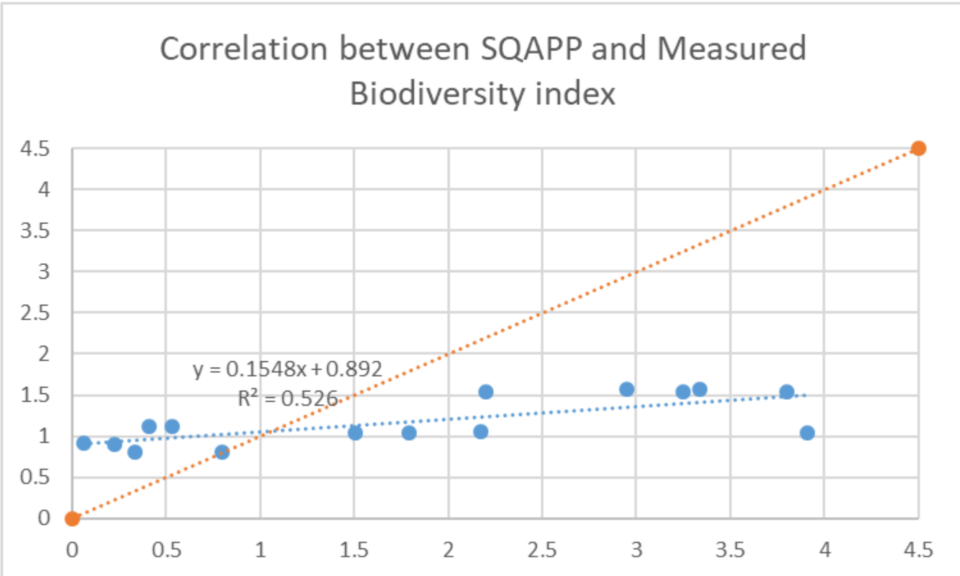



Figure 8. Correlation of biodiversity index, between measured (CSS) and estimated using SQAPP values. Blue: regression line. Orange: equality line.

When considered separately, microorganism C and macrofauna show distinct results. Microorganism C ($g/m^2$) estimated by SQAPP correlates well with measured values, r=0.60 for N=23 (7 CSSs) and is statistically significant for α=0.01. When Estonian values (4 fields) are

added, the correlation decreases to r=0.35 resulting in not statistically significant. Regardless of including or not Estonian values, agreement between estimated and measured values are very low.

Estimated (SQAPP) and measured (CSSs) macrofauna values, have a very weak correlation: r=0.08 for N=23 (6 CSSs).

*Acidification*

The agreement in the classification of the pH between SQAPP estimates and measured was 20 out of 45 fields (12 CSSs) (Figure 9). Although the moderate correlation coefficient, r=0.56 for N=45 (12 CSSs) and a statistically significance for α=0.01, the high standard error of the estimate (0.64) means that an estimate produced by SQAPP of a close to neutral pH soil may fall in any classification group (low, moderate or high threat).

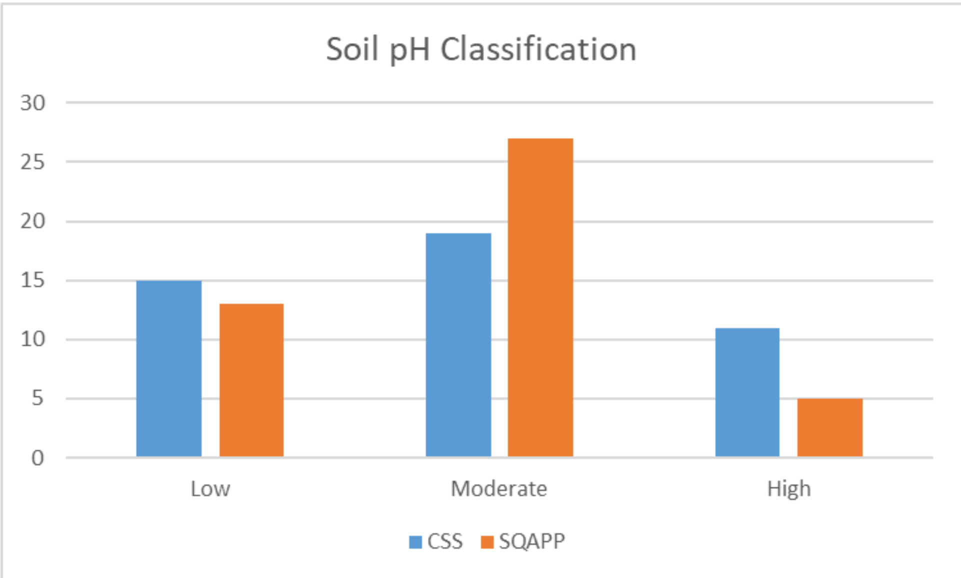



Figure 9. pH classification (threat posed), measured (CSS) and predicted by SQAPP (**y- axis: number of fields**).

