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INTERCROP VALUES

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D3.1 Prototype of Soil health check cards

Document Summary

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Author(s)	Paul Hargreaves (SRUC) and Marie Sauvadet (CIRAD)
Contributor(s)	Alexis Thoumazeau (CIRAD)

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Abstract

As part of the IntercropVALUES project there was a need to assess the contribution that intercropping could have on the health of the soil. Soil health is crucial to the sustainability of any cropping system and should be complimentary to the proposed EU soil protection and restoration strategy.

Soil health consists of three main areas: soil chemistry, soil physics and soil biology. It is important that these three areas are represented in any assessment or monitoring of soil health. It was crucial that any soil monitoring combined these three areas, and any monitoring was based on established methodology that had been seen to provide robust data across different soil types without developing a whole new set of criteria.

The Prototype of Soil health check cards was designed to be scientifically-based and also usable by agricultural advisors and farmers, under the format of an excel file with automated cell coloring indicating whether the level entered corresponds to soil is Good, Moderate or Poor health. The scorecard system was adapted to cover the three areas of soil health using an outline from the UK AHDB GreatSoils method but including the Biofunctool® (a soil management framework assessment tool). Bringing these two different methodologies together gave a prototype scorecard covering 3 indicators for soil physics [water infiltration, Visual Evaluation of Soil Structure (VESS) and bulk density], 4 indicators for soil biology [earthworms, macrofauna, soil organic matter and active carbon (POCX)] and 4 indicators for soil chemistry (inorganic N, available phosphorus, available potassium and soil pH).

As a proof of concept of the soil health prototype, the soil biology and soil physics parameters have been tested on data from the WP2 experimental sites in Germany, Greece, Scotland, Serbia, Sweden, Switzerland and Zimbabwe. These sites compared cereal and legume sole crops with cereal-legume intercropping, at the sowing of the crops (as a baseline) and then again at harvest of the crop/intercrops. These assessments will continue into the second year of crop production. Data status at the date of the deliverable 3.1. deadline allowed to test the prototype on physical indicators and on macrofauna abundance. The completeness of the results will be available by the end of the project, such as the soil chemistry, and will be included in the final report.

The prototype was built accordingly to the results available from experimental sites of WP2, and is ready for VESS notation, infiltration rates and macrofauna abundance. These indicators show interesting comparisons between sites indicating the relevance of the soil heath prototype, but more detailed analyses will need to be implemented to compare intercropping impacts on these short-term trials. These aspects will be discussed at the 3rd year annual meeting in September 2025. Data from the farmers’ intercropping fields in the CICS have been discussed and interest expressed for soil health scorecards to be produced for them. The prototype will be improved and will be diffusible at the end of the project.

01

1. The project in numbers

The focus on soils has moved over the last twenty years from being mainly on the chemistry of the soil to the broader concept of soil health. Soil health is a more holistic approach focusing not only on the soil chemistry but also on the soil physics and biology. Soil health is being outlined in a new strategy proposed by the EU Soil Strategy which aims to ensure by 2050 all European Union (EU) soil ecosystems are in healthy condition and are thus more resilient, and to aim for 75% of the soils of the EU to be healthy or improving by 2030.

Measures or indices of the soil health should include assessments of physics, chemistry and biology and be able to provide indicative levels of whether the soil is Good, Moderate or Poor. Several methods have been suggested to determine soil health, and these have been considered in the measure of soil health in the current project using intercropping systems (combining cereal and leguminous crops) compared to sole crops. There should be advantages in sustaining or improving the soil health for the growing of more than one crop in a field concurrently. For example, the leguminous crops should provide a complimentary rooting structure to sustain the soil structure and to provide additional nitrogen (N) for the cereal crops to utilise.
Two of these soil health monitoring methods that have already been widely employed are the AHDB GreatSoils scorecard and the Biofunctool® (for land management framework assessment). We have focused on existing methodologies to reduce the amount of work in replicating methods also making use of indicators that have already been tested.
The AHDB GreatSoils scorecard was developed in the UK to assess the soil quality of agricultural soils across a number of different soil types. It is important that the soil type be considered as not all soils respond in the same way to management, with a light, sandy soil having different properties than heavier, clay soils. The crops grown also need to be considered as there will be different values in the soil health criteria employed for different crops, i.e. grassland should have a greater number of earthworms than arable crops as a result of less disturbance in grassland from ploughing and greater soil organic matter as a food source. This needs to be reflected in the assessment and contribution to Good, Moderate and Poor soil health. These considerations were part of the development of the AHDB soil scorecard (https://ahdb.org.uk/knowledge-library/the-soil-health-scorecard).

