MEASURING MICRONUTRIENT PRODUCTIVITY IN INTEGRATED AQUACULTURE-AGRICULTURE TO PROMOTE NUTRITION-SENSITIVE FOOD SYSTEMS

By Liz Ignowski and Ben Belton

Crop diversification is considered an effective strategy to improve diets and nutrition, and is a key component of nutrition-sensitive agriculture (NSA). The authors compared the economic value and nutrient productivity per hectare for twelve distinct combinations of integrated aquaculture-agriculture (IAA), where aquatic and terrestrial foods are grown together on a single parcel of land, identified from a representative survey of 721 farms in southern Bangladesh. Their analysis shows positive associations between the integration of terrestrial foods into aquatic farming systems and nutrient productivity[1], but that nutrient productivity is partly disconnected from economic productivity. However, the production of specific combinations of aquatic foods and vegetables can simultaneously improve nutrient productivity and economic productivity, thereby promoting nutrition-sensitive agriculture (NSA).

Integrated-Aquaculture-Agriculture farms viewed from the air, with vegetables grown on trellises over ponds, and fruits and coconuts on pond banks

Malnutrition is persistent in many countries that experienced the green revolution, despite large increases in staple crop production per hectare of arable land and per capita over the past half-century. Growing awareness of this disconnect has led to calls for nutrition-sensitive approaches to agriculture that emphasise increasing consumption of micronutrient-rich foods, as opposed to prioritising meeting energy needs with staple grains. Nutrition-sensitive agriculture (NSA) programs are designed to address the underlying determinants of malnutrition within a population and incorporate specific nutrition goals. Our recent study published in Nature Food[2] analysed the nutrient productivity and economic productivity from differing combinations of aquaculture-agriculture integration from smallholder farms in southern Bangladesh. We found that production of specific combinations of aquatic foods and vegetables can simultaneously improve nutrient and economic productivity, therefore promoting NSA.

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[1] Nutrient productivity is expressed as the number of adults whose complete annual dietary requirements for energy, protein, calcium, iron, zinc, vitamin A, and vitamin B12 can each be met from one hectare.

[2] Ignowski, L., Belton, B., Ali, H., and Thilsted, S.H. Integrated aquatic and terrestrial food production enhances micronutrient and economic productivity for nutrition-sensitive food systems. Nature Food (2023). https://doi.org/10.1038/s43016-023-00840-8

The importance of nutrition-sensitive agriculture, and role of integrated aquaculture-agriculture

Food production and income generation are the two main pathways linking agriculture to household nutrition. Increased production of diverse, nutritious foods may improve home consumption by producers and can create spillovers for non-producer households through markets, while income from crop sales may allow households to purchase foods they are unable to produce on-farm to diversify their dietary intakes.

A farmer harvesting fish from a pond, with climbing vegetables growing on frames visible in the background.

Since the 1990s, rapidly growing domestic and export markets have increased aquaculture demand in Bangladesh. Aquatic foods are typically nutritious and economically valuable relative to staple foods. To promote enhanced production diversity, land productivity, and nutrient cycling on-farm, a wide variety of integrated aquaculture-agriculture (IAA) methods are practiced in Bangladesh. Examples of IAA include growing rice, fish, and crustaceans in the same plot, concurrently or in rotation or growing climbing vegetables on frames built over ponds.

However, to date, little attention has been paid to whether or how IAA practices enhance productivity of micronutrients by smallholder farmers. This is the motivation of this research, which presents a methodology for measuring the economic productivity and nutrient productivity of farming systems and identifying complementarities and trade-offs between these outcomes.

Productivity of IAA farms in Bangladesh

We analysed data from a representative survey of 721 farms in the seven most important aquaculture producing districts in southern Bangladesh, spanning a wide range of IAA practices. On each farm, detailed production data were collected for a single randomly-selected 'sample parcel' of land that had been used for aquaculture within the past 12 months, whether or not integrated with terrestrial foods. The sample represents the entire population of aquaculture farms in the seven selected districts.

Data on the production of 35 aquatic and 31 terrestrial foods harvested from these farms over the most recently completed cropping cycle (a period of approximately one year) were combined with food composition data to estimate the productivity per hectare of energy, protein, and five key micronutrients that are both critical for human health and commonly deficient: calcium, iron, zinc, vitamin A, and vitamin B12.