*Nutrient Status*

The comparison between the classification of the soil status regarding N total, P available (Olsen) and exchangeable K, by SQAPP and measured by the CSSs show that they agreed respectively: 12 times out of 45 (N total), 6 out of 25 (P avail.) and 12 out of 45 (exc. K). The classification agreements are due to chance because the correlations are too weak for N total and exc. K, respectively r=-0.07 and r=-0.13. For available P, despite the moderate negative correlation, r=-0.54 for N=25 (8 CSSs) and statistically significant for α=0.01, the agreement is very low, with the interval of the estimates between 2.65 and 5.48 (mg/kg soil) and the measured values ranging from 2.4 and 583 (mg/kg soil) (Figure 10).

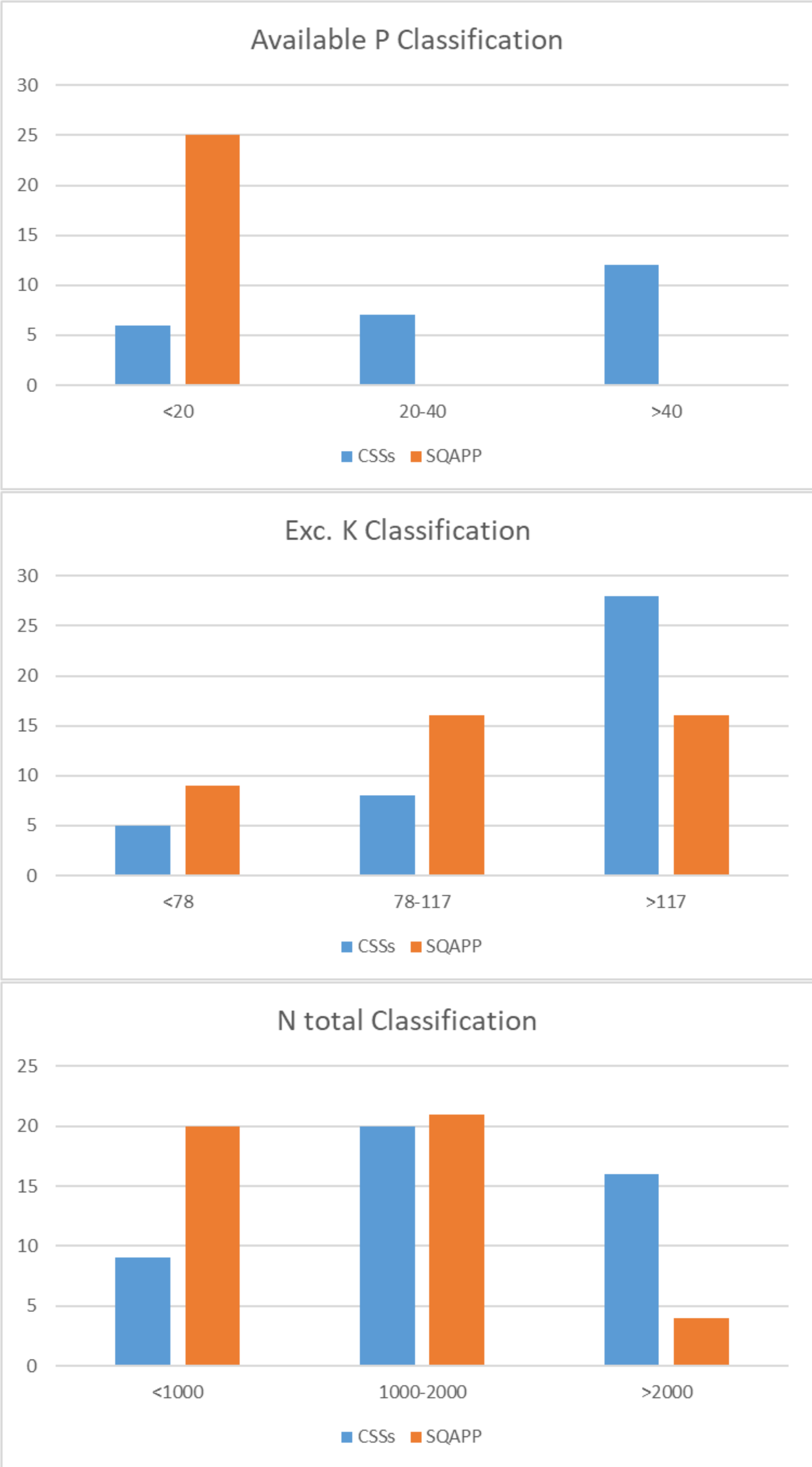



Figure 10. Nutrient status classification, measured (CSS) and predicted by SQAPP. Top, available P (Olsen) in mg/kg of soil; Middle, exc. K in mg/kg of soil; and Bottom, N total in mg/kg of soil (**y- axis: number of fields**).

*Contamination*

France, Portugal, Greece, Romania and the Chinese partners provided results from heavy metal soil analysis.

Only the Chinese partners (3 CSSs and 8 fields) provided the results for Arsenic (As), and only at one location (CSS 11, field 11.4 AMP) the results were moderate, all others were low. As said previously there is no SQAPP estimates for the Chinese partners regarding As, and all estimated values are low for the European partners. For all other heavy metals, the analysis at the Chinese partners show a low level threat.

