A novel cropping system for climate neutral and bio-diverse rice farming

1. Introduction and problem statement

Provision of sufficient amounts of nutritious food for the ever-increasing global population is probably the largest challenge facing mankind, which has been further complicated by alarming levels of environmental changes together with increasingly complex global economy. On one hand, being directly exposed to the effects of environmental extremes, agriculture is threatened by the climate change across globe and more so in underprivileged tropical parts. At the same time, being primary anthropogenic activity, agriculture has also been identified as an important contributor of greenhouse gas (GHG) emissions. Food systems cause 19%-29% of the total global anthropogenic GHG emissions, 80%-86% of which are attributed to agricultural activities alone[1]. Anaerobic soils of rice paddies, together with wetlands, account for two-thirds of 'natural' and one quarter of total emissions of methane (CH_4) globally[2]. Being a major staple crop, rice has a prominent role in ensuring global food security. To fulfil the needs of increasing population, production of rice needs to be increased, which will inevitably increase CH_4 emissions.

Aforementioned facts underline the strong need to develop new mitigation strategies and cultivation methods[3]. Some of the mitigation strategies proposed in the past (e.g. direct seeding, altered irrigation and/or fertilization regimes)[4,5] showed useful results at experimental stages but were not adopted on field for practical challenges. In this project, I explored the potential of developing new rice based cropping system integrated with a novel strategy to mitigate GHG emissions, while enhancing the agro-biodiversity in paddy fields. During my previous research with wetland plant species, I found that some plant species could reduce methane emissions from soil, whereas others don't[6,7,8]. As methane is produced in the soil under anaerobic conditions, taking cues from my findings, I hypothesised that the co-cultivation of rice together with the plants possessing high rhizosphere oxidation capability can significantly reduce CH_4 emissions from paddy fields. There are a number of aquatic plant species that exist naturally in rice producing regions and have been used by the local people, since ancient times, for food and/or medicinal values. Unfortunately, monocultures based agricultural intensification during the past decades ignored and largely eliminated these plants from the agricultural landscape. Such plants offer an incredible potential for systematic incorporation into rice based cropping systems. Co-cultivation of these species together with rice would not only reduce CH_4 emissions, but can also contribute towards diverse diets needed for nutrition of farming families, along with enhancing on-farm biodiversity.

2. Objectives

In order to develop an ecologically sustainable and economically viable cropping system for rice by intercropping with other aquatic plants having significant potential for CH_4 mitigation, I conducted this Post-Doc project at ETH, Zurich with following main objectives:

- To identify the required aquatic plant species used by local cultures in rice growing regions.
- To study the effect of plant species diversity on GHG emissions from paddy fields.
- To test various aquatic plant species for their potential to reduce CH_4 emissions while grown together with rice.

3. Materials and Methods

To identify the required species, I made an extensive literature review and travelled to the rice farming regions namely, China, Vietnam, Philippines and India. I short-listed a number of plant species, which share the environmental niche with rice and possess certain economic value (as food and/or medicine) in the local communities. To test the viability of the proposed approach, I conducted a field study in India and a mesocosm experiment in Switzerland. In both the experiments, collection and analysis of gas flux samples was simultaneously performed by using closed chamber technique coupled with photoacoustic field gas measurement equipment [7].

To understand the relationship between the plant species richness and GHG emissions from a paddy field, a field study was conducted on the experimental site of a long-term agronomic trial in the research fields of Punjab Agricultural University, India. This site offered a unique situation with different weed population densities resulting from various weed management practices applied on fixed plot basis in rice-wheat crop rotation, since 1993.

To quantify the potential reduction in CH_4 emissions by various aquatic plants upon co-cultivation with rice, a mesocosm experiment was conducted at ETH, Zurich. Five aquatic plant species were grown alone and in combination with rice, replicated 7 times. For this experiment, we used rice (*Oryza sativa*) mega variety IR64, which is the most widely grown *indica* rice in South and Southeast Asia; and five aquatic plant species, namely, *Anemopsis californica, Cyperus esculentus* L., *Cyperus rotundus* L., *Nasturtium officinale* and *Sagittaria latifolia*. These plants occur in nature under the same environmental conditions as rice, and do possess certain economic potential. *A. californica* has edible roots and is known as Yerba Mansa or lizard tail. Though, *C. esculentus* and *C. rotundus* – known as tiger nut and coco-grass respectively – are considered invasive weeds of rice in some areas, but they are also renowned for their edible tubers together with *S. latifolia*, known as duck potato. For its health benefits and nutritive value, the tiger nut has already been considered for commercial cultivation in some areas[9]. Apart from their dietary uses, all of these aquatic plants possess some sort of medicinal value[10,11,12].

4. Research Findings

The results of the field study proved that CH_4 emissions are correlated to the on-farm plant biodiversity (Figure 1). This provided a conceptual validation to the idea that CH_4 emissions could be reduced by enhancing plant biodiversity in the paddy fields. However, it would never be advisable to grow more weeds on the field. Therefore, we tested the carefully selected aquatic species in the mesocosm experiment.

