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Profit Optimization of Farmers in Different Locations Using Mixed Integer Linear Programming in Bangladesh

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Authors' contributions

This work was carried out in collaboration between all authors. Author MFU put the basic idea of the study. Author MKI designed the study, performed the statistical analysis, wrote the protocol and wrote first draft of the manuscript. Author MMA managed the analyses of the study. Author FMS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study, we formulate a mixed integer linear programming (MILP) model for sustainable optimization of agricultural production. The model is a mathematical programming model, based on multicriteria techniques, and can be used as a tool for the analysis and simulation of agricultural production plans, as well as for the study of impacts of the various policies in agriculture. The model can achieve the optimum production plan of an agricultural region combining in one utility function different conflicting criteria as the maximization of gross margin and the minimization of

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fertilizers used, under a set of constraints for land, labor, fertilizer, water, available capital and common agricultural policy. The formulated MILP has solved by branch and bound algorithm-using AMPL. In order to validate the model we have made a question survey on seven locations of three districts in Bangladesh. From the survey, it has observed that the selling prices of various agriculture products fluctuate depending on the natural calamities. In among locations, the optimum production plan achieves greater gross return, less fertilizers, labor and irrigated water use than the existent production plan. This study is to optimize the profit of farmers by using MILP model. Also this study completely wishes to focus on the poverty and economic development of Bangladesh.

Keywords: Agriculture products mixed integer linear program; optimization; various costs.

1. INTRODUCTION

People's Republic of Bangladesh is a densely populated developing country in the Southern Asia and its area is 147,872 km^2. In 2017 its populations become more than 160 millions. The population density of Bangladesh is about 1,082/km^2, which is the highest in the Southern Asian countries. Hence the large population became burden due to the limited resources of the country. Although Bangladesh is on course for Middle Income Country status by 2021, agriculture remains the largest employer in the country by far; and 47.5% of the population is directly employed in agriculture and around 70% depends on agriculture in one form or another for their livelihood. Agriculture is the source of food for people through crops, livestock, fisheries; the source of raw materials for industry, of timber for construction; and a generator of foreign exchange for the country through the export of agricultural commodities, whether raw or processed. It is the motor of the development of the agro-industrial sector including food processing, input production and marketing, and related services. As main source of economic linkages in rural areas, it plays a fundamental role in reducing poverty, which remains a predominantly rural phenomenon. The role of agriculture is also fundamental in promoting nutritious diets, especially in the countryside where production and consumption patterns are closely linked. According to the household income and expenditure survey (2010) 35.2% and 21.1% of the population in rural areas lives below upper and lower poverty line respectively. It also plays a fundamental role in the sustainable valorization and preservation of natural resources and in preserving and promoting the resilience to natural calamities and climate change of rural communities and agro-ecological systems. However, as Bangladesh develops, and other sectors grow (such as readymade garments), the share of agriculture in Gross Domestic Product (GDP) has naturally declined. During the fiscal year 2012-13 to 2016-17, the broad agriculture sector contributed 17.10%, 16.3%, 16.1%, 15.5% and 14.8 respectively to the total GDP (BBS). Nearly three fifth of the agricultural GDP comes from the crop sub-sector; the other contributors in order of magnitude are fishery, livestock and forestry. Bangladesh is also one of the most vulnerable countries to weather variability and natural disasters (World Bank, WB, 2007). The present government has targeted to reduce poverty rate to 25% and 15% by 2013 and 2021 respectively. Various microfinance programmes also help the poor to reduce the food insecurity and poverty of the country.

In this paper, Farmer location production problem is formulated as a MILP model which maximizes the profit of return on investment, and at the same time optimizes location, cost price and the investment. MILP model is also derived to determine the sites for the manufacturer and the best allocation for both the farmer and manufacturer. Serious arable land shortage and food security crisis could arise under disadvantageous rapid urbanization and industrialization, leading to complexities in identifying desired optimum plans for agriculture production Long et al. [1]. Akter and Uddin [2] argue that as an important sub-sector of livestock production, the poultry industry in Bangladesh plays a vital role in economic growth and simultaneously creates numerous employment opportunities. The poultry industry, as a fundamental part of the animal production, is committed to supplying the nation which a cheap source of good quality nutritious animal protein in terms of meat and eggs. Islam, Uddin and Alam [3] analyze challenges and prospects of the poultry industry in Bangladesh by using data collected from some important poultry industry. Mansini et al. [4] for properties analysis of different risk and safety measures including

