IRRIGATION SCHEDULING IN GANDAK COMMAND AREA – A CASE STUDY

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Abstract - In India, Agricultural is the predominant occupation of vast number of people, producing wide varieties of crop. Recently because of climate change effect, supply of irrigation water is very much affected. This result either in excess or deficit supply of irrigation water; affecting both quantity and quality of the produced crops. So, there is an essential requirement of designing the irrigation schedules. For the present study, command Area of Hajipur Distributary (Bihar, India) was taken as a case study using maize crop employing CROPWAT 8.0 software developed by Food and Agriculture Organization (FAO). For developing the same, five different scenarios have been taken. Scenario-1 is to "Irrigate at famers defined interval of 14 days and refill the soil up to field capacity". Scenario-2 is to "Irrigate at famers defined interval of 14 days and applying 75 mm fixed depth of water". Scenario-3 is to "Irrigate at critical depletion level and refill the soil up to field capacity". Scenario-4 is to "Irrigate at critical depletion level and applying 75 mm fixed depth of water" and Scenario-5 is "Applying no irrigation water, i.e. Rainfed". From the studies, it has been observed that out of five scenarios; scenario-1 and 3 are most suited for the case study area as the irrigation efficiency of first and third scenarios are higher and also they represent the maximum utilization of rainfall. Hence, this study recommends irrigation scheduling according to scenario-1 for the maize crop in the command Area of Hajipur Distributary.

Keywords: CROPWAT, Evapotranspiration, Irrigation Efficiency, Irrigation Scheduling, Maize Crop

I. INTRODUCTION

India is basically a tropical country with a vast diversity of climate, topography and vegetation. Rainfall in India varies considerably in its place of occurrence, as well as in its amount. Even at a particular place, the rainfall is highly erratic and irregular, as it occurs only during a few particular months of the year. Crops cannot, therefore, be raised successfully, over the entire land, without providing artificial irrigation to the fields. More than 70 percent of our population directly depends on agriculture, and the remaining depends indirectly on agriculture. The total geographical area of India is of about 328 M hectares; out of which about 184 M hectares is the cultivable area.

Yield of the crops largely depends on supplying the right quantity of water at the right time which requires designing of irrigation schedule. If proper scheduling has been implemented based on the moisture level requirements in the crop root zone; yield will be optimized and also wastage of water will be reduced tremendously. In designing, care should also be taken to ensure the maximum utilization of rainfall. The farmer's experience coupled with the scientific designing of irrigation scheduling, will definitely ensure high yield which in turns results in higher income of farmers. Hence, as irrigation scheduling is an important element in improving water use efficiency; many researchers and scholars have applied various methods and techniques for the problems of irrigation scheduling and presented their papers.

