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# Status of rice-fish farming and rice field fisheries in Northern Laos

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**Introduction:** Rice-fish farming can play an important role in increasing food production in less developed countries. The Lao People's Democratic Republic (Laos) is one of the least developed countries in the world, and rice is the most important crop in Laos.

**Methods:** The present study conducted field surveys in 2022 in order to get a better understanding of the status of rice-fish production systems in mountainous areas in Northern Laos. Rice-fish farming was defined as one form of aquaculture in the present study, characterized by seed stocking and feed input. Rice field fisheries is mainly the harvesting of wild fish with no seed and feed input.

**Results:** We found that rice-fish production systems, including both integrated rice-fish farming and rice field fisheries, are still in resources poor status with low input levels of fertilizer and chemicals. Rice-fish farms generally have higher intensification levels in rice farming than that rice field fisheries farms. Rice-fish farms generate significantly more value output of rice than that rice field fisheries farms. Overall, rice-fish farms use land and labor more efficiently and generate higher land and labor productivity measured in value output than rice field fisheries farms.

**Discussion:** We suggest that more rice field fisheries farms can be intensified with extra seed and feed input to move to rice-fish farming to produce more aquatic products and more value output with the same rice field areas in Northern Laos.

KEYWORDS

**integrated agriculture and aquaculture (IAA), intensification, commoditization, rice field capture fisheries, rice-fish production systems**

## 1. Introduction

Laos, officially the Lao People's Democratic Republic, is a lower-middle-income developing economy (World Bank, 2022). Laos is the only landlocked country in Southeast Asia with thickly forested landscapes mainly consisting of rugged mountains and some plains and plateaus (Tanaka et al., 2008). Laos is one of the fastest growing economies in Southeast Asia, the *per capita* GDP increased eight times from 326 USD *per capita* in 2000 to 2,629 USD *per capita* in 2019 (World Bank, 2022). The total population in Laos increased from 5.3 million in 2000 to 7.2 million in 2019 (World Bank, 2022). Meanwhile, the urbanization rate increased from 23% in 2000 to 35% in 2019, and the incidence of malnutrition reduced from 31% in 2000 to 5.4% in 2018 (GHI, 2019; World Bank, 2022). The trend is clear that along with rapid economic growth and population expansion, the need for more animal-sourced foods, including aquatic foods, has increased quickly in Laos since 2000.

Agriculture is one of the most important industries in Laos, and national food security relies largely on domestic agricultural production. Agriculture accounts for 20.9% national GDP and provides 73.1% employment (CIA, 2023). Rice is the most important staple food grain farmed in Laos, the total rice farming area increased from 0.72 million hectare (ha) in 2000 to 0.82 million ha in 2020 (World Bank, 2022). Rice production increased quickly, from 2.2 million mt (metric ton) in 2000 to 3.8 million mt in 2020, due to increased yield per unit area, from 3 mt ha$^{-1}$ in 2000 to 4.5 mt ha$^{-1}$ in 2020 (World Bank, 2022).

Insufficient consumption of animal protein is still considered major reason causing nutrient deficient in Laos (Chaparro et al., 2014). Aquatic foods represent a major source of animal protein and a wide range micronutrients, play important role in global food security (Golden et al., 2021; Naylor et al., 2021b; Kaminski et al., 2022; Zhang et al., 2022b). The total aquatic foods production in Laos has increased quickly from 71 thousand mt in 2000 to 200 thousand mt in 2020 (FAO, 2022). Meanwhile, the *per capita* aquatic foods supply increased from 13.7 kg in 2000 to 25.2 kg in 2017 (FAO, 2022). Almost all aquatic products are consumed domestically, and the international trade volume of Laos's aquatic foods is still very low (Vongvichith et al., 2018). Excluding fish sauce and fishmeal, Laos imported 1,930 mt and exported 19 mt of aquatic products in 2020 (FAO, 2022).

Freshwater aquaculture has become the most important source of aquatic foods in Laos in the new millennium, produced 65% of national aquatic foods in 2020 (FAO, 2022). However, there are much more households in Laos involved in capture fisheries than aquaculture. There were 526 thousand households involved in capture fisheries in 2007, much higher than 68 thousand households in aquaculture (Hortle, 2009; LAOPDR, 2016). There is much more area (1.236 million ha) used for capture fisheries, with a much smaller area (42 thousand ha) dedicated to aquaculture in Laos (Hortle, 2009; LAOPDR, 2016). Aquaculture production is higher than capture fisheries due to much higher yields per unit area.

Rice and fish production are often integrated within the same rice fields and time frame (Halwart and Gupta, 2004; Freed et al., 2020a). The production methods used in rice-fish production systems are highly diversified between different contexts and countries and span an agroecological continuum from the occasional catch of wild aquatic species to intensified farming of aquatic species in rice fields (Freed et al., 2020a). Fish yields can range widely depending on the type of rice-fish system, the species present, input use, and the management employed (Halwart and Gupta, 2004; Obiero et al., 2022).

Rice field fisheries, defined as one form of capture fisheries in the present study, is the harvest or capture of wild aquatic species from rice fields and other habitats within the rice field ecosystem, such as canals, streams, ponds, and ditches (Gregory, 1997; Freed et al., 2020a,b). Rice field fisheries are important for the provision of aquatic food and nutrition security to the local community and were the most widespread form of rice-fish production in major rice-producing countries in South East Asia such as Bangladesh, Cambodia, Lao PDR, Myanmar, and Vietnam (Gregory, 1997; Shams, 2007; Halwart et al., 2014; Funge-Smith and Bennett, 2019; Freed et al., 2020a,b).

Rice-fish farming, or rice-*cum*-fish farming, as one form of aquaculture, requires higher levels of intervention, especially the deliberate introduction of fish from cultured or wild sources into a rice field and using feed input (Miao, 2010; Freed et al., 2020a). Rice-fish farming can play an important role in contributing to the achievement of the 2030 Agenda for Sustainable Development across multiple goals, especially in increasing food production as the integrated farming system is better than rice monoculture in terms of resource utilization, livelihoods diversity, productivity, biodiversity protection, and both the quality and quantity of the food produced (Saikia and Das, 2008; Ahmed and Garnett, 2011; Halwart et al., 2014; Nayak et al., 2018; Freed et al., 2020a,b; Zhang et al., 2022a). Rice field is one of the most important fishing grounds in Laos. There was 662 thousand ha of rice field used to capture fisheries in 2007, accounting for 54% of the total fishing ground area and 91% of the total rice field area (LAOPDR, 2016; FAO, 2022). Rice field fisheries produced 33 thousand mt of aquatic foods in 2007, accounting for 37% of total capture fisheries production. On the contrary, rice-fish farming is a minor part of aquaculture in Laos. In 2007 there was 5 thousand ha of rice field used for rice-fish farming, accounting for 12% total aquaculture farming area and only 0.52% total rice field area (LAOPDR, 2016; FAO, 2022). Rice-fish farming produced 1.5 thousand mt of aquatic foods in 2007, accounting for 3% of total aquaculture production (LAOPDR, 2016; FAO, 2022).