CVaR). This is done by computing realizations through historical scenarios assuming they represent forecast data while satisfying all the constraints and resource requirements for the selected crops. Various modeling approaches have been applied to optimize the cropping pattern worldwide including the linear and nonlinear optimization models Haouari and Azaiez [5]; Montazar and Rahimikob [6]; Kaur et al. [7]; the goal program approach Vivekanadan et al. [8]. Using the suitable transformation of Charnes and Cooper [9], the formulated MILFP is solved by AMPL. Among these, Charnes and Cooper described a transformation technique which transforms the MILFP into the equivalent linear program. This method is quite simple but needs to solve two transformed model to obtain the optimal solution.

The challenge for major grain producing areas is to formulate complex, spatially and temporally interdependent strategy of agricultural production restructure to achieve multiple, non-commensurable and frequently conflicting goals (e.g., eco-social benefit maximization, food security, employment stability, and ecosystem balance). Despotis and Siskos [10]; Fang and Meng [11]; Huang et al. [12]. Currently, the agricultural production structure in major grain producing areas is still irrational and unbalanced. The proportion of the agricultural production structure for rice, wheat and potato was 347.10, 13.47, 92.54 lac Metric Ton in 2014-2015. Single grain production structure, which has not logically integrated various agricultural activities in a supplementary and/or complementary fashion, may have difficulties in improving the economic conditions of grain farmers Long et al. [13]. The multi-objectives of increasing food production, enhancing farmers' income and also maintaining ecological stability are met in mixed farming Othniel and Gopal [14]; Krishna et al. [15]; Dillon et al. [16]. Subsequently, the greatest potential opportunities for increasing agricultural productivity and improving the socioeconomic status of the rural dwellers exist through agricultural production structure optimization Ehui and Jabbar [17]; Agbonlahor et al. [18].

In agricultural production structure optimization, uncertainties may exist in many factors (e.g., weather, temperature, marketing, resources available, soil chemistry, diseases, water, mechanical engineering, biology, economy, society, policy, and ecology) and may be presented as multiple formats (e.g., fuzzy sets, probabilities, and/or interval values) Lien and Hardaker [19]; Itoh et al. [20]; Torkamani [21]. Such uncertainties can result in interactive and dynamic complexities in terms of agricultural resources allocation over multiple contexts and could affect the related optimization processes and the generated decision schemes. Therefore, uncertainties should be considered in developing agricultural production optimization strategies Ishbuchi and Tanaka [22]; Tong [23]; Inuiguchi and Sakawa [24]; Sengupta et al. [25]. Nevertheless, few previous studies were reported on the application of inexact interval-probabilistic optimization methods for agricultural production structure optimization and evaluating the appropriateness of different policies and practices regarding the balance between producing for the market versus producing for local food security.

Therefore, in response to the above challenges, a mixed integer linear programming (MILP) is developed in this paper. The developed MILP model will incorporate within a general framework for better accounting for complicated interactions, trade-offs uncertainties, and system reliabilities in agricultural production structure optimization. Then, the developed MILP model is applied to a case study of Bangladesh as a typical traditional agricultural region, in Mymensingh, Gazipur and Manikgonj district. The purpose of this paper is to optimize agricultural production structure of major grain producing areas, such that local food security could be guaranteed, grain farmers' welfare, food varieties could be increased, extra remuneration could be provided and farm labor could be fuller utilized. The detailed tasks entail: (i) gaining insight into the tradeoffs between socio-economic benefit maximization and food security policy restriction in typical grain producing areas in Bangladesh, (ii) developing a flexible optimization model MILP that can profit optimize of farmers, and (iii) achieving a better development of agricultural regions through a better agricultural production restructure in a mixed crop-livestock-processing system to satisfy the simultaneous needs of food security and rural households' income increase.

The reminder of this paper is organized as, Data collection; Model formulation which describes the concept of MILP problem, notations, assumption and the MILP model. Finally, the conclusions and contributions of this study are discussed.

