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Towards indicators of soil health

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Abstract: Soil is a finite and dynamic living resource. Soil health arises from multiple interactions between physicochemical and biological components, including microbial communities, of primary importance for soil functioning. Facing the threat of soilborne pathogens, cultural practices, as "ecological" crop protection methods, are more and more used. Their aim is to modify the soil microbial equilibrium. In order to measure soil health and to propose cultural practices to improve it, it is necessary to define indicators of soil health. The aim of this study is to propose indicators of soil health, through the evaluation of the impact of two cultural practices (amendment with composted cattle manure and biofumigation) on physicochemical and biological characteristics of the soil, in relation with the phytosanitary quality of a carrot crop. Multivariate analyses, associated with co-inertia analyses, revealed that some descriptors of the soil could be considered as potential indicators of soil health. In particular, these descriptors are associated with biofumigation, which enhance the soil suppressiveness to *Rhizoctonia solani* diseases. Descriptors could then be integrated in a minimum data set of indicators of soil health. This study could be continued by the confirmation of the interest of these descriptors, the construction of an indicator, and its validation.

Key words: organic amendment, biofumigation, biotic and abiotic characteristics, data analysis, co-inertia analysis

Introduction

Soil is a living system. The physicochemical matrix is inhabited by a huge living fraction, from macrofauna to microflora. For example, there are around 10^8 to 10^9 bacteria in a gram of soil, but also fungi and nematodes. There are numerous interactions among these organisms, and with the cultivated plants. The impact on plants can be either negative, with diseases and pests, but also positive, with mutualistic symbioses.

Soil health has been defined in 1996 (Doran *et al*., 1996) as the continued capacity of a soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health. We prefer this term to soil quality, because it clearly mentions the plant health. Soil health encompasses abiotic and biotic components of soil and their interactions. Our work is turned towards the phytosanitary aspect of soil health, mostly dependant on the biotic properties of soil.

Crops are threatened by numerous soilborne pathogens and pests. Broad spectrum pathogens, with conservation structures, such as *Rhizoctonia* or *Sclerotinia*, can impose quite long rotations. With several crops in a rotation, several pests and pathogens must be managed. However, there are less and less authorized products, and a growing societal concern. That is why there is a need to improve or to find effective alternative methods. Among these methods, cultural practices can be used as crop protection tools. For example, crop residue

management or biofumigation can modify the soil microbial equilibrium, and have a positive impact on soil inoculum potential, soil suppressiveness or inoculum density.

So, there is a need for *a priori* evaluation of the phytosanitary risks of a plot, for the different crops, and a need for *a posteriori* efficacy evaluation of the crop protection methods. That is why we need indicators of the soil health. Precisely, an indicator is a variable which supplies information on other variables which are difficult to access and which can be used as benchmarker to take a decision (Gras *et al*., 1989). So it must be descriptive but also usable as decision-making tool. Larson and Pierce (1991) proposed that given the complexity of soil, not only one unique indicator could be representative of the soil health, so we should use a minimum data set composed by several indicators. Thus, the aim of our work was to identify indicators of soil health in an agronomic context, where cultural practices were used as a perturbation tool. Modifications of the biotic and abiotic characteristics of soil, and modifications of the phytosanitary status of soil and plant were monitored. Physicochemical analyses of the soil were performed, and the density, activity and community structure of bacteria, fungi and nematodes were investigated. Soil health was assessed by soil receptivity bio-assays and plant health was rated at harvest. The compilation and analysis of all these data enable us to identify the soil parameters most linked with its phytosanitary status and to propose descriptors that could be integrated in a minimum data set to be used as soil health indicators (Janvier *et al*., 2007).

Material and methods

Experimental design

The experimental plot was located in Dordogne, France. It was divided in 3 sub-plots. The control part (Té) was conduced in integrated management, with only mineral fertilisation. The second part (MO) received a composted cattle manure amendment. The third part (Bd) was conducted with a biofumigation, with fodder radish cultivation, grinding and burying, followed by plastic covering. This was done during two years with the same practice on the same plot each year. The soil characteristics were monitored spatially, with 21 independent samples in each sub-plot, but also in the time. We analysed soil characteristics at three sampling dates each year. The first sampling (T0) was performed before organic amendment and radish sowing. The second sampling (T1) was done at the end of the biofumigation, when the plastic cover was removed. Then the whole plot was cultivated with a carrot crop, and the last sampling (T2) was performed a few days before harvest.

