Linear Programming Model to Optimize Water Supply and Cropping Area for Irrigation: A Case Study for Kalihati

Hasan Symum[1] and Mohamad F. Ahmed[2]

[1] Florida State University

Abstract

In this paper, an optimization model was formulated to maximize profit from cultivation while satisfying several factors like cropping area, irrigation water supply, cropping cycle, market demand. The model was applied at Kalihati, Tangail, Bangladesh for the Agricultural year 2012- 2013. The cropping area available at the location was 17750 hectors and maximum irrigation water available was 1267983700 cubic meter. The crops selected for the model were most traditional for the studied area and produced in large proportions compared to others. The model provided optimum value for cropping area and irrigation water depth that maximize the objective function.

Index terms— linear programming, optimization, water supply, irrigation depth, crop yield, net profit.

1 Introduction

conomy of Bangladesh is largely dependent of agriculture and the total yields in agriculture is largely depends on irrigation water and rainwater. The average annual rainfall is lowest in the northwest part and highest in the northwest part. In the postmonsoon (October -November) and winter period (December -February) only 10 percent of the annual rainfall is available (WB, 2000). Rainfall is extremely unreliable in the subsequent pre-monsoon period (March -May). On an average there is about 10 percent of the annual rainfall in this period (WB, 2000). [1]. Water is very scarce in the south and northwest region of Bangladesh during the winter. [2] In order to plan the water supply distribution for irrigation, in relation to the production level and to the water needs, the factors that are necessary are seasonal and monthly needs of water supply, crop production and crop selection.

In addition to water supply facility, availability of fertilizer also plays a great role for on time production of seasonal crops.The demand is based on the type of area of cultivation, type of crops and growth rate.

There are different types of irrigation project that have been undertaken for proper irrigation management which includes ground water irrigation, surface water irrigation through public and private ventures. But due to scarcity of resources, it is found that such projects cannot always manage to satisfy farmer needs for proper yield. That is why farmers often face shortage of water and in many cases they use empirical way to maximize profit.

Different crops have different cropping cycle. These cycles are distributed throughout the year with overlapping periods. A particular land can be used for a particular crop whereas others can be used for two or three crops in succession. This leads to multiple choices available to select from for crop area selection. Each choice have different impact on the producer's net income. In order to find the best possible combination for maximum net income, cropping pattern and crop area allocation should be brought into consideration.

So there is scope for improvement of the situation of the farmers by distribution of water resource for each areaand land allotment for particular crop through the help of optimization tool. This optimization problem can be represented bya profit maximization function. The function is the difference between gross income and production cost subject to land availability, water supply, cropping pattern, market demand and other specific

restrictions. [3,6] In this paper, the location that had been selected for evaluating and formulating the model is KalihatiUpazilla, Tangail, Bangladesh.

2   II.

3   Mathematical Model

The objective is specified as net profit maximization equation as a function of cropping area based on cropping pattern and irrigation water supply. Net profit is the difference of gross income and production cost.

?????? ???????????? = ?????????? ???????????? ? ??????????????????????? ???????? Gross income can be expressed as follows?? ?? = ? ?? ?? ?? ?? ?? ?? ?? ??=1 (1)

Where,?? ?? = ?????????? ????????????, ?????? ?? ?? = ???????? ?????????? ???? ???????? ??, ??????/???? ?? ?? = ?????????????? ???????? ???? ???????? ??, ??? ?? ?? = ?????????????????????? ???????? ???? ???????? ??, ????/??? ?? = ???? ?????????????? ???????????????????????? ??????? ???????? (1, 2, 3 ? ? ? ??) ?????????????????????? ???????? = ?????????? ???????? + ??????????????? ???????? ???? = ? ?? ?? ?? ?? ?? ??=1 + ? ?? ?? ?? ?? ?? ?? ?? ??=1 (2) ???? = ?????????? ?????????????????????? ????????, ?????? ?? ?? = ?????????? ?????????????????? ???????? ???? ???????? ??, ?????? ??? ?? ?? = ?????????? ???????? ?????? ?????????????????????, ?????? ??????? ?? ?? = ?????????????????????? ????????? ?????? ???????? ??, ????

The objective function can be expressed from equation (1) as follows?????????????????, ?? = ? ?? ?? ?? ?? ?? ?? ?? ??=1 ? ?? ?? ?? ?? ?? ?? ??=1 + ? ?? ?? ?? ?? ?? ?? ?? ??=1 ?**(3)**

Where,

4   ?? = ?????? ????????????, ??????