Rice-fish farming was introduced into Laos in 1937, but it is still not popular and the adoption rate remains low (Luu et al., 1995; Thongsamouth, 2021). Laos has a suitable climate, an adequate water supply, and relatively low land and labor costs, all providing high potential for developing rice-fish production systems. Recognizing the importance of developing rice-fish production systems, governmental, inter and non-governmental organizations such as the Food and Agriculture Organization of the United Nations (FAO), the WorldFish and Japan International Research Center for Agricultural Sciences have carried out a series of promotion and extension projects to promote integrated rice-fish production systems in Laos in the recent decades. However, the rice-fish production systems are. The lack of adequate knowledge and support for farmers keeps them away from the benefits of rice-fish production systems (Saikia and Das, 2008). The low adoption rate of rice-fish farming is also related to poor infrastructure. For example, the percentage of arable land equipped with irrigation systems in Laos even reduced from 32% in 2000 to 20% in 2020 (World Bank, 2022).

Rice-fish farming and rice field fisheries are parts of the agriculture and food system spectrum (Pounds et al., 2022). Agriculture development could be divided into three stages: resource-poor agriculture; green revolution; and industrial agriculture in modern societies (Edwards and Demaine, 1998; Pingali, 2012). Resource-poor agriculture primarily relates to the limited availability of land resources and limited inputs of fertilizers and chemicals (Chambers, 1985; Edwards and Demaine, 1998; Pingali, 2012). Integrated Agriculture and Aquaculture (IAA) was promoted to recycle nutrients to overcome the resources poor issue by using waste products from one component of the system as inputs for another component, such as animal manure or fish pond effluent, as used as fertilizer for crop production (Edwards, 1993, 2009, 2015; Little and Edwards, 2003). In most countries, agriculture presents a clear trend of intensification with increased inputs, mainly driven by the need to increase food production to meet growing global demand by producing more food using the same or less land and other resources (Tilman et al., 2011; Mueller et al., 2012; Garnett et al., 2013; van Ittersum et al., 2013; Kuyper and Struik, 2014; Zabel et al., 2019). Global aquaculture systems have also been intensified, fueled by factors such as expanding domestic and international markets for fish and the availability of new technologies (Bostock et al., 2010; Hall et al., 2011; Edwards, 2015; Gephart et al., 2017; Naylor et al., 2021a). Agricultural and aquaculture intensification often involves the increased use of fertilizers and other chemical inputs to increase crop yields (Tilman et al., 2002; Ludemann et al., 2022). There are emerging trends of intensification and commodification of rice-fish production systems through advanced technologies and management practices, resulting in increased productivity and sustainability (Ahmed and Garnett, 2011; Xie et al., 2011; Freed et al., 2020a). Rice field fisheries and rice-fish farming were both practiced in Laos (Freed et al., 2020a,b). Laos consists of three geographical areas: north, central, and south (National Statistics Centre, 2005). Mountainous Northern Laos was known as one of the only two areas with well-defined, traditional, artisanal, rice-fish farming where fish are produced in terraced rice fields (Edwards et al., 1997, 2015). Northern Laos' provinces, such as Oudomxay, have high poverty rates and populations (Lao Statistics Bureau and World Bank, 2020).

However, due to the limited statistical data and relevant literature, the overall picture of rice-fish production systems in Laos is largely unknown, which impedes rice-fish production systems from contributing more to a broad range of SDGs in the future. For example, there is no clear definition or distinction between rice field fisheries and rice-fish farming in the official statistical system and literature. It is unclear how much of the rice-fish production systems is devoted to rice field fisheries and how much is devoted to rice-fish farming. The production models and differences in yield and intensification levels between the two systems are also worth investing. In order to get a better understanding of the development status of rice-fish production systems in Laos, the present study conducted a field survey in mountainous areas in Northern Laos in 2022. The field survey covers both the production systems, rice field fisheries and rice-fish farming, in order to understand fisheries and aquaculture in rice fields in Laos. The implication of the rice-fish production systems to poverty alleviation and food security in Northern Laos was discussed based on an analysis of farm profiles, farming practices, and farm input and output.

# 2. Methodology

## 2.1. Survey and questionnaire

A structured systematic questionnaire was designed and then tested and refined in the field. The questionnaire was prepared in Chinese and translated into Laos in field by an MSc student who is Laos national. The survey questionnaire covers production system characters, interviewee and household profiles, farm and rice field characteristics, rice and fish production, stocking of seed, feed input, fertilizer and chemical input, fish sale prices, and use and consumption of fish and rice. All interviewees were informed of that the purpose of this study, how survey data will be used, and their anonymity are assured. The survey period was designed to understand practices in the previous year (2021) to cover the whole cycle of rice farming and aquaculture.

## 2.2. Sample design

Based on the literature review and results of the previous scoping study and key informant interviews with local government officers, major rice-fish producing areas were selected as the survey area, including Luangnamtha province and Oudomxay province in Northern Laos (Figure 1).

The total sample size was set at 100 farms according to resource availability. Due to no secondary data available to calculate proportional survey sample sizes and randomly select survey farms, we set survey sample sizes at 50 in each of the two survey targeting provinces in Northern Laos. Survey farm sampling was based on snowballing methods. The snowballing method is a well-established non-probability sampling technique that is commonly used when the population being studied is hard to reach or difficult to identify (Goodman, 1961; Atkinson and Flint, 2001). Google Earth satellite images were used to manage surveyed farms.

## 2.3. Data management and analysis

An Excel (Microsoft 2010) database was developed for data management and analysis. Data used for analysis were retrieved from the Excel database using pivot table tools. Farms that have stocking hatchery-produced seed or wild-collected seed, or have commercial or supplementary feed inputs, are classified as rice-fish farming. Contrary to rice-fish farming, rice field fisheries are defined as harvesting aquatic foods from rice fields without stocking seed or any form of feed input. Invalid results (e.g., questions interviewees unwilling or unable to respond to) are excluded from the analysis. Primary data were analyzed using SPSS 21 statistic software (IBM 2013). Independent-samples Mann–Whitney *U* test was used for the for pairwise comparison for continuous variables, and Pearson chi-square was used to test for dichotomy variables. The Kolmogorov–Smirnov test was employed to assess the distribution of the samples. Descriptive statistics are presented as the mean ± standard deviation (mean ± sd) for normally distributed data, and as the median and interquartile range (IQR, defined as the difference between the 25th and 75th percentiles) for non-normally distributed data. Spearman's correlation coefficients were calculated to perform two-tailed nonparametric tests. Multiple linear regression models were employed to explore the factors that contribute to the total value output per unit area and per labor. Currency was converted from LAK to USD using the current exchange rate as 1,000 LAK = 0.05785 USD[1]. The distributions of farms surveyed were visualized in Google Earth using GPS (Global Position System) coordinates collected in the survey.