No partners provided results for Mercury (Hg), with the exception of the Chinese partners CSS 11 and 12 (all results show a low level of threat).

At the Figure below, cadmium (Cd) poses a threat in Portugal (CSS 3, field 7 control) and Greece (CSS 5, fields 9 AMP and control). Chromium (Cr) poses a threat at CSS 5, fields 12 AMP and control. Copper (Cu) poses a threat at CSS 3, at fields 2 AMP and 7 control, and at CSS 5, field 12 AMP. Nickel (Ni) poses a threat at CSS 5, fields 12 AMP and control.

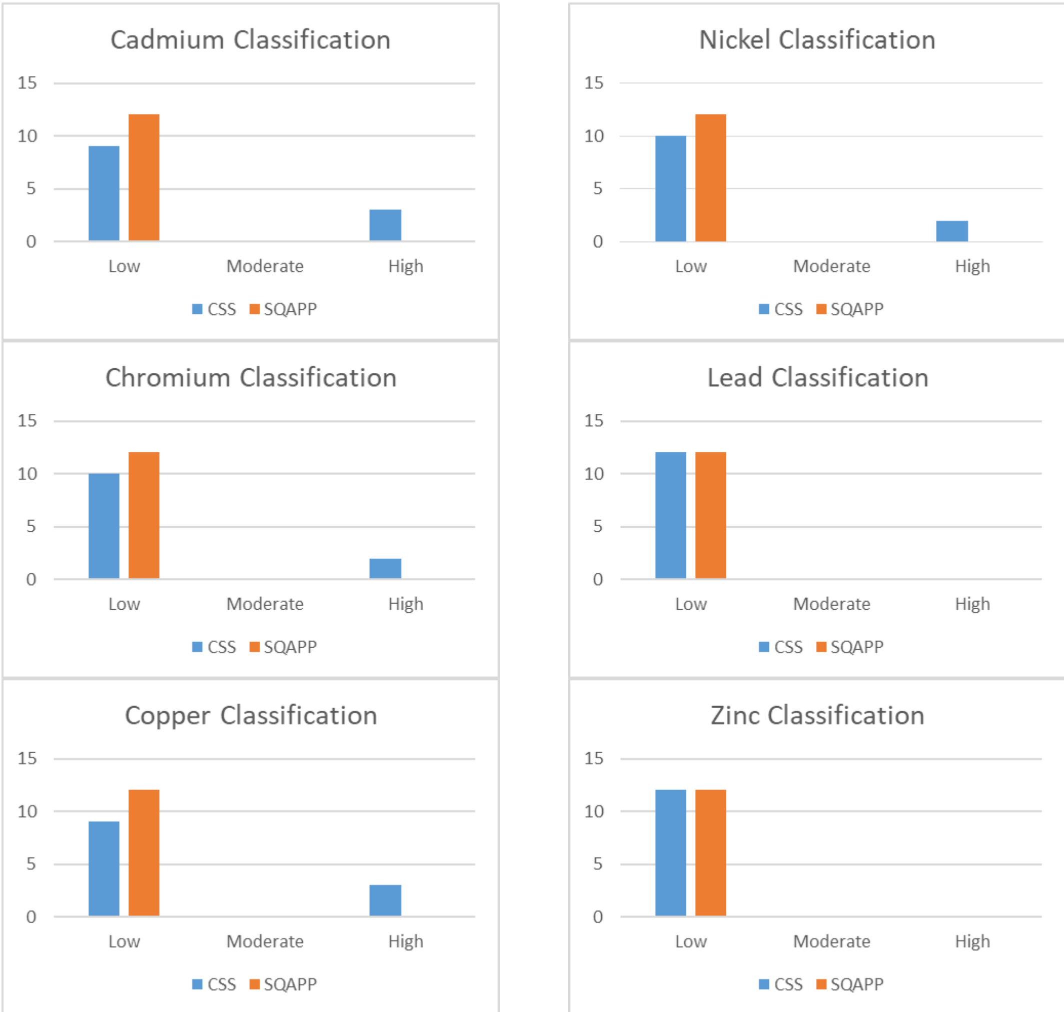



Figure 11. Soil's heavy metals threat classification, measured (CSS) and predicted by SQAPP (**y- axis: number of fields**).

Correlation between estimated SQAPP values for heavy metal concentration and measured by the CSSs were all negative, with the exception of Cu, and were all weak or moderate (Cr, Ni, Pb and Zn). Only Zn showed a significant correlation (Table 2).