We expressed economic productivity as the annual value of food production (USD/ha), calculated as income received from sales of food produced, plus the imputed value of any self-produced food consumed, minus the variable costs of food production. Nutrient productivity is expressed in annual adult equivalents per hectare (AEs/ha) for 12 combinations of IAA. AEs are equivalent to the number of adults whose requirements for a specific nutrient could be met from one hectare for a period of one year. We used regression analysis to estimate correlations between production of aquatic and terrestrial foods and economic value and nutrient production.

Figure 1: Sample distribution by farming system

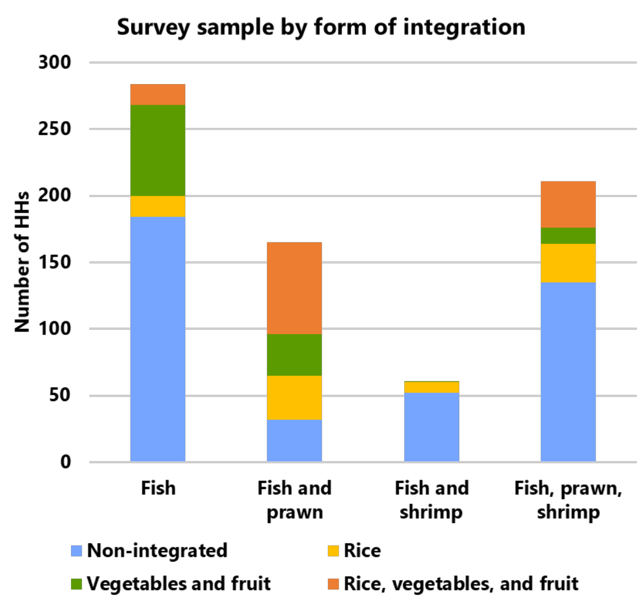

Figure 1 presents the distribution of 721 farms in our sample by farming system, defined in terms of four combinations of aquatic foods and four combinations of terrestrial foods. Among aquatic food combinations, production of only fish is most common (39%), followed by fish, prawn, and shrimp (29%), fish and prawn (26%), and fish and shrimp (8%). Among the households in our sample, 96% produce some carp species, 83% produce unstocked fish species, 82% produce other stocked fish species, and 59% produce crustacean species.

Some 56% of households do not integrate agriculture into their aquaculture production. Integration of aquatic foods with vegetables and fruits and rice is the most common form of IAA (17% of farms), followed by integration with only vegetables and fruits (16%), and integration with only rice (12%). The potential for integration of terrestrial foods is related to the type of aquaculture practiced. Giant freshwater prawn is produced in freshwater or low-salinity environments and is thus well-suited to integration with terrestrial foods. Shrimp (mainly black tiger shrimp) is produced in saline water that damages terrestrial food crops, making crop integration more difficult. However, there is significant overlap in the range of salinities in which both crustacean species can thrive, giving rise to a diverse mix of IAA. Most households producing prawn integrate with agriculture (81%), whereas IAA is only moderately common for households that produce only fish (35%), and comparatively rare for those producing shrimp (15%).

The diversity of production in our sample varies by farming system and by the combinations of foods produced on each farm. Farms harvested an average of nine aquatic products each, while the 32% of households that produced vegetables and fruits harvested 3.5 types each on average.