The Biofunctool® is a method of assessing the impact of land management on soil quality and considers the carbon transformation, nutrient cycling and structure maintenance. The Biofunctool® provides a set of in-field low-tech but meaningful indicators that assess soil functioning by reflecting the relationships between soil physico-chemical properties and soil biology. Again, it is important that sufficient data can be accumulated to assess the health of a soil without being too labour intensive, time consuming or expensive. It was felt that a combination of indices that had been tested through the AHDB soil scorecard and the Biofunctool® provided this. Additionally, by combining the 'traffic light' system of red for Poor, amber for Moderate and green for Good provided a useful visual indication of the health of the soil.

The soil heath check cards prototype was designed to be both scientifically-based and understandable and usable by agricultural advisors and farmers (farmer friendly)**.**

The results collected from the experimental plots across a number of countries as part of the IntercropVALUES project provided a useable database to test the relevance and utility of the soil health indicators for the prototype soil health scorecard (strong links with WP2, meta-experiment). The indicators used for the prototype scorecard were 3 indicators for soil physics [water infiltration, Visual Evaluation of Soil Structure (VESS) and bulk density], 4 indicators for soil biology [earthworms, macrofauna, soil organic matter and active carbon (PXOC)] and 4 indicators for soil chemistry (inorganic N, available phosphorus, available potassium and soil pH). The countries considered were Germany, Greece, Scotland, Serbia, Sweden, Switzerland and Zimbabwe.

The soils from the IntercropVALUES experiments were assessed at the sowing of the crops (as a baseline) and then again at harvest of the crops (assessment of the cropping effect). These assessments will continue into the second year of crop production. The cropping systems combining the two crops (legumes and cereals) were compared with sole crops (control) to assess any advantages to soil health of the intercropping.

Further validation of the prototype scorecard will be done for farmers who have shown an interest in the scorecard for farms in France and Poland (strong links with WP1 and CICS).

1.1 Human resources

The soil health component of the IntercropVALUES project has utilised the data being collected as part of the greenhouse gas assessments from intercrops being grown across six countries (Germany, Scotland, Serbia, Sweden, Switzerland and Zimbabwe) and at two time points – sowing of the experimental plots and harvest. This will continue into year two of the growing of the crops.
The methods for assessing soil health have been combined in the general handbook of the soil and plant assessment produced for the IntercropVALUES project, allowing all those interested in comparing the methods suggested and commenting on the usefulness in relation to the data collected and time and cost of providing the data.

1.1.1 Coordination team

Scientific group
The data for the assessment of the prototype soil scorecard have been provided by the individual teams associated with the current IntercropVALUES greenhouse gas experimental work across five countries (Germany, UK, Serbia, Sweden and Zimbabwe) using the methods out-lined in the program handbook.
Overall, the data are being collated by Paul Hargreaves (SRUC, Scotland, UK) and Marie Sauvadet (CIRAD, France). These are the coordinators of the soil health component for the IntercropVALUES project.

02

2. Prototype elaboration

Soils provide key ecosystem functions, enabling essential provisioning, regulating, cultural and supporting services (e.g., Adhikari and Hartemink, 2016). There are many different definitions of soil health but here we use the common definition based on the ability of soil to function (Karlen et al., 1997) and provide ecosystem services.

Soil health status depends on the interactions of physical, chemical and biological properties, which are strongly impacted by agricultural practices. There is increasing interest in developing integrative soil health frameworks based on functional evaluation and considering the links between physicochemical properties and the biological activity of soils. Soil health is being outlined in a new strategy proposed by the EU Soil Strategy. It aims to ensure that 75% of the soils of the European Union (EU) to be healthy or improving by 2030, and that all EU soil ecosystems are in healthy condition and thus more resilient by 2050.

As part of the IntercropVALUES project there was a need to assess the impacts of intercropping on soil health. Soil health is crucial to the sustainability of any cropping system and should be complimentary to the proposed EU soil protection and restoration strategy. Many indicators of soil health have been proposed in recent years, but in order to evaluate the impact of intercropping on soil function it is important to understand which of these indicators respond to this practice.

2.1 Soil health assessment needs in IntercropVALUES

2.1.1 Actions within the project

The assessment of intercropping impacts on soil health is involved in two WPs:

(i) **First testing of the soil Health check cards prototype in the two-year experiments from WP2, Task 2.3.** These sites compare cereal and legume sole crops with cereal-intercropping treatments, with 3 major sampling dates: at sowing of year 1, harvest of year 1 and harvest of year 2. Major soil and crop properties are analysed at each sampling dates; the description of the treatments tested, and indicators measured – including soil health indicators – are described in the deliverable D2.1. "Common protocols for on-farm and on-station field experiments". The controlled experimental conditions and high characterization of cultural practices and environmental conditions provide a good framework for a first test of the soil Health card prototype.