Table 2. Correlations between measured (CSS) and predicted (SQAPP) soil heavy metals concentration.

| | Cd | Cr | Cu | Ni | Pb | Zn |
|---|---|---|---|---|---|---|
| Pearson Coef. | -0,15 | -0,47 | 0,17 | -0,56 | -0,50 | -0,61 |
| N | 12 | 12 | 12 | 12 | 12 | 12 |
| Statistical signif. (level) | ns | ns | ns | ns | ns | **0.05** |

*Soil Quality Index based on SQAPP estimates*

Of the 8 soil threats considered in the frame of iSQAPER, the data available from SQAPP and provided by the CSSs only allowed to study 8 soil threats at 8 fields, 7 soil threats at 29 fields and 6 soil threats at 4 fields (CSS 1, Netherland, was not included as it would only allow to calculate 2 soil threats). The classification of the soil threats at the appropriate class (Low, Moderate, High) from SQAPP estimates was successful for circa 53% of cases. Where SQAPP failed to classify a threat level at the adequate class, in 21% of cases the error involved the wrong classification of a low level as high and vice versa (or, putting in another way, 10% of soil threats will be gross errors). The adequate classification of soil threats using SQAPP estimates, for each soil and expressed as a percentage of the total number of soil threats assessed, ranged from 14 to 83% of soil threats.

Calculating a simple soil quality index, based on the attribution of a value for each level of soil threat (Low= 1, Moderate= 0.5 and High= 0), their sum and division by the number of soil threats, we observe that on average the soil quality index is circa 0.75: using measured values, the soil quality index is a little higher: 0.77; SQAPP estimates: 0.76. This finding will be furthered discussed in the next section.

## Discussion and Improvement Suggestions

### Soil Threats

1. The use of the soil properties texture and OM estimated by SQAPP to calculate soil erosion (RUSLE, Wischmeier and Smith, 1978), and allowing the input by the end user of parameters for landscape features, land use, management and soil structure, will allow to calculate reliably soil erosion (a correlation coefficient r=0.98 between erosion calculated using texture and SQAPP estimates of SOM and user inputs, and measured + user inputs), and thus be a tool to soil quality improvement monitoring and/ or forecast based on land use and/or management change, even taking into account the uncertainty on the correctness of texture and SOM values estimated by SQAPP.

2. The values estimated by SQAPP for BD have a negative correlation with measured BD at the CSS's fields, for the same locations (Teixeira and Basch, 2019). Improving the predictability of BD values in SQAPP may be possible but not without a substantial effort, e.g. by the use of multi-regression models, based on the soil taxonomic classification and properties (SOC, clay, water content at a specific water potential) as showed by Manrique and Jones (1991).

3. Microorganism C, show a significant correlation between estimated and measured values (if we exclude Estonian values), but a very low agreement: measured interval [64, 924] and estimated interval [47, 150]. One approach we have tested to improve agreement was to indirectly assess microorganism C by studying the correlation between measured OM and

microorganism C, r=0.78 for N=29 (without Estonian values) and statistically significant for α=0.01 (Figure 12).

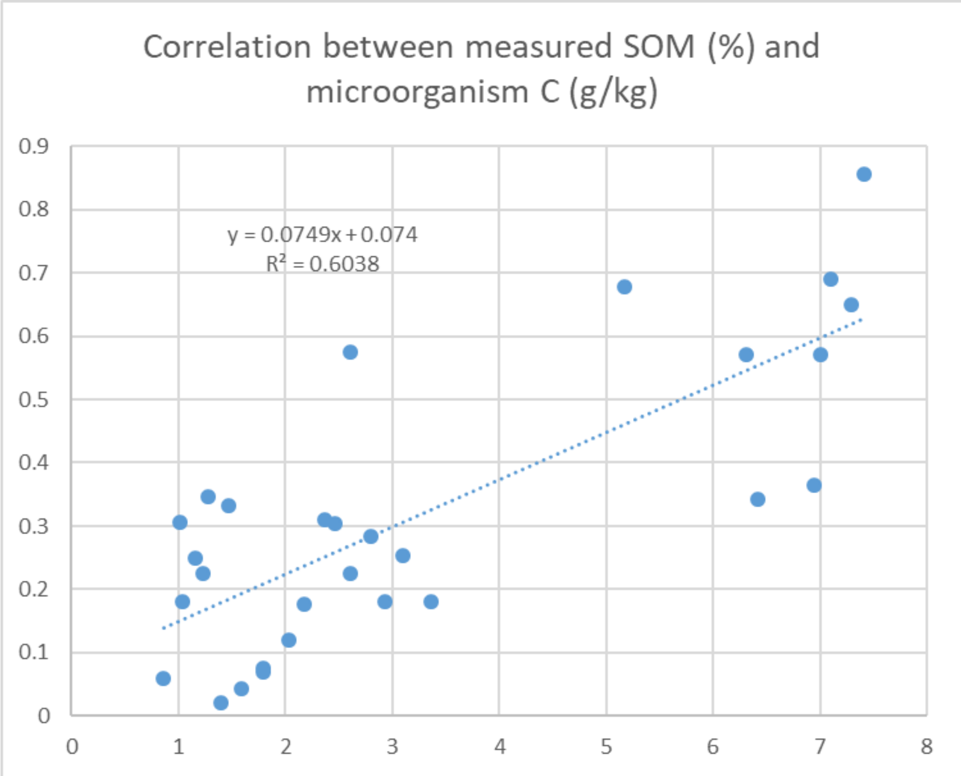
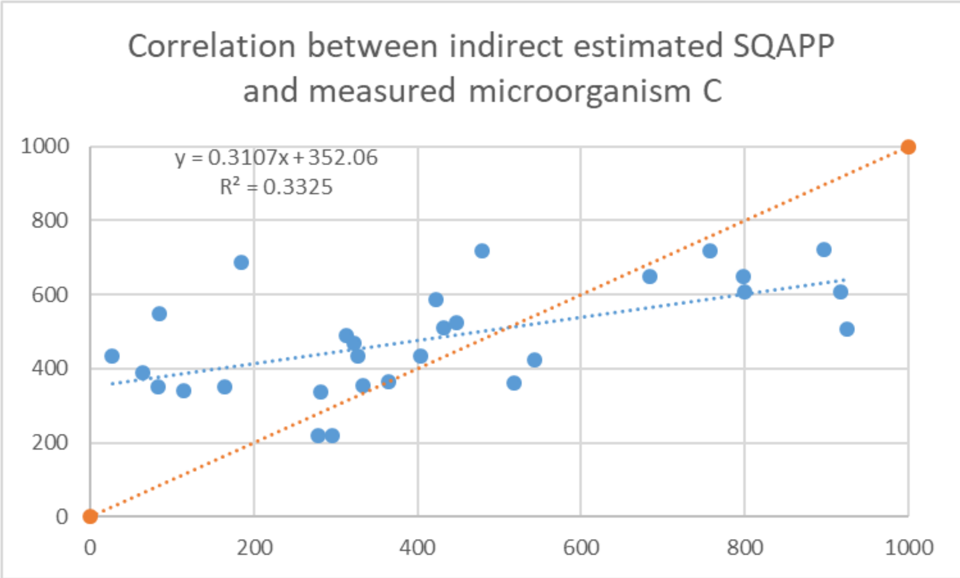