Methods

Abiotic soil characteristics were analyzed in a specialized lab (Laboratoire d'Analyse des Sols, Arras, France). Densities of bacteria and fungi were assessed by dilution plating, microbial biomass was measured with the chloroform fumigation-extraction method and soil basal respiration was considered as a measure of the soil activity. Bacterial and fungal community structures were analysed by terminal restriction fragment length polymorphism (T-RFLP) after total soil DNA extraction and specific PCR amplification of the 16S and 18S rDNA gene, respectively. Concerning nematodes, they were extracted and counted, and the phytoparasitic nematodes were identified by morphological criteria. Carrot rating at harvest concerned yield, plant density, but also symptoms of disease, without being able to separate the pathogens responsible, mainly *Pythium* spp. and *Rhizoctonia solani*. Soil receptivity to *R. solani* damping-off was measured for each sample at each sampling date.

Data analysis

Numerous data were collected, and most of them were analysed by Principal Component Analysis with ADE-4 (Thioulouse *et al.*, 1997). The relationships between different data sets were assessed by co-inertia analysis.

Results and discussion

Effect of perturbations on soil characteristics

The perturbations applied, that is biofumigation and organic amendment, had different effects on the microbial communities. Biofumigation had a strong effect on both bacterial and fungal community structure (data not shown). However, microbial communities showed some resilience, with similar community structures in the three sub-plots at the end of the carrot crop. This resilience was not complete for the fungal community after the second year of biofumigation, probably due to a cumulative effect. The sampling scheme also allowed us to identify spatial and temporal variability of the microbial community structure (data not shown).

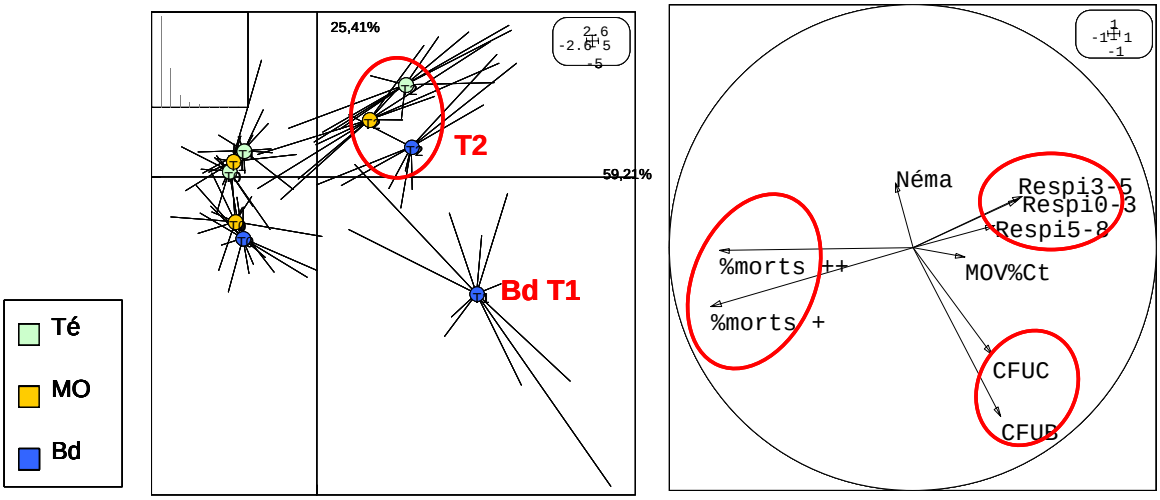

Figure 1. PCA of the biological quantitative characteristics of soil. Factorial map of the soil samples (left) and correlation circle of the variables (right). %morts + and ++ = % cumulative death rate in the bioassay, at low (+) and high (++) inoculum doses. CFUC and CFUB = colony forming unit for fungi and bacteria. Respi = respiration rate. MOV%Ct = living organic C in % of total C. Néma = total density of nematodes.

