Diversification of Farmland use in Bangladesh: Land Allocation Impacts on Farm Profitability

Md. Salauddin Palash*, Siegfried Bauer

Abstract: Smallholder farmers in Bangladesh face many difficulties. A trend towards fish farming has opened new opportunities in recent years. This research focuses on the concern, whether smallholders could improve their gross margins by improving the allocation of the available physical and non-physical resources. Combinations of the participatory, qualitative and quantitative methods were used for primary data collection. A linear programming based modelling approach shows that farmers can increase the farm gross margin by reallocating the land in the model solution. Essential requirements, e.g. determined by household consumption requirements, determine parts of the resource allocation. The remaining land is in tendency allocated to fish farming; where one specific fish farming alternative is dominant to others. In the scenario analysis, all farming groups keep the same proportion of land use pattern until a certain level of price change, beyond that crop farming is selected. Scenarios modifying the available fish feed show the significant sensitivity of this resource on the land allocation.

Keywords: Land allocation, Freshwater fish farming, Farm profitability, Bangladesh

1 Introduction

In Bangladesh, a country of 155.8 million people (BER 2014), farmers engage in smallholder subsistence crop (mainly rice) farming. Total cropland area of Bangladesh is 7.90 million ha (BBS 2011). Due to rapid population growth (1.37 percent per year (BBS 2011)), urbanization, industrialization and diversification of agriculture (redistribution of land between agricultural sub-sectors), per capita cropland has been decreasing over time. The cultivated area is at present 0.125 acre per person (Quasem 2011). Consequently, efficient use of the small pieces of land is becoming a great challenge for the farm households of Bangladesh.

Land use planning is related to many factors such as the type of land, yield rates of enterprises, weather conditions, and availability of the agricultural inputs, food demand, market price, capital availability, and the cost of production (Sarker et al. 1997). Not all factors are measurable, however if the available information can be utilized properly, it may give valuable suggestions. In Bangladesh, a wide variety of crops in different seasons (summer, locally known as Kharif season, and winter, locally known as Rabi season) are grown, and have different types of lands (Sarker et al. 1997).

The use of cropland for another non-crop agricultural use (such as fish, poultry and livestock farming) has been increasing over the last two decades. Especially in the northern part of Bangladesh, comparatively flood free cropland area is being converted to freshwater fish farming. Extensive extension services from the Department of Agriculture Extension (DAE) and NGOs are available in the study area that enriched the majority of farmers’ basic knowledge about fish farming and benefit of changing cropping patterns. Meanwhile, developed input and product markets also contribute to the changing process. Consequently, Bangladesh became the 6th largest aquaculture fish producing country in the world.

This research focused on increasing the gross margin of farm households by re-allocating the available resources. The freshwater fish farming area is expanding over time because of market demand and the favorable growth rate of the market price; conversely, the uncertainty of rice production and low market price of rice during the harvest season also enhances the process. Most of the input resources used for crop and fish farming are competing and getting scarcer day-by-day.

Mathematical programming tools are used in making the combined decision of different activities such as crop...
farming, mixed farming, horticultural crops and livestock farming (Yang 1995). It can be used for making the decision of physical resource allocation between different farming. Among different types of mathematical programming, the linear programming methodology is used successfully in operations research for devising agricultural and forestry production (Howard 1993; Nicholson et al. 1994; Osho 1995; Merrya et al. 2002).

Linear programming is a general optimization technique to examine the optimal allocation of scarce resources (Buongiorno and Gilless 1987; Igwe and Onyenweaku 2013). For example, Butterworth (1985) used linear integer programming to solve the problem of mixed cropping, particularly vegetables and livestock herds subject to resource constraints of land, labor and machinery. Majek and Majek (2010) used a linear programming model for farm resource allocation and observed that the results were more superior to those obtained by traditional methods. Apart from these two techniques, to maximize the total contribution from agricultural activities in Bangladesh; Sarker et al. (1997) developed a linear programming model to determine the national crop-mix plan that would contribute to the national economy and improve the socioeconomic conditions of the agricultural people. Linear programming is also used to make the decision of land allocation among different types of farming alternatives subject to resource constraints. Jolayemi (1990) and Jolayemi et al. (1992) developed a linear programming model for selecting crops for mixed cropping schemes.

However, the application of linear programming, according to farm size in Bangladesh, has not been observed in the literature. A model which is based on survey data collected from those farmers, who convert some part of their cropland to fish farming, was developed. The model was used to determine the farmland use plan that will maximize the gross margin of the farmer groups, subject to the available resources.