# 3. Results

## 3.1. Survey results

A total of 101 farms were surveyed in North Laos in August–September 2022, including 50 in Luangnamtha province and 51 in

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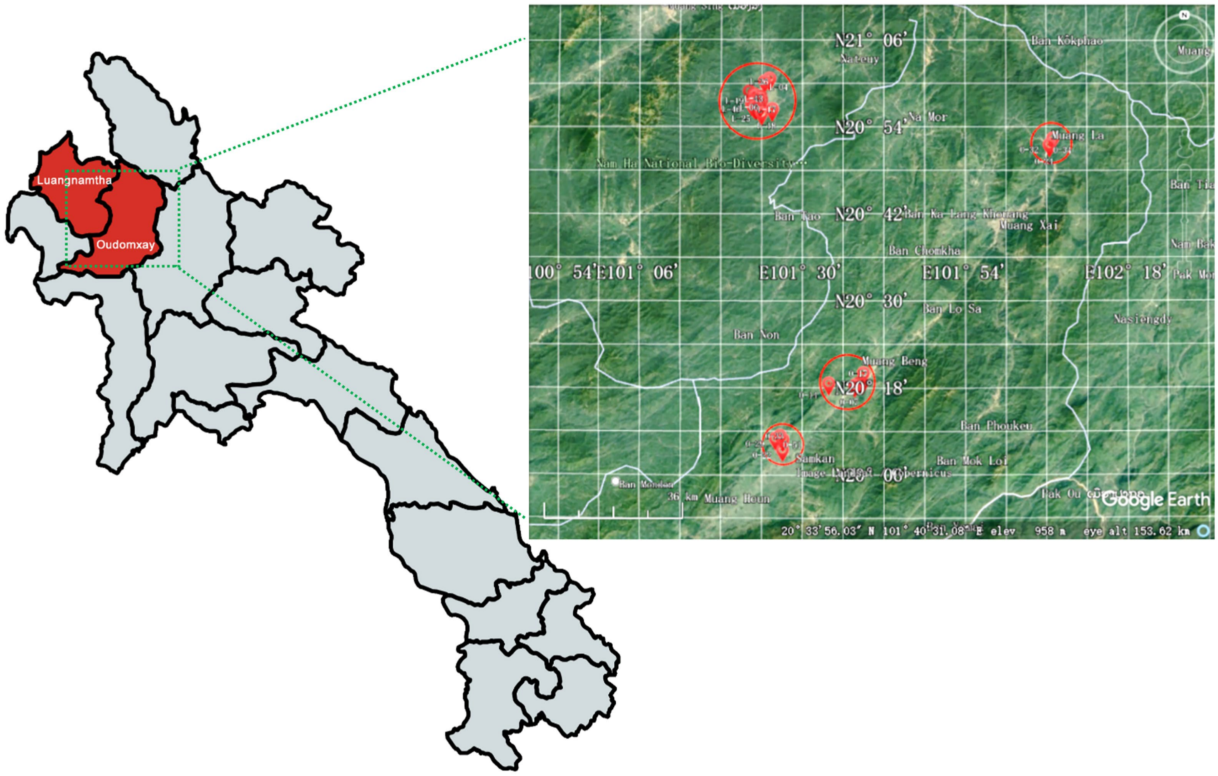


FIGURE 1
Location of two survey provinces in Northern Laos and distribution of surveyed farms visualized in Google Earth. Map source: www.mapchart.net.

Oudomxay province. There are 75 (74.3%, $n = 101$) rice-fish farms and 26 (25.7%) rice field fisheries farms, including 37 rice-fish farms and 13 rice field fisheries farms in Luangnamtha province, and 38 rice-fish farms and 13 rice field fisheries farms in Oudomxay province.

## 3.2. Interviewee profile

The majority of interviewees are farm owners (77.0%, $n = 100$), followed by 16.0% farm workers, 4.0% technicians, and 3.0% farm managers. Most of interviewees are male (79.2%, $n = 101$). The age of interviewees ranged from 25 to 73 years old and averaged 50.0 ± 11.4 ($n = 101$). Male interviewees (51.3 ± 11.2, $n = 80$) are significantly older than female interviewees (45.2 ± 10.8, $n = 21$) ($p < 0.05$). More than half of the interviewees (54.5%, $n = 99$) only have primary education, followed by 27.3% middle school education and 18.2% higher-level education.

## 3.3. Farm profiles

Most farms (97.9%, $n = 101$) are individual farms, and only 2.1% are cooperative farms. All farms (100%, $n = 90$) reported that the land was privately owned. Most farms (95.8%, $n = 97$) do not need to pay any rent for land use, and only 4.1% of interviewees reported that a small amount of rent needs to be paid. Farm surveyed were mostly very small, with areas varying between 0.015 to 3.4 ha, with an average of (median 0.60 ha, IQR 0.40–1.00 ha, $n = 101$). No significant farm area differences were found between the two production systems and survey provinces.

Half (50.5%, $n = 101$) of interviewees reported that only capture fisheries exist in their rice fields, 14.9% reported rice-fish farming, and 34.7% reported both capture fisheries in the rice field and rice-fish farming. However, three-fourth interviewees (74.3%, $n = 101$) reported stocking wild collected or hatchery-produced seed and/or having commercial or supplementary feed input, making these farms fit into the rice-fish farming category. Only 25.7% of interviewees reported no seed or feed input, making these farms fit into the rice field fisheries category. All interviewees (100%, $n = 101$) reported the production of fish from rice fields, followed by mollusks (89.1%), crabs (80.2%), prawns (56.4%), and frogs (36.6%). Rice-fish farming produces (median 4.00, IQR 3.00–5.00, $n = 75$) type of products, which was significantly more than rice field fisheries (median 3.00, IQR 2.00–4.00, $n = 26$; Mann–Whitney $U = 655$, $p = 0.010$).

All interviewees (100%, $n = 101$) reported reinforced banks as infrastructure for rice field fisheries and rice-fish farming, followed by ditches (94.1%), fish refuges and small ponds (94.1%), and feeding equipment (5.0%). There were 73 rice-fish farms and 22 rice field fisheries farms reported using ditches, 73 rice-fish farms and 22 rice field fisheries farms reported fish refuges and small ponds, and 5 rice-fish farms reported feeding equipment. The deepened water area ratio ranges from 0% to 80% of rice fields, with an average of % ($n = 101$). The ratio of the deepened water area of rice-fish farming (median 5%, IQR 2%–15%, $n = 75$) was significantly higher than that of rice field fisheries (median 2%, IQR 0.3%–3.3%, $n = 26$; Mann–Whitney $U = 457.5$, $p = 0.000$). The overall weighted ratio of deepened water area was 9.2%.

Family labor inputs ranged from 1 to 9 person, with an average of (median 3 person, IQR 2–5 person, $n=100$). No significant difference in family labor inputs was found between different production systems and the two survey provinces. Only 10% of farms have one or two hired laborers. There were more farms hired laborers in Oudomxay province (nine of 50 farms) than in Luangnamtha province (one in 50 farms, $p=0.007$). Total farm labor inputs include family labor and hired labor, ranging from 1 to 9 person, with an average of (median 3 person, IQR 2–5 person, $n=100$). No significant difference in total farm labor inputs was found between different farming systems and the two survey provinces. There is a significant correlation between farm area (median 0.60 ha, IQR 0.40–1.00 ha, $n=101$) and total labor input (median 3 person, IQR 2–5, $n=100$; Mann–Whitney U = 837.50, $p=0.000$) (Figure 2A). Meanwhile, the farm area available for *per capita* labor input (calculated as farm area divided by farm total labor input) (median 0.16 ha person$^{-1}$, IQR 0.10–0.33 ha person$^{-1}$, $n=74$) was significantly correlated with the individual farm area (median 0.60 ha, IQR 0.40–1.00 ha, $n=101$; $p=0.000$) (Figure 2B).

Most of the farms (92.9%, $n=98$) use water from the irrigation systems, followed by rainfall water (29.6%), water from rivers (8.2%), lakes (3.1%), and swamps (2.0%). Rice field fisheries rely more (96.0%, $n=25$) on irrigation systems than rice-fish farming (91.8%, $n=75$), but rice-fish farming uses more diverse water sources. Most interviewees reported sufficient water supply (96.9%, $n=98$), and only 3.1% reported water supply shortages.

