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HOW DO AGRICULTURAL PRACTICES INFLUENCE THE BALANCE BETWEEN SOIL ORGANIC MATTER STORAGE AND CROP YIELDS IN ORGANIC SYSTEMS?

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Abstract: In organic cropping systems, appropriate ecological agricultural practices (e.g., organic fertilization, rotation's diversification with perennial crops) must induce a balance between yield and soil organic matter storage, to sustain production while preserving soils. Their efficiencies depend on the whole cropping systems, the type of soil, the considered time scale and the climate. We will illustrate this issue with research results obtained from 3 different field studies conducted in Quebec (Canada) and Brittany (France).

Introduction: The challenge in organic cropping systems is to provide enough nutrients to optimize crop production while maintaining soil quality. This can be achieved through an appropriate soil organic matter (SOM) management since this property is related to several chemical, physical and biological soil properties involved in soil functioning, and is recognized as one of the most important soil quality indicator (Watson et al., 2002). Among several soil key indicators, the focus should be on SOM content, but also on associated properties such as aggregate stability (AS) and microbial biomass (MB). In addition, crop yield should be considered as an end point of soil quality assessment at the field and farm levels (Karlen et al., 2001). In a context of organic farming, the best way to improve nutrient release, water infiltration and storage, and soil structure at the same time is thus to adopt practices that increase soil organic matter. To achieve this goal, organic farmers utilize a range of management practices, such as diverse crop rotations, organic fertilization, crop residue management. One of the new challenges of organic cropping systems is to reduce tillage to preserve organic matter, and to answer the question how can we reconcile reduced tillage with organic fertilization. Numerous studies have demonstrated the positive influence of these practices when considered individually. However, results are highly variable and depend on the whole cropping system and each specific site conditions.
Based on a global meta-analysis, Oldfield et al. (2019) provided a global quantitative model to relate yield to soil organic matter, but they also concluded that more knowledge on the causative effects of SOM on yield is needed. In fact, it is not so obvious that management practices leading to an increase in SOM will necessarily increase crop yields. We have conducted studies under conventional conditions and, since an increase transfer from conventional to organic and vice et versa is envisaged (Watson et al., 2008), we believe that we can take advantage of the comparison of the results obtained. The objectives here are to sort out the agronomic and environmental conditions controlling the synergy and antagonism between soil quality indicators (SOM, AS, MB) and crop yield under different combinations of agricultural

practices, soil types and climate, and to allow organic farmers to comprehensively choose the appropriate management practices supporting sustainable organic cropping systems.

Material and methods: : We have conducted three field studies on forage and annual cropping systems under humid temperate climate, at different spatial and time-scales, and on different soil types. The first study (***S1***, Samson et al. 2019) was established in 2009 on an experimental site located at the Laval University agronomic research station (St Augustin, Québec, Canada, 46°44' N, 71°31' W), on two soils : a poorly drained silty clay soil (432 g kg^{-1} clay, 405 g kg^{-1} silt, 35 g C kg^{-1} and 2.7 g N kg^{-1}) and a moderately to well drained sandy loam soil (170 g kg^{-1} clay, 150 g kg^{-1} silt, 19 g C kg^{-1} and 1.5 g N kg^{-1}). Plots were cropped to a corn-soybean-wheat rotation. Two soil tillage treatments (moldboard plow [MP and minimum till [MT]), 6 fertilizer treatments (a no-N control, a complete mineral fertilization [NPK], liquid swine manure [LSM], liquid dairy manure [LDM] and solid poultry manure [SPM]) and two residue management treatments (residues exported with harvest [RH] and residues returned to soil [RR]) were randomly ascribed as respectively main plots, subplots and sub-subplots with 4 replicates per treatment. The second study (***S2***, Bottinelli et al. 2017) was conducted at the Chambre régionale d'Agriculture de Bretagne experimental station (Kérguehennec, Bretagne, France, 47°53' N, 02°44' W) on a loamy soil (170 g kg^{-1} clay, 420 g kg^{-1} silt, 25 g C kg^{-1}). Plots were cropped to a corn-wheat-rapeseed-wheat rotation. Three soil tillage treatments (moldboard plow [MB], surface tillage [ST] and no-tillage [NT]) and two fertilizer treatments (mineral [N] and solid poultry manure [SPM]) were randomly ascribed as respectively main plots and subplots with 4 replicates per treatment. The third study (***S3***, Viaud et al. 2018) was performed in a 12 km² agricultural landscape (Brittany, France, 48°00' N, 2°49' W) which is identified as an observatory of the research on the environment by the French ministry of research and part of the French network of agricultural watershed research (ore_agrhys). Soils predominantly have a silty loam texture (135-356 g kg^{-1} clay, 509-744 g kg^{-1} silt, 15-56 g C kg^{-1}, 1.42-6.22 g N kg^{-1}). The main crop rotations were grain maize-wheat or barley (40 % of the watershed agricultural area), silage maize-wheat or barley (12 %) and silage maize-grasslands (13 %). The associated agricultural practices differed in tillage frequency, manure application (quantity, manure type) and crop residue management. Yields, soil organic matter, aggregate stability and microbial biomass were measured in the S1 and S2 studies while only soil properties were assessed in S3 following methods described in the cited papers. Results (published and unpublished) of these 3 studies were statistically analyzed for each study using the appropriate approach described in the published papers. In the present conference some results will be integrated in a framework analysis following a qualitative approach to illustrate and prioritize the relationships identified in the figure 1.

