Final narrative report
ACTEA Small Grant Facility
FIRST Project

Functional IndicatoR of Soil ecosysTem (FIRST): investing in SMART tools to assess soil biological functioning

Contract in the Framework of ACTAE regional project
CANSEA component

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PARTNERSHIP

Cambodia: General Directorate of Agriculture (GDA) under the Ministry of Agriculture and Forestry (MAFF), Conservation Agriculture Service Centre (CASC) under the Department of Agricultural Land Resource Management (DALRM), Faculty of Agronomy Science of the Royal University of Agriculture (RUA), Institute of Technology of Cambodia (ITC), and CIRAD

Thailand: Khon Khaen University (KKU), Land Development Department (LDD), and Institut de Recherche pour le Développement (IRD)

Laos: Department of Agricultural Land Resources Management (DALAM) under the Ministry of Agriculture and Forestry (MAF), and CIRAD

France: Montpellier Supagro.

THE FUNDED INITIATIVE : Functional IndicatoR of Soil ecosysTem (FIRST): investing in SMART tools to assess soil biological functioning

Main field of involvement:

Land use impact assessment; Soil quality; Soil biological functioning; SMART tools

Summary of the initiative:

There is a need to better account for soil functioning in the evaluation of soil quality. Soil functioning is the result of soil physico-chemical and biological interactions. A set of ten biological functional tools (Biofunctool®) was developed and used to assess the impact of different land use and cropping systems on soil functioning in Laos and Cambodia.

First results show that the three major soil ecosystem functions (i.e. carbon transformation, nutrient cycling, and soil structure maintenance) are affected by soil disturbance (e.g. significant decrease of soil quality index - SQI - under tillage-based systems as compared to no-till systems) and total biomasses restituted to the soil (e.g. SQI mono-cropping < SQI inter-cropping systems).

In addition, Biofunctool® is a good, easy-to-apply, and cost-efficient pedagogical tool that allows sensitizing and building capacities on land use impact assessment. FIRST has contributed to the capacity building of a large range of partners (researchers, technicians, Bsc and Msc students) in Laos and Cambodia (4 trainings, 61 participants from 4 countries)

However, improvements are still needed to better adapt the tools to annual cropping systems, sloping land, and the current limited lab facilities in Laos and Cambodia (e.g. impossibility to locally analyze membranes and soils solutions).

The Permanganate OXidizable Carbon (Pox C) to Soil respiration (SituResp) ratio appears to be an excellent proxy of land use management impact on soil organic carbon (hence soil quality) dynamics, and should be promoted at minima in land use impact assessment studies.

Location:

Biofunctool was tested in three contrasted agrosystems:

- In Cambodia, Kampong Cham Province: Bos Khnor research station (red oxisols, 68% clay); assessment of 3 no-till and mulch-based (DMC) vs 1 conventional (tillage-based) cropping systems (soybean-based experiments conducted since 2009)
- In northern Laos, Xieng Khouang Province: maize-prone production area, permanent agriculture on moderate slope and clay-loamy soils (35-40% clay); assessment of four different land uses (LUs): maize mono-cropping, maize intercropped with rice bean, improved pasture of ruzi grass, and forest
- In northern Laos, Luang Prabang Province: upland rice-based area, shifting cultivation; assessment of four different LUs on steep slopes and clayey soils (55-60% clay): upland rice, upland rice intercropped with pigeon pea, improved pasture of ruzi grass, and forest

Backgroud of the intervention:

2015 was declared the “International Year of Soils” by the United Nations Organisation under the motto “healthy soil for healthy life”. The soils were also on the agenda of the COP21 meeting in Paris. Indeed, soils are seen as a key component of terrestrial ecosystems with respect to the achievement of major ecosystem services such as food production, regulation of climate change or provision of clean water.

However, soil quality, which can be simply defined as “the capacity of the soil to function” (Karlen et *al.*, 2003), is globally threatened by many risks such as erosion, contamination, organic matter depletion, compaction, or salinization. The current rate of soil degradation threatens the capacity to meet the needs for future generation.

In this perspective, there is a need to develop simple (low-tech) but effective tools to assess land use impact on soil quality. Considerable efforts have been made to develop evaluation tools to characterize the productivity and the sustainability of different management systems. Most of them are based on the measurements of soil physico-chemical parameters (i.e., pH, nitrate, water holding capacity etc.).