## 3.4. Farming practice

Most rice-fish farms (89.3%, $n=75$) reported stocking hatchery-produced seed, only 14.7% of farms stock wild-collected seed and 5.3% of farms have no seed stocked. Stocking density ranges from zero

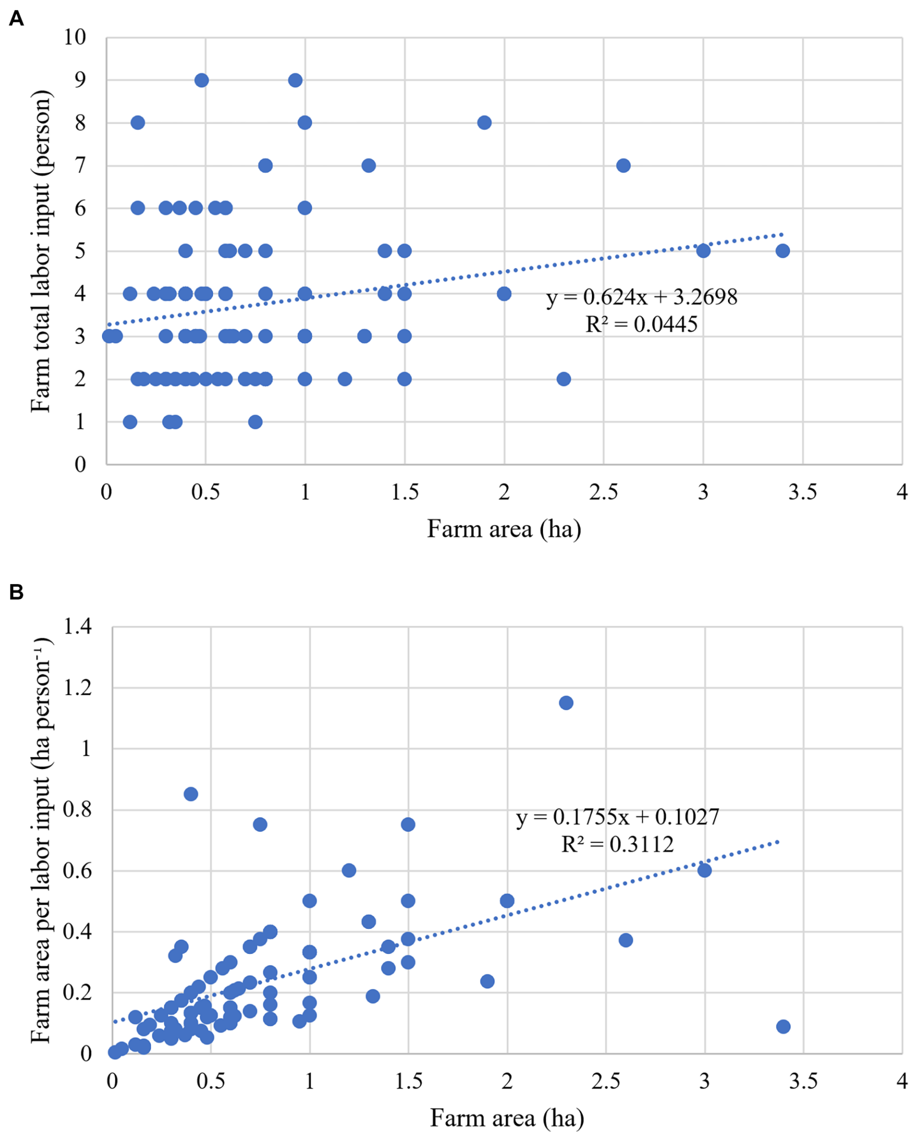


FIGURE 2
Correlation between farm labor input and farm area (**A**, $p<0.05$), and correlation between farm labor input and farm area per labor input (**B**, $p<0.01$). Data source: the present study.

to 120,000 pieces ha$^{-1}$, with an average of (median 2,500 pieces ha$^{-1}$, IQR 276.19–5,000 pieces ha$^{-1}$, $n = 69$). No significant difference in stocking density was found between the two survey provinces. Aligned with the definition, all (100%, $n = 26$) farms with rice field fisheries have no seed stocked in the rice fields.

Nearly one-third rice-fish farms (31.3%, $n = 65$) have no feed input, followed by 28.1% have supplementary feed input such as soybean cake and rice bran, 18.8% have commercial pellet feed, 15.6% using the both commercial and supplementary feed, 4.9% have the farm-made feed, and 1.6% have both commercial and farm-made feed. Aligned with the definition, all (100%, $n = 26$) farms with rice field fisheries have no feed input.

Half of the farms (56.3%, $n = 87$) have no fertilizer input, 21.8% have compound fertilizer input, 17.2% have organic fertilizer input, and 4.6% have nitrogenous fertilizer. There were 35 (71.4%, $n = 49$) rice-fish farming and 14 (28.6%, $n = 49$) rice field fisheries reported the use of fertilizer, including 15 (78.9%, $n = 19$) rice-fish farms and 4 (21.1%) rice field fisheries farms reported compound fertilizer input, 14 (93.3%, $n = 15$) rice-fish farms and 1 (6.7%) rice field fisheries farms reported organic fertilizer input, and 4 (100%, $n = 4$) rice-fish farms reported nitrogenous fertilizer input. The average fertilizer input was 9.8 ± 33.8 kg ha$^{-1}$ ($n = 23$) compound fertilizer, 5.28 ± 25.6 kg ha$^{-1}$ ($n = 21$) nitrogenous fertilizer, and 7.4 ± 25.6 kg ha$^{-1}$ ($n = 15$) organic fertilizer.

More than half of farms (60.7%, $n = 56$) have no chemical input, 26.8% have herbicide input, 10.7% have plant growth regulator input, and 1.8% have insecticide input. No significant chemical input differences were found between different production systems and the two survey provinces.

Most farms (85.4%, $n = 89$) reported one rice farming cycle in the whole year of 2021, only 13.5% of farms reported double-crop rice, and 1.1% triple-crop rice. 52 rice-fish farms and 24 rice field fisheries farms that reported single-crop rice, and 11 rice-fish farms reported double-crop rice.

