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Soc Recovery Pathway Beyond Topsoil under Conservation Agriculture Farming Systems

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Currently, Brazil has 36.8 million hectares under Conservation Agriculture (CA),[1] accounting for ~75% of total grain production area. South Brazil main grain producer States (Paraná and Rio Grande do Sul) were the pioneers in the adoption of CA in the early 1970s but the system was only farming scaled up after the 1990s. In 1990, the area under CA was 0.9 million ha (M ha), with an annual rate of 0.081 M ha per year, and in 2000 it was already 14.0 M ha, with an annual rate of 1.64 M ha per year. The CA area doubled in 2010 up to 30.3 M ha, with an annual rate of 1.51 M ha per year and in 2016/17 reached the current area 1 (Figure 1), placing Brazil in second position in the world CA adoption.[2] CA based on principles of minimum soil disturbance, permanent soil cover and diverse crop rotation including cover crops in single use or in consortium filling up all the windows between cash crops 3 is a key strategy to restore and to maintain SOC stock, improve soil quality, sustain a diverse microbiome and increase crop yield.[4, 5, 6, 7, 8]

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To promote SOC recovery in soil layers beyond topsoil with Conservation Agriculture, it is necessary to fulfill some requirements. Among them: maintaining the area under continuous (over the years) high organic material input and increase radish oil frequency in cropping system (Figure 2). It's important to mention that annual precipitation should be medium / high (≈ 1600 to 1750 mm year-1) and well distributed during winter (cultivation period of radish oil) to provide water and soil moisture, favoring cations transport along the soil profile and improving root development. In addition, the topsoil should have pH > 6,0 that allows calcium vertical translocation to subsoil with infiltration allowing deep root growth. These practices will:

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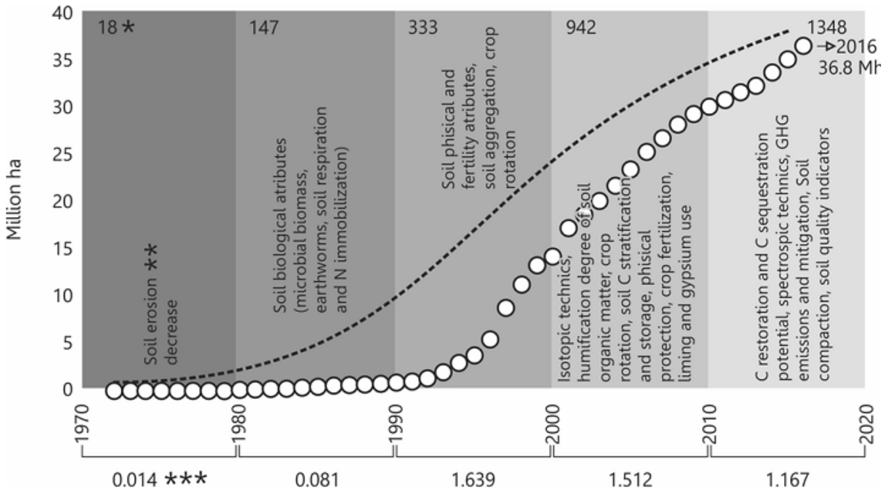

Fig. 1: Timeline by decades, published articles (*), most relevants events in each decade (**), and CA expansion rate (Mha yr^{-1}) by decade (***). Source: Sá and De Oliveira Ferreira, 2018

Create Biopores

the forage radish works as a biological soil ripper, creating biopores that are preferential pathways for root growth of the next crops.[9] In addition, it's necessary to keep average high plant density as 17 to 25 plants per m^2 and high radish frequency on crop rotation. As a consequence, the infiltration is increased, the runoff is controlled and the precipitation plant use efficiency is increased resulting in higher biomass input.

Soil Decompaction

As a consequence of biopores creation, soil is decompacted, creating favorable conditions for root growth [10, 9, 11] and microbiote activity and diversity is enhanced since the aeration is improved,[12] that are the most efficient source of organic C to soil.[13] In addition, the biopores formed by oilseed radish roots are stable and works as preferential paths for linked the topsoil with subsoil.[14]

Improve Soil Structure

Continuous pores associated with high biological activity and bioproducts input are essential to bio improvement of soil structure (through cimentant agents that increase aggregate stability and enhance soil macroaggregation buid up) with that the water infiltration through soil profile is stimulate.[6] In addition, this improvement of soil structure also affect positively the mesoporosity that are strategic to increase plant water availability.[15] Finally, it is necessary to adopt a crop rotation system with high C-biomass input and a diverse and deep root system to form SOC-rich soil layers and provide C source to vertical distribution along the soil profile reaching in medium to long-term the deepest layers. In this case, the deep and continuous biopores could connect the shallow layer and deep layer, supporting C translocation through the soil profile.[16, 17, 18]

