UNIVERSITÀ DI TORINO

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Department of Agricultural, Forest and Food Sciences

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OECD CRP Fellowship Summary Report

Torino, 8.11.2023

Name:	Daniel Said Pullicino
Title:	Belowground carbon allocation by rice plants: exploring the trade-off between soil carbon sequestration and methane emissions
Theme number:	Managing Natural Capital (Theme 1)
Host institution:	University of Sydney
Host collaborator:	Prof. Feike Dijkstra
Dates of Fellowship:	3rd April to 1st October 2023

I hereby consent to the use of this report by the OECD Co-operative Research Programme

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1. Objectives of the Research Project

Paddy soils represent essential resources for sustaining global food security through rice production. They however also represent major contributors to global GHG emissions though, at the same time, hold an important potential to sequester carbon (C). The main objectives of this collaborative research project was to shed light on the plant-soil-microbe interactions responsible for regulating the soil C cycle in rice paddies as a function of soil properties and water management. Although, various management practices have been previously shown to be effective in mitigating GHG emissions from rice paddies (e.g. alternative water, crop residue and fertilizer management practices), little is yet known on the trade-off between greenhouse gas emissions (i.e. carbon dioxide, CO_2; methane, CH_4) emissions and soil organic C storage, and even less on the contribution of belowground C allocation to the underlying soil processes. The influence of soil properties and agricultural management practices on this root C flux is largely unaccounted for in current agro-ecosystem C budgets. The outcomes of this research therefore aim to strengthen our understanding and correctly account for these under-studied processes, in order to improve the environmental sustainability of rice cropping systems worldwide.

2. Were the objectives of the fellowship achieved?

In this project we used a novel ^{13}C-CO_2 pulse-labelling method, previously developed for upland systems by the host institution, to quantify the contribution of rhizodeposition to belowground respiration by partitioning the emitted CO_2 between that derived from the mineralization of rhizodeposited C from root respiration in intact plant-paddy soil systems. We also quantified the contribution of rhizodeposited C to CH_4 emissions. Through the use of these stable isotope tracing techniques, we provided novel insights into the dynamics of photosynthesized C in the rice rhizosphere and the implications this C input may have on rhizosphere processes in these redox-dynamic environments as a function of soil properties and water management. The main scientific findings briefly included:

- Rice plants respond to changes in water management by increasing belowground C allocation under alternate wetting and drying (AWD) with respect to continuous flooding, and this has important implications on the relative contribution of root respiration, rhizodeposited and soil-derived C mineralization to total belowground respiration rates.
- Rhizodeposited C can contribute substantially to CH_4 emissions both directly by serving as a substrate for methanogens (10-50%), and indirectly by promoting the desorption of soil-derived DOC during the reductive dissolution of Fe oxides. The relative contribution of root and soil-derived C to CH_4 emissions depends on both water management and soil properties.
- The microbial mineralization of rhizodeposited C and root respiration contribute substantially to total belowground CO_2 emissions (32-82%). The contribution of these sources is directly related to root biomass and water management with AWD substantially increasing root respiration as well as the microbial mineralization of both rhizodeposited C and SOC.

3. What were the major achievements of the fellowship (up to three)?

- Establishment of a new research collaboration between the soil science groups of the University of Torino and the University of Sydney regarding plant-soil-microbe interactions and their role in driving soil functions.

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- Acquisition of essential know-how on the use of stable isotope tracing approaches for the study of complex below-ground processes responsible for GHG emissions and soil organic C stabilization.
- Provision of new understanding on the microbial utilization of rhizodeposited C in rice paddies as an important component of below-ground respiration that is sensitive to both management-dependent soil redox conditions and soil properties.

4. Will there be any follow-up work?

Over the next months we will continue to work together with the host institution to finalize the analysis of the remaining soil and microbial biomass samples, as well as data analysis. The findings of this project will contribute to the drafting of a manuscript for submission to an international peer-reviewed soil science journal. The methods developed and utilized within this project will be surely reproduced in the sending institution that has recently invested significant resources to the setting up of a new stable isotope research facility. Further research questions that derive from this project will surely be the subject of future MSc and PhD research projects. Moreover, Prof. Feike Dijkstra and myself have also jointly proposed a session *agricultural challenges*" that we will be co-chairing during the Centennial congress of the International Union of Soil Science to be held in Florence, Italy between the 19-21 May, 2024.
The fellowship has definitively set the grounds for maintaining a strong collaboration between our research groups on topics of common interest. This could take the form of joint funding applications as well as international mobility of early stage researchers that could further strengthen current relationships.