Annual farm rice production ranged from zero to 11.25 mt per farm, with an average of (median 3 mt, IQR 1.85–4.0 mt, $n = 101$). The rice yields per unit area ranged from zero to 15.7 mt ha$^{-1}$, with an average of (median 4.40 mt ha$^{-1}$, IQR 3.40–5.58 mt ha$^{-1}$, $n = 101$). Annual farm value outputs of rice ranged from zero to 2928.6 USD per farm, with an average of (median 694.20 USD, IQR 371.69–1015.27 USD, $n = 101$). Rice prices ranged from 0.06 to 0.46 USD kg$^{-1}$, with an average of (median 0.24 USD kg$^{-1}$, IQR 0.177–0.289 USD kg$^{-1}$, $n = 93$). Rice price in Luangnamtha province (median 0.289 USD kg$^{-1}$, IQR 0.260–0.323 USD kg$^{-1}$, $n = 50$) was significantly higher than that in Oudomxay province (median 0.185 USD kg$^{-1}$, IQR 0.155–0.231 USD kg$^{-1}$, $n = 51$; Mann–Whitney $U = 361.50$, $p = 0.000$). The rice value outputs per unit area range from zero to 4531.6 USD ha$^{-1}$, with an average of (median 1051.82 USD ha$^{-1}$, IQR 655.98–1590.88 USD ha$^{-1}$, $n = 100$). The rice value outputs per unit area of rice-fish farming (median 1145.43 USD ha$^{-1}$, IQR 668.89–1735.50 USD ha$^{-1}$, $n = 75$) were significantly higher than that of rice field fisheries (median 757.56 USD ha$^{-1}$, IQR 452.84–1227.50 USD ha$^{-1}$, $n = 26$; Mann–Whitney $U = 674.50$, $p = 0.020$). For each labor input, rice production was (median 0.80 mt labor$^{-1}$, IQR 0.42–1.25 mt labor$^{-1}$, $n = 100$), and value output was (median 173.55 USD labor$^{-1}$, IQR 86.78–307.33 USD labor$^{-1}$, $n = 100$). Farms in Luangnamtha province can get higher value output per labor (median 196.69 USD labor$^{-1}$, IQR 115.05–351.85 USD labor$^{-1}$, $n = 50$) than that in Oudomxay province (median 141.73 USD labor$^{-1}$, IQR 63.27–267.56 USD labor$^{-1}$, $n = 50$; Mann–Whitney $U = 943$, $p = 0.034$).

Only 17.9% of farms ($n = 78$) reported sales of aquatic foods in the whole year of 2021, a higher percentage of rice-fish farms (23.6%, $n = 55$) reported aquatic product sales in 2021 than rice field fisheries farms (4.4%, $n = 23$). Thirteen farms reported sale volumes of aquatic products, ranging from 30 to 15,000 kg in 2021. The highest production of aquatic products (15,000 kg) was reported by one farm in Oudomxay province, which also reported 80% farm area been deepened, making it more like a specialized pond farm, thus this farm was treated as outlier and excluded in the calculation of the total aquatic foods production, value output, and yield. The yield per unit area ranging between 0.06 to 2.2 mt ha$^{-1}$, and the average yield of aquatic foods was 0.84 ± 0.74 mt ha$^{-1}$ ($n = 12$). Aquatic foods sale volumes from rice-fish farming (480.9 ± 358.5 kg, $n = 11$) were higher than rice field fisheries (100 kg, $n = 1$), but the significance level cannot be tested due to limited sample sizes.

The unit price of aquatic foods sales ranged from 0.12 to 2.0 USD kg$^{-1}$, with an average of 1.3 ± 0.6 USD kg$^{-1}$ ($n = 13$). The total farm value output of aquatic foods sales ranged from 34.7 to 867.8 USD, with an average of 431.5 ± 310.4 USD ($n = 12$). Those farms reported no sales of aquatic foods in 2021 and also did not report production or value output of aquatic foods.

The total farm value outputs range between zero to 2928.7 USD, with an average of (median 694.20 USD, IQR 370.24–1018.16 USD, $n = 100$). Rice-fish farms have higher total value output (median 694.20 USD, IQR 404.95–1097.70 USD, $n = 74$), which was significantly higher than the value output of rice field fisheries farms (median 433.88 USD, IQR 216.94–727.75 USD, $n = 26$; Mann–Whitney $U = 684.50$, $p = 0.029$). Value outputs per unit area range between zero to 4531.6 USD ha$^{-1}$, with an average of (median 1118.43 USD ha$^{-1}$, IQR 667.50–1640.05 USD ha$^{-1}$, $n = 100$). Rice-fish farms also have higher value outputs per unit area (median 1210.03 USD ha$^{-1}$, IQR 744.82–1811.43 USD ha$^{-1}$, $n = 74$), which was significantly higher than the value outputs per unit area of rice field fisheries farms (median 743.79 USD ha$^{-1}$, IQR 399.50–1283.55 USD ha$^{-1}$, $n = 26$; Mann–Whitney $U = 633.50$, $p = 0.010$) (Figure 3A). Value outputs per labor input range between zero to 1446.3 USD labor$^{-1}$, with an average of (median 188.01 USD labor$^{-1}$, IQR 97.62–323.96 USD labor$^{-1}$, $n = 99$). Rice-fish farms also have higher value outputs per labor input (median 211.57 USD labor$^{-1}$, IQR 107.80–347.10 USD labor$^{-1}$, $n = 74$), which was significantly higher than the value outputs per labor input of rice field fisheries farms (median 121.49 USD labor$^{-1}$, IQR 81.95–231.40 USD labor$^{-1}$, $n = 25$; Mann–Whitney $U = 648$, $p = 0.026$) (Figure 3B).

## 3.5. Comparing key performance indicators

Comparing key performance indicators between rice-fish farming and rice field fisheries (Table 1), the two farming systems have similar level of land use and labor input (Figure 4A). However, rice-fish farms generally have significantly higher fertilizer input and more percentage of deepened water area than rice field fisheries. Moreover, by definition, rice-fish farms also have seed and feed input, while there was no such input with rice field fisheries farms. The overall input and intensification levels of rice-fish farming were higher than that of rice field fisheries, as rice-fish farming requires higher capacity in finance and technology.

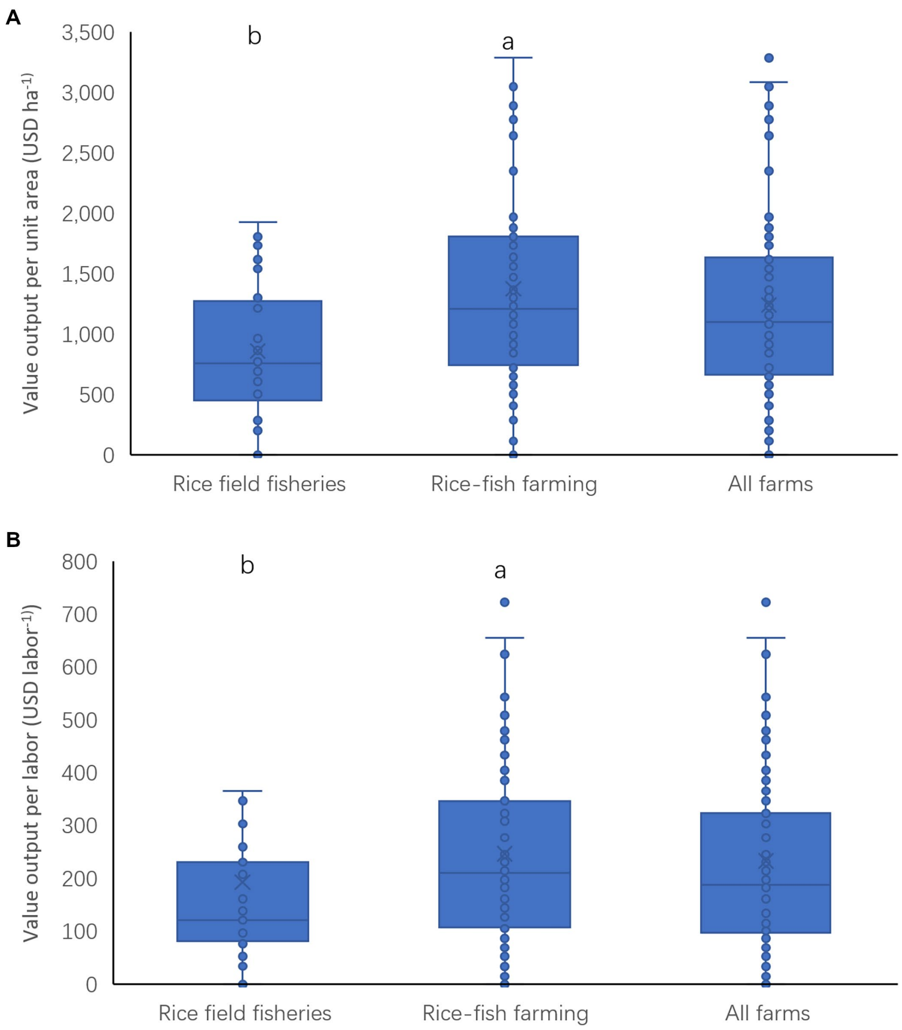


FIGURE 3
Farm value output $ha^{-1}$ rice field (**A**, *n*=100) and value output per labor input (**B**, *n*=99). Different letters indicate significant differences ($p$<0.05). Data source: the present study.