2 Material and Methods

2.1 Area selection

The land conversion from crop to fish farming is mostly concentrated in the northern part of Bangladesh. Therefore, the most land-converted area, Mymensingh District, from the north part of Bangladesh was considered for this project. Among 64 districts in Bangladesh, Mymensingh district is an area of 4,36348 square km and consists of 12 sub-districts. The soil formation of the district is flood plain, gray piedmont, hill brown and terrace (Palash et al. 2015). There are small valleys between the high forests; annual average temperature maximum is 33.3°C, minimum is 12°C; and annual rainfall is 2,174 mm. Agriculture is the main occupation (57.67 percent), followed by transport, commerce, service and others. The amount of land used for cultivation is 346,117 hectares; single crop is 18.58 percent, double crop is 70.20 percent, and treble crop land is 11.22 percent (Islam, 2013a). Four major concentrated sub-districts, such as Mucktagachha, Trishal, Phulpur, and Bhaluka, were considered among the 12 sub-districts of Mymensingh district. In total 230 samples were collected from four sub-districts following the purposive sampling procedure.

2.2 Farm classification according to landholdings

The sampling units were classified into different groups based on their land holding status. Most of the farmers in Bangladesh are small and medium-scale farmers (98.45 percent) who have less than 7.5 acres or 3 ha of land, with few large-scale farmers (1.55 percent). According to agricultural census of Bangladesh, a farm household was classified into three categories such as: small (up to 2.4 acres); medium (2.5 to 7.4 acres); and large (7.5 acres or more) (BBS 2011). The landless and the farmers not using their land in pond fish farming were excluded from the sample units. All farmers produced fish for commercial purposes except some small amounts kept for home consumption, but crop farming was not commercial farming for the small and medium-scale farmers. The primary target of crop farming was to fulfill the family food demand and only sell the surplus amount to the market.

2.3 Agricultural products selection

Product selection is one of the critical activities of farms, traditionally based on resource fixity, ancestor profession, and the influence of neighbor land use decisions. The areas of the north-central region of Bangladesh, i.e. greater Mymensingh, Bogra, Rajshahi, Nogaon, Natore etc. districts, are flood-free zones and suitable for different types of agricultural farming. Especially the road-side or near to road-side agricultural lands are suitable for pond fish farming, which provides manifold more income than crop farming. Sarker et al. (1997) found that the farmers of Mymensingh district, who make the decision to pond
fish farm, bear in mind the economic profitability of pond fish farming in comparison to cultivating rice or any other crops.

A crop calendar year represents two major growing seasons namely summer season (locally named *Kharif* season from April to October) and winter season (locally named *Rabi* season from November to March). The summer season is mostly rain-fed and the winter season is mostly irrigated in Bangladesh. The major portion of the cereal food supply comes from winter crops. Rice is the staple food in Bangladesh. Therefore, every farmer produces rice in both seasons along with other crops and vegetables. The major crops in Mymensingh district are rice, jute, and some winter vegetables (Islam 2013b), but the farmers who converted their land to fish farming confined themselves only to rice and fish farming activities. Although some farmers produced some vegetables, potatoes, sweet potatoes, and mustards, those are excluded in the study because they use a negligible amount of land. Farmers cultivate different varieties of rice and fish during summer and winter seasons. The names of the rice varieties are *Hori dhan*, BR11 (locally called *Mukta*), BR22 (Locally called *Kironmala*), BRRI Hybrid3 and BRRI Hybrid4, BR28, and BR29. Most of the farmers practice *Hori dhan* followed by *Mukta* and *Kironmala*. A very few farmers cultivate hybrid rice because of high production costs though its output is highest among all winter rice varieties. Among winter rice varieties, BR28 is the popular rice variety for the farmer though its output is the lowest among all winter rice varieties. The BR29 rice variety is also popular with those farmers who can apply more fertilizer to the field, which means comparatively larger farms have the capability of cultivating this variety. Like the summer rice, the winter rice hybrid variety is also unpopular with the farmer.

**Fig. 1: Map of the study areas (rectangle marked area). Source: Mymensingh District (Islam 2013b)**
There is a significant difference in fish farming varieties. One variety is significantly different from other varieties in stocking rate, yield and price. Particularly, in the study areas, farmers performed polyculture instead of monoculture to reduce risk. Six polyculture combinations were selected for the research. The names of the fish varieties are Pangus (*Pangasius hypophthalmus*), Koi (*Anabas testudineus*), Shing (*Heteropneustes fossilis*), Magur (*Clarias gariepinus*), Rohu (*Labeo rohita*), Catla (*Catla catla*), Mrigel (*Cirrhinus cirrhosis*), Silver carp (*Hypophthalmicthys molitrix*), Common carp (*Cyprinus carpio*), Tilapia (*Oreochromis mossambicus*), Gulsa (*Mystus cavasius*), Shorpunti (*Barbodes gonionotus*), and Bata (*Labeo bata*).

### 2.4 Data collection

Combinations of the participatory, qualitative and quantitative methods were used for primary data collection. The primary information was obtained through interview with key informants and questionnaire surveys with farm households. In total 115 small-scale, 90 medium-scale, and 25 large-scale farmers were purposively selected from four sub-districts. At first, the information was collected from the key informants and then followed by the household surveys. A short background of the research, study objectives, and data requirements was briefed with the participants.

The secondary information was collected by reviewing the literature (publications and research articles) and obtained through visiting some organizations such as BBS (Bangladesh Bureau of Statistics), DAM (Department of Agricultural Marketing), DOF (Department of Fisheries), *Upazila* Fisheries Officer (UFO), WorldFish center etc. Some important secondary data was obtained from the experts of this field through email communication.