(ii) Application and validation of the prototype in the Co-Innovation Case Studies (CICS) from WP1. These sites are selected in farmers' conditions, who manifested a specific interest in soil health.

2.1.2 WP2 sites and CICS constrains for soil health assessment

Soil health assessment within the IntercropVALUES project faces important challenges, which guided the building of the prototype:

- Widely contrasted pedoclimatic contexts;
- Assessment on short-term differentiation of cultural practices: few months to 1 year;
- Coordinating soil health assessment with the other sampling and measurement activities planned in the other WPs.

Concerning the last point, soil health indicators measurement strategy was built in accordance with the other analyses planned in T2.3., and measurement protocols of the indicators were included in deliverable D2.1. "Common protocols for on-farm and on-station field experiments".

2.2 Selection of Soil Health indicators for the prototype

2.2.1 Biofunctool and AHDB Health cards

The soil health check cards prototype was developed from two recently developed tools that are farmer friendly and use low-cost field indicators to evaluate three main soil functions, namely, carbon transformation, nutrient cycling and structure maintenance: the Biofunctool® (Thoumazeau et al., 2019) and the AHDB Soil Health Scorecard (Stockdale et al., 2018; https://ahdb.org.uk/knowledge-library/testing-the-soil-health-scorecard). It is important that if methodologies already exist these be employed in order to reduce the amount of work in replicating methods that currently exist and using the most useful of these indicators that have already been tested.

The AHDB GreatSoils scorecard was developed in the UK to assess the soil quality of agricultural soils across a number of different soil types. It is important that the soil type be considered as not all soils respond the same to management, with a light, sandy soil having different properties than heavier, clay soils. The crops grown also need to be considered as there will be different values in the soil health criteria employed for different crops, i.e. grassland should have a greater number of earthworms than arable crops as a result of less disturbance in grassland from ploughing and greater soil organic matter as a food source, and this should be reflected in the assessment and contribution to Good, Moderate and Poor soil health. These considerations were part of the development of the AHDB soil scorecard (https://ahdb.org.uk/knowledge-library/the-soil-health-scorecard).

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Again, it is important that sufficient data can be accumulated to assess the health of a soil without being too labor intensive, time consuming or expensive. It was felt that a combination of indices that had been tested through the AHDB soil scorecard and the Biofunctool® provided this. Additionally, by combining the 'traffic light' system of red for Poor, amber for Moderate and green for Good provided a useful visual indication of the health of the soil.

2.2.2 First prototype for soil health assessment in WP2 sites

The different exchanges for WP2 and CICS requirement and constrains during the Kick-Off meeting in 2022 and the following workshops, in addition to internal expertise, allowed to select a range of indicators covering the physical, chemical and biological components of soil health (Table 1).

Table 1: Prototype scorecard showing the indicators for soil physics, biology and chemistry.

	Indicator	Approach	Protocol references
Physical indicators	Infiltration rate	On field	Thoumazeau, et al. (2019). https://doi.org/10.1016/j.ecolind.2018.09.023
	VESS notation	On field	AHDB - How to assess soil structure: https://ahdb.org.uk/knowledge-library/how-to-assess-soil-structure
	Bulk density	On field	ISO 11272:2017 https://www.iso.org/standard/68255.html
Biological indicators	Earthworm abundance	On field	AHDB Great Soils earthworms https://ahdb.org.uk/knowledge-library/soil-macrofauna-earthworms.
	Other macrofauna abundance	On field	Anderson, J.M., Ingram, J.S.I., 1994. Tropical Soil Biology and Fertility: A Handbook of Methods. Soil Science 157, 265.
	Permanganate-oxidizable carbon (POXC)	Laboratory	Culman, S.W. et al. (2012). https://doi.org/10.2136/sssaj2011.0286

	Soil organic C	Laboratory	ISO 10694:1995 https://www.iso.org/standard/18782.html
Chemical indicators	Available N	Laboratory	ISO 14256-2:2005 https://www.iso.org/standard/32399.html
	Available P	Laboratory	Olsen, S.R. (1954). https://archive.org/details/estimationofavai939olse/page/n1/mode/2up
	Available K	Laboratory	Potash Development Association (2011). https://www.pda.org.uk/pda_leaflets/24-soil-analysis-key-to-nutrient-management-planning/
	Soil pH (H_2O)	Laboratory	ISO 10390:2021. https://www.iso.org/standard/75243.html

The assessment of these indicators followed a dual approach, i.e. physical indicators and macrofauna abundances being measured directly on-site, while the other biological and chemical indicators being measured in the laboratory, from auger sampling common to the WP2 sites for other indicators (Figure 1).