Rice-fish farms generally produce (albeit not significant) higher rice production per farm and higher rice yield per unit area than that rice field fisheries farms (Figure 4B). Unit value of rice from rice-fish farms was significantly higher than that from rice field fisheries farms for reasons yet to uncover. Consequently, rice-fish farms generate significantly more value output of rice than rice field fisheries. Rice-fish farming produces more type of products, such as fish, crabs, prawns, snails, and frogs.

Overall, rice-fish farming has a higher level of intensification and better economic performance than rice field fisheries (Figure 4C). Rice-fish farming uses land and labor more efficiently and generates higher land and labor productivity measured in value output than rice field fisheries. Aquatic foods sale volumes from rice-fish farming were also higher than rice field fisheries, indicating better contribution to poverty elimination and food security.

The multiple linear regression models show land area per labor (ha $person^{-1}$) and farm type (rice-fish farm, rice field fisheries) are the major causes of different value output per labor (USD $person^{-1}$) ($p < 0.01$; Table 2), and farm type (rice-fish farm, rice field fisheries) and land area per labor (ha $person^{-1}$) are the major causes of different value output per hectare land (USD $ha^{-1}$) ($p < 0.05$; Table 3). Results of the multiple linear regression models indicate farm type (rice-fish farm, rice field fisheries) is the major factor related to key performance indicators value output per labor (USD $person^{-1}$) and value output per hectare land (USD $ha^{-1}$).

## 4. Discussion

Rice-fish farming was defined as one form of aquaculture in the present study. Aquaculture is the controlled cultivation "*farming*" of aquatic organisms under controlled or semi-natural conditions and can be contrasted with fishing ("*capture fishery*"), which is the harvesting of wild fish (FAO, 2011). According to the FAO, "*aquaculture is understood to mean the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators,*

TABLE 1 Comparing key performance indicators between rice-fish farming and rice field fisheries.

| Indicator | | Rice-fish farming | Rice field fisheries | Significance level |
|---|---|---|---|---|
| Infrastructure | Farm area | Median 0.60 ha IQR 0.40–1.00 ha, $n = 75$ | Median 0.50 ha IQR 0.34–1.40 ha, $n = 26$ | No difference |
| | Farm labor | Median 3 person, IQR 2–5 person, $n = 75$ | Median 4 person, IQR 3–4.5 person, $n = 25$ | No difference |
| | Water sources | Mainly irrigation system | Mainly irrigation system | No difference |
| | Deepened water area | Median 5%, IQR 2–15%, $n = 75$ | Median 2%, IQR 0.3–3.3%, $n = 26$ | $p < 0.01$ |
| Farm input | Seed stocking | 94.70% of all farms | 0% of all farms | $p < 0.01$ |
| | Use of feed | 69.10% of all farms | 0% of all farms | $p < 0.01$ |
| | Use of fertilizer | 48.53% of all farms | 26.32% of all farms | No difference |
| | Use of chemical | 38.10% of all farms | 42.86% of all farms | No difference |
| Farm output | Rice production | Median 3,000 kg, IQR 2,000–4,000 kg, $n = 75$ | Median 2,100 kg, IQR 1,275–4,000 kg, $n = 26$ | No difference |
| | Rice yield | Median 4.50 mt $ha^{-1}$, IQR 3.46–5.60 mt $ha^{-1}$, $n = 75$ | Median 4.00 mt $ha^{-1}$, IQR 2.81–5.15 mt $ha^{-1}$, $n = 26$ | No difference |
| | Rice price | Median 0.289 USD $kg^{-1}$, IQR 0.260–0.323 USD $kg^{-1}$, $n = 50$ | Median 0.185 USD $kg^{-1}$, IQR 0.155–0.231 USD $kg^{-1}$, $n = 51$ | $p < 0.05$ |
| | Value output per unit area | Median 1145.43 USD $ha^{-1}$, IQR 668.89–1735.50 USD $ha^{-1}$, $n = 75$ | Median 757.56 USD $ha^{-1}$, IQR 452.84–1227.50 USD $ha^{-1}$, $n = 26$ | $p < 0.05$ |
| | Value output per labor | Median 196.69 USD $labor^{-1}$, IQR 115.05–351.85 USD $labor^{-1}$, $n = 50$ | Median 141.73 USD $labor^{-1}$, IQR 63.27–267.56 USD $labor^{-1}$, $n = 50$ | No difference |
| | Types of aquatic product | Median 4.00, IQR 3.00–5.00, $n = 75$ | Median 3.00, IQR 2.00–4.00, $n = 26$ | $p < 0.05$ |
| | Aquatic foods production | 480.9 ± 358.5 kg | 100 kg | Not tested |
| Overall performances | Farm reported sales of aquatic foods | 23.60% | 4.35% | No difference |
| | Total farm value output | Median 694.20 USD, IQR 404.95–1097.70 USD, $n = 74$ | Median 433.88 USD, IQR 216.94–727.75 USD, $n = 26$ | $p < 0.05$ |
| | Total value output per unit area | Median 1210.03 USD $ha^{-1}$, IQR 744.82–1811.43 USD $ha^{-1}$, $n = 74$ | Median 743.79 USD $ha^{-1}$, IQR 399.50–1283.55 USD $ha^{-1}$, $n = 26$ | $p < 0.05$ |
| | Total value output per labor | Median 211.57 USD $labor^{-1}$, IQR 107.80–347.10 USD $labor^{-1}$, $n = 74$ | Median 121.49 USD $labor^{-1}$, IQR 81.95–231.40 USD $labor^{-1}$, $n = 25$ | $p < 0.05$ |

Data source: the present study.

etc." (Edwards and Demaine, 1998; FAO, 2011). All the farms that stocked hatchery-produced or wild-collected seed, or have commercial or supplementary feed inputs, are classified as rice-fish farming in the present study. Thirty interviewees reported that only capture fisheries exist in their rice fields but also reported stocking wild collected or hatchery-produced seed and/or having commercial or supplementary feed input, making these farms fit into the rice-fish farming category. The perceived concept of rice-fish farming by interviewees is not the same as the conventional definition (e.g., (Edwards and Demaine, 1998; Freed et al., 2020b)) and could have implications on the classification of rice field fisheries and rice-fish farming in Laos official statistical data.

