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INTRODUCING CONSERVATION AGRO-ECOSYSTEMS TO ENHANCE SOIL QUALITY AND SUSTAIN FOOD PRODUCTION

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GENERAL ABSTRACT

The introduction of conservation agro-ecosystems has been suggested for increasing soil organic carbon (SOC) sequestration and enhancing soil fertility.

Continuous organic fertilization such as compost distribution and cover crops incorporation promotes SOC sequestration (+1.3÷2.5 Mg C ha^{-1} yr^{-1}) and soil total nitrogen (STN) accumulation (+~1 Mg N ha^{-1} yr^{-1}). However, when the organic fertilization is stopped, SOC rapidly decreases.

In intensive agro-ecosystems, no till (NT) can ensure yields comparable to conventional tillage (CT) immediately after transition. The major contribution of NT to soil organic matter (SOM) and STN increase is detected in the top 5 cm of soil, although the cultivation of rye as cover crop ensures SOM accumulation down to 30 cm depth (+30% than CT). No till and minimum tillage (MT) may increase SOC and STN levels in the 0-30 cm soil layer, both as concentration and as mass, compared with CT. Most of such a SOC and STN increase is due to C- and N-rich macroaggregates. Within macroaggregates, microaggregates (mM) are of primary importance for soil organic matter stabilization since C and N pools associated to mM account for between 41 and 65% of total C and N content in the NT and MT systems.

RIASSUNTO GENERALE

L’introduzione di agro-ecosistemi conservativi viene indicata come strategia per aumentare il sequestro del carbonio organico nel suolo (SOC) e migliorarne la fertilità.

La continua applicazione di concimi organici, come il compost e il sovescio, favorisce il sequestro di SOC (+ 1.3 ÷ 2.5 Mg C ha^{-1} $anno^{-1}$) e l'accumulo di azoto totale del suolo (STN) (+ ~ 1 Mg N ha^{-1} $anno^{-1}$). Tuttavia, quando le fertilizzazioni organiche vengono interrotte, il SOC diminuisce rapidamente.

Negli agro-ecosistemi intensivi, il no till (NT) garantisce rese comparabili a quelle dei sistemi convenzionali (CT) immediatamente dopo la transizione. Il NT aumenta la sostanza organica (SOM) e il STN principalmente nei primi 5 cm di terreno, sebbene la cover crop di segale assicuri l'accumulo di SOM fino a 30 cm di profondità (+ 30% rispetto alla CT). Il NT e la minima lavorazione (MT) portano ad un aumento del SOC e del STN nei primi 30 cm di suolo, rispetto al CT. Gran parte di tale aumento è dovuto ai macroaggregati, all'interno dei quali, i pool di C e N associati ai microaggregati (mM) rappresentano tra il 41 e il 65% del contenuto totale di C e N nei sistemi NT e MT.

SUMMARY

SUMMARY

Intensive conventional agriculture [conventional tillage (CT)] can contribute to high crop productivity; however, with its excessive use of pesticides and mineral fertilizers, it may have a negative impact on the environment by decreasing biodiversity, causing pollution and water eutrophication, and degrading soil quality. Many common agricultural practices, especially ploughing and rotary-tillage, indeed accelerate the decomposition of soil organic matter (SOM), leaving the soil susceptible to wind and water erosion.

SOM affects the chemical and physical properties of the soil and its overall health. Its composition and breakdown rate influence the soil structure and porosity, the water infiltration and moisture holding capacity of soils, the diversity and biological activity of soil organisms and the availability of nutrients (mainly N and P) for plants.

Conservation agriculture (CA) represents an effective management for maintaining or increasing SOM content; it includes a range of practices that combines no till (NT) or minimum tillage (MT) with cover crops (CCs) cultivation and crop rotations. It maintains surface residues and roots and enhances soil aggregation and porosity, in turn allowing water infiltration and reducing runoff and erosion. Moreover, the potential of CA management for contributing to soil C sequestration may guarantee soil fertility increase and food production support, reducing at the same time soil greenhouse gas emissions, thus mitigating the climate change.