Li [14] has presented an irrigation water allocation model in which he had considered conflicting objectives and uncertainties using fuzzy programming model and applied it to Hulan River Irrigation district (North-East China). Parmar and Nimisha **[17]** proposed a model for canal irrigation scheduling using Genetic Algorithm in which as per user request, provision has been done to open some outlet at specific time slot. Malaterre et al [15] has optimized on-demand distribution policies of delivery based on Mixed Integer Quadratic Programming (MIQP) in which illustration for scheduling has been presented by taking the command area of the Gignac Canal. In their studies, objective function has been framed to meet the demand load profile as much as possible with minimum manpower work for gate operation. Lasharri et al [13] has developed software for irrigation scheduling named as "Mehran Model" which can generate irrigation schedules for 66 types of crop using Soil-Water Balance approach**.** Bellingham [3] presented a study for irrigation scheduling based on the concept of Soil-Water Balance approach and acquisition of data. A multi-objective model for irrigation development is presented by Jha and Singh [11**]** in which they had discussed the optimal resource allocation like crop, water and land for Kosi Irrigation System, Nepal; with the integrated use of surface as well as ground water resources. Kuo and Liu [12**]** had used both Optimization and Simulation Model and applied in Delta irrigated area of Utah in order to achieve the optimized monetary benefit and also simulating the demands of water under the constraints of specified water supply and area to be planted. Talpaz and Mjelde [2] have presented a method for optimizing the irrigation scheduling for corn using soil moisture levels as control variables. Arora et al [2] has tested the Hank's model for wheat in Punjab, India, for finding the value of the stress sensitivity factor with the variation of consecutive growth periods. In this paper, best predictions were obtained for three growth periods 0-70 days ($\lambda 1 = 0.16$), 70-90 days ($\lambda 2 = 1.21$) and 90 days to harvest ($\lambda 3 = 0.58$). The 70 to 90 day growth period had the highest value of λ and corresponds to the booting – heading phases of wheat development. Bras and Cordova [5**]** have tried to solve the problem of optimal irrigation water allocation by considering the stochastic variation of the requirements of the crop irrigation water and the process of the Soil-Water Depletion Dynamics. In their studies, they replaced the simulation segment with analytically derived physically based models. Singh and Mann [19] indicated that crop yield (Y) vs. seasonal Evapotranspiration (ET) functions for many crops are linear. Howell et al. [10] has used the Jensen yield function and dynamic programming techniques for optimal allocation of irrigation water for sorghum crop over its growing season. In this study, the Jensen yield function was used to determine the timings and amounts of irrigation water using dynamic programming in order to get the maximum crop yields. Blank [4**]** tested his model for maize crops considering three growth periods -vegetative, pollination and maturation stages in which a high correlation coefficient ($r^2 = 0.98$) was obtained between measured yields and those computed by the model. Stewart et al [20] has presented an optimal irrigation programs to maximize the crop yield, under deficit water supply conditions. The model was based on a comparison between the estimated sequences of potential ET rates throughout the season with the sequence of actual ET rates when no irrigations were given. The difference between the two constituted an expected sequence of ET deficits. Dudley [**7**] has suggested a method for improving the Flinn and Musgrave model by solving the optimization problem by considering two state variables Stochastic Dynamic Programming Model. In this, the two state variables were – water level available in the soil at the commencement of the stage and irrigation water available over the remaining season. This model also maximized the net returns from irrigations. De Lucia [6] has developed a model based on a three state variable stochastic dynamic programming incorporating the production function developed by Moore in which soil moisture, quantity of water in storage and stream flow in the period were used as the state variables and stream flow and rainfall as random variables. Flinn and Musgrave [9] developed a programming model based on one state variable - the water allocation over the remaining growing season at any time in which the stage was defined as a 30 day period. Moore [16] was one of the first to recognize the problem of deficit irrigation water allocation over time in a mathematical model framework. He viewed plant growth as composed of cycles between consecutive irrigation applications.

From the literature review, it was abstracted that various methods have been employed for different scenarios. For the present study, irrigation scheduling in the command area of Hajipur Distributary of the Tirhut Main Canal System of the Gandak Project in Bihar (India) was done as there was no work done earlier in this command area for which CROPWAT program version 8.0 from FAO was used.

II. STUDY AREA

The study area consists of areas commanded by the Hajipur distributary of Vaishali Branch Canal (VBC) in the Eastern Gandak Canal System in North Bihar (India). The VBC is a direct off take from the Tirhut Main Canal (TMC) – the main canal of the Eastern Gandak System. The Hajipur Distributary takes off from 155.07 RD in the tail end of Vaishali Branch Canal on its right hand side with an off-take angle of $48^0 15''$. It is 31129.6 m in length. A provision for the discharge of 8.23 cumec has been made in this distributary with a view to command an area of 52317 acres. The Schematic Diagram of Vaishali Branch Canal and its System is shown in Fig.1.