Rice-fish farming and rice field fisheries are parts of the agriculture and food system spectrum (Pounds et al., 2022). Agriculture development could be divided into three classes: resource-poor agriculture; green revolution; and industrial agriculture in modern societies (Edwards and Demaine, 1998; Pingali, 2012). Resource-poor agriculture primarily relates to the limited availability of land resources, limited inputs of fertilizers and chemicals. The present study found that rice-fish production systems, including both rice-fish farming and rice field fisheries in Northern Laos, are still in resource-poor status with limited land and input levels, especially fertilizers and chemicals. Average farm area is very limited, only (median 0.60 ha, IQR 0.40–1.00 ha, $n = 101$), and farmland *per capita* is only (median

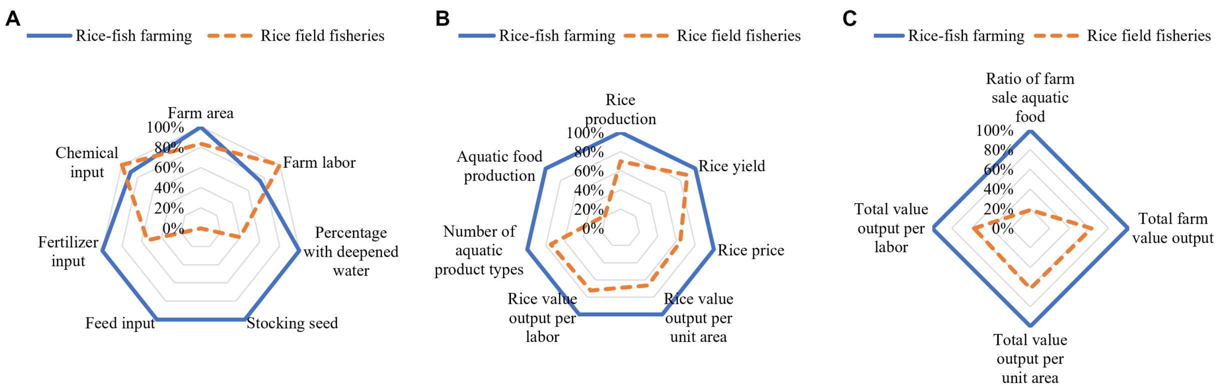


FIGURE 4
Infrastructure and input **(A)**, farm output **(B)**, and overall performance of rice-fish farming and rice-fish fisheries **(C)**. See Table 1 for all the data used. Data source: the present study.

**TABLE 2** Model summary and coefficients of linear regression analysis.

| Model | Unstandardized coefficients | | | Standardized coefficients | *t* | Sig. | Collinearity statistics | |
|---|---|---|---|---|---|---|---|---|
| | *B* | | Std. error | Beta | | | Tolerance | VIF |
| 1 | (Constant) | −27.116 | 174.164 | | −0.156 | 0.877 | | |
| | Gender | 59.519 | 45.332 | 0.118 | 1.313 | 0.193 | 0.786 | 1.271 |
| | Age | 1.553 | 1.716 | 0.085 | 0.905 | 0.368 | 0.709 | 1.410 |
| | Education | 2.348 | 23.978 | 0.009 | 0.098 | 0.922 | 0.730 | 1.370 |
| | Farm type (rice-fish farm, rice field fisheries) | 124.079 | 57.807 | 0.265 | 2.146 | 0.035 | 0.414 | 2.414 |
| | Family labor (person) | −5.791 | 13.233 | −0.048 | −0.438 | 0.663 | 0.519 | 1.927 |
| | Hire labor (person) | −7.431 | 38.770 | −0.016 | −0.192 | 0.848 | 0.853 | 1.172 |
| | Farm area (ha) | −108.856 | 45.082 | −0.317 | −2.415 | 0.018 | 0.365 | 2.737 |
| | Province | −25.603 | 35.871 | −0.062 | −0.714 | 0.477 | 0.829 | 1.207 |
| | Land area per labor (ha person$^{-1}$) | 897.472 | 173.909 | 0.698 | 5.161 | 0.000 | 0.344 | 2.904 |
| | Depended area (%) | −193.347 | 161.014 | −0.108 | −1.201 | 0.233 | 0.784 | 1.276 |
| | Seed input | −65.095 | 44.631 | −0.172 | −1.459 | 0.148 | 0.455 | 2.198 |
| | Fertilizer input | −51.001 | 32.791 | −0.129 | −1.555 | 0.124 | 0.915 | 1.092 |
| | *F* | 6.299 | | | | | | |
| | Adjusted *R* square | 0.401 | | | | | | |
| | Sig. | 0.000 | | | | | | |

Dependent variable: value output per labor (USD person$^{-1}$). Model results show land area per labor (ha person$^{-1}$) and farm type (rice-fish farm, rice field fisheries) are the major causes of different value output per labor (USD person$^{-1}$) (higher coefficients). The linear regression model is significant ($p < 0.01$).

0.16 ha person$^{-1}$, IQR 0.10–0.33 ha person$^{-1}$, $n = 74$). Larger farms can provide more area for each labor input, which implies there is no sufficient farm area for most small farms. The average fertilizer input of rice fields in Northern Laos was less than 23 kg ha$^{-1}$, which is only one-tenth of fertilizer input levels in many major rice-producing countries in Asia (Devkota et al., 2019). Inorganic fertilizer has played a vital role in enhancing rice yield in the past 50 years (Yang et al., 2022). Rice-fish farming can often reduce the use of fertilizer-nitrogen (N) through the complementary use of feed-N between rice and fish (Xie et al., 2011; Hu et al., 2016). However, the limited fertilizers and chemical inputs are important reasons for low rice yield (LAOSIS, 2022; World Bank, 2022), especially when feed input and the complementary effect of feed-N are also limited. We also found that three-fifths of farms have no chemical input, while chemicals have been wildly used in many major rice-producing countries in Asia (Devkota et al., 2019). Rice-fish farming can also reduce the use of chemicals such as pesticides for rice by reducing the incidence of diseases, insect pests and weeds (Xie et al., 2011; Hu et al., 2016).

TABLE 3 Model summary and coefficients of linear regression analysis.

| Model | | Unstandardized coefficients | | Standardized coefficients | *t* | Sig. | Collinearity statistics | |
|---|---|---|---|---|---|---|---|---|
| | | *B* | Std. error | Beta | | | Tolerance | VIF |
| 1 | (Constant) | 171.446 | 829.092 | | 0.207 | 0.837 | | |
| | Gender | 396.524 | 215.801 | 0.189 | 1.837 | 0.070 | 0.786 | 1.271 |
| | Age | 3.013 | 8.169 | 0.040 | 0.369 | 0.713 | 0.709 | 1.410 |
| | Education | 181.498 | 114.143 | 0.170 | 1.590 | 0.116 | 0.730 | 1.370 |
| | Farm type (rice-fish farm, rice field fisheries) | 711.814 | 275.184 | 0.366 | 2.587 | 0.011 | 0.414 | 2.414 |
| | Family labor (person) | −7.958 | 62.993 | −0.016 | −0.126 | 0.900 | 0.519 | 1.927 |
| | Hire labor (person) | −95.667 | 184.563 | −0.051 | −0.518 | 0.606 | 0.853 | 1.172 |
| | Farm area (ha) | −266.662 | 214.606 | −0.187 | −1.243 | 0.218 | 0.365 | 2.737 |
| | Province | −98.603 | 170.758 | −0.058 | −0.577 | 0.565 | 0.829 | 1.207 |
| | Land area per labor (ha person$^{-1}$) | −1008.241 | 827.875 | −0.189 | −1.218 | 0.227 | 0.344 | 2.904 |
| | Depended area | 226.987 | 766.492 | 0.030 | 0.296 | 0.768 | 0.784 | 1.276 |
| | Seed input | −262.144 | 212.460 | −0.167 | −1.234 | 0.221 | 0.455 | 2.198 |
| | Fertilizer input | −193.244 | 156.097 | −0.118 | −1.238 | 0.219 | 0.915 | 1.092 |
| | *F* | 3.117 | | | | | | |
| | Adjusted *R* square | 0.211 | | | | | | |
| | Sig. | 0.001 | | | | | | |