Figure 2: Economic productivity by farming system

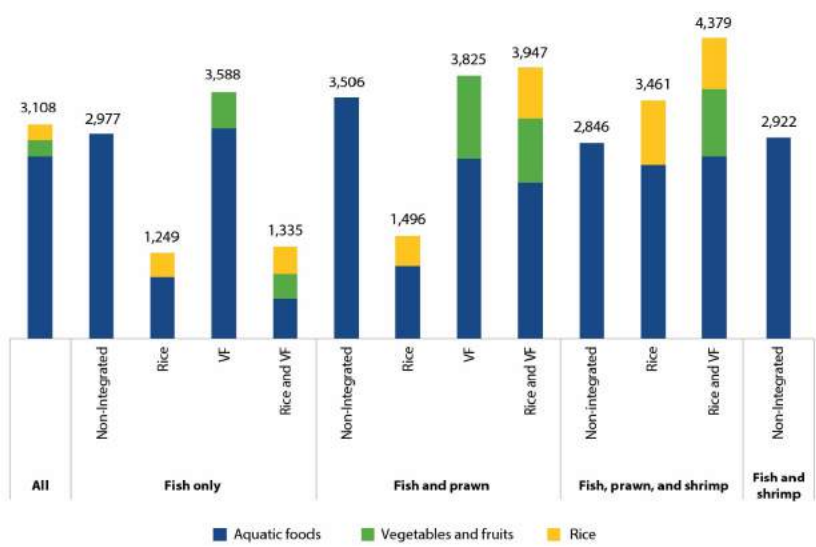

Figure 3: Economic productivity and estimates of nutrient productivity by farming system

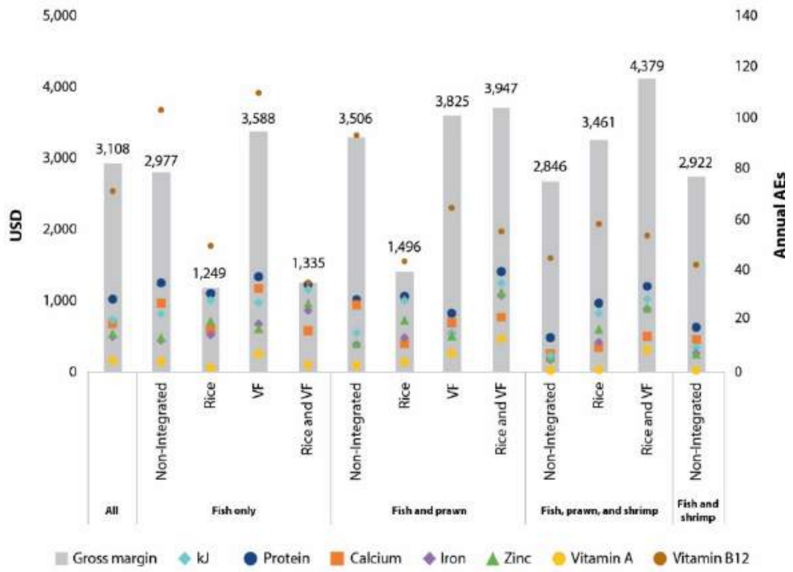

Figure 2 presents the economic productivity per hectare by farming system, disaggregated into aquatic foods, vegetables and fruits, and rice. The most profitable farming systems produce fish, prawn, and shrimp with rice, vegetables, and fruits (4 379 USD/ha), and fish and prawn with rice, vegetables and fruits (3 947USD/ha). The least economically productive farming systems produce fish integrated with rice (1 249 USD/ha), and fish integrated with rice, vegetables, and fruits (1 335 USD/ha).

Figure 3 extends this comparison by presenting the economic productivity per hectare, overlaid with estimates of productivity of energy, protein, calcium, iron, zinc, vitamin A, and vitamin B12, expressed as AEs/ha, by farming system. The Figure shows that the nutrient productivity of farming systems is partly disconnected from their economic productivity. IAA systems that combine fish and prawn with vegetables and fruits and rice – one of the most economically productive food combinations – also have the highest productivity of energy, protein, iron, zinc, and vitamin A. However, whereas the economic productivity of farming systems that include shrimp but are not integrated with terrestrial foods is close to the sample average, these systems supply much lower-than-average quantities of almost all nutrients per hectare. These results point to positive associations between the integration of terrestrial foods into aquatic farming systems and nutrient productivity.

Further analysis

The relationships outlined above are analysed with greater precision in a regression analysis presented in the full paper, where we divided the three main food groups into four sub-categories of aquatic food and eight sub-categories of terrestrial food, and regressed economic productivity and nutrient productivity against the quantities of each group of foods produced and numerous control variables. We found a positive and significant relationship between the productivity of three out of four aquatic food groups and economic productivity, with yields of crustaceans having the largest positive correlation with economic productivity, followed by yields of carp species. Yields of other stocked fish species, nuts/oilseeds, and vitamin A-rich vegetables are also positively and significantly associated with economic productivity.

