Biofunctool®, a multifunctional approach of soil health related to soil biota activities

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Abstract summary

In a context of global soil biodiversity loss, we need to find effective way to measure the functions supported by biodiversity. This constitutes the main challenge of soil health assessments, particularly in the agroecological transition context. The most shared definition of soil health is based on the ability of soil to function (Karlen *et al.*, 1997) and to provide ecosystem services. However, most methods focus on stock measurements rather than functions. Also, measurements are usually performed in the laboratory, reflecting the potential level of soil functions rather than true field performance. To overcome these methodological limitations, a new framework is proposed to assess soil health based on functional methods that considers the links between abiotic and biotic soil compartments. This method, called Biofunctool®, incorporates nine rapid, cost-effective, and in-field indicators to evaluate three main soil functions: C transformation, nutrient cycling, structure maintenance. The capacity of the set of indicators to assess the impact of land management on soil health will be illustrated in various agroecological contexts in the tropics. Biofunctool® allows to better understand the impacts of agricultural practices on soil functions driven by soil biodiversity and could be in the future included in environmental analyses.

Keywords: Soil health, Soil functions, Soil functional biodiversity, Soil C dynamic, Soil Structure, Nutrient cycle

Introduction, scope and main objectives

In order to move towards a more environmentally friendly and sustainable form of agriculture that preserves biodiversity, we need an effective way to measure the multiple functions (C transformation, nutrient cycling, structure maintenance etc.) provided by this biodiversity. The vision of a multifunctional soil, whose functioning results from the interactions between biotic and abiotic compartments, explains the emergence of the soil health concept (Ng and Zhang, 2019). Doran *et al.* (1994) defined it shortly as "the capacity of living soil to function within the limits of natural or managed ecosystems". However, this functional vision of quality is hardly reflected in the literature (Wienhold, Andrews and Karlen, 2004) and the majority of studies are based on additive vision of soil physical, chemical and biological properties. Some authors, as Kibblewhite, Ritz and Swift (2008) for example, noticed that these additive methods do not allow to assess the soil functioning. Integrated approaches taking into account the functions driven by soil biodiversity should be developed. Those integrated assessment methods do not allow to estimate the specific role of each species but rather assess the result of their interactions. Following this functional vision suggested by Kibblewhite, Ritz and Swift (2008), a set of indicators was developed to evaluate the functions carried by soil biological assemblages. The selection of indicators was made by a panel of experts who had to choose methods from the literature following three criteria. The indicators had (i) to assess one of the 3 functions exposed by Kibblewhite, Ritz and Swift (2008) (carbon transformation, maintenance of the structure and nutrient cycling); (ii) to be implementable in the field to capture the dynamics of undisturbed soil (iii) to be low tech and cost effective to facilitate the transfer to various stakeholders. Based on these different criteria, a set of nine field indicators called Biofunctool® was proposed. This set has been validated over a wide range of pedo-climatic and agronomic contexts (Thoumazeau *et al.*, 2019a; Thoumazeau *et al.*, 2019b; Pheap *et al.*, 2019). Results of the indicators have then been aggregated in an index (Biofunctool® Index - BI), that synthetize the impact of land management tested on soil quality. In this presentation, various case studies will be presented, showing that BI provides a synthetic score of soil functioning that is sensitive to land management and robust in various pedo-climatic contexts.

Methodology

Case studies

The first case study was over various land uses in Chachoengsao province in Thailand. The second case study was designed to compare various agricultural practices in Kampong Cham province in Cambodia. The third case study was achieved in immature rubber tree plantations after logging disturbance in Bongo, Ivory Coast. The different sites are briefly described in Table 2.

