UNIVERSITÀ
CATTOLICA
del Sacro Cuore

Doctoral School on the Agro-Food System

cycle XXX

S.S.D: AGR/02

TOWARDS REDUCING THE IMPACT OF SOIL MANAGEMENT AND TILLAGE PRACTICES ON THE GLOBAL CLIMATE CHANGE

Coordinator: Ch.mo Prof. Marco Trevisan

Candidate: Dr. Andrea Fiorini

Matriculation n°: 4412048

Tutor: Prof. Vincenzo Tabaglio

Academic Year 2016/2017

Fiorini A. (2018). Towards reducing the impact of soil management and tillage practices on the global climate change, 172 pages.

PhD thesis, Università Cattolica del Sacro Cuore, Piacenza (IT).

Contents

General Abstract

Adoption of sustainable (agro)ecosystems has been widely suggested to increase soil organic carbon (C) sequestration, to mitigate climate change and enhance soil fertility.

Although its carbon sequestration potential has been generally overestimated, no-till (NT) results in an extra C sequestration of 0.26 ± 0.18 Mg ha^{-1} yr^{-1} as compared to conventional tillage and 76.6% of this extra C is located in C pools which could be considered relatively stable.

NT increases root development of field crops (i.e. maize, soybean, winter wheat) in the top soil (0-5 cm), while does not in the deeper soil (5-60 cm). Positive correlations between root density and soil physical parameters shows how roots are main drivers of soil physical properties under NT.

Cover crop residues may affect nitrous oxide (N_2O) emissions under NT: rye residues enhances soil-nitrogen (N) immobilization, thus increasing N use efficiency and decreasing N_2O, while hairy vetch residues as cover crop under NT increases N_2O as a consequence of soil-N mineralization.

N_2O emissions and shoot productivity may be positive correlated in grasslands, because other mechanisms than plant-induced regulation of soil N pool may control N_2O: C could be a major factor regulating nitrification and denitrification processes.

Keywords: C sequestration; no-till; roots development; cover crops; nitrous oxide emissions; grasslands.

Riassunto generale

L'adozione di (agro)ecosistemi sostenibili viene indicata come una efficace strategia in grado sequestrare carbonio (C) nel suolo, mitigando così il cambiamento climatico e migliorando la fertilità.

Sebbene il potenziale di sequestro del C della non-lavorazione (NT) sia stato generalmente sovrastimato, esso risulta essere di 0,26 Mg ha^{-1} $anno^{-1}$ superiore rispetto al regime arativo. Inoltre, il 76,6% di questo quota è localizzato in frazioni considerabili come relativamente stabili.

Il NT aumenta lo sviluppo radicale delle colture erbacee (es. mais, soia, frumento) negli stati superficiali del suolo (0-5 cm). Le correlazioni tra i parametri di densità radicale e le proprietà fisiche del suolo mostrano come lo sviluppo radicale sia un fondamentale indicatore di qualità del suolo in NT.

I residui delle *cover crops* influenzano le emissioni di protossido d’azoto (N_2O) in NT: i residui di segale favoriscono l'immobilizzazione dell’azoto (N), aumentandone così l'efficienza d’utilizzo e diminuendo le emissioni, mentre i residui di veccia vellutata aumentano l’N_2O come conseguenza della mineralizzazione dell’N.

Le emissioni di N_2O e la produttività dei prati stabili possono essere positivamente correlate, perché meccanismi diversi rispetto alla regolazione indotta dalla disponibilità di N possono controllare l'N_2O: il C potrebbe essere un principale fattore di regolazione per nitrificazione e denitrificazione.

Parole chiave: sequestro del C; non-lavorazione; sviluppo radicale; cover crops; emissioni di protossido d’azoto; prati stabili.

SUMMARY

SUMMARY

Globally, more than two-thirds of terrestrial carbon (C) is stored in soils, with a pool size more than twice that of the total C in the atmosphere. Thus, changes in soil C stocks have an important impact on the global C cycle. Due to human land-use activities, such as the conversion of natural vegetation to agricultural land, soil organic C has declined by 10%-59%, resulting in approximately 35% of historical anthropogenic carbon dioxide (CO_2) emissions between 1850 and 1990. This contributed to global warming and related environmental problems.