### 2.5 Model Specification

Linear programming is a technique for the optimization of a linear objective function, subject to linear equality/inequality constraints. In general, a linear programming problem can be expressed in matrix form, and then becomes (Dantzig and Thapa 1997):

Maximize $c^T x$, subject to $Ax \leq b$

$x \geq 0$

Where, $x$ represents the vector of variables (unknowns), $c$ and $b$ are vectors of coefficients (known), $A$ is a matrix of coefficients (known), and $T$ is the matrix transpose.

### 2.6 Assumption underlying for model specification

In social science, running any model is always connected to some limitations. This model also abstracts from some factors that may affect land allocation patterns. The following assumptions were adopted to ease off the model formulation:

1. The available farming land area is given during a cropping year. Therefore, it is not possible to increase or decrease the farming land area at short notice.
2. Although few farmers cultivate some crops such as sweet potato, mustard, etc. the model only considers the summer and winter rice varieties.
3. In the fish farming combinations, fish farmers have combinations of different species in different ponds.
4. The variable inputs such as hired labor, seed, fertilizer, feed, irrigation, etc. are available during a cropping year.
5. The prices of crop and fish, and yields per hectare are given and treated as exogenous factors.

### 2.7 Objective function

Though almost 85 percent of the households belong to the small farm household in the country (BBS 2011), they are also considering diversifying their agriculture to increase their family income as well as contributing to the national GDP growth rate. There is a well-known concept that developing country farmers run their farms to maximize their utility, where this utility maximization is deviating more from the pure profit maximization than in other countries (Palo and Mery 1996). This is partially applicable for Bangladesh also, but at the same time some parts of Bangladesh are becoming specialized for some types of farming. Examples are commercial small-scale poultry, vegetable, fish farming etc., which are spreading throughout the country with the help of government and NGO extension services.

The objective function of the model is the maximization of the farm profits, which is defined as expected total return minus production cost, which includes all types of variable cost items in the production process. The farmers must allocate the total available land to the farming alternatives so that the gross margin will be maximized. Thus, the objective function is formulated as follows:

$$GM_{S,c} = \sum_{S=1}^{2} \sum_{c=1}^{n} TR_{S,c} - \sum_{S=1}^{2} \sum_{c=1}^{n} PC_{S,c}$$

Where $GM_{S,c}$ is the gross margin for the farm, $TR_{S,c}$ is the total return for the farm, and $PC_{S,c}$ is the production cost for the farm.
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Maximize Gross Margin \( Z = \sum_{s=1}^{2} \sum_{c=1}^{n} G M_{s,c} X_{s,c} \)  

Where, \( G M_{s,c} \) = Gross margin from commodity \( c \) in the growing season \( s \) in BDT/ha, \( TR_{s,c} \) = Total return from commodity \( c \) in the growing season \( s \) in BDT/ha, \( P C_{s,c} \) = Production cost from commodity \( c \) in the growing season \( s \) in BDT/ha, \( X_{s,c} \) = Simulated area of the selected commodity \( c \) in the growing season \( s \) (ha), \( c \) = Represents the growing commodities ( \( c = 1, 2, \ldots, n \) ), \( s \) = Growing season \( s \), \( s_1 \) = Summer season (Kharif); \( s_2 \) = Winter season (Rabi)

Total return in a year is equal to the sum of the total return of all crops and fish produced in the two growing seasons (summer and winter). A commodity’s total revenue is the product of the total volume of production and the average price (the average of the farm gate price) of that commodity. The following equation is used to calculate the total return, which is the total return from all crops:

\[ TR_{s,c} = \sum_{s=1}^{2} \sum_{c=1}^{n} Q m_{s,c} P m_{s,c} \]

Where, \( Q m_{s,c} \) = Total production of commodity \( c \) in the growing season \( s \) (ton), \( P m_{s,c} \) = Farm gate price of commodity \( c \) in the growing season \( s \) (BDT/ton)

According to Garrison et al. (2011), variable costs change in proportion to the production of goods and services. In this research, agricultural farming cost calculation is a challenge, because the farmers do not keep any written records of farming. However, all costs incurring activities of rice and fish production were considered to estimate the total production cost of farming.

\[ PC_{s,c} = P C r_{s} + P C f_{s} \]

\[ P C r_{s} = r t r a c_{s} + r l a b o r_{s} + r s e e d_{s} + r f e r t_{s} + r w a t e r_{s} + r c r e d i t_{s} + r o t h e r_{s} \]