Table 1: Site description of the three case studies

	Chachoengsao - Thailand	Kampong Cham - Cambodia	Bongo – Ivory Coast
GPS position	13°34′; 101°27′	12°12′; 105°19′	5°29′; 3°35′
Soil texture (0-10 cm depth)	Clay: 21% Silt: 21% Sand: 58%	Clay: 68% Silt: 30% Sand: 2%	Clay: 11% Silt: 2% Sand: 87%
Mean annual precipitation ($mm.yr^{-1}$)	1 328	1 577	1 640

Biofunctool® indicators

All Biofunctool® indicators are briefly presented in Table 1. The set was applied in field on the 0-10cm soil layer. The detailed protocols of laboratory preparations and field measurements for the nine indicators are presented in Thoumazeau *et al.* (2019a)

Table 2: Biofunctool® indicators (adapted from Thoumazeau *et al.* (2019a))

Soil function	Indicator name	Measured variable	Biological assemblages	References
Carbon transformation	POXC	Permanganate oxidable carbon	All assemblages	Weil et al., 2003
	SituResp	Soil basal respiration	Micro-organisms	Thoumazeau et al., 2017
	Lamina	Lamina baits	Mesofauna	von Törne, 1990
	Cast	Earthworms cast density	Earthworms	Adapted from Ponge et al., 2002
Nutrient cycling	AEMNO3	Fixed NO3- on ion exchange membranes	All assemblages	Qian et Schoenau, 2002
	NminSoil	Available nitrogen (NO3- and NH4+)	All assemblages	Maynard and Kalra, 1993
Structure maintenance	AggSurf / AggSoil	Aggregate stability (0-2 cm / 2-10 cm)	Macrofauna, fungi	Herrick et al., 2001
	Beerkan	Infiltration rate	Soil engineers	Adapted from Lassabatère et al., 2006
	VESS	Visual evaluation of the soil structure	Soil engineers	(Guimarães et al., 2011)

Statistical analysis

For every case study, statistical analyses were performed with a similar pathway, starting from descriptive statistics on each indicator to the analysis of the BI (Figure 1).

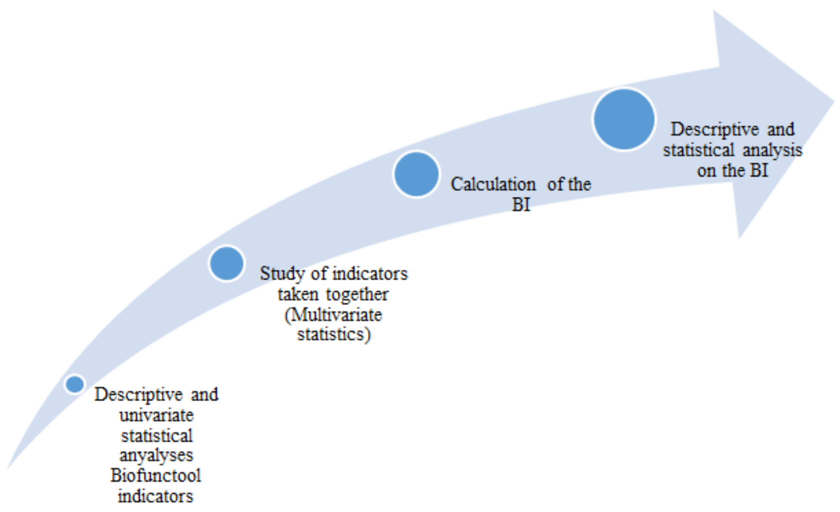

Figure 1: Scheme of data analysis trajectory of Biofunctool® indicators

Results

Impact of land uses changes

The rapid expansion of perennial crops such as rubber is a major threat to biodiversity in Southeast Asia. However, the impact of the conversion from intensively managed annual crops to perennial crops on soil health has not yet been addressed. We assessed in Thailand (Chachoengsao) the land use change impact from a cash crop (cassava) to rubber plantation and to forest on the soil health. BI was (i) not significantly impacted by land conversion (cassava to rubber); (ii) improved with tree ageing after 10 to 13 years of tree plantation due mainly to canopy closure and litter input; (iii) the highest in the forest, reaching twice the score of the cash crop (Figure 2). The three functions measured showed a different trend: the soil structure was mainly affected by land use change whereas the carbon transformation and nutrient cycling were more sensitive to tree ageing.