The cultural practices also had a strong impact on the quantitative biological characteristics: microbial densities, biomass and activity, the density of nematodes and soil receptivity measured in the bio-assay. The PCA analysis of all these data showed that in the biofumigated soil, microbial activity and densities were higher, and that this soil was more suppressive to *R. solani* damping-off (Figure 1). As for the microbial community structure, quantitative biological characteristics showed some resilience during the carrot crop (Figure 1). At T2 the biofumigated soil was no longer different from the control soil concerning receptivity to *R. solani* damping-off (Table 1).

The amendment with composted cattle manure had almost no effect on the soil biological characteristics, and even a negative effect on soil receptivity, the soil becoming more susceptible to *R. solani* after 2 years of such amendment (Table 1).

Table 1. Results of the bioassays of soil receptivity to *R. solani* damping-off of carrot plantlets (the higher the value, the higher the disease).

% cumulative death rate 10 days post-inoculation		Dose 1/30		
		Té	MO	Bd
2004				
	T1	77 a	77 a	55b
	T2	95	96	95
2005				
	T0	91	91	94
	T1	88 a	90 a	64b
	T2	72b	79 a	69b

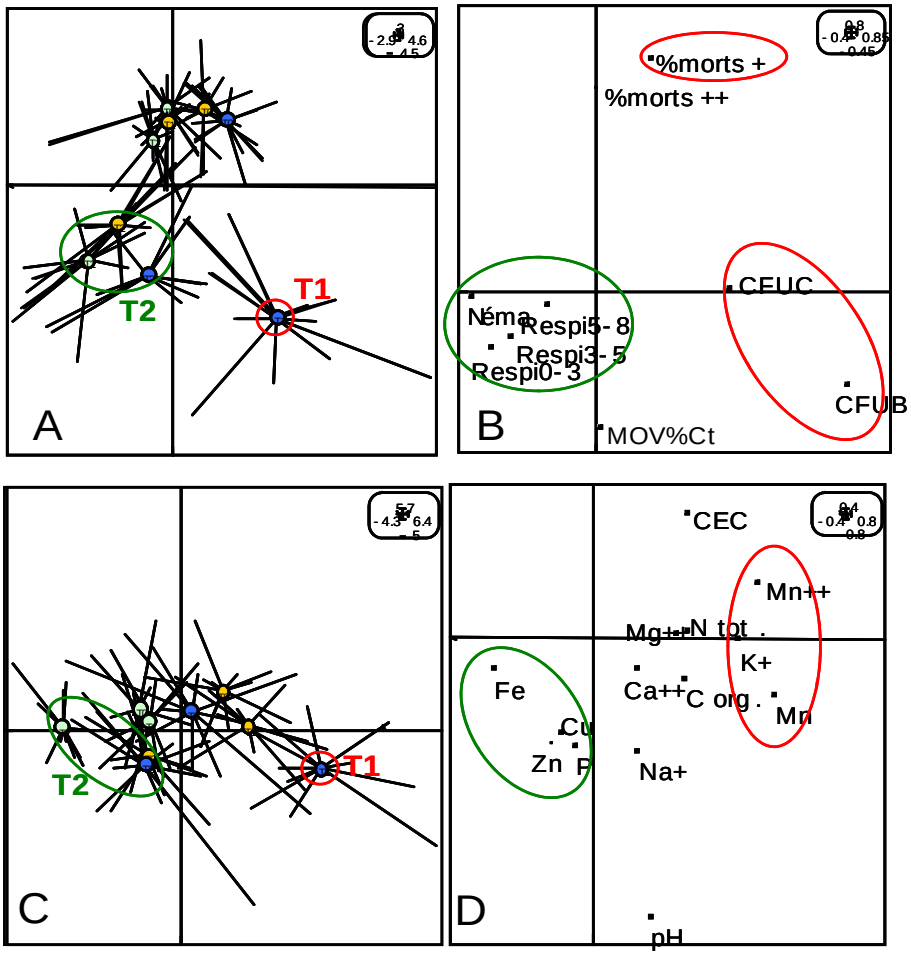

Figure 2. Co-inertia analysis of the quantitative biological and chemical characteristics of soil, in 2005. Factorial map of (A) quantitative biological and (C) chemical characteristics of soil samples, and (B) biological and (D) chemical variables.