Where, \( P C_{s} \) = Production cost of all types of rice farming in the growing season \( s \) (BDT/ha), \( r t r a c_{s} \) = Tractor cost in the growing season \( s \) (BDT/ha), \( r l a b o r_{s} \) = Labor cost for rice field preparation, maintenance, harvesting and marketing in the growing season \( s \) (BDT/ha), \( r s e e d_{s} \) = Rice seed cost in the growing season \( s \) (BDT/ha), \( r f e r t_{s} \) = Fertilizer for rice in the growing season \( s \) (BDT/ha), \( r w a t e r_{s} \) = Water (irrigation) cost in the growing season \( s \) (BDT/ha), \( r c r e d i t_{s} \) = Credit cost in the growing season \( s \) (BDT/ha), and \( r o t h e r_{s} \) = Other cost in the growing season \( s \) (BDT/ha)

\[ P C f_{s} = f l a b o r_{s} + f f i n g_{s} + f f e e d_{s} + f f e r t_{s} - \]

\[ + f w a t e r_{s} + f p o n d m g t_{s} + f c r e d i t_{s} + f o t h e r_{s} \]

Where, \( P C f_{s} \) = Production cost of all types of fish farming combination in the growing season \( s \) (BDT/ha), \( f l a b o r_{s} \) = Labor cost for pond preparation, maintenance, harvesting and marketing in the growing season \( s \) (BDT/ha), \( f f i n g_{s} \) = Fish fingerling cost in the growing season \( s \) (BDT/ha), \( f f e e d_{s} \) = Feed cost in the growing season \( s \) (BDT/ha), \( f f e r t_{s} \) = Fertilizer cost in the growing season \( s \) (BDT/ha), \( f w a t e r_{s} \) = Water cost in the growing season \( s \) (BDT/ha), \( f p o n d m g t_{s} \) = Pond management cost in the growing season \( s \) (BDT/ha), \( f c r e d i t_{s} \) = Credit cost in the growing season \( s \) (BDT/ha), and \( f o t h e r_{s} \) = Other cost in the growing season \( s \) (BDT/ha)

### 2.8 Formulation of the constraints

The decision concerning the production of rice and fish is constrained by the following constraints.

#### 2.8.1 Availability of cultivable land

The total land available for cultivation was fixed and limited for a particular period. The land constraint limits the level of crop and fish production activities to the on-farm availability of land (Tiwary 2014).

For all growing season \( s \),

\[ \sum_{c=1}^{n} X_{s,c} = l u s e d_{s} \leq l a \]

Where, \( X_{s,c} \) = Area of the selected for commodity \( c \) in the growing season \( s \), \( l u s e d_{s} \) = Total cultivated land for selected commodity \( c \) in the growing season \( s \), and \( l a \) = Total available land (ha)

#### 2.8.2 Household consumption requirement

The focus of this research was to increase the gross margin of the farmers using available agricultural land. There was a challenge to compare the crop and fish farming, because the fish farming gross margin was manifold higher than that of crop farming. Therefore, without the consumption requirement restriction, the model would allocate all available land for fish farming. This was not justifiable nor was it possible to convert all cropland to pond fish farming because of having some limitations of land and farmers were not interested in converting the entire land for fish farming whether it was more profitable or not. Thus, there should be some land for crop farming in each season. The
empirical result shows that all groups of farmers want to keep a minimum amount of cropland to avoid purchasing required food (rice) items from the market. Although some small farmers sold their produce in the market during harvesting season and purchased it back later, but in the model, it is assumed all farmers should keep such amount of land that will provide the entire year’s cereal food requirement. The model also estimates the quantity of the cereal food that the household needs to purchase from the market (if necessary) to fulfill the household cereal food consumption requirement. It imposes the constraint as;

For each commodity \( c \),

\[
\sum_{s=1}^{2} \sum_{c=1}^{n} Qm_{s,c} + \sum_{s=1}^{2} \sum_{c=1}^{n} Purch_{s,c} \geq \sum_{s=1}^{2} \sum_{c=1}^{n} Cons_{s,c} \tag{8}
\]

Where, \( Qm_{s,c} \) = Total production of commodities \( c \) in the growing season \( s \) (ton), \( Purch_{s,c} \) = Purchase of the commodities \( c \) in the growing season \( s \) (ton), and \( Cons_{s,c} \) = Household consumption requirement of the commodities \( c \) in the growing season \( s \) (ton)

### 2.8.3 Family labor availability

Farmers use labor (family and hired) for agricultural farming throughout the year. Small and medium farmers try to provide all labor from the family, but during the intercultural operations and harvesting time they need to hire some labor. In the LP model, like the land constraint, labor is also restricted and the restriction applies to family labor availability. It is easy to calculate the total family labor availability but not the hired labor availability in a year. Therefore, hired labor is treated as an endogenous variable in the model. A farmer can hire labor as much as needed during the farming season.

Family labor was compensated in the model like hired labor and the wage or compensation rate was calculated by opportunity cost basis, considering the best job alternative. In Bangladesh, the wage of hired labor is always calculated in consolidate the system. That means there is no system of exchanging labor among farmers living in the same community. When the study was conducted, the average labor wage rate was BDT 300 per day.