Figure 12. Correlation between measured (CSS) SOM (%) and microorganism C (g/kg) values (**x –axis: SOM %; y-axis: microorganisms' C (g/kg**)).

We used this model to calculate microorganisms' C (g/kg) from the estimated SOM values provided by SQAPP and, with the estimated value of BD from SQAPP, to calculate the microorganisms' C per $m^2$. The correlation between modelled and measured microorganism C (g per $m^2$) has a r=0.58 for N=29 and it is statistically significant for α=0.01. This correlation coefficient is a little lower than the correlation coefficient between directly estimated SQAPP value and measured, r=0.60 for N=23 (statistically significant for α=0.01), but the agreement between estimated and measured values is much higher: measured interval [64, 924] and estimated interval [219, 719] (Figure 13).



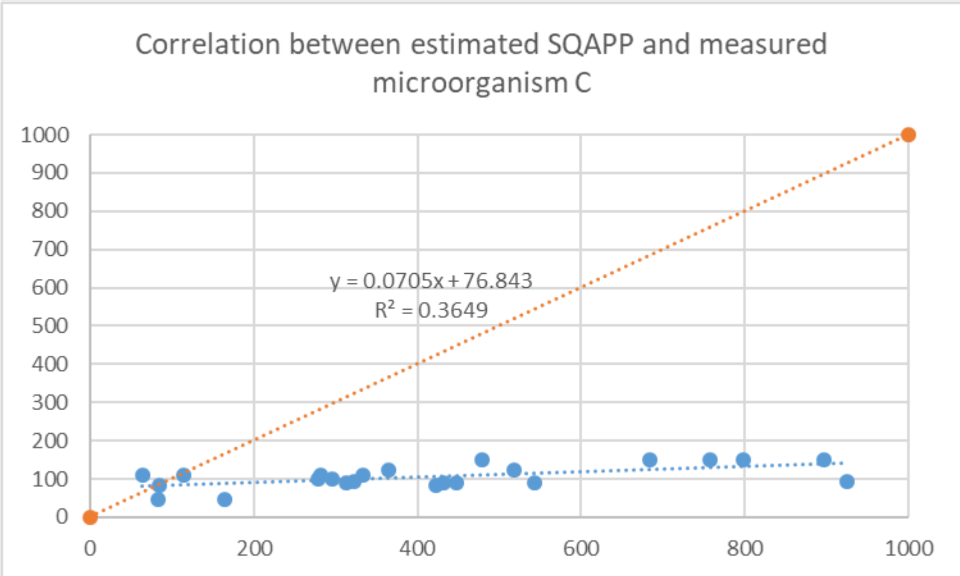




Figure 13. Top: Correlation between measured (CSS, **x-axis**) and modelled (SOM and BD) SQAPP microorganism C (g/m$^2$); Bottom: Correlation between measured (CSS, **x-axis**) and SQAPP microorganism C (g/m$^2$). Blue: regression line. Orange: equality line.

The very low values from Estonia may be the result of procedure/ calculation error, or the result of the climate over the soil microorganism population (reference needed).

4. Of the 3 nutrients considered to assess the soil nutrient status only N total can be indirectly assessed by other soil properties (SOM). Correlations between soil total P and available P are very weak and the same is true between P concentrations in the parent materials of the soil and available P; and C : P organic ratios in SOM vary too much for being of any use. K is released to the soil solution by plant material decomposition and it is not a SOM constitute.