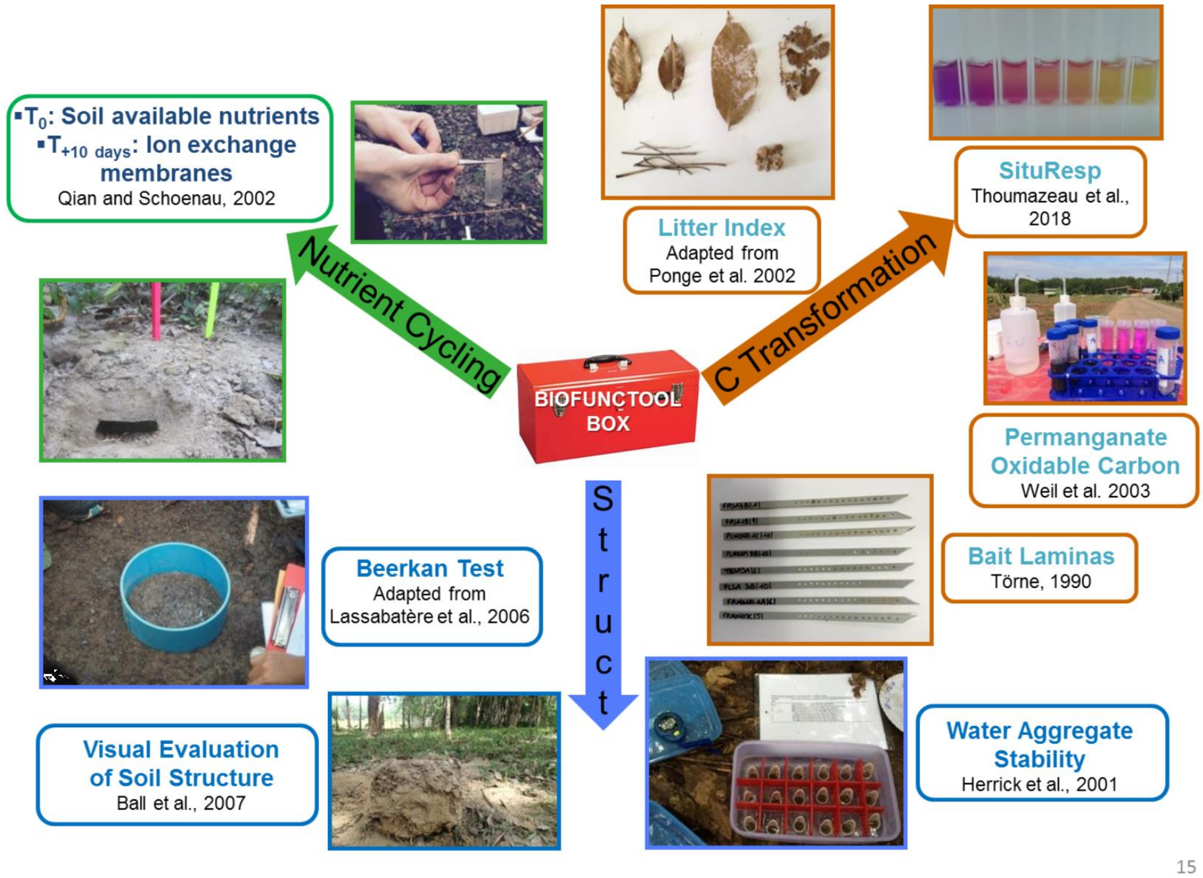
However, these approaches do not take into consideration the complex biotic interactions that makes the soil to function. Soil quality is dependent on the maintenance of three major ecosystem functions: 1/ carbon transformation, 2/ nutrient cycling, 3/ soil structure maintenance. Each of these three functions is related to a specific functional assemblage of soil organisms under the influence of abiotic factors.

Past action research experiences (references and previous works)

Many different tools exist to assess soil quality. The 10 tools selected in the Biofunctool® kit box were selected based on their SMART (Specific – Measurable – Achievable - Relevant & Time bound) potential. References are given in the figure below for each independant tool.

The orignilaty of the approach was to combine these different tools into a soil quality index (SQI).