Carbon is the main components of soil organic matter (SOM), which plays an essential role in determining soil fertility and providing nutrients for plant growth. Reduced soil fertility due to depletion of SOM is imposing an unprecedented challenge for our rising food demand in the context of a rapidly growing human population. Increasing soil organic carbon (SOC) sequestration in soil is indeed a key way not only to mitigate climate change, but also to enhance soil fertility and thus sustain food production. Therefore, adoption of sustainable (agro)ecosystems management can lead to preserve existing C stocks and to remove at the same time C from the atmosphere, while having a positive impact on food security, agro-industries, water quality and the environment.

The overall objective of this thesis is (i) to understand the long-term potential of no-till (NT) for C sequestration in soils, exploring key environmental and management drivers and identifying mechanistic relationships between tillage and SOC inclusion within aggregates; (ii) to study how the main traits of root architecture and its composition (C and nitrogen (N)) are affected by tillage system (CT *vs* NT) in the top 60 cm of soil under maize, soybean, and winter wheat; (iii) to assess the impact of tillage system (CT *vs* NT) and cover crop (CC) residue (*Secale cereale vs Vicia villosa*) on nitrous oxide (N_2O) emission from soybean and maize; and (iv) to examine how a plant community composed of three grasses (*Lolium perenne*, *Festuca arundinacea*, and *Poa trivialis*) and one legume (*Trifolium repens*), across a diversity gradient (monocultures, two- and four-species

mixtures), affect N_2O emissions. This thesis has 4 research chapters, next to a general introduction (Chapter 1) and a general discussion (Chapter 6).

In Chapter 2, the effects of NT on the increase of SOC storage, focusing also on C distribution within aggregate-size soil fractions, were reviewed. We assess these effects in a comprehensive meta-analysis encompassing 358 observations from 72 studies. On average, NT increases SOC stock, especially in the upper 0-5 cm. Nevertheless, our results support the concern that C sequestration potential of NT is generally overestimated, and the effect of NT to increase SOC in the surface soil is partially offset by losses of C storage near the bottom of the plow layer. Overall NT resulted in an extra C sequestration of 0.26 ± 0.18 Mg ha^{-1} yr^{-1}. Furthermore, C stock accumulation due to NT is for 85.7% related to increases in large (>2000 µm, LM) and small (250-2000 µm, sM) macroaggregates. Within these macroaggregates, most extra C is located in microaggregates- (mM) (25.4%) and silt and clay-within-macroaggregates (s+cM) (51.2%). As these pools are physically (mM) and chemically (s+cM) protected and their inclusion inside LM and sM turns into a further physical stabilization, it means that 76.6% of the total additional C due to NT could be considered relatively stable for long-term C sequestration.

In Chapter 3, a transparent and uniform methodology for characterizing root systems of field crops were adopted in a three-year crop rotation under CT and NT. Root length density (RLD), diameter class length (DCL), root dry weight (RDW) and roots composition (C and N) in the top 60 cm of soil were characterized. The total amount of roots C (TRC) was calculated by multiplying RDW by roots C content and relationships among roots, soil bulk density (BD) and penetration resistance (PR) were investigated. The effect of NT on roots development was evident on all crops (maize, soybean and winter wheat) in the top soil layer (0-5 cm), where it increased RLD and RDW, compared to CT. Moreover, TRC suggests that the positive effect of NT on the potential C storage derived from roots is limited to the top layer (0-5 cm) for silty clay soils. Therefore, 5 cm soil depth could be indicated as a critical threshold for differences between CT and NT induced by crop root growth. We found that chemical composition of roots was related to roots diameter size and roots N and C:N variations were mainly dependent on the effect of NT on the percentage of roots coarser than 2 mm. Furthermore, roots promoted a physical improvement of soil conditions and both soil BD and PR decreased with time in the topsoil. Last but not least, the significant correlation between root traits (RLD, RDW) and soil physical parameters (BD, PR) under NT corroborates the hypothesis that roots are a main driver of soil physical properties and stability of continuous biopores induced by NT is more relevant than the total porosity amount to affect root growth.