2. MATERIALS AND METHODS

The present study is based on primary and secondary data. The data were collected to

Table 1. Bangladesh: Commodity, rice, milled, PSD (area in thousand hectares, quantity in thousand metric tons)

Rice, milled	2015/2016		2016/2017		2017/2018	
Market begin year	**May 2015**		**May 2016**		**May 2017**	
Bangladesh	**USDA official**	**New post**	**USDA official**	**New post**	**USDA official**	**New post**
Area harvested	11,765	11,765	11,748	11,748	11,300	11,272
Beginning stocks	1,592	1,592	1,205	1,205	853	908
Milled production	34,500	34,500	34,578	34,578	33,000	32,650
Rough production	51,755	51,755	51,872	51,872	49,505	48,980
Milling rate (.9999)	6,666	6,666	6,666	6,666	6,666	6,666
MY imports	217	217	70	129	2,500	3,400
TY imports	35	35	2,200	2,467	1,600	1,200
TY Imp. from U.S.	0	0	0	0	0	0
Total supply	36,309	36,309	35,853	35,912	36,353	36,958
MY exports	4	4	0	4	0	4
TY exports	4	4	0	4	0	4
Consumption and residual	35,100	35,100	35,000	35,000	35,200	34,900
Ending stocks	1,205	1,205	853	908	1,153	2,054
Total distribution	36,309	36,309	35,853	35,912	36,353	36,958
Yield (Rough)	4.40	4.40	4.42	4.42	4.38	4.35

Source: GAIN Report-2018

Table 2. Bangladesh: Commodity, wheat, PSD (area in thousand hectares, quantity in thousand metric tons)

Wheat	2015/2016		2016/2017		2017/2018	
Market begin year	**Jul 2015**		**Jul 2016**		**Jul 2017**	
Bangladesh	**USDA official**	**New post**	**USDA official**	**New post**	**USDA official**	**New post**
Area harvested	420	420	405	405	420	390
Beginning stocks	1,667	1,667	2,077	2,077	1,883	2,017
Production	1,290	1,290	1,250	1,250	1,300	1,210
MY imports	4,720	4,720	5,556	5,690	6,200	6,500
TY imports	4,720	4,720	5,556	5,690	6,200	6,500
TY Imp. from U.S.	87	87	257	257	0	260
Total supply	7,677	7,677	8,883	9,017	9,383	9,727
MY exports	0	0	0	0	0	0
TY exports	0	0	0	0	0	0
Feed and Residual	0	0	0	0	0	0
FSI consumption	5,600	5,600	7,000	7,000	7,600	7,500
Total consumption	5,600	5,600	7,000	7,000	7,600	7,500
Ending stocks	2,077	2,077	1,883	2,017	1,783	2,227
Total distribution	7,677	7,677	8,883	9,017	9,383	9,727
Yield	3.07	3.07	3.09	3.09	3.10	3.10

Source: GAIN Report-2018

achieve the result for the purpose and scope of this study. The primary data was collected by means of a questionnaire survey and interview with the farmers in seven different locations districts of Mymensingh, Gazipur and Manikgonj of Bangladesh. Questions were asked to know the production cost and profit margin. In the first time the farmers had given their valuable data to complete the study. The secondary data were collected from renowned national and international organization, viz. Bangladesh Bureau of Statistics (BBS), Export Promotion Bureau of Bangladesh (EPB), Directorate of Agricultural Marketing (DAM), Food and

Agricultural Organization (FAO), Statistics Department of Bangladesh Bank, The Bangladesh Journal of Agricultural Economics, The Indian Journal of Agricultural Economics, Bangladesh Economic Review, Hortex Foundation, Asian Vegetables Research Development Center (AVRDC), NGOs reports, newspapers and Internet Files.

There is tendency of not to disclose the actual information and figures in order to maintain the secrecy of the business. Another limitation of this study is farmer's or company's production and marketing strategies and practices is very confidential for any firm, for obvious reasons. So they don't disclose all the information which may make this report more authentic. And some major players of the industry denied disclosing the information and some interviewers failed to answer the questions. I have overcome all kind of constraints to collect actual data from farmers.

2.1 Rice

Production:

MY 2017/18 (May-April) rice production estimate is reduced slightly to 32.65 million metric tons (MMT) on lower Aman production (planted in July/August and harvested in November/ December) due to three days of unusually heavy rains from December 10-12, 2017. Due to an atmospheric depression in the Bay of Bengal during December, more than 508 mm (20 inches) of rain in downpours caused damage to the Aman rice crop. Some farmers reported that they had yield loss due to 75 percent lodging during the grain maturing stage caused by heavy rains combined with high speed winds. Boro rice for MY 2018/19 transplanting generally begins from mid-December to mid-January. Sources reported that Boro rice planting has completed, and harvesting will start in April.

