Exploring trade-off and synergy for improving irrigated rice-based farming systems in the Senegal River Valley

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1. Abstract

Rice is the staple food for millions of people in Senegal. However, only about 40% of total rice consumption is satisfied through domestic production. The Senegalese government aims to increase rice production in the Senegal River Valley (SRV) through promotion of double rice cropping and reduction of yield gap with improved management practices. The objectives of this study were to (1) describe the main drivers influencing irrigated rice-based farming systems, (2) characterize current farming systems functioning along with farmers' strategies, and (3) investigate trade-offs and synergies between production, economic, social, and environmental performance indicators of irrigated rice-based farming systems. Farming systems functioning and their main drivers were qualitatively analyzed through data collected through interviews in the Delta and the middle valley of the SRV. The FarmDESIGN model was used to quantitatively evaluate farm performance indicators. We considered rice production, farm profit, leisure time, and N balance as production, economic, social, and environmental performance indicators.

Cropping systems differed between two locations and across farmers. Major crops were rice, tomato, and onion. Rice is grown in the wet and hot dry season, while two vegetables are grown in the cool dry season. Farms with large areas had more options and room for improvement than small farms. Double rice cropping was more common in the Delta than in the middle valley. Rice grown in the hot dry season produced higher yields and was perceived to have lower risks than rice grown in the wet season. As a result, farmers massively shift rice cultivation from the wet season to the hot dry season. Tomato and onion cultivation in the cool dry season was more profitable, more time-consuming and had larger N losses to the environment than rice cultivation. The major risk for vegetable cultivation was household self-sufficiency for rice, since rice and vegetable cropping calendars could overlap (end in the cool dry season and start in the hot dry season). Furthermore, lack of financial and technical support, high labor requirements, and lack of knowledge on vegetable cultivation are major constraints to their cultivation. Finally, crop diversification from rice cultivation was desired by most farmers, but smallholder farmers had limited room for their decision making due to institutional and financial service arrangements, and land size.

Results from FarmDESIGN model indicate that farm profit can be increased with reduced household leisure time and increased N losses, and rice production could be increased by cultivating rice in the hot dry season in

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the fields currently dedicated to vegetables. The latter option can reduce farm profit and N losses, but increase household leisure time. In conclusion, there are substantial trade-off and synergy in irrigated rice-based farming systems in the SRV. The government policy for enhancing rice production through promotion of double rice cropping is not likely to be effective for farmers aiming for high profit. Technical, financial, and institutional supports to smallholder farmers are essential for developing both vegetable and rice sectors in the SRV.

2. Context and challenge, including key interactions (range and nature) the case study addresses

Rice is the staple food for millions of people in Senegal (Tanaka et al., 2015). However, only about 40% of total rice consumption is satisfied through domestic production (Saito et al., 2015). Nearly 1 million tonnes of milled rice are annually imported (Fiamohe et al., 2018). High dependence on imported rice renders the country vulnerable to international market shocks with severe consequences for food security and political stability (Saito et al., 2015). The Senegalese government aims to support smallholder rice farmers and increase rice production in the SRV through the promotion of double rice cropping and reduction of yield gap with improved management practices. Furthermore, international R&D organizations have been supporting rice sector development in the SRV (MAER, 2014). However, such supports might be inefficient if not aligned with farmers' objectives, constraints, and decision-making processes.

The objectives of this study are to (1) describe the main drivers influencing irrigated rice-based farming systems, (2) characterize current farming systems functioning along with farmers' strategies, and (3) investigate trade-offs and synergies between production, economic, social, and environmental performance indicators of irrigated rice-based farming systems. Farming systems functioning and their main drivers were qualitatively analyzed through data collected through interviews in the Delta and the middle valley of the SRV. The FarmDESIGN model was used to quantitatively evaluate trade-offs between productive, socio-economic, and environmental performance indicators at farm-system level through a multi-objective Pareto-based Differential Evolution algorithm (Brosseau, 2018; Groot et al., 2010, 2012).

The aim of multi-objective optimization is to create alternative farm configurations with respect to a selected set of farm parameters and objectives (Groot et al., 2010, 2012). In this study, four objectives were defined based on interviews with farmers and expert knowledge of the three co-authors:

O1: maximize the area of rice (for enhancing rice production) as production performance indicator (the government's objective towards national rice self-sufficiency, and the smallholder farmers' objective towards household rice self-sufficiency);

O2: maximize farm profit as an economic performance indicator (farmers' objective towards farm economic prosperity);

O3: maximize farmer leisure time as a social performance indicator (farmers' desire and ambition to find or keep off-farm jobs, raise more animals, and spend more time with their family and for their hobbies); and

O4: minimize N balance as environmental performance indicator (experts' objective to lower nitrogen losses in the environment; a positive N balance implied a surplus of nitrogen that could be lost in the environment whereas a negative N balance implied soil nutrient mining, therefore, a minimum value of 0 was set up to avoid unsustainable soil mining)

3. How did research efforts deal with the synergies and trade-offs?

b) in the development of partnerships/delivery approaches

This study explored the synergies and trade-offs in irrigated rice-based farming systems for identifying the potential intervention areas for researchers and policymakers.