This maximization functions is restricted by some constraint equations pertaining to total water supply availability, maximum crop area availability, irrigation depth range, seasonal and market demand restrictions.

Total water supply availability constraint? ?? ?? ?? ?? ? ?? ?? ?? ??=1**(4)**

Where,?? ?? = ???????????? ?????????????????????? ?????????? ????????????, ??????? Maximum crop area availability constraint ? ?? ?? ? ?? ?? ?? ??=1**(5)**

Where, ?? ?? = ???????? ?????????????????????? ?????? ????????? ??, ???

Irrigation depth constraint has upper and lower bound. Too low irrigation water depth can cause the production to fall drastically and too much water depth can also flood the land which in turn again drops the crop productivity. Valid range for this irrigation depth were collected from Agricultural Specialist.?? ???????? ? ?? ?? ? ?? ???????? (6)

Where,?? ???????? = ?????????????? ?????????? ????????? ???????????????, ???? ?? ???????? = ?????????????? ?????????? ?????????, ???? ?? ?? ? ?? ??**(7)**

Where,?? ?? = ???????????? ?????? ???????? ??, ??? Non-negativity constraint ?? ?? ? 0 (8) III.

application of the model: a case study at kalihati

The model was applied to KalihatiUpazilla Irrigation System which is located at Kalihati, Tangail, Bangladesh. The required data was collected from "Monitoring Report for the Agriculture Year 2012-2013" which is published by Department of Agricultural Extension, Bangladesh.

For application of the model, the crops that were selected are the most traditional ones in the stated region. Also, in order to keep the model simple, not all the crops were included in the study as some of them had very little land allocation requirements. The selected crops are Aman(Transplanting), Aus, Aman(Broadcast), Boro Potato, Wheat, Mustard seeds, Jute, Onion and Garlic of which first four fall into rice category. These crops have different cropping cycle throughout the year which is summarized in Table 1. **??**4] The production rate of crops (Y_i) were collected from the report as well. The selling price (P_i) were collected from online database of Department of Agricultural Marketing, Ministry of Agriculture, Government of the People's Republic of Bangladesh. [5] These data are stated in Table 2.

5   G e XV Issue II Version I

Production cost is divided into two components. One is for fixed cost related to each crop and the other one is variable cost proportional to irrigation depth. Fixed cost excludes irrigation cost. It includes labor, fertilizer, seeds, maintenance cost etc.

Different crops have varied monthly basis demand pattern which depends on seasonal and market requirements. Some crops may also have location restriction for high or low land cultivation. These restrictions can be addressed as follows The water depth requirements as well as production cost (C_i) were collected from the Monitoring report. The cost of irrigation (C_w) was acquired from Irrigation Institutions of Bangladesh: Some

6   Irrigation depth constraint

Lessons. [2] The cost of irrigation is 8.56 BDT/mmha. These data are represented in Table 3.

The water volume capacity (V_w) for irrigation was calculated and found to be 126798372 mmha. The data for this calculation are provided in Table 4.The Data were taken from Irrigation "Manual for Farmer and Monitoring report for the agricultural year 2012-13". The table shows the different types of water pump and their

maximum irrigation capacity. Pumps can run 12 hours a day due to Electricity problem and maintenance of the water pump. Annual volume water supply for the KalihatiUpazilaIrrigation project is 1.2679837e+12 Liter or 1267898372mmha. [2,9] 1300 ? ??

7 Results and Discussion

After carrying out the study for irrigation project at Kalihati with yearly water availability of 126798372 mmha and land availability of 17750 ha, optimum crop planning and recommended values for water depth for different crops were identified using the maximization function while satisfying maximum and minimum crop area requirements. The problem was solved using Lingo, an optimization modelling software. The results of the model obtained from the software after going through 34 iterations and 0.21s elapsed time are shown in Table 5. The T-Aman crop was indicated a recommended area for cropping of 3000 ha associated with its lowest bound. B-Aman represented an area of 10920 ha with 150 mm water depth requirements. While Boro and Aus had greater impact on objective function having high net volume coefficient, only Boro seemed to achieve highest cropped area (i.e. 15670 ha). This is due to the land allocation limit for Aus crop which is 1850 ha. As Potato and Mustard seeds have upper bounds they were found to have reached that bound with minimum water depth requirements. Even though Wheat and Jute had no upper bounds, Wheat had no area allocated for production whereas Jute had 1980 ha allocation. Such scenario can also be attributed to the difference in their net income factor in maximization function. Garlic and Onion had good productivity but production were limited to their restriction for availability of land. The net income worth for this project was 1,856,910,000BDT. V.