The affected districts Netrokona, Sunamganj, Brahmanbaria, Moulovibazar, Hobignaj, Kishoreganj and Sylhet are located at the foothills of Indian Meghalaya and Assam states. Known as "haor" or wetland, this region is typically inundated every year in mid-May and stays underwater for six months. The problem this year was not the volume of rain, but the timing. Flash floods came at the end of March, before the farmers had harvested the "boro" crop they rely on for their annual income.

"My 6 acres of boro paddy has completely been submerged under water, which ultimately made my family destitute," said Mala Rani Biswas, a farmer from Sunamganj district. "It is clear to me that the coming days will be harder because we have lost our crop and we have to wait for one more year to recover that," she said.

March, April and May is pre-monsoon season in Bangladesh and India, while the monsoon prevails from June to September. This year saw unusually high pre-monsoon rainfall both in Bangladesh's haor basin and upriver across the border in India. On the Bangladesh side, March rainfall was more than three times the average – 905mm instead of 275mm, according to official data. This was followed by 1,748mm in April, compared to a typical 720mm. The Indian Meteorological Department recorded higher than normal rainfall across the northeast of the country from the beginning of March to mid-May. That swelled rivers, contributing to the havoc downstream.

Market price:

For January 2018, the average retail price for coarse rice was BDT 44 ($0.54) per kilogram, which was 16.7 percent higher than last year (Fig. 1).

2.1.1 Weat

Production:

In MY 2017/18, Post's area and production estimates are down to 390,000 ha and 1.21 MMT respectively, due to increased Boro cultivation area in order to recover production losses from last season. As rice (unhusked) price is higher than wheat, farmers are more interested to cultivate rice instead of wheat to gain higher margins. Wheat harvest will start in April 2018.

Market price:

Average retail price of wheat flour was BDT 32 ($0.39) per kilogram, which was 28.50 percent higher than last year (Fig. 2). For MY 2017/18, strong global production and high global exportable supplies have kept international prices low. Because Bangladesh is a net wheat importer, international prices influence its domestic markets and overall demand.

3. MATHEMATICAL FORMULATION

Optimization techniques are applied to decisions made for the optimal allocation of land. Using

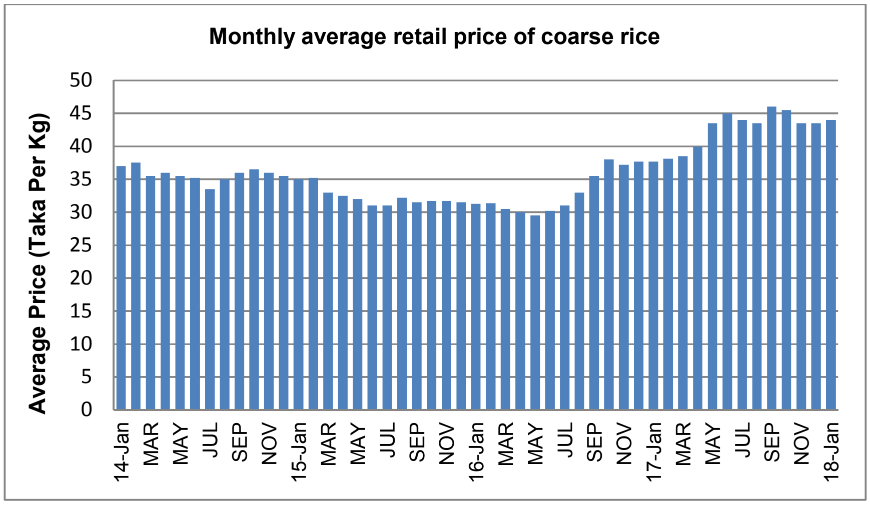

Fig. 1. Monthly retail prices of coarse rice in Bangladesh
Source: Department of Agricultural Marketing, and Trading Corporation of Bangladesh