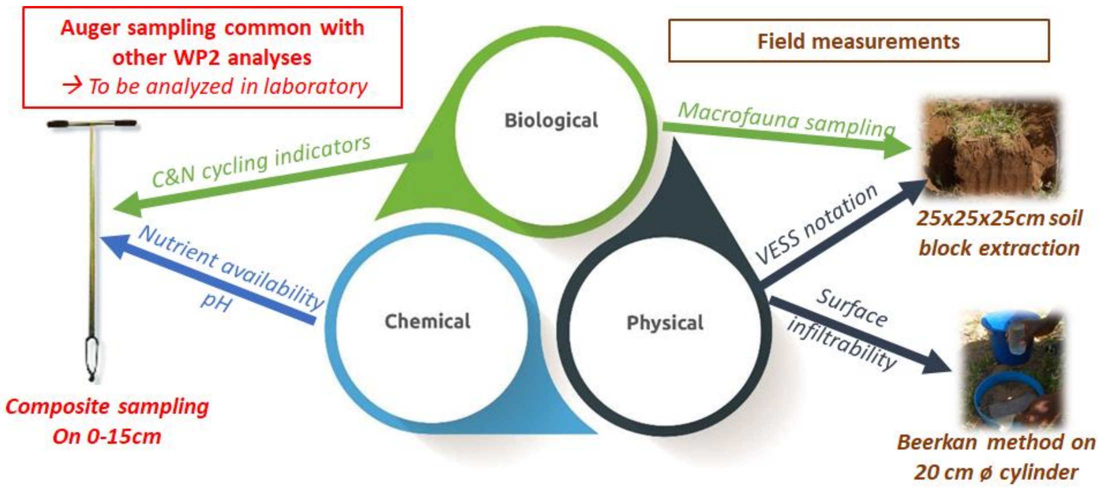

Figure 1: Soil health cards indicators analysis strategy

This dual analytical strategy allows a faster availability of data from the field indicators – Soil infiltrability, VESS score and macrofauna abundance – while the other indicators are dependent on the analytic data from laboratories and were not received by the date of this Deliverable 3.1. reporting.

Nonetheless, physical indicators and fauna abundance were essential to be obtained quickly, as these datasets have less published information than the soil chemistry and needed greater validation. The soil chemistry and what constitutes Good, Moderate or Poor soil health has greater background published data and there is more confidence in the bands that represent Good, Moderate and Poor. These methods are more understood, as they are commonly undertaken analyses that most agronomists would understand for soils. The soil chemistry results will be integrated into the scorecard as the results become available from the various experiments.

This led to a first version of the health cards bandwidth rating, proposed in Table 2.

Table 2: Prototype scorecard rating bandwidth.

Indicator	Unit	Reference for rating	Good	Moderate	Bad
Infiltration rate	mm / h	FAO class of permeability	> 360	3.6 - 360	< 3.6
VESS notation	-	AHDB	1-2	3	4-5
Bulk density	g / cm^3	AHDB	< 1.12	1.12 – 1.60	> 1.60
Earthworm abundance	ind / m^2	AHDB	> 144	49 - 143	< 49
Other macrofauna abundance	ind / m^2	None – to be determined			
POXC	mg / kg soil	None – to be determined			
Soil Organic C	% C	AHDB – conversion from SOM data – Light soil	> 1.3	0.6 – 1.2	<0.6
		AHDB – conversion from SOM data – Medium soil	> 2.0	1.0 – 1.9	<1.0
		AHDB – conversion from SOM data – Heavy soil	> 2.6	1.3 – 2.6	<1.3
Available N	mg / kg soil	None – to be determined			
Available P	mg / L	AHDB	16 - 45	10 – 15 and 46 - 70	< 9 and > 71
Available K	mg / L	AHDB	> 121	61 - 120	< 60
Soil pH (H_20)	-	AHDB (Cropping)	6.50 - 7.49	5.50 - 6.49	< 5.49

** Soil Organic Matter (SOM) thresholds from AHDB score cards were converted into Soil Organic C values by multiplying SOM per 0.58 (the van Bemmelen factor)*

03

3. Application of the scorecard prototype on WP2 experimental sites

3.1 WP2 sites involved in the test of the prototype

Seven experimental sites within WP2 were part of the soil health assessment initiative (Figure 2). The diversity of the sites allowed to test intercropping impacts on soil health through a wide variety of pedoclimatic contexts.