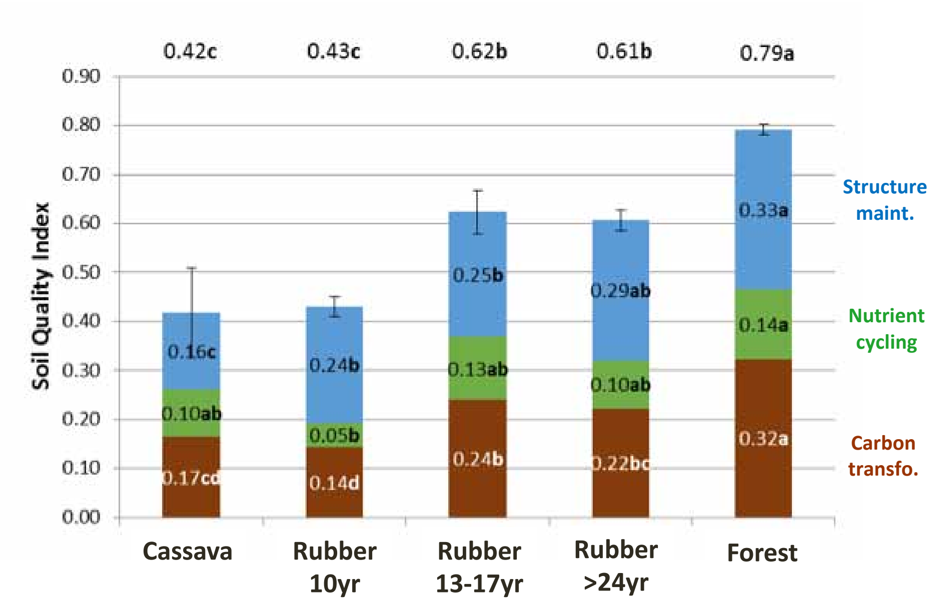

Figure 2: Impact of land uses changes on soil health in a rubber plantation chronosequence (Thailand)

Impact of agroecological practices (conservation agriculture)

Cambodia is a country facing a high level of soil degradation due to agriculture intensification (43 percent). Conservative agriculture (CA), characterized by (i) minimum soil disturbance; (ii) cover crop residues; (iii) use of diversified cropping patterns, has been considered as a way to restore soil fertility (FAO, 2014). The aim of this study was to assess the impact of contrasted agriculture practices on soil health in a long-term experiment in Cambodian uplands. Soil health was twice higher under the CA treatments than under conventional tillage (CT) treatment (Figure 3). Although it was similar in the three CA treatments, the contribution of each soil function to the soil health diverged within the CA (figure 3).

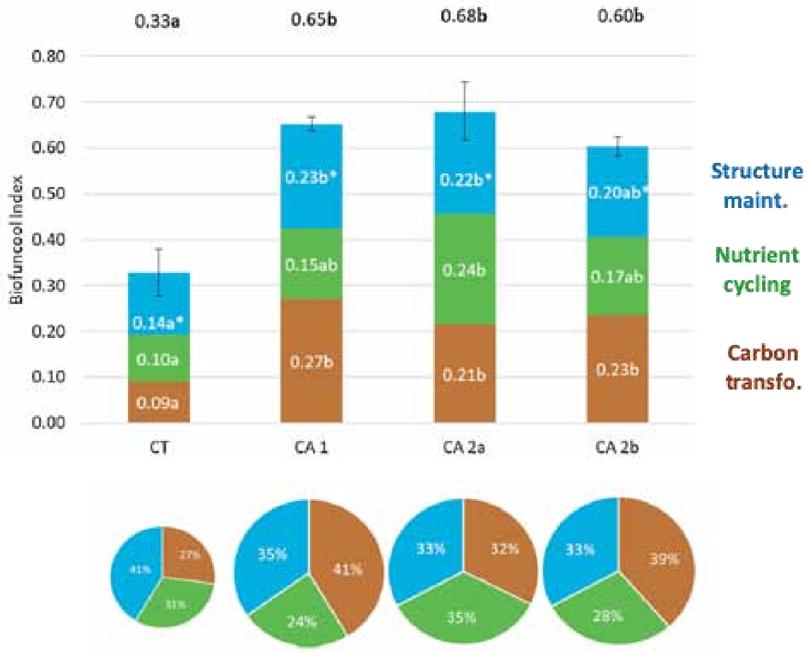

Figure 32: Impact of CT versus CA on soil health (Cambodia) (adapted from Pheap *et al.*, 2019)