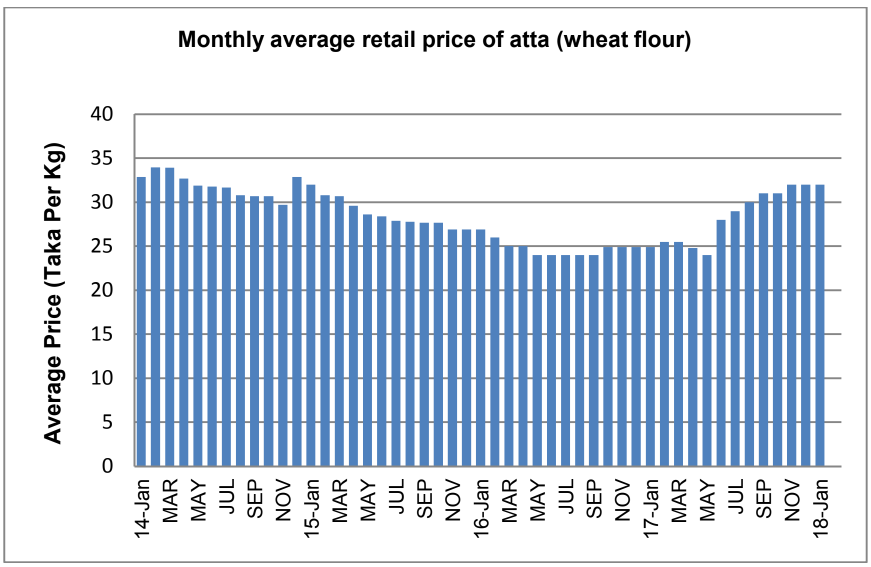

Fig. 2. Monthly average retail price of atta (wheat flour) in Bangladesh
Source: Department of Agricultural Marketing, and Trading Corporation of Bangladesh

optimization, resource allocation problems are formulated as a mathematical programming model by defining the objective function, decision variables and constraints. The optimal solution of the model is determined by the objective function and values of the decision variables and constraints. A MILP problem results when some of the variables in a model are real-valued (can be taken on fractional values) and some of the variables are integer valued the model is therefore mixed. When the objective function and the constraints set are all linear, then it is MILP.

Index and parameters:

- i Index for product, for all i=1, 2,………………..,m.
- j Index for location, for all j=1, 2,………… …….,n.
- u_{ij} The price of i^{th} product at j^{th} location ($/kg).
- v_{ij} Yield of i^{th} product at j^{th} location (kg/ha).
- l_{ij} Labour Requirement of i^{th} product at j^{th} location (ha).

b_{ij} Labour cost of i^{th} product at j^{th} location ($/unit).
w_{ij} The amount of water need of ith product at jth location (ha).
h_{ij} Water cost of i^{th} product at j^{th} location ($/unit).
f_{ij} Fertilizer Requirement of i^{th} product at j^{th} location (kg/ha).
c_{ij} The price of unit raw materials for ith product at jth location ($/unit).
a_{ij} The amount of raw materials need to produce i^{th} product at j^{th} location($/unit). .
t_{ij} Unit transportation cost of raw materials for i^{th} product at j^{th} location ($/unit).
p_{ij} The production cost of i^{th} product to j^{th} locationat ($/unit).
h_{ij} Unit holding cost of i^{th} product from j^{th} location for some given unit of time ($/unit-time).
y_{ij} Fertilizer cost of i^{th} product at j^{th} location ($/unit).

Decision variables:

$$z_j = \begin{cases} 1, \text{if location } j \text{ is used,} \\ 0, \text{else} \end{cases}$$

The basic assumptions of the model are as follows:

i. There are no temporal changes in soil physical and chemical properties
ii. Each manufacturing facility is able to produce all of the products
iii. The selling price for a product may vary from retailer to retailer depending on the discussions, order
iv. The objective function and all constraints are linear

MILP model:

In this subsection, we formulated the equivalent mixed integer programming problem that estimate the total profit as well as optimal allocation and distribution. The objective function is the difference between return and investment.