In Chapter 4, firstly the impact of tillage (CT *vs.* NT) practices on nitrous oxide emission was investigated; then, we evaluated the influence of cover crop residue (rye *vs.* vetch) on N_2O under NT. Gas sampling took place during three periods of soybean growing season (emergence phase, N-fixation phase, and maturity phase) in 2015 and the entire cropping season of maize in 2017. During soybean, cumulative N_2O emissions were different between tillage systems (CT *vs* NT) in the emergence phase, but not in the maturity phase. Higher N_2O in CT than in NT (with rye as CC) was the consequence of higher NO_3^--N availability in CT than in NT soil and N availability could be indicated as a main factor affecting N_2O emission differences between CT and NT in our study. Cover crops affected N_2O emission during maize under NT. Vetch, which increase soil NO_3^--N content, significantly enhanced N_2O losses compared to rye. Beyond N availability, CC residues with lower C:N ratio in vetch (15) than in rye (30) stimulated microbial activity and, thus enhanced N_2O emissions. Our results suggests that applying NT system together with rye as CC can be recommended as a suitable management approach to mitigate N_2O in agricultural soils.

In Chapter 5, a field experiment to examine how three grasses (*Lolium perenne*, *Festuca arundinacea*, and *Poa trivialis*) and one legume (*Trifolium repens*), across a diversity gradient (monocultures, two- and four-species mixtures) affect N_2O emissions was conducted. The most productive species, *Lolium perenne*, resulted in the highest emissions ($P < 0.01$) after the expected peak in emissions. Additionally, yield-scaled N_2O emissions increased with species richness ($P < 0.01$). The presence of *Lolium perenne*, rather than the legume, greatly increased emissions (by 89%; $P < 0.001$). Emissions were lowest overall from bare soil plots, which had the highest soil moisture and N availability values. Therefore, soil carbon (C) availability, not mineral N, was likely the main factor regulating N_2O emissions from denitrification in this system. *Festuca arundinacea* in combination with *Trifolium repens* demonstrated the best potential for reducing N_2O emissions (59% reduction compared to the commonly used *Lolium perenne* monoculture) without compromising productivity. We conclude that judicious selection of plant species combinations shows considerable potential for reducing N_2O emissions from grasslands, but controlling pathways are intricate, including both C and available N in the soil.

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

- NT increase C storage in soils but its C sequestration potential has been generally overestimated (Chapter 2);
- C sequestration increase under NT is limited to the top 5 cm of soil but it does not seem to be somehow limited for C saturation also after 30 years, suggesting further sequestration potential over longer periods (Chapter 2);
- most of C increase (76.6%) in NT soil is physically (microaggregates within-macroaggregates) and chemically (silt and clay within-macroaggregates) protected and also included inside macroaggregates with a slower turnover in NT than in CT, which turns into a further physical stabilization and reduced decomposition rate (Chapter 2);
- NT positively affects roots development of maize, soybean and winter wheat in the 0-5 cm layer (Chapter 3);
- Significant correlation between root traits and soil physical parameters under NT corroborates the hypothesis that roots are major drivers for soil physical quality and stability of continuous biopores induced by NT is more relevant than the total porosity amount to affect root growth (Chapter 3);
- NT (with rye as winter cover crop) enhances immobilization of residual soil-N compared to CT, thus promoting a more efficient use of N and decreasing N_2O emissions (Chapter 4);
- Residues of hairy vetch as cover crop increases N_2O emissions from the following maize compared to rye mainly as a consequence of vetch derived N-fixation and C:N ratio of vetch residue, which increase microbial activity (Chapter 4);
- N_2O emissions and shoot productivity may be positive correlated, thus supporting the hypothesis that other mechanisms than plant-induced regulation of the soil N pool may control N_2O emissions in grasslands (Chapter 5);
- larger N_2O emissions may derives from soils with lower NO_3^- concentration because C could be a major factor regulating nitrification and denitrification processes (Chapter 5).