We also found multiple positive and significant correlations between the productivity of foods and nutrients. Unstocked fish species which enter ponds naturally, such as when water is exchanged, are strongly associated with the productivity of multiple key micronutrients. Productivity of green leafy vegetables is highly significantly associated with productivity of iron, zinc, and vitamin A, as is the production of vitamin A-rich vegetables and other vegetables, but with a smaller coefficient. Production of vitamin A-rich fruits and other fruits has smaller and/or insignificant correlations with most nutrients, as do root crops. The yield of nuts/oilseeds is highly positively correlated with calcium and iron productivity. As expected, rice is an important source of energy and plant protein.


Credit: Md. Mahfujul Haque

Women transplanting rice in the raised central portion of a gher also used for fish and giant freshwater prawn cultivation.

Further results show that two unstocked small fish species, *mola* and *tengra,* are particularly significant sources of micronutrients. Consumption of small fish species such as these has been shown to improve intakes of calcium, iron, and vitamin A in Bangladesh. This result underlines the importance of the region's aquatic biodiversity in supporting human nutrition, with the Sundarbans (the world's largest contiguous area of mangrove), located adjacent to the southwestern portion of the study area acting as a nursery ground for many of the unstocked aquatic species harvested.

Among vegetables and fruits, okra, gourds, and long beans are all statistically significantly correlated with the productivity of protein, iron, and zinc. Pumpkins (vitamin A-rich vegetables), *shak* (leafy vegetables), mangoes, and betel nut are important sources of vitamin A. Coconuts are also positively statistically correlated with the productivity of energy and all nutrients in our study, except vitamin B12.

Our results indicate that the species and combinations of aquatic and terrestrial foods produced matter for economic and nutrient productivity, and that the mix of aquatic foods and vegetables included in integrated farming systems could be key to optimising economic productivity and nutritional adequacy. Aquatic foods are more nutritious per kilogram for certain nutrients, but their integration with terrestrial foods improves the overall availability of the nutrients included in this analysis. These results only relate to the production of foods, not the effects of their sale or consumption.

Discussion

Our study contributes to a growing body of research on nutrition-sensitive food systems and NSA. Most literature on NSA to date has been conceptual or has evaluated the impact of planned nutrition-sensitive interventions on demand-side outcomes. Our study's key contribution is to provide a supply-side methodology for estimating the nutrient productivity of farming systems.

Agricultural productivity is conventionally measured in terms of biomass or income per area of land. Our study introduces a nutrition-sensitive metric for agricultural productivity, expressed as production of kilojoules (kJ), protein, and micronutrients, relative to human nutritional requirements (AEs/ha). This approach made it possible to explore the relationship between economic and nutrient productivity across a range of IAA systems, identified inductively from a representative survey in Southwest Bangladesh. The results provide an intuitive measure of nutrient sensitivity that may be easily understood by researchers and policymakers and mobilised by development practitioners and food producers.

We find strong empirical evidence that production diversity associated with integration of aquatic and terrestrial foods in IAA systems can be beneficial for both economic and nutrient productivity. This finding has important implications for the design of NSA programs to enhance the contributions that aquaculture makes to nutrition security in Bangladesh and other countries where IAA is commonly practiced, and for the realisation of nutrition-sensitive food systems.

A crop of nutritious gourds, grown on trellises over a pond.

These results can also be used to identify and promote culturally and agroecologically suitable combinations of foods that optimise nutritional and economic outcomes. For example, common crops such as bitter gourds, bottle gourds, and long beans are associated with high levels of nutrient productivity, in addition to better-known vitamin A-rich crops such as green leafy vegetables.

However, increasing production diversity is not necessarily the most effective path to improving diet diversity. Income is another pathway to nutrition, and households that earn money from economically productive but less nutritious foods such as crustaceans may use it to purchase nutritious foods instead of producing them. This is a crucial point as shrimp (which are economically valuable) are produced in saline ponds, making integration with terrestrial crops challenging. It may be more beneficial for these households to seek to increase yields of shrimp and diversify production of aquatic crops to maximise income and aquatic source nutrients.

The approach presented in this paper can also be used to identify possible improvements to farming practices such as facilitating the entry of nutritionally and economically productive unstocked fish species into ponds, or identifying suitable candidate fish species for domestication via investments in fish breeding research. Future research using the methods developed here can also seek to identify and promote recommendations for specific crop combinations that maximise economic and nutrient output for a given level of salinity.

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