The objective function is:

$$Maximize = z1 - z2 \tag{1}$$

Where,

$$\sum_{i=1}^{m}\sum_{j=1}^{n}(u_{ij} * v_{ij}) * x_{ij} = z1 \tag{1a}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{m}(z_j * a_{ij} + l_{ij} * h_{ij} + f_{ij} * p_{ij} + w_{ij} * y_{ij} + a_{ij} * t_{ij} + a_{ij} * c_{ij}) = z2, \forall j \tag{1b}$$

Constraints:

These constraints restrict the use of available resources such as land, labor, fertilizer and water. For utilization of available resources, the following relationships are used:

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \le A \tag{2}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} b_{ij} x_{ij} \le L \tag{3}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} w_{ij} x_{ij} \le Q \tag{4}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} x_{ij} \le F \tag{5}$$

$x_{ij}, b_{ij}, c_{ij}, w_{ij}, a_{ij}, u_{ij}, v_{ij}, p_{ij}, l_{ij}, h_{ij}, t_{ij}, f_{ij} \ge 0$, z_l is binary (6)

Where i is the type of product i_1, i_2, i_3 represent wheat, rice and livestock; l is the produce location of that product. A is the total farm land available for products of location l; L is the total labor available for products of location l; Q is the total water available for products of location l and F is the total fertilizer available for the product of location l.

The constraints help define the interrelationships among the decision variables and the agriculture production conditions. In detail, constraints (1a) express the total return and (1b) express the total investment production of the total products; constraint (2) indicate the total land allocated to different products should be less than or equal to the total land area available; constraints (3), (4), (5) indicate that the maximum requirement of such factors of production as labor, water and fertilizer must be less than or equal to the regional resource available. The last equation (6) is the nonnegative constraints. The program was executed on a Pentium IV personal machine with 1.73 GHz processor and 2.0 GB RAM.

3.1 Solution Approach and Result Discussion

In order to solve the formulated MILP, we need to apply the suitable transformation. In this section, we have applied the Charnes and Cooper transformation to solve the formulated MILP as described in above section. Let the new decision could be redefined as follows:

$z_j = x_j$, for j=1….n

$z_{ij}=x_{ij}$, for j=1…n, i=1….m

Since x_j is binary as a result z_j is also binary. Further, since, x_{ij} is non negative, consequently, z_{ij} are also remaining non-negative. Therefore, MILP can be reformulated as follows:

Maximize:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}(u_{ij} v_{ij}) x_{ij} - \qquad (7)$$

$$(\sum_{j=1}^{n}\sum_{i=1}^{m}(z_j a_{ij} + l_{ij} h_{ij} + f_{ij} p_{ij} + w_{ij} y_{ij} + a_{ij} t_{ij} + a_{ij} c_{ij})), \forall j$$

Subject to

$$\sum_{i=1}^{m}\sum_{j=1}^{n} z_{ij} \le A \qquad (8)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} b_{ij} * z_{ij} \le L \qquad (9)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} w_{ij} * z_{ij} \le Q \qquad (10)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} * z_{ij} \le F \qquad (11)$$

$z_{ij}, b_{ij}, c_{ij}, w_{ij}, a_{ij}, u_{ij}, v_{ij}, p_{ij}, l_{ij}, h_{ij}, t_{ij}, f_{ij} \ge 0$, z_j is binary (12)

In order to estimate the effect of the sensitivity of production cost, fixed opening cost and raw material price parameter we employ sensitivity on these costs of different location. Fig. 3 shows that, MILP model provides optimal locations of the farmer; all the locations are profitable for product-2. When production cost of any product of any location were high, then that location do not produce that product.

The sensitivity of the production, raw material price, fertilizer cost, labor cost and fixed opening cost demonstrates that all the cases the increment of the raw material price, labor cost and fertilizer cost about 5%, decrease the profit by MILP model have 0.003%, 1.2% and 1.5% correspondingly, since this additional cost increases the investment as well as cost. The fertilizer cost changes the profit more than the raw material cost. Also labor cost of the product changes the profit more than the raw material cost and fertilizer cost of the product which shows Fig. 4.