Impact of soil disturbance (logging)

Soil functioning resilience after a perturbation constitutes a key scientific issue but remains poorly addressed. The objective of this study, in a rubber plantation in Ivory Coast, was to assess the effect of a gradient of logging residues input on soil health and resilience in the case of logging disturbance (Figure 4). We confirmed a significant recovery of soil health with logging residues 18 months after logging. Moreover, we observed that soil health recovery depended on the quantity and quality of the organic matter added, since legumes alone did not improve soil functions.

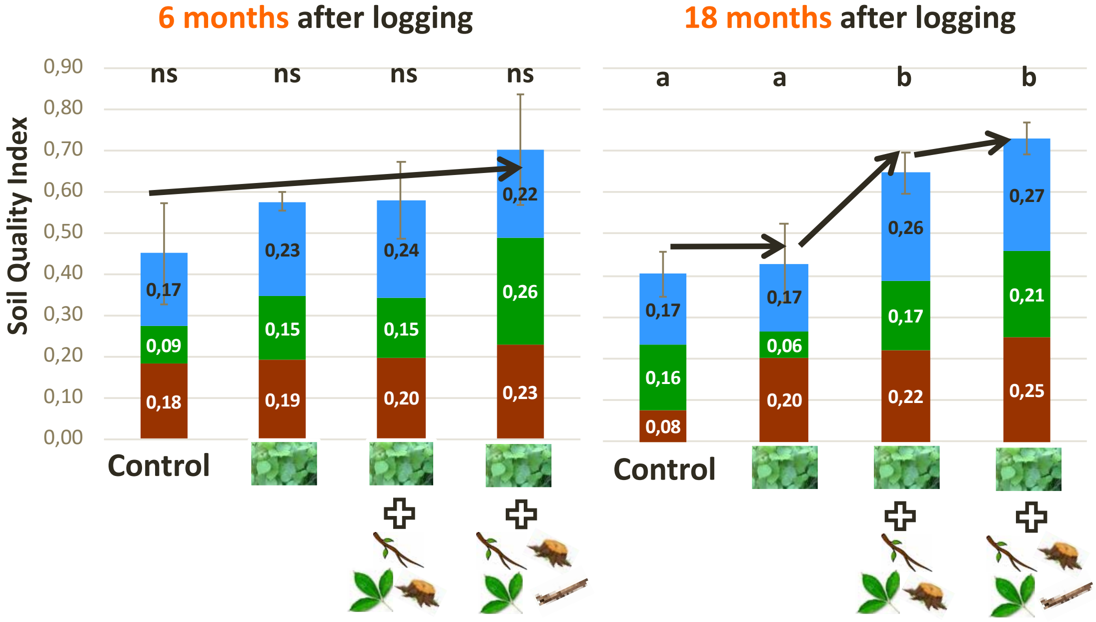

Figure 43: Impact of tree residues on soil health recovery at 6 month (left) and 18 months (right) after logging of mature rubber tree plantation (Ivory Coast)

Discussion

The functional approach of soil health provided by Biofunctool® allows an integrated analysis of changes in soil functioning at the soil system level as affected by land management. This assessment discriminated all the land management contexts explored in this study (land use change in Thailand, comparison of agricultural practices in Cambodia, impact of logging disturbance in Ivory Coast). The examples given in this article illustrate the benefits of the functional approach of soil health provided by Biofunctool® that are (i) multifunctionality; the BI makes it possible to consolidate information provided by all the indicators into a unique score that may be subdivided into scoring for three key soil functions (ii) genericity of certain results; as an example, the positive impact of the age of trees on soil health has been validated in various pedoclimatic contexts (Thoumazeau *et al.*, 2019b) (iii) adoptability: the Biofunctool® approach has been adopted and already used in other agricultural contexts by the different partners associated in these studies (RUA in Cambodia, LDD in Thailand, UNA in Ivory Coast).