Since the total available land was restricted, the required amount of labor changed, based on different farming activities; the restriction ensures enough hired labor utilization. The labor constraint is formulated as the sum of the product of the estimated number of laborers required and area of the commodity \( c \) in a year. This must be less than the total number of family laborers available during the season plus/minus hired labor and family labor should not exceed the initial family labor endowment. The mathematical expression is;

\[
\sum_{s=1}^{2} \sum_{c=1}^{n} W_{s,c} X_{s,c} \pm HL \leq FL \tag{9}
\]

Where, \( W_{s,c} \) = Labor requirement of the commodity \( c \) in the growing seasons \( s \) (md/ha), \( X_{s,c} \) = Simulated area of the commodity \( c \) in the growing season \( s \) (ha), \( HL \) = Hired labor requirement in the whole year (md/farm), and \( FL \) = Family labor availability in the whole year (md/farm)

### 2.8.4 Availability of operating capital

There are some heterogeneous inputs used in crop and fish farming. Major crop farming inputs were labor, seed, fertilizer, tractor, water and other items (manure and pesticide); and fish farming inputs were labor, fingerlings, feed, fertilizer, water and other items (medicine, electricity and guarding). Labor cost was one of the major input costs of crop farming, whose share was about 31 percent, but in fish farming, feed cost had a major share (about 75 percent) whereas, labor was a typical input cost for both types of farming. The share of fertilizer cost was about 25 and 0.5 percent of crop and fish farming respectively, which had a great difference.

Huge differences in production costs exist between these two types of farming. It is impossible for small and lower end medium type farmers to cover the operating cost from their own sources for fish farming. All types of farmers use credit from formal and informal sources. The informal source is the main source of credit for fish farming. It is possible to calculate the available operating cost from the farm sources but not the credit availability from other sources. A farmer can receive credit as much as needed if they are eligible. Therefore, the home supplied operating cost availability amount is considered as the available operating cost of each farming group. It happened that higher credit cost (interest rate of credit) restricted the model from using more credit for farming. The formulation of the constraint is set up as;

\[
\sum_{s=1}^{2} \sum_{c=1}^{n} PC_{s,c} X_{s,c} \pm Cr \leq Hoc \tag{10}
\]

Where, \( PC_{s,c} \) = Production cost of all commodities \( c \) in the growing seasons \( s \) (BDT/ha), \( X_{s,c} \) = Simulated area of the commodity \( c \) in the growing season \( s \) (ha), \( Hoc \) = Home supplied operating cost (BDT/farm), and \( Cr \) = Credit requirement (BDT/farm)
2.8.5 Fish farming feed availability

Feed is the major cost item as well as major decision making factor of fish farming land use. There are two types of feed use in fish farming namely traditional and commercial feed. Traditional feeds are locally made and consist of unbalanced food nutrients, as well as cheaply available forms such as rice bran, khoil, green grass etc. On the contrary, commercial feeds are scientifically manufactured and consist of balanced food nutrients. The price of commercial feed is the major concern of fish farming. The availability and quality are also a burning issue in fish farming. Commercial feeds are made by grinding and mixing together the ingredients such as water, fishmeal, vegetables, proteins, and a binding agent such as wheat.

Farmers could have more hired labor in the higher wage rate or more credit amounts in higher interest rate, but it is not possible to provide the boundless amount of feed for a certain period. Therefore, whether a farmer has the ability of getting more hired labor from the market and more credit from the formal or informal sources, but the feed availability determinants dominate the decision of fish farming land use in the study area.

Aggregating the fish feed requirement in weight is difficult due to the high variation in per unit price of traditional and commercial feeds. Therefore, feed availability is calculated by multiplying the total amount of traditional and commercial feed use in fish farming by its respective market price. It imposes the constraint as:

\[
\sum_{s=1}^{2} \sum_{c=1}^{n} Feed_{s,c} X_{s,c} \leq Feed_{avl}
\]  

Where, \( Feed_{s,c} \) = Feed cost of all types of fish combination \( c \) in the growing season \( s \) (BDT/ha), \( X_{s,c} \) = Simulated area of the commodity \( c \) in the growing season \( s \) (ha), and \( Feed_{avl} \) = Total feed availability (BDT/farm/year)

2.8.6 Non-negativity conditions

All variables are required to be non-negative.

\[
X_{s,c} \geq 0
\]

2.9 Overview of the variables and parameters

Mentioning the variables under the categories of endogenous and exogenous is necessary for developing an economic model. The identity (endogeneity/ exogeneity) of a variable depends on the model (Kaplan 2004). An endogenous variable of a model can be exogenous in another model. Table 1 presents the endogenous and exogenous variables that were used in the mathematical programming model.