Within these sites, soil health was assessed on three common treatments, with four field blocks (three in the case of Zimbabwe):

- **Cereal sole crop, full N fertilization** (treatment 1 in deliverable D2.1, Table 1)
- **Cereal – legume intercrop, half N fertilization** (treatment 4 in deliverable D2.1, Table 1)
- **Legume sole crop, no N fertilization** (treatment 2 in deliverable D2.1, Table 1)

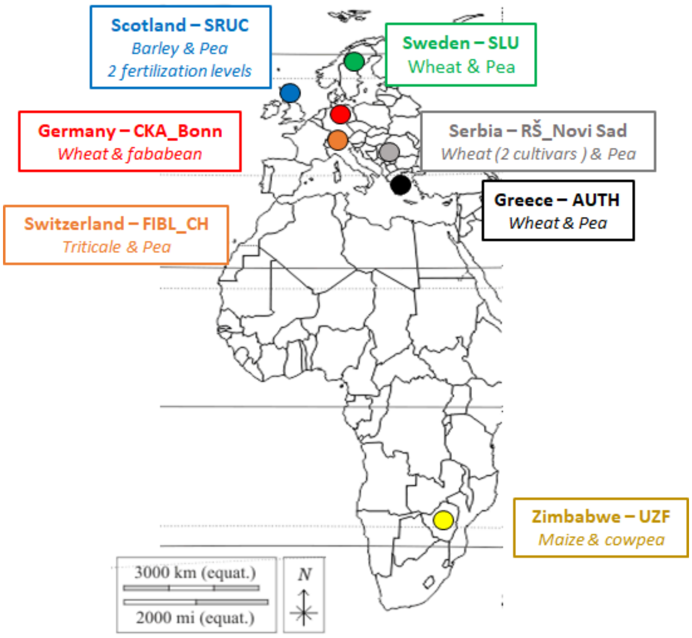

Figure 2: WP2 experimental sites involved in the test of soil health card prototype

The full description of the experimental sites can be found in deliverable D2.1. of the IntercropVALUES project. Two sites included additional treatments to be assessed for soil health:

- **In Serbia, RŠ Novi Sad** tested cereal sole crop and intercrop for two wheat cultivars: Marvel and Zvezdana (Table 7)
- **In Scotland, SRUC** tested additional no N fertilization treatments for cereal sole crop and intercrop (Table 9)

3.2. Global inter-sites comparisons

A first application of the prototype was performed at the site scale, in order to have a global appreciation of their main strength and weaknesses. We averaged the soil health indicators per site (i.e. all treatments and blocks confounded) from the first sampling campaign – Sowing stage of the first crop.

3.2.1. Prototype application to compare WP2 experimental sites

As stated in section 2.2.2, not all data could be obtained before the deliverable deadline, especially regarding the indicators relying on laboratory analyses. Nonetheless, field indicators could be reported and analysed early and are summarized in Table 3. Soil bulk density is planned to be measured but only once and is included for the inter-site comparison as it brings valuable complementary information.

Table 3: Soil health cards for each WP2 sites available data as of April 2025. Cells indicate Good (green), Moderate (yellow) and Poor (red) soil health for this indicator. Data are the average of all plots included in the trials (treatments and replicated blocks confounded) – except for Germany where only a composite measurement was made per treatment. The number of replications is indicated below each site name.

		Germany *n = 4*	Switzerland *n = 12*	Serbia *n = 20*	Sweden *n = 12*	Scotland *n = 20*	Zimbabwe *n = 9*
Physics	**Infiltration** *(mm/h)*	87 ± 26	508 ± 412	356 ± 110	199 ± 113	344 ± 223	72 ± 40
	VESS	2.5 ± 0.0	2.9 ± 0.4	1.9 ± 0.4	1.8 ± 0.5	1.0 ± 0.0	2.7 ± 0.4
	Bulk density *(g/cm³)*	1.68 ± 0.06	1.34 ± 0.10	1.33 ± 0.08		0.88 ± 0.06	
Biology	**Earthworms** *(ind/m²)*	80 ± 54	63 ± 42	114 ± 53	718 ± 336	90 ± 52	55 ± 66
	Total macrofauna *(ind/m²)*	80 ± 54	63 ± 42	114 ± 53	821 ± 365	90 ± 52	73 ± 67

This assessment will need to be completed with the remaining indicators, along with global soil information such as soil type, soil texture and organic matter content. Nonetheless, key information can already be observed from Table 3, with the Swedish site showing the best physical and biological health, followed by the soils from Serbia and Scotland sites. These score cards provide a baseline from which any changes in the soil health of the given sites can be compared.

3.2.2. Prototype adaptation following the inter-site comparison

This first output allowed to propose several adjustments.

First, **infiltration,** an indicator chosen from the Biofunctool ®, is classically interpreted according to the rating “more is better” (Thoumazeau et al., 2019), and was first translated according to overall permeability classes proposed by the FAO. However, the high values found in some of the sites, due to soil tillage, made us reconsider this approach, as a soil permeability that is too high may be detrimental to water retention in soil. Classification for the health card prototype was hence adjusted following the classification proposed by FAO Global Soil Doctors Programme (https://www.fao.org/global-soil-partnership/soil-doctors-programme/about-the-programme/en/), with the following rating:

- **Poor infiltration rates**: impermeable soils (< 0.04 mm/h)
- **Moderate infiltration rates:** very slow rates (0.04 to 5 mm/h)
- **Good infiltration rates:** moderate rates, from 5 to 150 mm/h
- **Increased infiltration rates:** increasingly rapid rates, 150 to 500 mm/h
- **Rapid infiltration rates:** very rapid infiltration rates (> 500 mm/h)

This allows for the more rapid infiltration rates to be included in the ratings and indicate if there could be potential problems from a lack of water retention by the soil.