Alexis Thoumazeau (PhD student who defended his PhD thesis in November 2018) was the first to use the set of 10 biofunctools to assess the impact of land use changes on soil quality for a chronosequence of rubber plantations in Thailand.



Historical presence in the area of the proposed project, and potential knowledge of local stakeholders in agriculture

• Bos Khnor station in Cambodia, is the oldest conservation agriculture research station in South East Asia with trials comparing no-till vs till-based cropping systems conducted since 2009

• On-farm experiments in Laos are part of the Eco-Friendly Intensification and Climate-resilient Agricultural Systems (EFICAS) project that support the intensification and diversification of agricultural systems since 2015.

Several studies have been conducted prior to the project (impact of no-till sytems on soil agregate stability, carbon turnover, and soil microbial communities) but using tools more costly and time-consuming.

Farmers and technicians are well aware of land degradation issues (e.g. erosion, decrease in productivity, increased weed pressure) and assess changes in soil quality based on visual and mainly aboveground indicators (e.g. changes in top soil color, changes in weed pressure and weed types, changes in a in these changes.

Targeted beneficiaries of the intervention and target audience:

Researchers, technicians, Bsc and Msc students.

Main objectives of the funded initiative:

The objective was to better take into account the functional role of soil biota in the evaluation of soil quality. A set of ten biological functional tools (biofunctools) was developed and tested to assess the impact of different land uses and cropping systems on soil quality.

Soil function	Tools used and functions measured	Description	Unit
Carbon transformation	Permanganate OXidizable Carbon (Pox C)	Estimation of the labile fraction of SOC	$mg.kg^{-1}$ soil
	Basal Soil respiration (SituResp®)	Assessment of soil biological activity through CO2 release from a fresh soil sample	Difference of absorbance between T0 and T+24h
	Lamina baits	Assessment of soil biological activity through the decomposition of a substrate in contact with the soil	Score from 0 (no degradation) to 1 (complete degradation)
	Cast density	Quantification of earthworm casts density	$g.m^{-2}$ soil
Nutrient cycling	Ion exchange membranes	Assessment of the dynamic of soil available nutrients using an exchangeable membrane that easily adsorb nutrients in a solution	mg $N.kg^{-1}$ soil
	Soil available nitrogen	Measurement of soil available nitrogen per mass of soil	$\mu gN\text{-}NO3\text{-}.cm^{-2}.d^{-1}$
Soil structure maintenance	Aggregate stability AggSurf AggSoil	Assessment of soil structure behaviour under the effect of water at two depths: ▪ 0-2 cm ▪ 2-10 cm	Score from 1 (poor aggregate stability) to 6 (high aggregate stability)
	Beerkan	Assessment the soil infiltration rate in situ	Water infiltration rate ($ml.min^{-1}$)
	Visual Evaluation of Soil Structure (VESS)	Assessment of soil structure linked to the biological assemblages in the field, classifying the soil structure of each layer into five scoring classes	Score from 1 (very friable soil) to 5 (very compacted soil)

Approach & methodology:

Projects study sites and facilities were used in Laos and Cambodia to test the biofunctools® while FIRST facilities helped building the capacities of the partners et national and regional levels. In a second test, preliminary results and tools were used by the national partners (e.g. the Faculty of Agronomy Science of the Royal University of Agriculture in Cambodia) to assess land use management impact on soil quality in othe sites.

Main activities implemented:

1. Assessing Biofunctool® kit relevancy in a context of annual-based cropping systems using SMART analysis grid (Specific – Measurable – Achievable - Relevant – Time bound)