### Table 1: List of endogenous and exogenous variables used in the model

<table>
<thead>
<tr>
<th>Variables</th>
<th>Symbol</th>
<th>Unit</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endogenous</td>
<td>g(margin)</td>
<td>BDT</td>
<td>Gross margin</td>
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<tr>
<td></td>
<td>(TR)</td>
<td>BDT</td>
<td>Total revenue of commodity ( c )</td>
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<td></td>
<td>(Q_{ms,c})</td>
<td>ton</td>
<td>Total production of commodity ( c ) in the growing season ( s )</td>
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<tr>
<td></td>
<td>(X_{s,c})</td>
<td>ha</td>
<td>Land allocation for the commodity ( c ) in the growing season ( s )</td>
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<tr>
<td></td>
<td>(W_c)</td>
<td>md</td>
<td>Labor requirement for the commodity ( c )</td>
</tr>
<tr>
<td></td>
<td>(HL)</td>
<td>md</td>
<td>Hired labor requirement in a year</td>
</tr>
<tr>
<td></td>
<td>(Cr)</td>
<td>BDT</td>
<td>Credit requirement in a year</td>
</tr>
<tr>
<td>Exogenous</td>
<td>(la)</td>
<td>ha</td>
<td>Initial land endowment</td>
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<tr>
<td></td>
<td>(Cons)</td>
<td>ton</td>
<td>Household consumption requirement of the commodities (ton) in a year</td>
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<tr>
<td></td>
<td>(FL)</td>
<td>md</td>
<td>Availability of family labor in a year</td>
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<tr>
<td></td>
<td>(OC)</td>
<td>BDT</td>
<td>Availability of owned supplied capital</td>
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<tr>
<td></td>
<td>(Feed_{avl})</td>
<td>BDT</td>
<td>Availability of feed in a year</td>
</tr>
<tr>
<td></td>
<td>(P_c)</td>
<td>BDT</td>
<td>Farm-gate price of the commodity ( c )</td>
</tr>
<tr>
<td></td>
<td>(PC)</td>
<td>BDT</td>
<td>Production cost of all commodities</td>
</tr>
</tbody>
</table>

BDT = Bangladeshi Taka, ha = hectare, kg = Kilogram

3 Results and interpretation

Table 2 presents the overview of the empirical parameters in the model. At first, farm households were categorized into small, medium and large, after taking the averages of farm
Model results (basic solution level) show the maximum gross margin can be achieved for all types of farmers by reallocation of land use. In the case of small farms, the gross margin increased from BDT 134,18 thousand to BDT 154,94 thousand which was about 15 percent higher than the given situation. The cropland use pattern was almost the same in the basic solution level, but the model suggests only one fish polyculture instead of six fish polyculture practices in the study areas. The excess gross margin came from reallocation of fish farming land in different fish farming combinations.

The gross margin was also increasing in case of medium and large farms and the increasing rate was level data according to each farm households. For example, the farm size of small farm household has computed by dividing the total farm size with the number of farms. All types of farm level data were calculated in this way for small, medium and large-scale farmers in the study areas.

### 3.1 Gross margin of the farmers

In the linear programming model, calibration is necessary to check the suitability for simulating the current situation. Table 3 shows the evaluation of current/observed situation results of three types of farming with the model results. Model results (basic solution level) show the maximum gross margin can be achieved for all types of farmers by reallocation of land use. In the case of small farms, the gross margin increased from BDT 134,18 thousand to BDT 154,94 thousand which was about 15 percent higher than the given situation. The cropland use pattern was almost the same in the basic solution level, but the model suggests only one fish polyculture instead of six fish polyculture practices in the study areas. The excess gross margin came from reallocation of fish farming land in different fish farming combinations.

The gross margin was also increasing in case of medium and large farms and the increasing rate was
about 22 and 33 percent for medium and large-scale farm respectively. Unlike small farmers, both types of farmers increased the cropland area and decreased the fish farming land area. Notwithstanding, the gross margin was increasing due to the reallocation of fish farming land area in a specific fish farming combination.

### 3.2 Commodity-wise land use situation

Land use for fish farming depends on various factors such as realizing home consumption from self-produced cereal food, suitability of land for conversion and feed availability from the feed dealer. Particularly, the model depicts that all farmers’ groups increase the crop farming area and decrease the fish farming area to maximize the gross margin with the adjustment of existing resources. However, small farmers followed all farming alternatives but medium and large farmers followed all crop farming alternatives but not all fish farming alternatives in the given situation. All groups of farmers allocated a very small amount of land for fish farming combination two, three, four and six. Even medium-scale farmer groups did not allocate any land for fish farming combination three and five, and large-scale groups avoid allocating land for fish farming combination three and four in the existing situation. Less profitability, riskiness, and low output rate were the main reasons for not allocating or lower allocation of land for these fish farming alternatives.

Model results always kept the same amount of land for crop farming alternatives and the lower limit of land amount is set by the home consumption requirement restriction. If there was no restriction, the model would allocate all available land for fish farming which is not possible in the real situation. The model chooses only one fish-farming alternative among six alternatives based on production cost, yield rate and price of the output. The model suggested fish poly-culture farming ‘Fish combination five’, which includes all major species cultured in the study areas. The majority share in this poly-culture system is occupied by different species of catfishes followed by different carp species, and other native and alien species in different proportion. In comparison to the existing situation, medium and large farmer groups also allocated more land for the fish combination five which indicates that fish combination five was the most popular fish-farming alternative for all farmer groups.