These actions (Figure 2) need to be associated with minimum soil disturbance, improvement of soil fertility, pH increase, maintaining nutrients availability and high plant biomass input. In Brazilian tropical soils, the chemical improvement of subsoil has been associated to high crop performance[19. 5] adjusted a linear model with carbon recovery as independent variable and highlighted these processes importance: i) For top layers (0-15 cm) [SOC Recovery = 25.9 (pH) + 70.9 (Low intensity crop rotation) + 93.4 (Med intensity crop rotation) + 1.3 (Altitude) + 219.7 (Average temperature) - 13.6 (Max temperature)] and subsurface (60-100 cm) [SOC Recovery = - 40.0 (pH) + 21.5 (Ca^{2+}) + 60.6 (Low intensity crop rotation) + 0.1 (Altitude) + 2.4 (Max temperature)]. In that study, the authors also showed that SOC recovery was smaller for areas with low crop rotation intensity, higher Al^{3+} levels and lower levels of Mg^{2+} and P. Sites with medium / high crop rotation intensity, lower levels of Al^{3+} and higher levels of P, Ca^{2+}, Mg^{2+}, and K^+ showed higher C recovery.[5]

In this context, the high and diverse crop residue input should be combined with management that enhance the C stabilization mechanisms.

Therefore, the higher SOC recovery under conservation agriculture is related to crop intensity and diversity, microbial diversity, greater frequency of radish and consequently soil decompaction in the arable layer, soil structure improvement, moisture maintenance, improved soil fertility and reduction of soil disturbance (Fig. 2).

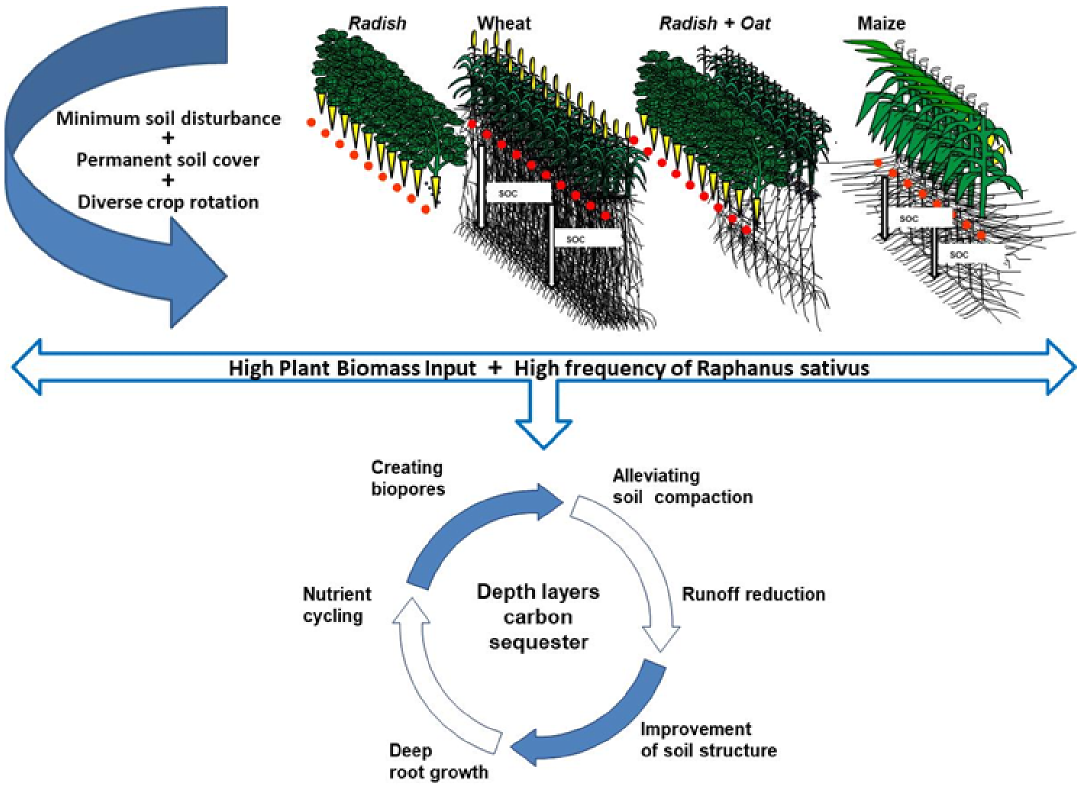

Fig. 2: Rationale of the SOC recovery pathway in soil profile under Conservation Agriculture farming systems. Source: Adapted of De Oliveira Ferreira *et al*. (2021b)

Conclusion

To promote SOC recovery in deepest soil layers with Conservation Agriculture, it is necessary to fulfill some requirements. Among them: maintaining the area under continuous (over the years) high organic material input and radish frequency. These practices will: i) Create biopores; ii) Alleviating soil compaction, creating favorable conditions for iii) root growth, that are the most efficient source of organic C to soil and finally iv) Improve soil structure keeping soil moisture levels high. These actions need to be associated with minimum soil disturbance, improvement of soil fertility, pH increase and maintaining nutrients availability.

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