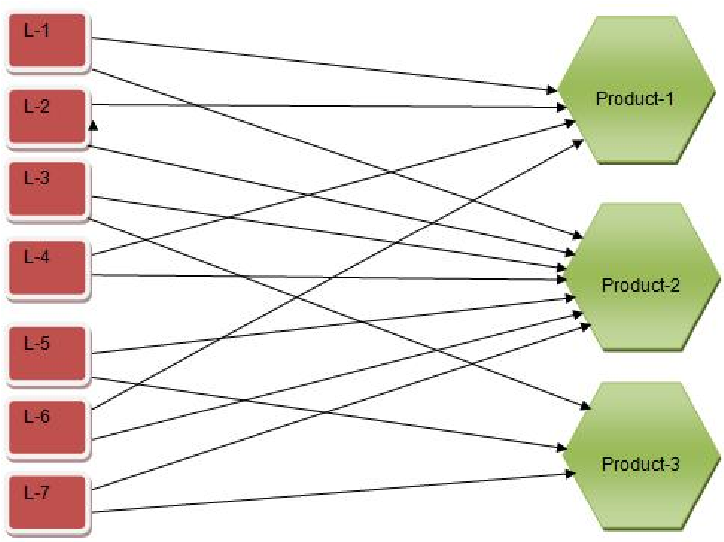

Fig. 3. Farmer production allocations for different location by MILP model

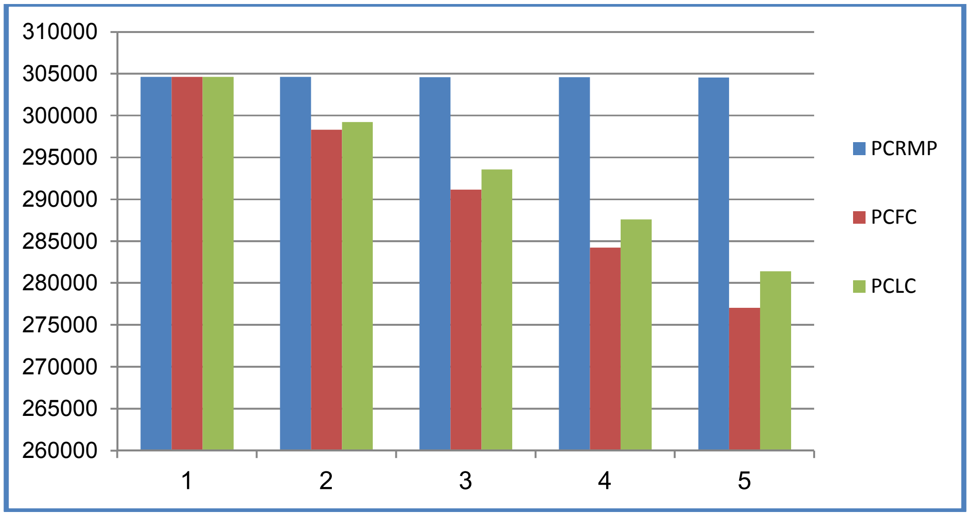

Fig. 4. The sensitivity analysis of raw material price, fertilizer cost and labor cost on profit

4. CONCLUSION

In this study, MILP based model is developed for the integrated supply chain network and using the suitable transformation the model is solved by AMPL. The formulated model simultaneously maximizes the profit on investment. Moreover, from the sensitivity analysis of the raw material price, fertilizer cost and labor cost, it is concluded that fertilizer cost and labor cost is one of the momentous factors to increase and decrease the profit of a farmer. Further, the raw material price, fertilizer cost and labor cost have increase 5%, then the total profit decrease 0.003%, 1.2% and 1.5% correspondingly. Therefore, MILP model could be one of the relevant approaches in a logistic model which seeks to find the optimum manufacturer as well as optimum distribution with profit maximization and cost minimization.

It was observed from the agriculture production and sub-sector margin analysis that agriculture production was a profitable business. The findings, therefore, suggest that there is a wide scope for the development of agriculture production in Bangladesh. Development of this enterprise is helpful in employment generation and poverty alleviation of the country. On the basis of the findings of this study, some recommendations are put forward with a view to improving the production as well as marketing of agriculture production in the study area.

i. Government should take appropriate policy for ensuring steady supply of quality agriculture production materials at reasonable price to the farm owners
ii. Training needs to improve technical knowledge and management skill of the farm owners
iii. Financial institutions and NGOs should provide credit facility at easy terms and conditions to the farm owner
iv. Communication and transportation system must be developed to increase the efficiency of agriculture production marketing system. Adequate transportation facilities should be made available for carrying agriculture production from farm yard to market for reducing wastage of agriculture product.
v. Strict policy needs to be formulated to protect the infant industry from the effect of price instability and demand fluctuation.

The study will be recommends that government, private entrepreneurs and different NGOs can play an important role for development of agriculture production and sub-sector in Bangladesh.

Also this study will be helpful to the researchers, agriculturist and common readers to know about the real picture of agriculture and economic development of Bangladesh. It will help to increase the production of agriculture product and enhance economic development of the country. It will give the current situation of the agriculture and economy of the country. It will be helpful to businessman, policy makers, customers and government to promote it to advance their activities in the respective areas.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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