### Table 3: Overall gross margin in observed and base solution level

<table>
<thead>
<tr>
<th>Farm types</th>
<th>Gross margin ('000 BDT/farm/year)</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Base solution</td>
</tr>
<tr>
<td>Small</td>
<td>134.18</td>
<td>154.94</td>
</tr>
<tr>
<td>Medium</td>
<td>490.18</td>
<td>599.98</td>
</tr>
<tr>
<td>Large</td>
<td>1290.91</td>
<td>1721.78</td>
</tr>
</tbody>
</table>

Source: Author’s calculation

### Table 4: Land allocation pattern in observed and base solution level

<table>
<thead>
<tr>
<th>Commodities</th>
<th>Observed (ha)</th>
<th>Base solution</th>
<th>Percentage deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>Summer rice</td>
<td>0.28</td>
<td>0.87</td>
<td>1.88</td>
</tr>
<tr>
<td>Winter rice</td>
<td>0.32</td>
<td>0.94</td>
<td>2.06</td>
</tr>
<tr>
<td>Fish combination one</td>
<td>0.07</td>
<td>0.31</td>
<td>0.99</td>
</tr>
<tr>
<td>Fish combination two</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>Fish combination three</td>
<td>0.02</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fish combination four</td>
<td>0.01</td>
<td>0.02</td>
<td>-</td>
</tr>
<tr>
<td>Fish combination five</td>
<td>0.06</td>
<td>0.44</td>
<td>1.09</td>
</tr>
<tr>
<td>Fish combination six</td>
<td>0.02</td>
<td>-</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Source: Author’s calculation
3.3 Marginal value of land at basic solution level

The meaning of marginal value in mathematical programming is the amount of objective value that would change if the right side exogenous values were increased by one unit. It is only related to the differential changes in constant terms in the equation. The marginal value of land causes the increase or decrease in land demand for specific purposes. In the study areas, the marginal value of fish farming land was much higher than cropland. Therefore, the higher marginal value of land created a utility to the farmer to involve in fish farming or to increase the fish farming land area.

Table 5: Marginal value of land in different types of farms

<table>
<thead>
<tr>
<th>Farm types</th>
<th>Marginal value ('000 BDT/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>65.13</td>
</tr>
<tr>
<td>Medium</td>
<td>69.10</td>
</tr>
<tr>
<td>Large</td>
<td>67.07</td>
</tr>
</tbody>
</table>

Source: Author’s calculation

Table 5 shows the marginal value of land over farmland holdings, which were higher than the average market price of renting cropland, but less than the average market price of renting fish farming land. The average land rental price for crop farming was BDT 5320/ha/year and for fish farming was 104336/ha/year. The marginal value of the basic solution level is almost the same for each type of farming group, which implies that adding one unit of land increases the objective value in the study areas. However, extra land had a positive effect in the objective function.

3.4 Scenario analysis

According to Mauch (2010), scenario analysis is a process of analyzing possible future events by considering alternative possible outcomes. In this research, two important scenarios were considered to see the effects on land allocation and farm gross margin such as the falling down of fish market price, and fish feed supply.

Table 6: Fish price decreasing effect on gross margin

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Gross margin ('000 BDT/farm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small farm</td>
</tr>
<tr>
<td>Base solution</td>
<td>154.94</td>
</tr>
<tr>
<td>Fish price (↓ 10 %)</td>
<td>131.08</td>
</tr>
<tr>
<td>Fish price (↓ 25 %)</td>
<td>95.28</td>
</tr>
<tr>
<td>Fish price (↓ 50 %)</td>
<td>63.06</td>
</tr>
</tbody>
</table>

Source: Author’s calculation

3.4.1 Effect of fish price uncertainty on land use pattern

Schiller (2014) noted that the market price is the economic price for which a good or service is offered in the marketplace. In the scenario analysis, ‘fish price decreasing’ situation was considered to measure the price uncertainty effect on land use. Per year per ton fish price was obtained from the average price of different fish varieties such as Pangus, Rui, Katla, Mrigel, Tilapia, Koi, Shing and Magur species of fish.

The fish price was higher than the crop price in the study areas. To see the fish price uncertainty effect, this research considered the outcome ‘fish price decrease’ not the ‘fish price increase’ because, if the fish price increases then the farm will follow the basic solution level land use pattern. Three scenarios were considered for the mathematical programming such as when the fish price is decreased by 10, 25, and 50 percent.

Fish farming is a capital-intensive farming, so the land use pattern could be changed with a small change in the fish price. Table 6 and Figure 2 show the ‘fish price decreasing’ effect on land use and farm profitability in different scenarios.

All types of farms allocated the same proportion of land for crop and fish farming up to the scenario when fish price decreased by 25 percent, where the gross margins become half compared with the basic solution. Since, fish farming represents the major contribution to the farm profitability, therefore, when the fish price is reduced by 10 or 25 percent, the gross margin was not reduced by the same percentage. However, gross margin reduction was more for large scale farmers in compare to others which implies that the large farmers were more vulnerable to the change of market price.

In the third scenario (fish price decreased by 50 percent), all types of farms change land use patterns from mixed farming to only crop farming. Fish farming was no more profitable in that situation; therefore, the farm gross margin was very low in the third scenario (Figure 2).