8 Conclusion

The model applied to the studied area found to be suitable for irrigation and cultivation decision making which gave optimum result for required variables such as irrigation water depth and cropping area allocation. The land area limitation and constraints of water supply became effective restriction for the model. The local market demand also significant impact in setting the production requirements.

The author would like tothank the course teacher Dr. Abhishek Kumar Shrivastava for prompting them to carry out this project as a part of their course. Aus and Potato can be cropped in a particular area of land which have the following limit g) Local demand and available land constraint for Garlic and Onion Both of them have limits for available land due their particular cropping procedure. But considering the need of local markets they have minimum bounds [1]

Figure 1: Linear

1

Crops

Figure 2: Table 1 :

2

Crops

Figure 3: Table 2 :

3

different crops[7,8]

Crops	T-Aman	B-Aman	Boro	Aus	Potato	Mustardseeds	Wheat	J
Maximum depth, W_{imax} (mm)	600	200	1500	860	220	100	200	5

Issue II Version I e XV

G

(BDT/ha)

Minimum depth, W_{imin} (mm) Production Cost, C_i : 550 37560 30250 70510 25620 64680 41950 58628 50000 682

Type	Number	Capacity (Lt/s)	Total (Lt/
Deep Tube well	59	56.64	3341.76
Shallow Tube well	5327	14.16	75430.20
Power Pumps	58	28.32	1642.56
		Total	80415.00

The objective function for this case study can be extended after calculating all the available data

$????????????????, ?? = 25800??_1 + 24728??_2 + 82744??_3 + 43180??_4 + 84720??_5 + 5885??_6 + 4277??_7 + 82120??_8 +$ c) Constraint for irrigation depth

$550 ? ?? 1$

Figure 4: Table 3 :

4

Figure 5: Table 4 :

5

Crops	Area(ha)	Water depth(mm)	Sowing time
T-Aman	3000	550	August
B-Aman	10920	150	July
Boro	15670	1300	January
Aus	1850	650	June
Potato	400	180	September
Mustard seeds	1860	10	December
Wheat	0	-	-
Jute	1980	10	April
Garlic	100	100	October
Onion	120	120	December

Figure 6: Table 5 :

8 CONCLUSION

131 [Bank ()] 'Bangladesh: Climate Change and Sustainable Development, Bangladesh Report No. 21104-BD, Rural
132   Development Un it'. World Bank . *South Asia Region, Document of the World Bank* 2000.

133 [Chowdhury] Nasimatanveer Chowdhury . *Irrigation Institutions of Bangladesh: Some Lessons*,

134 [Alastairorr et al. ()] *Irrigation for small farmers in Bangladesh*, Alastairorr , A S M Islam , Gunnar Nazrul ,
135   Barnes . 1991.

136 [Brouwer and heibloem ()] *Irrigation water management: Irrigation water needs. Training manual, 3*, C Brouwer
137   , M &heibloem . 1986.

138 [Frizzone et al. ()] 'Linear Programming Model To Optimize TheWater Resource Use In Irrigation Projects: An
139   Application To The Senator Nilo Coelho Project'. J A Frizzone , R D Coelho , D Dourado-Neto , R Soliant .
140   *Numero Especial)* 1997. p. . (Sci. Agri.)

141 [Online Database of Department of Agricultural Marketing, Ministry of Agriculture, Government of the People's Republic of Ban
142   *Online Database of Department of Agricultural Marketing, Ministry of Agriculture, Government of the People's*
143   *Republic of Bangladesh*, `http://www.dam.gov.bd/jsp/yearlyMarketPriceComparision.jsp` 2013.

144 [Online database, Agricultural Statistics] *Online database, Agricultural Statistics*, `http://www.dae.gov.bd/`
145   `Dae_Agriculture_Statistics.aspx` Department of Agricultural Extension

146 [Fortaleza ()] *OtimizaçãoEconômica Da ExploraçãoAgrícola Para O Distrito De IrrigaçãoBaixoAcaraú-Ce,*
147   *UtilizandoModelo De Programação Linear*, C E Fortaleza . 2005. (Irriga 10.1)