We studied the correlation between SOM and N total measured by the CSSs, and found a very strong correlation, r=0.98 for N=45 (12 CSSs) and statistically significant for α=0.001 (Figure 14). The model was then used to calculate the N total using SOM values estimated by SQAPP. The correlation between modelled N total (SQAPP) and measured N total (CSSs) is r=0.69 for N=45 (12 CSSs) and statistically significant for α=0.001. This correlation is a little bit lower than

the correlation between the estimate of SOM by SQAPP and measured SOM by the CSSs (r=0.71), but it is much better and would estimate N total more accurately than the current approach.

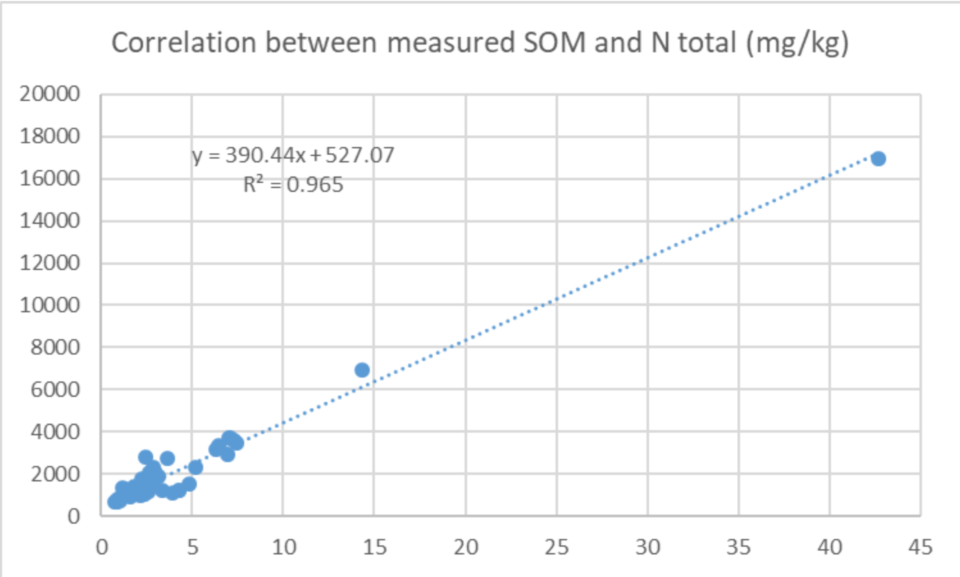



Figure 14. Correlation between measured (CSS) SOM (%) and N total (mg/kg) values (**x –axis: SOM %; y-axis: N total (mg/kg)**).

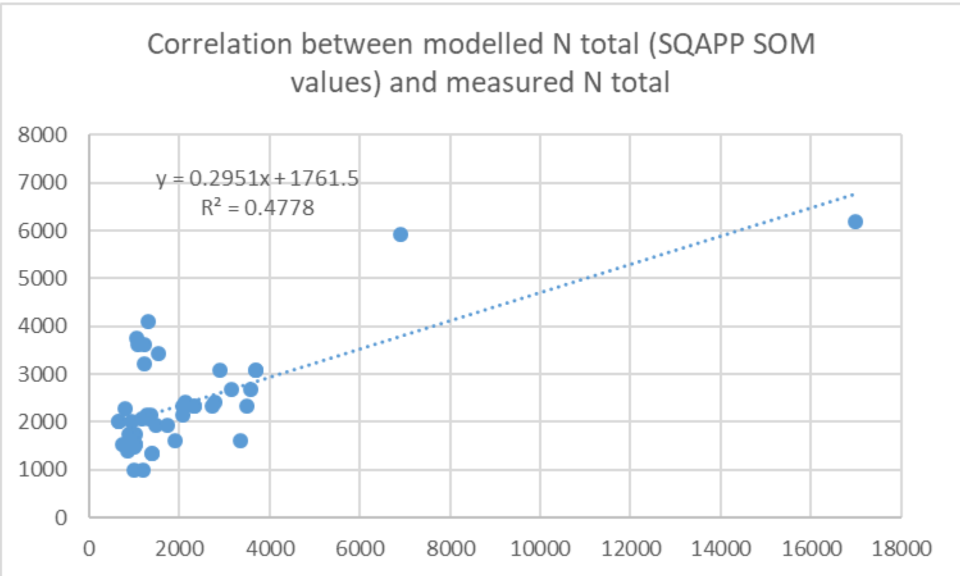



Figure 15. Correlation between modelled N total (mg/kg) (SQAPP SOM values) and measured N total values (CSSs, **x-axis**) (mg/kg).

### Soil Quality Index and Recommendation System

The convergence between measured and estimated values of an aggregated soil quality index based on class levels, a value circa 0.75 (or 75%) on average, conceals the fact that measured and estimated indexes of individual soils can be quite disparate, and that the threat levels contributing to express the overall index probably will not coincide. A recommendation system

based on threat levels classes will lead to gross mistakes (classifying low as high and vice versa) in circa 10% of the threats.