From parameters to descriptors: co-inertia analysis

Co-inertia analysis is a multivariate method that describes the relation between 2 data sets, concerning the same samples, but different variables. It enables to identify the variables that change together. In this paper, only one analysis is fully described, the one concerning the

quantitative biological and the chemical characteristics, in 2005. Figures 2A and 2C showed the projection of the samples in the co-inertia plan, according to either their biological (2A) or chemical (2C) characteristics. The same way, figures 2B and 2D showed the projection of the 2 variable sets. This analysis revealed a significant co-structure between these 2 data sets. The biofumigated soil, at the end of the plastic covering, is more suppressive to *R. solani* damping-off and it supports higher microbial densities. It also has higher concentration of manganese, manganese- and potassium ions. At the end of the carrot crop, the soil of the plot is characterised by higher microbial activity and nematode density, but also by higher content in iron, zinc, copper and phosphorus.

Conclusion

The spatio-temporal variability of the soil characteristics is not negligible, and it might be taken into account in this kind of study on soil health. However, this study revealed that different perturbations can lead to different impacts on the soil characteristics and by the way on the soil health. In this work, biofumigation was the cultural practice that has the strongest effect, and it was still limited, concerning soil health, probably due to the resilience of microbial populations.

The co-inertia analyses revealed significant co-structures for almost all the pairs of data sets. It was certainly due to strong biofumigation and sampling time effects. We were able to propose some variables that could be included in a minimum data set. For physicochemical variables, the content in iron, zinc and phosphorus always changed in the same way, as for manganese and manganese and potassium ions. In each group, it is sufficient to control only one of these characteristics. For quantitative biological parameters, microbial densities, assessed by soil dilution plating, are robust and reliable measures. They were often related to more suppressive soil. For qualitative biological variables (data not shown in this article), PCA analyses revealed some molecular markers, specific of biofumigated soils. The corresponding microbial populations or species could be identified, and their possible involvement in soil health could be assessed. For nematodes, such molecular methods would be very useful.

This work should be continued with the construction of the indicators. For that task, it seems necessary to have more "soil health" variables (e.g. more disease-related variables), and to use predictive data analysis methods. This would permit to definitively choose the variables to be included in a minimum data set. After this, it would be needed to validate the indicators. To do that, they must be tested in several pedoclimatic contexts, several pathosystems, and to evaluate several cultural practices. And finally, for the soil indicators to be effectively used, it would necessary to increase the user awareness and to construct diagnostic and decision grids. The aim is to propose, given the type of soil and some indicators, which crops could be implemented, and which cultural practices could be useful to improve soil health.

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References

Doran, J.W., Sarrantonio, M. & Liebig, M.A., 1996: Soil health and sustainability. – Adv.Agron. 56: 1-54.

Gras, R., Benoit, M., Deffontaines, J.P., Duru, M., Lafarge, M., Langlet, A. & Osty, P.L. 1989: Le Fait Technique en Agronomie. Activité Agricole, Concepts et Méthodes d'Etude. – L'Harmattan, Paris, France.

Janvier C., Villeneuve F., Alabouvette C., Edel-Hermann V., Mateille T. & Steinberg, C. 2007: Soil health through soil disease suppression: which strategy from descriptors to indicators? – Soil Biol. Biochem. 37: 1-23.

Larson, W.E., Pierce, F.J. 1991: Conservation and enhancement of soil quality. Evaluation for sustainable land management in the developing world. – International Board for Soil Research and Management Proceedings 2: 175-203.

Thioulouse, J., Chessel, D., Dolédec, S. & Olivier, J. M. 1997: ADE-4: a multivariate analysis and graphical display software. – Statistics and Computing 7: 75-83.