Based on results from interviews with farmers, we found that cropping systems differed between locations (the Delta, the middle valley) and across farmers. Major crops were rice, tomato, and onion. Rice is grown in the wet and hot dry season, while the two vegetables are grown in the cool dry season. Farms with large areas had more options and room for improvement than small farms.

Double rice cropping was more common in the Delta than in the middle valley. Rice grown in the hot dry season produced higher yields and was perceived to have lower risks than rice grown in the wet season. Risks for rice cultivation in the wet season include delayed sowing causing yield reduction, birds, diseases and pests. As a result, farmers massively shift rice cultivation from the wet season to the hot dry season (Zwart et al., 2017). We also found that complex socio-economic and institutional structures (e.g., Farmers' union, in French: Union des producteurs) exist within a village and shape farming activities such as decisions regarding which crop to grow, and farm machinery purchase and usage schedule. Also, successful rice cultivation, especially double rice cropping, was very much dependent on machinery availability (combine harvester and tractor). Number of machines are limited, and furthermore once they are broken, they cannot be easily repaired locally, as most of the machines are imported with no spare parts. As optimum sowing window in the wet season cropping is immediately after harvesting rice in the hot dry season, such machinery unavailability results in delayed sowing in the wet season, causing significant yield reduction (Tanaka et al., 2015). It is also noted that delay in credit procurement also caused delayed sowing (Tanaka et al., 2018).

Tomato and onion cultivation in the cool dry season was more profitable, more time-consuming and had larger N losses to the environment than rice cultivation. High labor requirements and lack of knowledge on vegetable cultivation are major constraints to vegetable cultivation. In fact, the difficulties encountered to develop the vegetable sector are mainly due to limited technical, financial, and organizational support to producers, and improper dissemination of agricultural information (David-Benz and Seck, 2018; MAER, 2014).

It was found in this study that crop diversification through the integration of (more) vegetables was desired by many farmers. In theory, crop diversification could increase and spread farmers' income, spread risks, and increase rural food security (Gay and Dancette, 1995; PNUE, 2005). However, the major risk for vegetable cultivation was the objective of the household to be self-sufficient in rice, since rice and vegetable cropping calendars could overlap (end in the cool dry season and start in the hot dry season). Moreover, the integration of (more) vegetables was constrained by institutional and financial service arrangements, and land size, letting limited room for smallholder farmers decision making (Diagne et al., 2013; Poussin et al., 2005; Tanaka et al., 2015).

Results from FarmDESIGN model indicate that farm profit can be increased with reduced household leisure time and increased N losses, and rice production could be increased by cultivating rice in the hot dry season in the fields currently dedicated to vegetables. The latter option can reduce farm profit and N loss, but increase household leisure time.

4. What kinds of partnerships were critical?

This research was done in collaboration with Wageningen University as part of the RICE CRP.

5. Lessons learnt, including knowledge gaps and good practices in employing these approaches at scale

In the current situation, the Senegalese government policy for enhancing rice cultivation through the promotion of double rice cropping conflicts with farmers' objectives. Therefore, policy-based interventions to promote double rice cropping are unlikely to be effective for farmers aiming for profit. Vegetable cultivation generates significant profit, but is time-consuming and has high nutrient losses. In fact, technical, financial, and institutional supports to smallholder farmers are essential for developing both vegetable and rice sectors in the SRV. Rice production enhancement to close the yield gap and support to double rice cropping requires further mechanization as well as repair and maintenance of the existing farm machinery (Diagne et al., 2013; MAER, 2014). Agronomic research and assistance to producers are needed to develop the vegetable sector (MAER, 2014). Nutrient management practices should be improved for vegetable crops, where both farmers and extension services could increase their expertise. Labor-saving technologies are needed for reducing labor inputs for vegetable cultivation. Improvement of transport infrastructures and post-harvest facilities, and dissemination of agricultural information, especially about market fluctuations would also be needed to develop the sector (David-Benz and Seck, 2018). Moreover, new cropping options through the integration of more different crops (e.g. maize, sorghum, cowpea, mung bean, sweet potato, chili, eggplant, watermelon) and/or the consideration of crop rotations of two or three years, instead of focusing on annual cropping(s), are needed to enhance rice-based farming systems in the SRV (Gay and Dancette, 1995).

To maintain benefit from vegetable cultivation in the cool dry season without reduction of total rice area, following interventions will be considered.

1. Further mechanization as well as the repair and maintenance of existing farm machineries to reduce the yield gap for rice cultivation and to reduce labor inputs for vegetable cultivation
2. Improving decision-making process at farmers' union level, so that farmers will be able to grow what they want to do
3. Rice irrigation schemes should be increased for rice area expansion
4. Improved crop management practices for enhancing rice yield in the wet season should be developed (addressing problem with diseases pressure and bird damages, improving weed management, etc.)
5. Improved nutrient management practices for vegetable crops to lower environmental impacts
6. Stable market price for rice for encouraging rice production
7. Agricultural information dissemination to enable farmers to adapt their strategy (e.g., market prices fluctuations)
8. Improving financial service for rice and vegetable cultivation as following:
    a) Increase credit duration to 12 months or longer months to avoid delayed pay-back to finance service > delayed credit attribution > delayed planting > delayed harvesting > delayed pay-back to finance service > etc. This vicious cycle should be broken
    b) Credit distribution for (more) broad range of crops

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