Results: As an example of results, in ***S1*** conducted in Canada, reduced tillage is the most effective practice for increasing soil organic matter (SOM), microbial biomass (MB) and aggregate stability (AS) in both poorly drained silty clay and well drained sandy loam soils. Under moldboard plow tillage, organic fertilization increased SOM only marginally in both soils. Combined to minimum tillage, poultry manure induced the most important increase in SOM compared to a mineral fertilization in the silty clay soil (26 %), while slurries induced the most important increases in the sandy loam (27 and 29 %). For all crop species (corn, soybean and wheat), yields were more responsive to fertilizer treatments in the sandy loam than in the silty clay. The effect of fertilizer treatments was exacerbated when weather conditions did not favor soil and manure mineralization. In fact, different weather patterns among years impacted soil nitrogen mineralization and availability for crop. Also, a year effect showed the positive effect of minimum tillage on crop yield built up with time in the silty clay soil due to an improvement in soil structure over time (figure 2). This positive built up was not observed in the sandy loam. This could be attributed to the moderate population of yellow foxtail that developed over time under MT. In the same experiment, crop residue retention combined to minimum tillage, which favor soil surface organic matter, has decreased crop yields by increasing the contact between the liquid manure and crop residues and lowering their availability.

In ***S2***, conducted in Brittany, manure amendment had a relatively small effect on AS due to the small increase of OC. In fact, the amount of carbon applied to the soil as poultry manure (2.2 Tons C ha^{-1} yr^{-1}) is relatively low compared to the high SOM content of the soil. The low application rates were based on typical application rates in this region. As found in Canada, under different types of soil and climate, organic fertilization combined to reduced tillage led to a greater increase in SOM, MB and AS than under conventional moldboard plowing (table 1).

In ***S3,*** we found that at the landscape and long-term scales, in a context of a homogeneous climate and type of soil, temporary grassland in the rotation was the main factor contributing to an improvement of SOM, AS and MB. Fifty percent of the variability in soil aggregate stability at this scale were explained by the rotation. As expected, SOM and MB and SOM and AS were significantly correlated. More specifically, a positive correlation between AS and fungal diversity was found reflecting the critical role of fungi in forming and stabilizing soil aggregates. This role is particularly emphasized under grasslands, which are characterized by abundant roots and low soil disturbance.

Integrating the results of these three field studies in figure 1 will highlight the differential effects of these practices of interest to organic farmers and will inform on the degree of balance between long-term improvement in SOM storage and yield achievement, as a function of the identified control factors.

Discussion: Agroforestry systems and organic management are two key elements that allow improving the energy efficiency of cacao production while reducing their dependence on fossil fuels and GHG emissions. Despite the higher yield per hectare of cacao grown under conventional systems and monocultures, organic management makes it possible to reduce the non-renewable energy demand per kilogram of cacao produced and, when considering as well the by-crops, the agroforestry systems were more efficient than monocultures, especially when organically managed. In addition, agroforestry systems have a higher energy return on labour.

To reverse the current scenario of systems with low energy efficiency, high demand for non-renewable energy and GHG emissions, stakeholders should promote the adoption of organic agroforestry, which can better ensure the sustainability of the plantations than the organic monocultures. Moreover, agroforestry systems improve farmers' livelihood, food security and ecosystem services.

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