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Rice-soft shell turtle coculture effects on yield and its environment

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ABSTRACT

Although traditional rice-fish farming (involving extensive aquaculture and low fish yields) can supply food and protect the environment, the economic viability and environmental effects are unknown for intensive rice-aquaculture systems that use high quantities of feed to produce high fish yields. Here, we studied an intensive, soft-shelled turtle (*Pelodiscus sinensis*) farm to determine whether an intensive rice-turtle system can produce high yields of turtle and rice without negatively affecting water and soil quality. Using a 6-year field survey and a 2-year field experiment, we compared the three production systems: rice monoculture (RM), rice-turtle coculture (RT), and turtle monoculture (TM). The field survey indicated that turtle yield did not significantly differ between RT and TM, and that rice yield did not significantly differ between RM and RT. The field survey also showed that soil nitrogen (N) and phosphorus (P) were increased in TM but not in RT even though the same quantities of N and P were applied to TM and RT. In the field experiment, yields were similar for rice in RT vs. RM and were similar for turtles in RT vs. TM. Levels of N and P in field water were significantly higher in TM than in RT or RM. At the end of the field experiment, N and P levels in soil had significantly increased in TM but not in RM or RT. Only 20.4% of feed-N and 22.8% of feed-P were used by turtles in TM, resulting in large quantities of feed-N and feed-P remaining in the environment. In RT, however, some of the feed-N and -P that was unused by turtles was taken up by the rice plants. The results suggest that integrating intensive turtle aquaculture with rice culture can result in high yields and low environmental impacts.

1. Introduction

Because overfishing, pollution, coastal development, and climate change are threatening global marine biodiversity and fish stocks (Garcia and Rosenberg, 2010; Pauly et al., 2002), the farming of aquatic organisms, i.e., aquaculture, is considered a viable way to meet the human demand for aquatic products (Cressey, 2009; Costello et al., 2012; Naylor et al., 2000). Marine and freshwater aquaculture provides nearly 50% of the world's supply of seafood and 13% of the world's animal-source protein (excluding eggs and dairy) (Bush et al., 2013). Freshwater aquaculture that raises fish and other freshwater animals in ponds, lakes, canals, cages, or tanks is becoming a major part of aquaculture because of the increased cost and pollution in marine aquaculture (Troell et al., 2014). Freshwater aquaculture, however, requires large quantities of water that are also needed for irrigation, drinking, household use and industrial use (Foley et al., 2011; Liu and Yang, 2012). In addition, new suitable land is limited, and intensive, high-yield freshwater aquaculture has generated environmental concerns (e.g., water pollution and the spread of disease) (Cao et al., 2007; Li et al., 2011a,b). Thus, new aquaculture approaches are required to meet the increasing need for aquatic protein.

Rice fields can provide a suitable environment for a wide range of aquatic animals, such as freshwater prawns, shrimp, crabs, and turtles (Fernando, 1993; Halwart, 2006). The culturing of fish with rice in paddy fields is a traditional practice in China and many other Asian countries (Halwart and Gupta, 2004; Ruddle, 1982; You, 2006). By efficiently using the same land resources to concurrently or serially produce both carbohydrate and animal protein, rice–fish farming has substantial potential for securing food supplies and alleviating poverty in rural areas (Ahmed and Garnett, 2011; Halwart and Gupta, 2004; Xie et al., 2011). It can also help conserve the environment. In rice–fish farming, the use of pesticides can be reduced or even eliminated (Berg, 2002; Dwiyana and Mendoza, 2008) because fish reduce weeds (by consuming or uprooting them) and consume some insect pests (Frei et al., 2007; Vromant et al., 2002b; Vromant et al., 2003; Xie et al., 2011). Raising fish in rice fields can also reduce fertilizer requirements for rice because

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rice plants can use the unconsumed fish feed and because fish feces can serve as organic fertilizers (Frei and Becker, 2005a; Oehme et al., 2007). In addition, rice–fish farming can reduce some problems generated by freshwater aquaculture. For example, nutrients in the effluents generating by the raising of fish can be absorbed by rice plants, which reduces a potential source of pollution (Hu et al., 2013; Ding et al., 2013). Thus, integrating rice culture with aquaculture can result in an efficient use of resources and a cleaner and more healthful rural environment.

In recent decades, rice culture integrated with aquaculture (e.g., rice–carp, rice–crab, and rice–prawn) has developed rapidly in China and other Asian countries. As of 2012, the area of rice-field aquaculture in China had increased to 2.23 Mha (Fishery Bureau of China's Ministry of Agriculture, 2013). In Bangladesh, rice-field aquaculture has been established as a national strategy for food security, poverty alleviation, and resource conservation (Ahmed and Garnett, 2011; Ahmed et al., 2014; Dey et al., 2013; Haque et al., 2014). Indonesia has also recently set a national target of allocating 1 million ha for rice–fish farming. In India, the organic farming of rice and giant river prawns as rotational crops is part of the Indian Organic Aquaculture Project (Nair et al., 2014).