Second, results for **macrofauna indicators** from AHDB scorecards, led to two main decisions regarding the prototype application to assess intercropping impacts on soil health.

- Considering the variability and level of earthworm abundance, it was decided to leave aside for now the distinction of the different ecological classes (epigeic, endogeic and anecic earthworms)

- Two of the seven sites (Sweden and Zimbabwe) found macrofauna other than earthworms. Considering that (i) the macrofauna groups found belong mainly to the same functional groups than the earthworms (soil engineers and litter decomposers), and (ii) that the AHDB score cards has not yet established a rating for macrofauna groups other than earthworms, we decided for now to merge all macrofauna indicators into a single one – macrofauna total abundance – and to apply the current rating scale used for AHDB earthworm abundance score cards.

3.3. Intercropping impacts on soil health

Following the initial assessment of the health card prototype for the inter-site comparison, we applied the change relatively to infiltration rating and macrofauna indicators strategy.

Analyses were performed for all treatments tested within each experimental site (see section 3.1 for more details), at both available sampling dates (sowing and harvest stage of year 1).

Table 4: Soil health cards for Germany (University of Bonn) experimental site. Cell colours indicate Good (green), Moderate (yellow) and Poor (red) for the soil health indicator, respectively.

		Physics		Biology
		Infiltration *(mm/h)*	**VESS**	**Macrofauna** *(ind/m²)*
At sowing *n=1 per treatment*	Cereal sole crop	98	2.5	144
	Cereal – Legume intercropping	78	2.5	64
	Legume sole crop	56	2.5	96
At harvest *n=4 per treatment*	Cereal sole crop	287 ± 193	1.0 ± 0.0	100 ± 126
	Cereal – Legume intercropping	248 ± 56	1.3 ± 0.5	80 ± 73
	Legume sole crop	181 ± 149	1.5 ± 0.6	144 ± 79

Table 5: Soil health cards for Greece (AUTH) experimental site. Cell colours indicate Good (green), Moderate (yellow) and Poor (red) for the soil health indicator, respectively.

		Physics		Biology
		Infiltration *(mm/h)*	**VESS**	**Macrofauna** *(ind/m²)*
At sowing *n=4 per treatment*	Cereal sole crop			
	Cereal – Legume intercropping			
	Legume sole crop			
At harvest *n=4 per treatment*	Cereal sole crop	116 ± 23	2.0 ± 0.0	
	Cereal – Legume intercropping	119 ± 32	1.5 ± 0.0	
	Legume sole crop	137 ± 45	1.6 ± 0.5	

Table 6: Soil health cards for Switzerland (FIBL) experimental site. Cell colours indicate Good (green), Moderate (yellow) and Poor (red) for the soil health indicator, respectively.

		Physics		Biology
		Infiltration *(mm/h)*	VESS	Macrofauna *(ind/m²)*
At sowing *n=4 per treatment*	Cereal sole crop	378 ± 392	2.5 ± 0.5	68 ± 33
	Cereal – Legume intercropping	348 ± 316	3.1 ± 0.2	52 ± 42
	Legume sole crop	797 ± 448	3.2 ± 0.3	68 ± 58
At harvest *n=4 per treatment*	Cereal sole crop	194 ± 102	2.9 ± 0.0	
	Cereal – Legume intercropping	238 ± 113	3.1 ± 0.3	
	Legume sole crop	436 ± 244	3.1 ± 0.2	

Table 7: Soil health cards for Serbia (RŠ Novi) experimental site. Cell colours indicate Good (green), Moderate (yellow) and Poor (red) for the soil health indicator, respectively.