The results from the mesocosm experiment clearly suggest that co-cultivation of rice with the selected aquatic plants can substantially reduce CH_4 emissions – by more than 60% with tiger nut and coco-grass (Figure 2). Though the mesocosms with two rice plants grown together showed a tendency towards lower emissions, but they were statistically similar to single rice plant mesocosms. This shows that the reduction of emission by co-cultivation with other aquatic species was not because of direct competition; rather it was likely a result of increased rhizosphere oxidation and might be associated to occupation of different rhizosphere zones by the roots of two different plants (i.e. rice and another aquatic plant). As no nitrogen fertilizer was applied, the emissions of N_2O from all the mesocosms were negligible.

Besides the reduction of CH_4 emissions, some of the species however, gave strong competition to rice e.g. co-cultivation with duck potato caused around 80% reduction in plant biomass of rice. Therefore, despite significant reductions in CH_4 emissions, it could not be the plant of choice for intercropping with rice. Whereas, co-cultivation with lizard tail, for example halved the CH_4 emissions, without harming the productivity of rice, and hence could be a suitable plant for intercropping with rice in the field. This underlines the need for careful selection and testing of plant species in accordance with their growth form, local conditions and cultural practices. The findings of this study confirm that a novel cropping system could be developed by co-cultivation of rice with other aquatic plant species, which would be climate neutral, bio-diverse and would contribute towards nutritional enhancement by diet diversity.

5. Capacity building and dissemination

Being funded by the 'Research Fellow Partnership Program' of the 'Swiss Agency for Development and Cooperation (SDC)' via (former) North-South Centre of ETH Zurich, development of human resources for agro-ecological research was an important objective of this Post Doc project. The professional development of the fellow (Gurbir S. Bhullar) himself and the completion of a semester project in Switzerland and a master thesis in India are strong evidence that this objective was successfully achieved. Furthermore, the project results were widely disseminated in various international meetings and scientific conferences in Asia, Australia and USA and were enthusiastically received by the scientific community. Soon, a research article based on the study results would be published in a reputed peer-reviewed journal.

6. Development Potential, Outreach and Future Outlook

Globally, there is a growing understanding about the importance of biodiversity for sustainable agro-ecosystems as large scale monocultures with high-energy inputs have proven to be unsustainable in the long run, though being highly productive in the short term[13]. The innovation demonstrated in this project has immense adoption potential and it opens up a new area of development-oriented research for on-farm adoption. It is foreseen that the economic and nutritional advantage associated to the new plant species will encourage farmers to adopt this technology. Besides, the need to adapt locally available agricultural technologies and to develop new approaches for processing and marketing of products from these aquatic plants would also encourage entrepreneurship at the local level.

Encouraged by the positive results from this Post Doc project, the further steps required for implementation are already being planned. Before releasing any such technology for implementation, it is important to understand the farmers' perceptions and their willingness to adopt the proposed technology. In partnership with Punjab Agricultural University and Palmyrah Workers Development Society, I plan to conduct a survey of farmers in two distinct agro-climatic zones of India. The interactive design of the survey will help to gain knowledge from the farmers while updating their information on facts about climate change. Besides, I also intend to conduct field trials on farmers' fields using participatory research approach.

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Figures and Images:

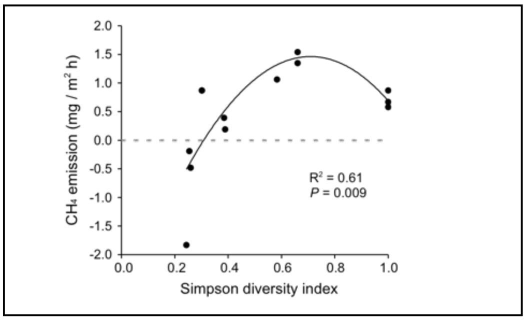

Figure 1: Effect of plant species diversity on CH_4 emissions Simpson diversity index value 0 corresponds to infinite diversity, and 1 is no diversity i.e. only one species (rice)

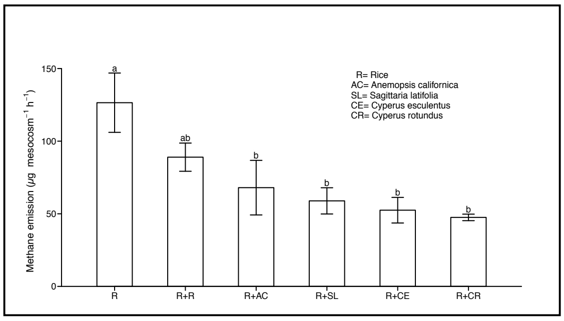

Figure 2: CH_4 emissions from mesocosms planted with rice alone and rice in combination with other aquatic plant species




Picture 1: Aquatic vegetables on sale in a vegetable Market in Najing, China

Picture 2: Capacity building: A semester student receiving hands-on training on GHG flux measurement

Pictures 3 and 4: Measurement of GHG emissions from paddy fields at the research farm of Punjab Agricultural University, India.