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Ecological mechanism and diversity in rice based integrated farming system

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ABSTRACT

The dynamic and transitional characteristics of rice field ecosystems provide an excellent environment for integration with compatible components such as fish and duck, which enhances the overall productivity through the effective nutrient recycling. The ecological mechanisms underlying the rice-fish-duck system sustainability have not been studied in detail especially on soil and water chemistry, dynamics of plankton, microbe and benthic populations and their community compositions. Therefore, the present study was undertaken to understand the ecological significance and diversities of organisms in the processes of maintenance of soil health, nutrient recycling and sustainable productivity in different rice-based integrated farming systems. In the integrated system such as rice-fish (RF), rice-duck (RD), and rice-fish-duck (RFD); the physico-chemical parameters of water (dissolved oxygen, nitrate, ammonia, total alkalinity, dissolved organic matter, and total suspended solid) and soil nutrient levels were significantly higher compared to conventional system due to the continuous addition of fecal matters, scooping and churning of soil by fish and ducks in the paddy field ecology. The aquatic biological diversity including planktons (phyto- and zooplankton), soil benthic fauna and microbial populations were dynamic in integrated rice-based system, provides an indication of enhanced soil fertility and production sustainability. The observed decreasing trends of plankton and soil benthic populations in integrated systems (RF, RD and RFD) indicated that fish and ducks fed these materials in rice ecology. Higher productivity and profitability in term of rice equivalent yields (REY) and the ratio of output value and cost of cultivation (OV/CC) were achieved in integrated farming system as compared to conventional rice farming (CRF). Thus, the present study reveals that adoption of rice-fish-duck integrated farming system enhances total farm production and income. Besides, the evaluation of different indicator indices *viz.,* water quality index (WQI) and soil quality index (SQI) have shown a good prediction about ecological aspects of agro-ecosystems and will be helpful in farm management decisions making processes for improving farm productivity, profitability, and overcome any potential limiting factors in the rice-fish-duck integrated farming system. Finally, the present study concluded that rice-fish-duck integration utilizes maximum ecological niches and converted into potential production processes, which enhances farm production, farmer income and improved the soil health through the effective nutrient recycling in the rice ecologies.

1. Introduction

Production of sufficient food for growing population with minimizing the negative impacts on ecosystems is one of the major challenges for modern agriculture today (Xie et al., 2011). Substantial enhancements of food production by the adoption of green revolution in the past resulting a distinct environmental degradation which is a concern of ecological safety. Human interference dramatically alters the natural habitats, influencing biogeochemical cycles and modifying biotic communities with consequence of loss of biodiversity and

Abbreviations: CRF, Conventional rice farming; RF, Rice fish integrated farming; RD, Rice duck integrated farming; RFD, Rice fish duck integrated farming; REY, Rice equivalent yield; WpH, Water pH; Temp, Temperature; EC, Electrical conductivity; DO, Dissolve oxygen; ORP, Oxidation-reduction potential; TDS, Total dissolve salt; N, Nitrate; A, Ammonium ion; TA, Total alkalinity; WQI, Water quality index; SQI_{Biol}, Soil quality index (biological); DOM, Dissolve organic matter; P, Phosphate; D, Diatoms; BGA, Blue green algae; WGA, Green algae; Eug, Euglena sp.; Cld, Cladocera; Pro, Protozoa; Cop, Copepod; Rot, Rotifer; Ba, Bacteria; Fun, Fungi; Act, Actinomycetes; Bra, Bradyrhizobia; SQI, Soil quality index; Den, Denitrifier; AO, Ammonia oxidizer; Nio, Nitrate oxidizer; SpH, Soil pH; TN, Total nitrogen; AN, Available nitrogen; AP, Available phosphorus; AK, Available potassium; SOC, Soil organic matter; Oli, Oligochaeta; Hir, Hirudinae; SGA, Gastropoda; Ne, Nematode; Ins, Insect larvae; SQI_{pc}, Soil quality index (physico-chemical)

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ecosystem in general. As humanity extracted the beneficial benefits from the ecosystem for its survivals, it is paramount importance to protect ecosystem with introduction of suitably management practices for continuance of functioning and delivering the ecosystem services in the face of human induced perturbations (Tomomatsu et al., 2013; Borja, 2014). In modern agriculture practices, the conventional system of rice intensification are subjected to application of heavy doses of varied agri-chemicals which adversely impacting the quality of ecosystem in general; thereby advocating the adoption of integrated systems such as rice-fish, rice-duck, and rice-fish-duck systems with substantially reduction of chemical fertilizer and pesticides resulting minimization of environmental health degradation *vis a vis* enhancing farm productivity and income. Additionally, future technicalized crop production trends may also adopt the integrated farming system where potentials of environmental degradation and global warming effects are substantially reduced along with reduction/minimization of agricultural operational cost, which may act as advantageous factors for adoption of integrated farming system by the farmers in the future.