The Chinese soft-shelled turtle *Pelodiscus sinensis* is an aquatic animal of great economic value because of its high protein content and medicinal uses (Chen et al., 2009; Shi et al., 2008). In China, this turtle has recently been cultured widely in an industrial manner (Shi et al., 2008; van Dijk, 2000), and soft-shelled turtle production reached 0.33Mt in 2012 (Fishery Bureau of China's Ministry of Agriculture, 2013). The rapid increase in soft-shelled turtle production has been the consequence of intensive farming operations that include high animal densities, massive feed inputs, and substantial inputs of chemicals. These intensive farming operations have resulted in environmental damage and the spread of disease (He and Hu, 2012; Wu et al., 2014; Xu, 2000). For example, Cai et al. (2013) reported that among the effluents generated by various kinds of aquaculture, turtle culture effluents contained the largest concentrations of pollutants (total nitrogen, total phosphorous, chemical oxygen demand, and total suspended solids).

To reduce these problems, the Ministry of Agriculture of the People's Republic of China has encouraged turtle farmers to transform turtle monocultures into rice–turtle cocultures. Since 2005, rice–turtle coculture on large-scale commercial farms has been expanding in southern China (Li et al., 2011a,b). Unlike the traditional rice-fish systems that use low quantities of feed and small field areas for fish and that do not negatively affect rice yield or the environment (Halwart and Gupta, 2004; Xie et al., 2011), the large-scale commercial rice-turtle farms are intensive operations that use relatively high quantities of commercial feed to achieve high turtle yield and significant farmer profits (Li et al., 2011a,b; Hu et al., 2015). However, it is unknown whether the rice or turtle yield can be maintained at the levels of rice monoculture or turtle monoculture and whether the pollution generated by turtle monoculture can be avoided at these large-scale and commercial rice–turtle coculture farms.

We therefore conducted a 6-year field survey and a 2-year field experiment to determine whether the integrated culturing of turtles with rice can achieve high yields of turtle and rice without negatively affecting water quality or the soil environment.

2. Materials and methods

2.1. Study site and rice-turtle system

We conducted this study at a large farm managed by an agricultural company (Qingxi Soft-Shelled Turtle Company) located in Deqing County, Zhejiang Province, China (30°33′N, 119°32′E). An adjacent rice farm that was managed by the same company was also used as described in the next section. The area is flat, and the principal crop is rice, which is grown from May to November. The climate is subtropical monsoon with a mean annual air temperature of 14°C and a mean annual precipitation of 1379 mm.

The large turtle farm was started in 1994, when a 300-ha section of a rice field was modified by constructing an 80-cm high concrete ridge around the border; the area within the ridge was used for raising turtles in the summer and was planted with wheat or vegetable crops in the winter. Since 2010, about 200 ha of the turtle farm was modified for the coculture of turtles and rice. The turtle is a common variety, named Qing-Xi, of the indigenous species *P. sinensis*. In this rice-turtle coculture system, the turtles are retained in the rice field all year, but they are temporarily driven to a refuge in the middle of the field when rice is transplanted (in June) and harvested (in November). The refuge area represents about 10% of the total field area.

2.2. Field survey

2.2.1. Field selection

To compare turtle yields in turtle monoculture (TM) and rice-turtle coculture (RT), and to compare rice yields in rice monoculture (RM) and RT, we conducted a 6-year (2010–2015) field survey of the turtle farm, where TM and RT were practiced, and in a nearby rice farm where only RM was practiced. The turtle and rice farms are located the same village and have similar climates and soil types. We randomly selected six fields of TM and six fields of RT (about 1.2 ha per field) within the turtle farm, and six fields of RM (about 1.2 ha per field) within the rice farm. The first year of RT culture in the six RT fields was 2010; these were TM fields before 2010.

The rice variety cultured in RM and RT fields was Qing-Xi No. 8. Each TM and RT field had the same initial population density of turtles, which was 6000 ha^{-1}. Young turtles (150 g each) were added to TM and RT fields after rice was transplanted in spring. The turtles were harvested in early November when rice was harvested.

2.2.2. Application of nitrogen (N), phosphorus (P), and pesticides

Without influencing normal field operations, we recorded the applications of fertilizers, pesticides, and feeds during the rice growing season. The quantities of fertilizer-N and -P or feed-N and -P were recording as kg of N or P per ha per year. The total application of pesticides was expressed as kg of active ingredient (a.i.) per ha per year.

2.2.3. Measurement of rice grain and turtle yields

Each year, yields were determined from all surveyed fields when the farmer harvested turtles from entire TM fields and turtles and rice from entire RT fields. Rice yield was measured as air-dried weight, and turtle yield was measured as fresh weight. Rice and turtle yields are expressed as ton ha^{-1}. The turtle yield was determined in accordance with the approved guidelines of the Zhejiang University Experimental Animal Management Committee.

2.2.4. Measurement of soil organic matter, N, and P

After rice was harvested in 2010 (the beginning of the field survey), 2012, and 2015, soil samples (0–15 cm) were collected from each surveyed field. Soil samples were air-dried and digested by the K_2SO_4-$CuSO_4$-Se method. N and P contents were analyzed with a San^{++} Continuous Flow Analyzer (Skalar, Netherlands) (Lu, 1999).