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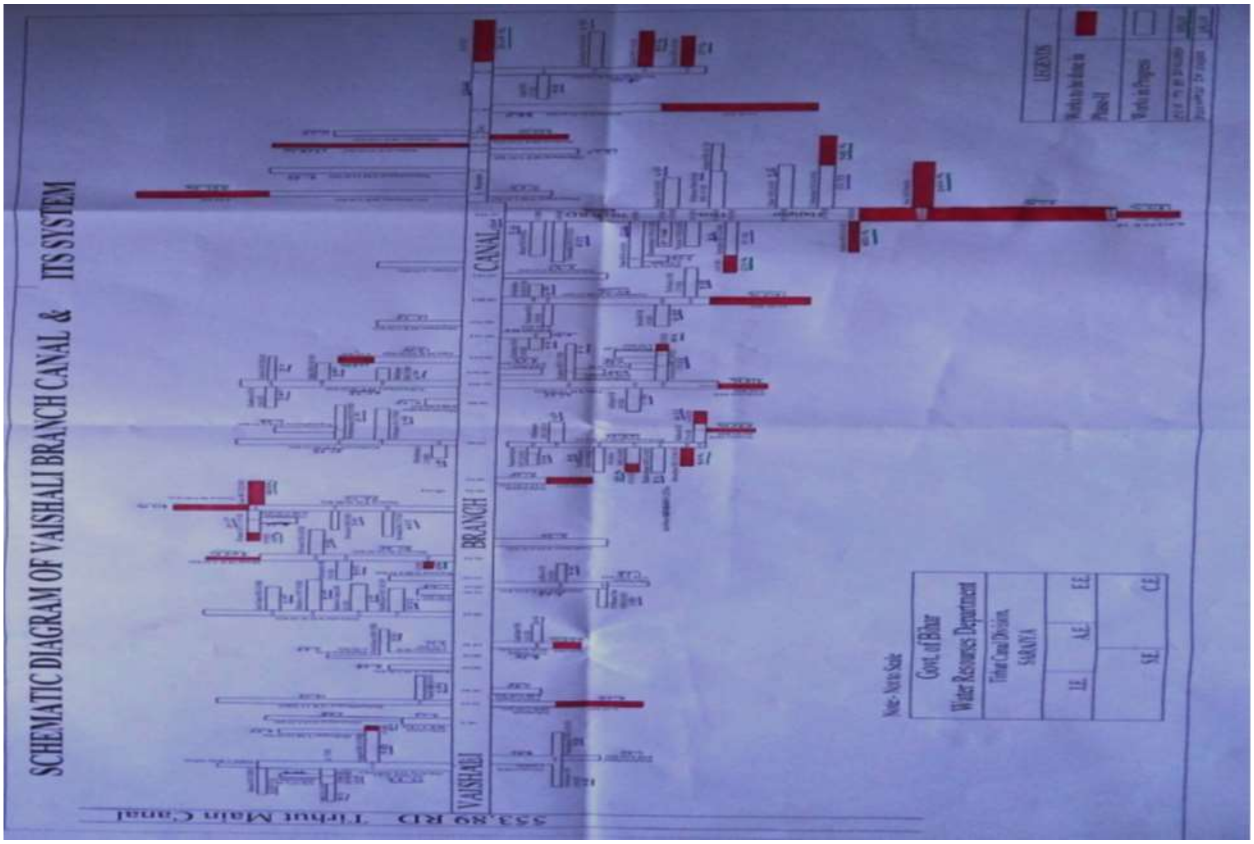

Fig.1 Schematic Diagram of VBC and Its System
(Source: Water Resource Department, Govt. of Bihar)

Hajipur Distributary can be divided into four reaches, the details of which are shown in Table 1.

Table 1 Design Statement of Hajipur Distributary

Sr. No	**Extent from R.D. to R.D.**	**Length in ft.**	**Discharge taken off each reach in cusecs**	**Total discharge in cusecs**	**Water surface slope per R.D.**	**Bed width**	**F.S.D.**	**Velocity (ft./sec)**	**Critical Velocity (ft./sec)**
1.	0.0 to 30.10	31360	61.32	290.98	0.185	24´3´´	5´0´´	2.103	2.31
2.	30.1 to 55.70	24340	55.90	229.60	0.185	22´0´´	4.60´	2.062	2.23
3.	55.70 to 76.97	21870	116.84	173.61	0.185	19´0´´	4.40´	1.920	2.17
4.	76.97 to 102.40	25340	56.77	56.77	0.200	11´3´´	3.00´	1.510	1.69

III. METHODOLOGY AND SOURCES OF DATA

3.1 Methodology

3.1.1 CROPWAT Model

CROPWAT Model is the open source software of FAO. It is a Decision Support Tool (DSS) which is used for estimating the irrigation water requirements of the crops based on soil, climatological and crop data. This software also gives the irrigation scheduling under different irrigation scenarios/criterion taken into consideration and also provides the schemes for the supply of irrigation water for different types of cropping pattern adopted.

a. Computation of Reference Evapotranspiration

In field practice, potential evapotranspiration (PET) is invariably used in estimation of crop water requirements. FAO recommends a reference evapotranspiration denoted as ET_0 which gives the PET of uniform height well-watered grass, growing actively and completely covering the ground. For this green surface, height of the crop - 0.12 m, surface resistance - 70 s/ m and albedo - 0.23; have been assumed. The Penman-Monteith Method is adopted by FAO to estimate ET_0 by using climatological parameters such as radiation, maximum and minimum temperature, sunshine hour, humidity and wind speed. For any other crop, PET is calculated by multiplying ET_0 with the crop coefficient K_C, the value of which varies depending upon the crop growth stage. The value of K_C generally ranges from 0.5 to 1.3.