Conclusions

This new functional, low tech, cost effective approach of soil health is consistent with the multifunctional role of soil. From an ecological perspective, this functional assessment will acknowledge the linkage between soil functions and biotic assemblages. Combined with others environmental, economic, and social criteria, this functional assessment will allow a better integration of soil biodiversity in the evaluation of agroecological transitions.

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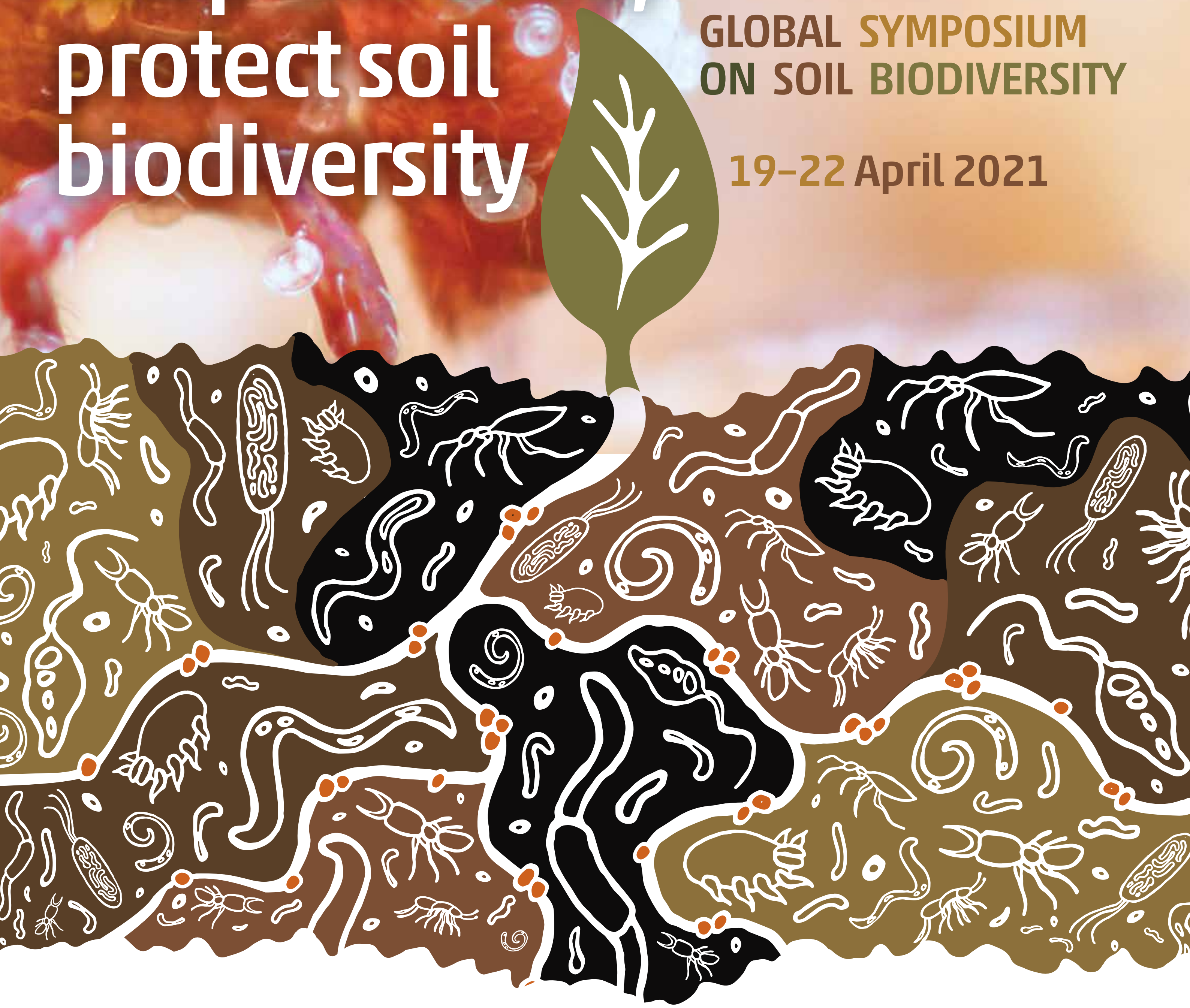

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