5. How might the results of your research project be important for helping develop regional, national or international agro-food policies or practices, benefit for society?
Paddy rice agro-ecosystems are nowadays facing important challenges linked to the adaption to and mitigation of climate change. In this context, the adoption of water management practices alternative to the conventional continuous flooding of rice paddies are becoming more widespread. Practices such as AWD in which fields are drained and reflooded multiple times during the growing season, are effective in reducing the dependence on fresh water resources that are becoming increasingly scarce, and at the same time contribute to mitigate the CH_4 emissions thereby lowering the global warming potential with respect to continuous flooding. This project has provided novel insights into how changes in irrigation regimes may affect root C fluxes and plant-soil-microbe interactions responsible for belowground CO_2 and CH_4 emissions, including feedback mechanisms driving the partitioning between plant and soil-derived sources, and the stabilization of rhizodeposited C. These findings may contribute to improve our understanding on how changes in water management could affect the C budgets and environmental sustainability of rice cropping systems.

6. How was this research relevant to the objectives of CRP and the CRP research theme?
The relevance of the research to the objective of CRP Theme 1 "Managing natural capital" lies in the provision of new insights into belowground C cycling and plant-soil-microbe interactions in rice paddies as a function of soil properties and water management, as well as their implications for GHG emissions and soil organic C stabilization. Rice is generally monocropped in flooded paddy fields using large amounts of freshwater. However, the limited water availability as a consequence of climate change and the need to enhance environmental sustainability by mitigating methane emissions is leading to an increasing adoption of alternative water-efficient agricultural practices. In particular, alternate wetting and drying (AWD), which involves intermittent field irrigation, has been shown to be effective in increasing

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WUE and GHG mitigation potential compared to continuous flooded practices. The outcomes of this research project have evidenced how a shift to AWD could not only reduce CH_4 emissions but also impact belowground C allocation by the plant, microbial utilization of the rhizodeposited C, its mineralization and stabilization on soil minerals. Moreover, results have shown that these rhizosphere processes also depend on the intrinsic edaphic factors and could be therefore site-specific.

7. Satisfaction

The OECD CRP fellowship exceeded all my expectations both from a scientific and social point of view. The Fellowship has enabled me to make valuable new connections within and outside academia, with individuals and organisations concerned with the environmental sustainability of intensive cropping systems. The research environment I found at the Centre for Carbon, Water and Food (CCWF) of the University of Sydney is a fully inclusive and friendly one, and the research infrastructures made available were fully adequate to carry out the planned work. The time spent working with the Soil Biogeochemistry group at the University of Sydney was enlightening and truly stimulating. Over and above, it was a great pleasure to spent time with and get to know all the wonderful members of this research group. I am hugely grateful to Professor Dijkstra for supporting my application and visit to the CCWF, including facilitating meetings with relevant researchers in different parts of the University. This experience will surely benefit the future research I carry out, and indirectly any future career opportunities as international mobility for faculty staff is highly regarded and supported by my University.

I did not encounter any practical problems, and I was also facilitated in my Fellowship experience by having the opportunity to be accompanied by my family for the whole duration of the research period in Sydney, even though their costs were not covered by the fellowship. Communication with the CRP administrative staff was always very cordial and timely. In my opinion the CRP Fellowship programme works very well and gives a highly recommended and excellent opportunity to a substantial number of researchers each year.

8. Advertising the Co-operative Research Programme

I learnt about the CRP fellowship program from our Department's Research Support Team and obtained full details from the website. I subsequently contacted the advisory board members for the theme I was interested in and they helped by answering questions regarding the relevance of my research ideas for the specific call and its objectives. I think the visibility of the programme could be increased by liaising with the various national and international scientific societies that already have a capillary contact with potential applicants. CRP could also involve and support previous Fellowship winners in dissemination activities benefiting from their research networks.