Dependent variable: value output per hectare land (USD ha$^{-1}$). Model results show farm type (rice-fish farm, rice field fisheries) and land area per labor (ha person$^{-1}$) are the major causes of different value output per hectare land (USD ha$^{-1}$) (higher coefficients). The linear regression model is significant ($p < 0.05$).

Chemicals used in rice farming have severe adverse consequences on fish and indicate their potential risk to human health due to their bioaccumulation in farmed fish (Clasen et al., 2018). The increased chemical input and intensification level impact on fish production warrants further investigation.

Resource-poor agriculture can be benefited by integration with other human activity systems *in situ* such as animal husbandry, aquaculture sanitation, processing wastes from local agro-industry, making rice-fish farming a more efficient agriculture system to recycle and reuse nutrient elements, and maintaining soil fertility (Little et al., 1996; Edwards and Demaine, 1998; Halwart and Gupta, 2004; Lu and Li, 2006).

Rice is the most important staple food grain farmed in Laos, with greater than 60 percent of all agricultural land devoted to its cultivation. Laos has severe limits to its ability to expand future production due to limited arable land and increasingly depends on intensifying rice farming to improve average rice yields and higher national rice production (USDA, 2011). In 2018, arable land accounted for 6.2% of the country's area, although only 0.7% was permanent cropland and rice field accounts for 80% of the arable land area (World Bank, 2022; CIA, 2023). Laos has severe limits to its ability to expand future production due to limited arable land. The rice yield per unit area increased quickly, from 3 mt ha$^{-1}$ in 2000 to 4.5 mt ha$^{-1}$ in 2020 (LAOSIS, 2022; World Bank, 2022). The present study revealed a similar yield level at (median 4.40 mt ha$^{-1}$, IQR 3.40–5.58 mt ha$^{-1}$, $n = 101$). However, the yield level is still lower compared to other major rice-producing countries such as China (7.04 mt ha$^{-1}$) and Vietnam (5.92 mt ha$^{-1}$) (World Bank, 2022). With the current rice yield, farms only produce (median 3 mt rice, IQR 1.85–4.0 mt rice, $n = 101$), with a value output of (median 694.20 USD, IQR 371.69–1015.27 USD, $n = 101$).

It was reported that the yield of aquatic foods was 250 kg ha$^{-1}$ for rice-fish farming and 50 kg ha$^{-1}$ for rice field fisheries in 2007 (Ministry of Agriculture and Forestry, 2014). The present study found that the yield of aquatic foods was 874 kg ha$^{-1}$ for rice-fish farming in 2021, which is higher than previously reported. The higher yields of aquatic foods are related to better infrastructure, such as more deepened water areas, rice field modification with more ditches, refuges, ponds, reinforced banks, and more feeding equipment. The farming practices of rice-fish farming also have been intensified with increasingly adopted hatchery-produced seed and commercial feed.

The present study found that rice-fish farms have higher intensification levels of rice farming. Rice-fish farming has higher (albeit not statistically significant) rice yields (median 4.50 mt ha$^{-1}$, IQR 3.46–5.60 mt ha$^{-1}$, $n = 75$) than rice field fisheries (median 4.00 mt ha$^{-1}$, IQR 2.81–5.15 mt ha$^{-1}$, $n = 26$), making it more promising in reducing poverty and contributing to food security. Rice-fish production systems in Laos urgently need advanced technology and financial support. With extra feed inputs, more nutrient elements were added in the production system, thus rice-fish farms could produce higher rice yields than paddy field fisheries. The output of rice-fish farming is higher, and the output value of rice per unit area is significantly higher than that of rice field fisheries. Meanwhile, rice-fish farming can provide higher land and labor productivity when land and resource inputs are limited (Frei and Becker, 2005; Gurung and Wagle, 2005). Increasing the intensification levels of rice production systems could be an important way to generate more rice and value output in Northern Laos to reduce poverty and contribute more to food security.

Agriculture farms in Laos are still transitioning from subsistence-based to market-oriented production (Alexander et al., 2017; Manivong and Cramb, 2020). Approximately 77% of farm households in Laos are self-sufficient in rice (Shrestha, 2006). Similarly, it was reported that a high portion of fish caught in rice fields was for home consumption in Cambodia (Freed et al., 2020b). We also found that only 23.60% of all rice-fish farms and 4.35% of all rice field fisheries farms reported sales of aquatic foods in Northern Laos in 2021, the majority of farms only produce aquatic foods for home consumption. Currently, the commoditization rate of rice-fish production systems is low in Northern Laos, and many are still subsistence farming. This is likely due to poor or insufficient infrastructure and limited local demand for aquatic foods in mountainous Northern Laos. Producing aquatic foods for home consumption is important for food and nutritional security, but the potential of rice-fish production systems to generate more income and alleviate poverty is limited. Industrialization, commoditization, and spatial expansion are the major factors driving aquaculture increase in global south (Belton et al., 2020). Increasingly commoditization of major aquaculture species and global trade accelerated the rapid growth of aquaculture production and *per capita* aquatic foods consumption (Anderson et al., 2018). Higher level of commoditization is needed with the rice-fish production systems in Northern Laos, but it may constrained by a range of factors such as technical and financial assistance, access to markets, and forming farmer associations and organizations (Alexander et al., 2017).

## 5. Conclusion

The present study found that rice-fish production systems, including both integrated rice-fish farming and rice field fisheries, are still in resources poor status with low input levels of fertilizer and chemicals. Rice-fish farming generally has higher intensification levels than rice field fisheries and generally produces higher production per farm and yield per unit area of rice than rice field fisheries. Rice-fish farming generates significantly more value output of rice than rice field fisheries, producing more types of products such as fish, crab, prawn, snail, and frog. Aquatic foods sale volumes from rice-fish farming are also higher than rice field fisheries, indicating more contribution to poverty elimination and food security. Overall, rice-fish farming has higher levels of commoditization and better economic performance than rice field fisheries. Rice-fish farming uses land and labor more efficiently and generates higher land and labor productivity measured in value output than rice field fisheries. Based on survey results, there is a high potential to develop rice-fish production systems in Northern Laos. More rice field fisheries farms can be intensified with extra seed and feed input to move to rice-fish farming to produce more aquatic products and more value output with the same rice field areas in Northern Laos.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Shanghai Ocean University Ethics Committee. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

## Author contributions

WZ, JL, CL, and YL contributed to conception and design of the study. MP, ZZ, CL, and JL conducted the survey. YL, MP, and ZZ organized the database. YL and WZ performed the statistical analysis. YL, MP, and WZ wrote the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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