In India, out of 44.5 million ha rice cultivated area; 20 million ha are suitable for adoption of integrated rice-fish production system, mainly in rain fed, waterlogged low lands, and canal commands area (Mohanty et al., 2009). Integration of rice with fish and ducks are mutually beneficial and sustainable (Halwart and Gupta, 2004; Zhang et al., 2011; Long et al., 2013; Hu et al., 2016), because integrated system utilizes lower input energy and farm waste and also reservoir for effective nutrients recycling (Sinhababu et al., 2009; Sasmal et al., 2010; Nayak et al., 2012; Long et al., 2013; Nayak et al., 2016). The rice-fish-duck integration has potentials for control of weeds, pests, plant diseases, role of enhancing the soil fertility (Noorhosseini-Niyaki and Bagherzadeh, 2013; Long et al., 2013; Pernollet et al., 2015) and potentialities of global warming mitigation (Xu et al., 2017). However, only 0.23 million ha area are being used for rice-fish culture in India (Rao and Singh, 1998; Radheshyam, 1998; Mohanty et al., 2009). Therefore, it is necessary to bring the rest of the potential area under integrated farming system which will subsequently improve the productivity of rice field ecology (Likangmin, 1988; Mohanty et al., 2009). Low degrees of adoption of this technology in farming community of India are primarily because of lack of scientific knowledge about the harmful effect of intense use of agricultural chemicals and pesticides and proper water management measures etc., therefore it needs specific scientific intervention in respect of organic manures, water conservation and monitoring for technological improvements (Mohanty et al., 2009; Kumar et al., 2017). Additionally, integrated farming system serves as an artificial wetland and assumed to provide numerous ecological roles in agro-ecosystem including maintenance of trophic structures, nutrient recycling, ground water recharge, harbors diverse ecological niches (Dhyani et al., 2007; Che-Salmah et al., 2017), and biodiversity conservation (Bambaradeniya and Amerasinghe, 2003; Maltchik et al., 2011). The humid and waterlogged environments of rice ecologies caused organic matter decomposition in the presence of varied biological organisms (microorganisms, diatoms, phyto and zooplanktons, micro invertebrates and benthic macro invertebrates) responsible for sediment bio-revolving, releasing nutrients and accelerating the cyclic processes for maintaining soil fertility and productivity (Rizo-Patron et al., 2013). In flooded paddy field, the available nutrients and diversified biological organisms are directly or indirectly performing important ecosystem services (Melo et al., 2015), and sensitive to multiple environmental stresses, therefore, it can be considered as indicators for overall assessments of ecosystem (Sharma and Rawat, 2009; Rizo-Patron et al., 2013; Dimitriou et al., 2015; Chen et al., 2016; Costa et al., 2016; Gleason and Rooney, 2017).

Farmer received higher profit with integration of rice-fish-ducks because this integration had additional income besides rice production (Khumairoh et al., 2012; Hu et al., 2016). Eventhough, the significance of the co culture (rice-fish-duck) has long been recognized, the ecological mechanisms underlying the system sustainability have not been studied in detail and reports are scarce, especially on multiple aspects of rice-based integrated agro-ecosystems. Modern studies emphasized the development of combined indicators (physical, chemical and biological properties) for better assessments of ecosystem quality and sustainability (Borja et al., 2012; Borja, 2014; Nesbitt and Adl, 2014; Liu et al., 2015; Che-Salmah et al., 2017). To harness the ecosystem services towards the benefits of society, essentially requires the knowledge of all biodiversity components (microbes, phytoplankton, zooplankton, microalgae, macro invertebrates, fishes, mammals and birds) including structure, function of species diversity and ecosystem habitat and integrity including food web and complex bio-physical interrelationship within the system (Borja, 2014). Evaluation of consolidated indices is a major challenge but ultimately provides accurate and efficient information regarding better ecosystem managements (Borja et al., 2009). The basic aspects of rice-fish-duck integrated system is that the waste products and activities of one components have been efficiently utilized by others, converted into utilizable products, thus sustainability, productivity and profitability of farms can be improved. We hypothesized that switching to integrated systems can improve environmental quality, productivity and profitability of the system. The ecological mechanism and assessment of agro-ecosystem qualities could be better explained through the evaluation of physico-chemical and biological variables of soil and water quality and their correlation with overall farm productivity along with elucidating specific WQI and SQI indicators. The specific questions need to be addressed are: Can the integrated system is more sustainable as compared to the conventional rice mono-cropping system? Do the richness, abundance and composition of aquatic fauna of soil and water varied under different integrated management systems which resulted in improvements in nutrient status and over all farm sustainability?

2. Materials and methods

2.1. Experimental site

The study was undertaken in the long-term experiment on rice-based integrated farming system, which was initiated in 1990 under tropical flooded shallow lowland ecology at ICAR- National Rice Research Institute, Cuttack, Odisha, India (20° 25′ N, 85° 55′ E; elevation 24 m above mean sea levels. The present study was conducted during 2009–2012 to assess the components (fish and duck) effects in rice-based integrated farming system. The soil is an Aeric Endoaquept with sandy clay loam texture (25.9% clay, 21.6% silt and 52.5% sand), pH 6.0 and electrical conductivity 0.35 $dS\,m^{-1}$. Mean annual maximum and minimum temperatures were 37.1 and 22.1 °C, respectively, and the mean annual temperature is 25.5 °C. The annual average precipitation was 1340.6 mm, out of which 75–80% is received during the month of June to September of the year.

2.2. Experimental details

A rain fed medium shallow lowland (0–40 cm water depth) rice field area was uniformly assigned to 4 treatments which were replicated thrice having plot size of 375 m^2. In each treatment excluding conventional rice farming (CRF), a refuge pond (10.0 m × 6.0 m) having 1.0 m depth was constructed on eastern side of each experimental field (Fig. 1a, b). Risen dykes of 50 cm height were prepared on all sides of the plot to ensure complete impounding and prevention of escape of fishes from the rice fields. A duck shed (3 m × 2 m) was constructed above the water refuge area adjoining the bund area where ducks used as a component for sheltering ducks during night times. The rice based system having components of ducks was further partitioned by fixing fish net of 1 m height, which prevented ducks from foraging in the adjoining rice field during day times.

The experiment was conducted during kharif season (July to December) for four consecutive years (2009–2012) using four types of