The marginal value of land shows that the contribution of one extra unit of land to the objective function (total
uncertainty of fish feed reduces the allocated land for fish farming which ultimately reduces the farm profitability. Three scenarios such as fish feed availability reduced by 10, 25, and 50 percent were considered for the mathematical programming to see the effects on the land use pattern and farm profitability.

Table 7: Less fish feed availability effect on farm profitability

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Gross margin ('000 BDT/farm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small farm</td>
</tr>
<tr>
<td>Base solution</td>
<td>154.94</td>
</tr>
<tr>
<td>Fish feed (↓ 10%)</td>
<td>145.76</td>
</tr>
<tr>
<td>Fish feed (↓ 25%)</td>
<td>131.97</td>
</tr>
<tr>
<td>Fish feed (↓ 50%)</td>
<td>109.00</td>
</tr>
</tbody>
</table>

Source: Author’s calculation

Table 7 shows the gross margin of different types of farms in different scenarios of fish feed availability. In the gross margin) declined with declining fish prices according to the scenarios. In this situation, agricultural land should be used for only crop farming purposes until the marginal value of the land becomes higher. Therefore, there was no chance of increasing the fish farming land area any more if the fish market prices did not stay as in the base situation. At the same time, decision makers’ concern about ‘higher market prices’ will have no effect on the land use pattern if the input market prices of respective commodities increase at the same rate. The higher input price is always a burning issue from the farmers’ point of view. Aggregately, farm profitability is the important factor of maintaining land in the agricultural sector.

3.4.2 Decreasing fish feed availability and land use pattern

This section explains the effect of decreasing fish feed availability on the farmers’ land use decisions. The
third scenario where fish feed availability reduced by 50 percent, small farm gross margin reduced by 30 percent and medium and large farm gross margin reduced by 32 and 36 percent respectively. Therefore, large farmers are more affected by less availability of fish feed.

Small farms allocated 0.33 ha of land for crop farming at the basic solution level and the rest of the land for fish farming. The cropland amount is determined by the household consumption requirement and fish feed availability restrictions in the model. In different scenarios, cropland area was increasing because of less availability of feed for fish farming (Figure 3). The allocated land for crop farming was 0.35, 0.38, and 0.43 ha in three different scenarios respectively. It was clear from the analysis that fish feed availability only reduces the fish farming area.

Medium-type farmers allocated a major portion of land for crop farming (1.19 ha) in the basic solution level that can provide the yearly cereal requirement of the household, as well as for sales in the market. With the less availability of fish feed, medium type farmers made the adjustment of land use by increasing the crop farming area and reducing the fish farming area. In every situation, the farmer tries to achieve the maximum farm profits against available factors of production.

Large-type farmers used more land for crop farming (2.41 ha) in the basic solution level than the cropland required to provide yearly cereal requirements of the household. Therefore, large farmers earned a significant portion of their farm profit from crop farming. Large farmers allocated more land in crop farming due to lack of fish feed at the basic solution level. There was a restriction on the availability of fish feed, which was determined by the average fish feed uses of the individual large farms in the study areas. If they had more feed available, they would also allocate less amounts of land for crop farming. However, in different scenarios of fish feed availability, the fish farming area was gradually occupied by crop farming (Figure 3). Respectively, crop-farming areas were
In all scenario levels, the marginal value of land was the same for small, medium, and large farms respectively. The value was lower than the given average land rental price, but more than the cropland rental price in the study areas. The result was plausible since the lack of availability of fish feed reduces the fish farming area, which ultimately reduced the contribution of an extra unit of land to the objective function in the model.

4 Conclusions

The objective of this paper is to model the agricultural land between crop and fish farming in such a way that it increases the farm household gross margin with respect to available physical and non-physical resources. In line with the objective, the following constraints are considered: total available agricultural land of different types of farmers, household consumption requirement, availability of total family labor, and availability of own operating capital.

Model results show that the gross margin is higher for all types of farmers in the basic solution level of land use. The requirement of factors of production, such as total labor use, is changing changes in the model situation level for changing the land allocation among farming alternatives. Obviously, per farm labor use will be higher for the large-scale farm. Because of reallocation of fish farming land area, operating capital requirement increases in the basic solution level over a given situation. In the case of credit requirements, it depends on operating capital requirements of a farm. Therefore, higher capital-intensive farming requires more credit amounts.

Model results always keep the same amount of land for crop farming alternatives, which are set by the household consumption requirement and other constraints. The model allocates the rest of the land for fish farming; among six fish farming alternatives, the model chooses only the fish farming combination five after considering cost, yield, and price. Scenario analyses give some ideas about the possible outcomes and their effect on the land use pattern and farm profitability in dependence of different changing situations. All types of farmers keep the same proportion of land use until a certain level of price and yield change occurs; beyond which, they are moving to crop farming completely. The land allocation is different in the fish feed availability scenario; with the greater or lesser availability of fish feed, land allocation for fish farming shrinks or expands as well as does the farm’s gross margin. In the credit adjustment process, the scenarios with high savings rate from marketed surplus can adjust the basic solution level operating capital very quickly and avoid credit.

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