The specific objectives of this thesis are: (i) to investigate the effects of different land use (cropland *vs.* grassland) and fertilizers (mineral fertilizers *vs*. organic fertilizers) on SOC and soil total N (STN) accumulation and summer crops (maize, sunflower and soybean) yield; (ii) to assess the medium-term influence of NT coupled with different CCs (rye, hairy vetch and a 5-species mixture) on main components of soil fertility (SOM, STN and available P) and the productivity of winter wheat, maize and soybean; (iii) to measure the effect of contrasting tillage systems (NT, MT and CT) on grain yield and biomass return during a 8-year maize monoculture, examining how those tillage systems affect the evolution of SOC and STN levels and the soil aggregates dynamics.

The thesis has 3 research chapters, next to a general introduction (Chapter 1) and a general discussion (Chapter 5).

In Chapter 2 the effects on SOC sequestration and STN accumulation of land use and organic/mineral fertilization were assessed. In particular, we investigated the consequences of an “enriching” period (EP), when C- and N-enhancing strategies (e.g. incorporation of CCs and compost distribution) have been applied, on temporal patterns

of SOC and STN during a “depleting” period (DP), when those strategies have been stopped. During EP, SOC sequestration and STN accumulation at 0-30 cm depth increased under compost and CC treatments, while during DP, SOC rapidly decreased under all cropland treatments. The decline in SOC was twice than the annual C applied every year under both CC treatments, 31% higher than the annual C applied under compost, and only 16% higher than the annual C input under mineral fertilizer. Converting cultivate land to grassland increased both SOC and STN stock to the highest level of the study.

In Chapter 3 we investigated the influence of 6 years of NT with CCs on SOM, STN, and soil P concentration, in comparison with CT, and we evaluated how these effects are affected by different types of winter cover crops (rye CC as gramineous monoculture; hairy vetch CC as leguminous monoculture; 5-species mixture including gramineous, leguminous brassicaceous plants as “high diversity” mixture). The effects of those management systems on grain and total yield were annually evaluated. In the present study, NT with CCs did generally not reduce yields of winter wheat, maize and soybean since the first year after transition.
After six years, SOM and STN concentration in the 0-30 cm soil layer increased under NT with CCs treatments. SOM concentration was +30%, +23% and + 20% higher than CT under NT-rye, NT-mix and NT-vetch, respectively, while STN concentration was +28% higher under NT-rye and NT-vetch and +21% higher under NT-mix, than CT. The SOM gain was the highest in the uppermost soil layer (0-5 cm), mainly under NT-rye (+89% than CT). Also STN pattern showed a consistent increase (+75% under NT than under CT) in the topsoil (0-5 cm). Conversely, P concentration was not influenced by the NT-CCs system.

In Chapter 4, firstly the impact on grain yield and biomass return of CA systems (NT and MT) compared to CT was evaluated under a 8-year maize monoculture, and secondly SOC and STN concentration and mass, as well as soil aggregation were studied under contrasting tillage systems. Soil samples (at 0-10 and 10-30 cm depth) were collected at the beginning of the experiment and every two years after maize harvest to determine SOC and STN concentration. Soil aggregate stability and aggregate size distribution (at 0-5 cm, 5-10 cm and 10-30 cm) were evaluated at the end of the experiment. Results showed that MT increased maize grain yield and total biomass compared with CT. Conversely, NT reduced maize grain and biomass production during the initial 5-year transition, but afterwards increased maize yield up to that of CT. SOC and STN accumulation were increased under NT and MT. Most of such SOC and STN increase was located into C- and N-rich macroaggregates.

To resume, main conclusions of this PhD thesis are as follows:

i) Introducing winter CCs into a summer crop rotation could be an efficient practice to (i) increase organic matter inputs to the soil, (ii) mitigate SOC and STN losses at the cropping system level, and (iii) potentially increase crop productivity. In addition, since converting cultivate land to grassland led to the highest SOC and STN stock, reducing soil disturbance should be considered to primarily enhance soil fertility (Chapter 2);

ii) In fine-textured soil under temperate climate, the elimination of soil tillage and the continue fresh organic matter inputs to the soil derived from crops residues generates a consistent increase of SOM and STN levels at 0-30 cm depth under NT, compared with CT, without penalizing yield (Chapter 3);

iii) MT may immediately increase maize grain yield and total biomass compared with CT. Most of SOC and STN increase is due to C- and N-rich macroaggregates. This highlight the importance of macroaggregates for C and N sequestration as affected by changes in soil tillage practices. Within macroaggregates, microaggregates (mM) are of primary importance for soil organic matter stabilization since C and N pools associated to mM accounted for the half of total C and N content in the NT and MT systems across different soil layers (Chapter 4.