Tool	SMART assessment	
Permanganate OXidizable Carbon (Pox C)	S	Specific to labile carbon
	M	Quantified measure of labile C which is strongly correlated to soil C input
	A	Low unit cost/sample; some initial investments needed (portable spectrophotometer ~600 US; some lab equipment e.g. pipette needed for dilutions); smartphone reading tool under validation
	R	Highly relevant
	T	Instant measurement
Basal Soil respiration (SituResp®)	S	Specific to soil microbial respiration
	M	Direct and quantified measure of soil basal respiration
	A	Low unit cost/sample; some initial investments needed (portable spectrophotometer); some lab products possibly difficult to find (Cresol Red, soda lime); smartphone reading tool under validation
	R	Highly relevant
	T	24H needed
Lamina baits	S	Specific to soil mesofauna activity
	M	Direct measure of activity; scoring method; indirect measure of soil C degradation
	A	Variable costs (locally-made baits and substrate vs purchased); relatively expensive if C substrate purchased; possible damages by fauna
	R	Relevant
	T	Time-consuming (baits preparation and installation; 7 to 10 days needed; reading and computing)
Litter index and cast density	S	Specific to macrofauna and mesofauna activity
	M	Quantified measure of litter degradation status
	A	Limited material needed; low-cost (if labor not included in cost calculation)
	R	Globally relevant; little relevant for till-based systems (litter annually buried in soils)
	T	Time-consuming (sampling and drying operations; data computing)
Ion exchange membranes	S	Specific to nutrients dynamics in soils
	M	Quantified measure of soil available nutrients
	A	Membranes (anion & cations) to be purchased in foreign countries; membranes re-use opportunity to be tested; limited lab with capacities to analyze membranes solutions; possible damages by fauna
	R	Globally relevant; difficult to implement on slopes
	T	Time-consuming (membranes preparation and installation; 7 to 10 days needed; solution extraction)
Soil available nitrogen	S	Specific to soil available N
	M	Direct and quantified measure of soil available N
	A	Cost of lab analysis (+ lab analysis capacity)
	R	Relevant notably in cereal-prone production area (rice, maize)
	T	Dependent of lab facilities

Aggregate stability (AggSurf and AggSoil)	S	Specific to soil aggregate stability
	M	Direct measure; scoring method
	A	Low unit cost/sample; some initial investments needed (sieves)
	R	Relevant but site specific. For cross-sites analysis, co-variables such as soil texture are needed
	T	10 minutes/ 18 samples
Beerkan	S	Specific to soil water infiltration capacity
	M	Direct and quantified measure of water infiltration
	A	Low-cost and limited material requirements
	R	Globally relevant; soil texture as supplementary data would improve the quality of indicator; not relevant on slopes
	T	5-40 minutes/sample
Visual Evaluation of Soil Structure (VESS)	S	Not specific; assessment of global soil structure quality
	M	Qualitative assessment; scoring method
	A	Low-cost and limited material requirements
	R	Moderately relevant; observer-dependent data
	T	5-10 minutes/sample

2. Capacity building/ training

Two main trainings were organized in Thailand by the Land Development Department, Khon Khaen University, UMR Eco&Sols and LMI LUSES bringing together 29 participants from 4 countries (Cambodia, Laos, Thailand, France). Two additional trainings were organized in Laos and Cambodia bringing together 20 and 12 participants respectively in October and November 2017.

Biofunctool® training in Xieng Khouang Province, Laos; on-farm testing of soil aggregate stability (credit photo @ Lienhard 2017)

Beyond capacity building, another objective of these trainings was to facilitate the emergence of a Community of Practitioners with competences in impact assessment et regional level.

3. Data collection and analysis/ impact of LU management on soil quality

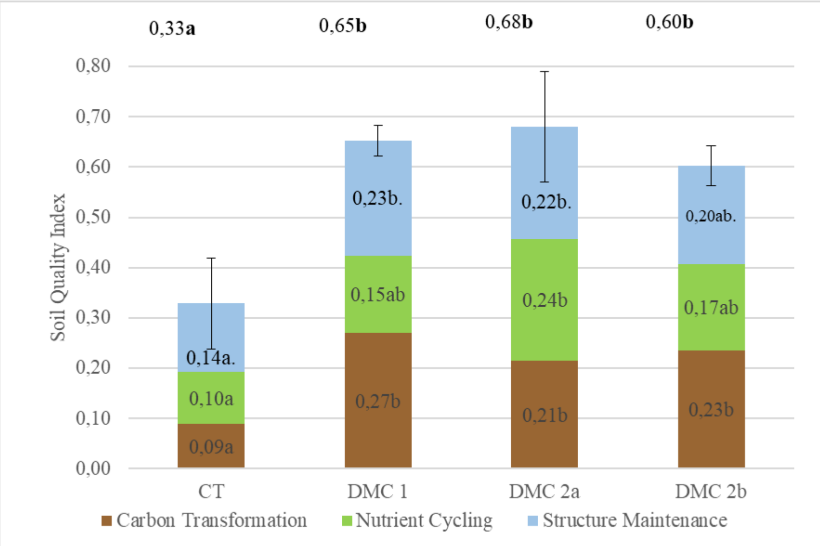
> Capacity of Biofunctool® to discriminate land use and agricultural practises impact on soil quality?