		Physics		Biology
		Infiltration *(mm/h)*	VESS	Macrofauna *(ind/m²)*
At sowing *n=4 per treatment*	**Cereal sole crop** *Marvel cultivar*	290 ± 59	2.0 ± 0.5	140 ± 48
	Cereal sole crop – *Zvezdana cultivar*	405 ± 98	2.2 ± 0.5	104 ± 31
	Cereal-Legume Intercr. *Marvel cultivar*	393 ± 49	1.7 ± 0.2	64 ± 23
	Cereal-Legume Intercr. *Zvezdana cultivar*	436 ± 126	1.7 ± 0.5	92 ± 53
	Legume sole crop	256 ± 112	2.0 ± 0.4	168 ± 46
At harvest *n=4 per treatment*	**Cereal sole crop** *Marvel cultivar*	290 ± 82	2.4 ± 0.1	59 ± 37
	Cereal sole crop *Zvezdana cultivar*	367 ± 83	2.2 ± 0.2	64 ± 47
	Cereal-Legume Intercr. *Marvel cultivar*	336 ± 96	2.0 ± 0.5	36 ± 33
	Cereal-Legume Intercr. *Zvezdana cultivar*	315 ± 133	2.4 ± 0.2	48 ± 45
	Legume sole crop	299 ± 120	2.0 ± 0.2	32 ± 26

Table 8: Soil health cards for Sweden (SLU) experimental site. Cell colours indicate Good (green), Moderate (yellow) and Poor (red) for the soil health indicator, respectively.

		Physics		Biology
		Infiltration *(mm/h)*	**VESS**	**Macrofauna** *(ind/m²)*
At sowing *n=4 per treatment*	Cereal sole crop	254 ± 132	1.5 ± 0.6	723 ± 305
	Cereal – Legume intercropping	149 ± 119	2.0 ± 0.0	874 ± 514
	Legume sole crop	193 ± 88	1.8 ± 0.5	867 ± 337
At harvest *n=4 per treatment*	Cereal sole crop	297 ± 186	1.7 ± 0.8	151 ± 92
	Cereal – Legume intercropping	326 ± 142	1.3 ± 0.5	277 ± 133
	Legume sole crop	384 ± 115	1.4 ± 0.5	444 ± 187

Table 9: Soil health cards for Scotland (SRUC) experimental site. Cell colours indicate Good (green), Moderate (yellow) and Poor (red) for the soil health indicator, respectively.

		Physics		Biology
		Infiltration *(mm/h)*	**VESS**	**Macrofauna** *(ind/m²)*
At sowing *n=4 per treatment*	**Cereal sole crop –** *Unfertilized*	284 ± 76	1.0 ± 0.0	84 ± 75
	Cereal sole crop – *Fertilized*	416 ± 267	1.0 ± 0.0	100 ± 44
	Cereal-Legume Intercr. *Unfertilized*	325 ± 402	1.0 ± 0.0	60 ± 27
	Cereal-Legume Intercr. *Fertilized*	420 ± 120	1.0 ± 0.0	112 ± 68
	Legume sole crop	274 ± 188	1.0 ± 0.0	92 ± 46
At harvest *n=4 per treatment*	**Cereal sole crop –** *Marvel cultivar*		1.0 ± 0.0	60 ± 44
	Cereal sole crop – *Zvezdana cultivar*		1.0 ± 0.0	92 ± 44
	Cereal-Legume Intercr. *Marvel cultivar*		1.0 ± 0.0	76 ± 8
	Cereal-Legume Intercr. *Zvezdana cultivar*		1.0 ± 0.0	44 ± 27
	Legume sole crop		1.0 ± 0.0	64 ± 61

Table 10: Soil health cards for Zimbabwe (UZF-CIRAD) experimental site. Cell colours indicate Good (green), Moderate (yellow) and Poor (red) for the soil health indicator, respectively.

		Physics		Biology
		Infiltration *(mm/h)*	**VESS**	**Macrofauna** *(ind/m²)*
At sowing *n=3 per treatment*	Cereal sole crop	50 ± 34	2.9 ± 0.7	37 ± 33
	Cereal – Legume intercropping	83 ± 59	2.5 ± 0.2	91 ± 49
	Legume sole crop	83 ± 24	2.8 ± 0.2	91 ± 107
At harvest *n=3 per treatment*	Cereal sole crop	96 ± 69	2.6 ± 0.7	5 ± 9
	Cereal – Legume intercropping	123 ± 25	3.0 ± 0.2	37 ± 40
	Legume sole crop	115 ± 21	3.0 ± 0.5	32 ± 28

An analysis of the health cards per site shows little variation of the scoring when comparing the three treatments (cereal sole crop, cereal-legume intercropping and legume sole crop), and/or present higher influence of sampling date, both through natural seasonal variations, cultural practices and crop properties evolution.

These results are to be considered in the light of the short time scale of the experimental trials (few months- to one year-old). Even though the indicators with the fastest response time were selected for this prototype, consistent changes of enough amplitude to affect the overall cards rating usually require cumulative effects of longer-term differentiation from cultural practices.

Nonetheless, a complementary analytical approach on the indicators allowed a clearer view of intercropping impacts on soil health indicators (

Figure 3).