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# Annex 1. Selected 24 pairs AMP-Control, CSS, climatic region and georeferenced coordinates.

| CSS | CLIMATIC REGION | PLOT Nº | GEOREFERENCED coordinates | | FARMING SYSTEM | FARMING SYSTEM DETAIL | SOIL TYPE | AMP Nº |
|---|---|---|---|---|---|---|---|---|
| The Netherlands | Atlantic | 1.1 | 51,53948° N | 5,848589° E | Irrigated land with arable and vegetable crops | Potato-pea/grassclover-leek-springbarley-carrot-silage maize (both in AMP and control) | Podzol/ Anthrosols | 2 |
| | | Control | 51,539474° N | 5,848187° E | | | | |
| | | 1.3 | 51,543047° N | 5,849341° E | Irrigated land with arable and vegetable crops | Potato-pea/grassclover-leek-springbarley-carrot-silage maize (both in AMP and control) | Podzol/ Anthrosols | 12 |
| | | Control | 51,539442° N | 5,846824° E | | | | |
| France | Atlantic | 2-1 AMP b | 48,001360° N | 1,449080° E | Arable land | Maize/cereal rotation | Cambisol | 1; 9 |
| | | 2-1 Control | 48,070890° N | 1,109390° E | | | | |
| | | 2-3 AMP | 48,068970° N | 1,108080° E | Pasture intensive | Cows | Cambisol | |
| | | 2-3 Control a | 48,068390° N | 1,105920° E | | Cows | | |
| Portugal | Mediterranean temperate | 3.2 | 40,237883° N | 8,466333° W | Arable land | Maize | Fluvisols | 8 |
| | | Control | 40,220333° N | 8,48125° W | | | | |
| | | 3.7 | 40,422117° N | 8,485689° W | Permanent crops | Vineyards | Cambissols | 13 |
| | | Control | 40,422667° N | 8,485667° W | | | | |
| Spain | Mediterranean semi-arid | 4.5 | 38,164218° N | 0,712572° W | Permanent - fruit trees and berry plantations | Pomegranate | Regosol | 2; 3 |
| | | Control | 38,190709° N | 0,687498° W | | | | |
| | | 4.12 | 37,855917° N | 0,830250° W | Arable permanently irrigated | Pepper | Cambisol | 9; 7 |
| | | Control | 37,853980° N | 0,831980° W | | | | |
| Greece | Mediterranean temperate | 5.9 | 35,320803° N | 25,236560° E | Permanent crops | Olives | Regosol | 1 |
| | | Control | 35,321462° N | 25,236689° E | | | | |
| | | 5.12 | 35,295923° N | 24,907333° E | Pastures | A grazing system in which the main grazing vegetation is sowed (cereals and legumes) | Cambisol | 18 |
| | | Control | 35,296190° N | 24,907585° E | | A grazing system in which the main vegetation consists of schlerophyllous, olive trees and annual natural vegetation | | |
| Slovenia | Southern sub-continental | 6.9 | 46,093771° N | 14,495881° E | Non irrigated arable land | Organic farming with diverse rotation; manure | Cambisol | 9 |
| | | Control | 46,093537° N | 14,495542° E | | Only vegetable crops; compost | | |
| | | 6.12 | 46,124762° N | 14,495882° E | pastures | Grazing | Cambisol | 18 |
| | | Control | 46,124491° N | 14,497139° E | | Grass cutting | | |
| Hungary | Southern sub-continental | 7.1 | 46,788694° N | 17,489417° E | Permanent crops | Vineyards | Cambisols | 5; 8 |
| | | Control | 46,788611° N | 17,488778° E | | | | |
| | | 7.5 | 46,715722° N | 16,812917° E | Non irrigated arable land | Cereals; Maize; Oil crops | Luvisols | 2; 8; 9; 11 |
| | | Control | 46,703139° N | 16,817944° E | | | | |
| Romania | Northern sub-continental | 8.8 | 45,229629° N | 27,579469° E | Non irrigated arable land | Maize | Chernozems | 14 |
| | | Control | 45,197142° N | 27,580508° E | | | | |
| | | 8.11 | 45,284859° N | 27,850021° E | Pastures extensive | | Chernozems | 18 |
| | | Control | 45,304876° N | 27,835111° E | | | | |
| Poland | Northern sub-continental | 9.1 | 51,993824° N | 22,550696° E | Non irrigated arable land | Maize | Podzols | 7 |
| | | Control | 51,996773° N | 22,547874° E | | Cereals | | |
| | | 9.3 | 51,313861° N | 22,450944° E | Permanent crops | Hops | Cambisols | 12 |
| | | Control | 51,302610° N | 22,422940° E | | | | |
| Estonia | Boreal to sub-boreal | 10.12 | 58,99181° N | 24,871640° E | Grassland; conventional; intensive | Grassland for silage | Eutric Histosol | 18 |
| | | Control | 58,99232° N | 24,874360° E | Non irrigated arable land; conventional | Cereals | | |