Good discrimination capacity at site level (e.g. DMCs vs CT; annual vs perennial land use systems); good sensitivity to early changes (e.g. recent integration of legume crop in rice/maize mono-cropping systems).

Function	**Carbon transformation**				**Nutrient cycling**				**Structure maintenance**							
Treatment	**POXC (mg C/kg soil)**		**SituResp® (Absorb. diff)**		**NO_3 (mg/kg)**		**NH_4 (mg/kg)**		**VESS (Score)**		**Beerkan (ml/min)**		**AggSurf (Score)**		**AggSoil (Score)**	
	mean	s.e	mean	s.e	mean	s.e	mean	s.e	mean	s.e	mean	s.e	mean	s.e	mean	s.e
CT	272.1a	44.9	0.12a	2.9.10^{-2}	0.5	4.8.10^{-2}	8.3a	0.5	2.1	0.3	124.7a	19.3	2.5a	0.4	3.3a	0.4
DMC 1	723.5b	97.2	0.43b	8.1.10^{-2}	0.5	4.6.10^{-2}	13.0b	1.0	2.3	0.2	263.7b	25.6	5.4b	0.3	4.7b	0.4
DMC 2a	704.9b	55.2	0.26ab	4.9.10^{-2}	2.7	0.7	15.8b	0.9	2.5	0.1	214.7ab	40.7	5.5b	0.2	4.8b	0.5
DMC 2b	762.1b	67.9	0.29ab	5.5.10^{-2}	2.1	1.1	14.8b	0.7	2.4	0.1	140.9a	33.5	5.5b	0.2	3.9b	0.4
ANOVA	p <0.001		p=0.01		p=0.1*		p<0.001		p=0.4		p<0.001		p<0.001		p<0.001	

Till vs no-till cropping systems impact on soil biological functioning in Cambodia, Bos Khnor station

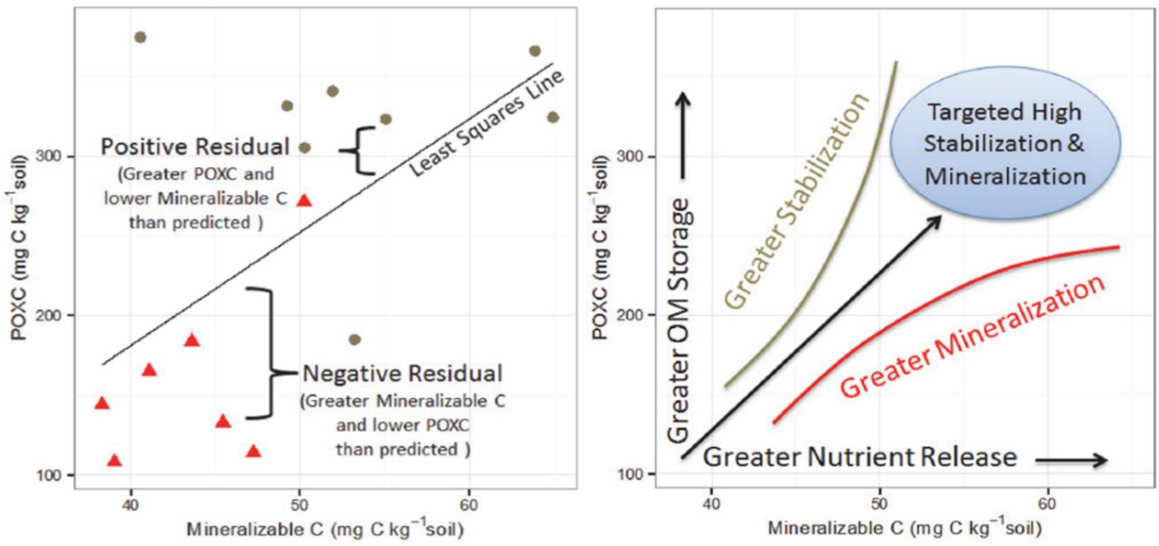
CT: soybean/sesame annual succession under conventional tillage; **DMC1**: soybean mono-cropping under DMC; **DMC2a**: soybean // maize bi-annual rotation under DMC (maize in 2017); **DMC2b**: soybean // maize bi-annual rotation under DMC (soybean in 2017). Analysis made on 0-10 cm soil layer, except for AggSurf (0-5 cm) and AggSoil (5-10 cm). N=9 for each treatment except for VESS (N=3)