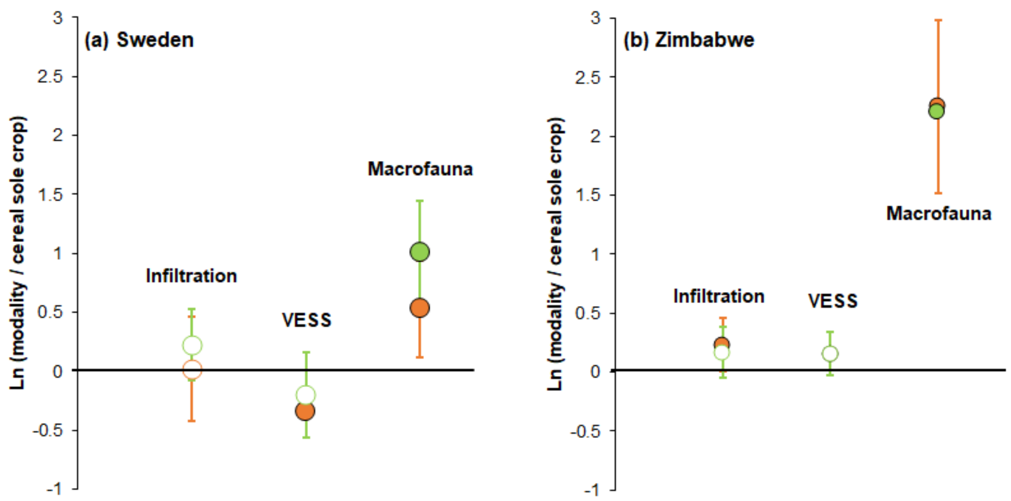

Figure 3: Intercropping impacts on soil health at harvest stage of year 1 for Sweden (a) and Zimbabwe site (b). Data in orange and green represent the logarithmic ratio of the average of cereal-legume intercropping or legume sole crop divided by the average observed

under cereal sole crop, respectively. Full circle and empty circle represent significant and non-significant differences with the cereal sole crop, respectively.

This approach allowed a first synthesis of intercropping impacts on soil health indicators for each sampling date, presented in Table 11.

Table 11: Synthesis of intercropping impacts on soil health in the WP2 experimental sites. Effects were assessed with comparison of the cereal sole crop. 0 : no significant impacts, ↗ positive impact ; ↘ negative impact

		Physics		Biology
		Infiltration	**VESS**	**Macrofauna**
At sowing	**Germany**			
	Scotland	0	0	↘
	Serbia	↗	↗	↘
	Sweden	↘	↘	0
	Switzerland	0		
	Zimbabwe	0	↗	↗
At harvest	**Germany**	0	↘	0
	Scotland			↘
	Serbia	0	↘	0
	Sweden	0	↗	↗
	Switzerland	0	↘	0
	Zimbabwe	↗	0	↗

4. Perspectives

The first prototype is promising, and allowed to build a first automated version under the format of an excel file (See Figure 4). However, several complementary steps will need to be achieved for the final soil health scorecard tool.

Write the average value of each indicator without copy paste					
		Field 1	Field 2	Field 3	Good
Physics	Infiltration (mm/h)	550	300	50	Moderate
	VESS	1.8	2.6	4.2	Poor
	Bulk density (g/cm3)	1.0	1.2	3.2	
Biology	Macrofauna (ind/m²)	248	100	20	
	Soil organic C (%)				
	POXC (mg C / kg soil)				
Chemistry	Available P (mg / L)				
	Available K (mg / L)				
	Soil pH (H20)				

Figure 4: Screenshot of the soil health card prototype, filled with dummy values.

First, it will need to include the remaining indicators that have not yet been received: SOM and POXC for the biological indicators, and available P, Mg, K and soil pH for chemical parameters. The integration of these data will help to provide a comprehensive view of intercropping impacts on soil health and may help improving the scoring strategy in a similar way to that in section 3.2.2 for infiltration and macrofauna indicators. The prototype is ready for that step but no data of chemical status was available at the time of writing this deliverable.

Second, collection of the remaining data, and exchanges with the partners from WP2, WP3.2 and WP4 would help to develop a more suitable indicator for N availability. As mentioned in section 2.2.2, neither Biofunctool nor the AHDB indicators of N could be measured in WP2 experimental sites or CICS. Assessment of soil N availability at sowing and harvest showed impacts of intercropping (Figure 3 methodology), yet cannot be considered as a soil health indicator in itself as a result of high temporal variability. Whether a more integrative indicator could be developed from the available N dynamic (measured from WP2 sites), it remains to be tested and will be brought to attention to finalised the tool.

Finally, the integration of indicators at the different scale – overall site soil health, or short-term intercropping impacts on soil health – is planned to be discuss during a specific data analysis workshop, including partners from WP1, WP2 and CICS within the next IntercropVALUES 3rd annual meeting in September 2025.

INTERCROP VALUES

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