| CSS | CLIMATIC REGION | PLOT Nº | GEOREFERENCED coordinates | | FARMING SYSTEM | FARMING SYSTEM DETAIL | SOIL TYPE | AMP Nº |
|---|---|---|---|---|---|---|---|---|
| | | 10.14 | 58,2844° N | 26,491210° E | Non irrigated arable land; conventional | | loamy sand Stagnic Luvisol | 2; 3; 5; 9 |
| | | Control | 58,2861° N | 26,493190° E | | | | 9 |
| China - Qiyang | Central Asia tropical | 11.4 | 26,761111° N | 111,865278° E | Permanent crops | | Acrisols | 6; 7a |
| | | Control | 26,758333° N | 111,871390° E | Permanent crops | | | |
| China - Suining | Central Asia tropical | 12.1 | 30,613067° N | 105,022033° E | Arable land | Maize-Wheat rotation | Plaggic Anthrosols (Eutric) | 8 |
| | | Control | 30,613067° N | 105,022033° E | | | | |
| China - Gongzhuling | Middle Temperate | 14.1 | 43,6125° N | 124,794440° E | Non irrigated arable land | | Phaeozems | 8 |
| | | Control | 43,6125° N | 124,794440° E | | | | |
| | | 14.4 | 45,258333° N | 124,896389° E | Irrigated arable land | | Chernozem | 8; 14 |
| | | Control | 45,262778° N | 124,875560° E | | | | |

Annex 2. Required information for soil quality assessment.

| Main Group | Group | Fields |
|---|---|---|
| General farm, plot and management information | General farm Information | • Plot location (CSS)<br>• Plot number (in iSQAPER)<br>• Researcher responsible for the collection/analysis<br>• Contact email<br>• Phone contact |
| | General plot information, land use and agricultural measures | • Plot centre coordinates<br>• Plot area [ha]<br>• Slope angle [%]<br>• Slope length [m]<br>• Do you expect heavy metal contamination in your plot?<br>• If yes, what is the source?<br>• If yes: Which heavy metal contamination (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) do you expect?<br>• Do you expect pesticide contamination in your plot?<br>• Is there an input of manure / slurry / sludge in your soils?<br>• If yes: is there any analysis of heavy metal content?<br>• If there's an input of manure/ slurry/ sludge: Please provide details concerning the type applied and the amount [kg ha-1].<br>• Is salinity or any other soil crust/hardpan inducing source a problem in your plots?<br>• If yes, please mention the source of soil salinity, and whether or not it induces a soil crust, and hardpans you may encounter in the profile.<br>• Do you use plastic mulch in your soils?<br>• If yes: Please describe the plastic mulch management.<br>• Number of stone walls in the plot.<br>• Number of grass margins / stripes in the plot.<br>• Is there any contour farming measure?<br>• If yes: please describe the contour farming measure.<br>• What is the importance of soil threats in your plot? (8 threats to be evaluated)<br>• What is the farming system?<br>**Arable Land:**<br>• Please indicate the main three crops / plants in your rotation.<br>• Please indicate more details of the actual or the normal crop rotation in your plot relevant for 2018.<br>• Tillage type.<br>• If your tillage practice is not in the list, please name it.<br>• Tillage frequency per year.<br>• Tillage depth [cm].<br>• Secondary soil tillage type.<br>• Secondary soil tillage frequency per year.<br>• Fate of plant residues for the cropping season of 2018. Type of plant residues.<br>• Amount left [t ha-1].<br>• Percentage of soil covered [%].<br>• Cover crops during winter?<br>• Cover crop (specie). If it's a mixture (species).<br>• Sowing date (dd-mm-yyyy)<br>• End date (date of the final intervention (cut, burried, etc))<br>• Percentage of soil covered [%]<br>• Approx. biomass left [t DM/ha]<br>**Non-arable system:**<br>• Details of the farming system: Plants species; management practices.<br>• Percentage of soil covered by crop canopy.<br>• Percentage of soil covered by other vegetation. |

| | | |
|---|---|---|
| Soil examinations, soil properties | Soil physical properties | • Is there anything particular about the soil at your testing site? If Yes: please mention them.<br>• Estimation of the stone content. Granules and pebbles (2-64 mm). Cobbles (64-256 mm). Boulders (>256 mm). Form of the stones. Content in [Vol.-%] >2mm.<br>• Soil texture. Sand [%] (2 - 0.1 mm). Fine Sand [%] (0.1 - 0.05 mm). Silt [%] (0.05-0.002 mm). Clay [%] (< 0.002 mm).<br>• Bulk density [t m-3].<br>• Soil Structure. |
| | Soil biological properties | • Microorganisms Carbon Content [g kg-1].<br>• Number of different co-occurring soil macro fauna groups. |
| | Soil chemical properties | • OM content [%].<br>• pH (CaCl2).<br>• Electrical conductivity [dS m-1].<br>• Total N (mg kg-1 of soil).<br>• Total P (mg kg-1 of soil).<br>• Extractable P (mg kg-1 of soil).<br>• Extractable K (mg kg-1 of soil).<br>• Heavy Metals (mg kg-1 of soil): As, Cd, Cr, Cu, Hg, Ni, Pb, Zn. |

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

| 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 | |