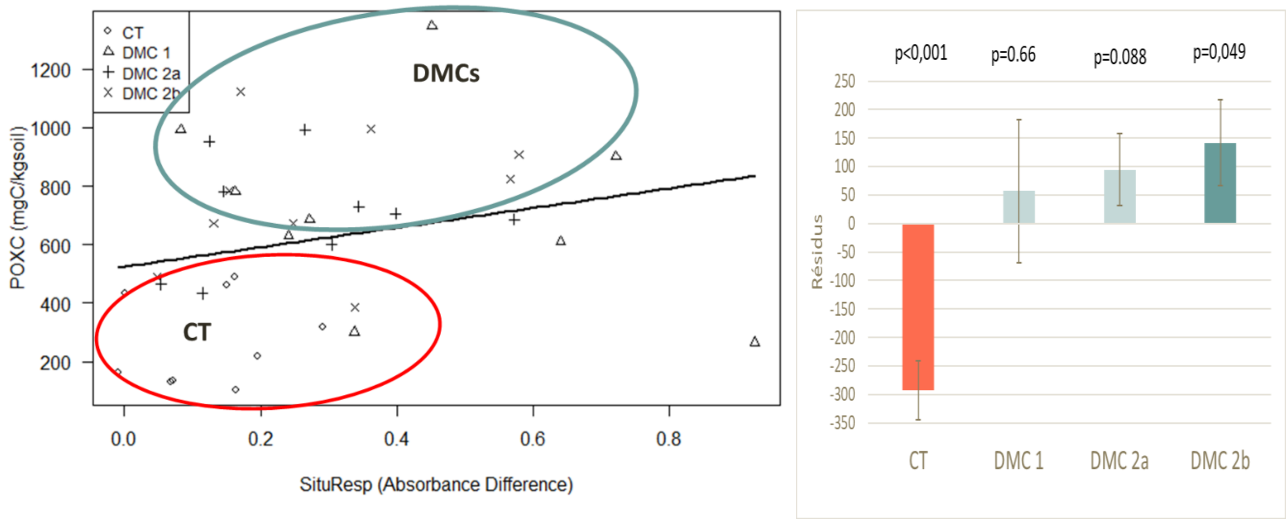
Biofunctool® soil quality index calculated for till vs no-till cropping systems in Cambodia, Bos Khnor station

> Focus on PoxC to SituResp ratio to assess land use management impact on soil organic carbon (SOC) dynamics

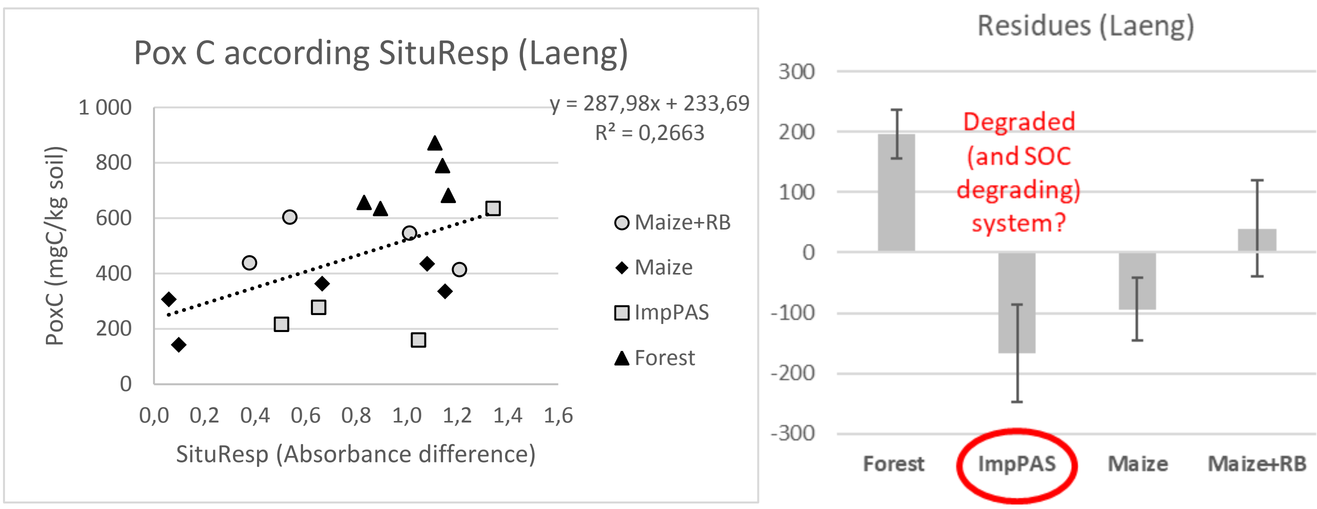
According to Hurisso et *al*. (2016), labile carbon (as assessed e.g. through Pox C) to mineralizable C (as assessed through soil respiration) ratio allows to assess OC dynamics in soils (C stabilization vs C mineralization). This ratio appears as a good proxy of land use management early impact on soil quality and can be used as a simple-but-relevant decision-making tool to adapt agricultural practises (e.g. excessive animal stocking rate negatively impacting soil carbon dynamics under managed pasture and jeopardising the sustainability of the investment).



Pox C to mineralizable C ratio used to assess OC dynamics in soils (Hurisso et al. 2016)



***Left:** Pox C to SituResp ratio according to cropping systems (Cambodia, Bos Khnor station); **Right:** Residues (observed values – predicted values) according to cropping systems. Significant trends of SOC stabilization under DMC systems vs SOC mineralization under CT.*



***Left:** Pox C to SituResp ratio according to land use management in Laos, Laeng village; **Right:** Residues (observed values – predicted values) according to cropping systems. Too high animal stocking rate might explain the results observed under the improved pasture treatment*

How the project has contributed promoting agroecology transition ?

By providing evidence that agroecology-based innovations support soil quality maintenance up to improvement.

Communication & dissemination activities:

The 4 trainings (61 participants) organized have been major events to communicate and exchange about the tools mainly amongst researchers and technicians.

The Agroecology forum (6-8 November 2018, Siem Reap, Cambodia; https://ali-sea.org/agroecology-futures-regional-forum-6-8-november-siem-reap-cambodia/) has been a major opportunity to communicate with development workers, decision markers and donors about the tool.

Lessons learnt from the project:

Biofunctool® allows discriminating land use management and agricultural practices based on their early impacts on soil biological functioning. Biofunctool® could therefore be used to support decision-making by providing science-based evidences of land use early impacts on soil quality.

In addition, Biofunctool® is a good, easy-to-apply, and cost-efficient pedagogical tool that allows sensitizing and building capacities on land use impact assessment.

However, improvements are still needed to better adapt the tools to annual cropping systems, sloping land, and the current limited lab facilities in Laos and Cambodia. The aggregation of existing Biofunctool® data with local-specific supplementary data (e.g. plots history, soil texture, pH, soil humidity and temperature at sampling etc.) could be used to calibrate a predictive model allowing better cross-sites analysis.

The Permanganate OXidizable Carbon (Pox C) to Soil respiration (SituResp) ratio appears to be an excellent proxy of land use management impact on soil organic carbon (hence soil quality) dynamics, and should be promoted at minima in land use impact assessment studies.

Main outputs of the projects (and their intended use / impacts):

The main output of the project is certainly the raising interest and the takeover of the tool by the partners: in Cambodia, the Faculty of Agronomy Science of the Royal University of Agriculture has the lead today regarding the implementation of the Biofunctool at the national level and has the ability to answer to request from development operators, research teams, among others. In Laos, capacities are there and the PoxC to SituResp ratio will be used in upcoming impact assessment studies.

AFD

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The ideas and the opinions presented in this document are the ones of its authors and do not represent necessarily those of the AFD.

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