b. Computation of Effective Rainfall

For computation of effective rainfall, CROPWAT model has given four options - Empirical Formula, Dependable Rain, Fixed Percentage and USDA Soil Conservation Service Method. In its determination, surface runoff and deep percolation are considered as losses which are abstracted from the total rainfall. In this study, USDA Soil Conservation Service Method has been adopted.

c. Crop Data

For running the model, maize crop of 9 types which is grown throughout the year; have been chosen named as Maize1, Maize2, Maize3, Maize4, Maize5, Maize6, Maize7, Maize8 and Maize9. For each type, planting and harvesting date has been finalized as per the practice followed in the command area. Further, other crop information such as base period, rooting depth, crop height, crop coefficient (at initial, mid- season and at harvest), critical depletion factor (at initial, mid and late season) and yield response factor (at initial, development, mid and late season) has to be collected.

d. Soil Data

Following soil data is required for CROPWAT model:

- Total moisture available in the soil in mm/meter
- Maximum rate of infiltration in mm/day
- Maximum depth of rooting in cm
- Initial moisture depletion in the soil as % of total moisture available (TAM)
- Initial moisture available in the soil in mm/meter.

All the above information has to be collected for the case study area by taking the soil samples and their testing.

e. Crop Water Requirement (CWR)

For the different types of maize crops to be grown in the command area, an assessment is to be made regarding the crop water requirements.

f. Irrigation Scheduling

Irrigation scheduling basically determines the correct quantity and timing of water to be delivered to the crops. CROPWAT model develops the irrigation schedule by utilizing the input data such as climatic, soil, crop and irrigation scheduling scenario/criteria adopted. It helps in promoting better irrigation practices and to design the improved schedules for rotational delivery system.

3.2 Sources of Data

3.2.1 Meteorological Data

Thirty years meteorological data on daily basis for Patna station from 1980 to 2009 has been collected from IMD Pune to be used as input data in CROPWAT model.

3.2.2 Crop Data used in CROPWAT

The crop data required for CROPWAT is obtained from the publication of FAO – 56. The total crop duration for the maize crop is of 120 days, the division of which is as follows:

Stages of Growth	Days
Initial	20
Development	30
Mid- Season	40
Late - Season	30

- Crop- Coefficients (Kc) - 0.5, 1.2 and 0.35 for various stages
- Initially depth of rooting - 0.20 m and final constant value as1.0 m.
- Critical depletion Factor - 0.70, 0.66 and 0.70 for various stages
- Yield response Factor - 0.40, 1.50, 0.50, and 0.20 for various stages with 1.25 as average value for crop season.
- Height of the Crop - 2.0 m.

The planting and harvesting date for different maize as per the current practice are given in Table 2:

Table 2 For different Maize Crops Planting and Harvesting Date

Types of Crop	Date of Planting	Date of Harvesting
Maize1	14 Jun.	11 Oct.
Maize2	20 Jun.	17 Oct.
Maize3	27 Jun.	24 Oct.
Maize4	02 Oct.	29 Jan.
Maize5	09 Oct.	05 Feb.
Maize6	16 Oct.	12 Feb.
Maize7	26 Feb.	25 Jun.
Maize8	5 Mar.	02 Jul.
Maize9	13 Mar.	10 Jul.

3.2.3 Soil Data

Five soil samples have been collected from the case study area and testing have been done in the laboratory to get the various soil data as required for the calculation of irrigation scheduling through the CROPWAT model. Test results are as follows:

- Type of soil = Loam
- Total moisture available in the soil = 200 mm/meter
- Maximum rate of infiltration =192 mm/day
- Maximum depth of rooting = 100 cm
- Initial moisture depletion in the soil = 170 mm/meter.

IV. DATA ANALYSIS

4.1.1 Calculation of ET_0

Minimum, maximum temperature (ºC), humidity (%), wind speed (km/day), sunshine hours for monthly average of thirty years of Patna station were given to CROPWAT. Based on these data, CROPWAT model has calculated ET_0 from Penman-Monteith Equation. Monthly variation of ET_0 is shown in Fig 2.

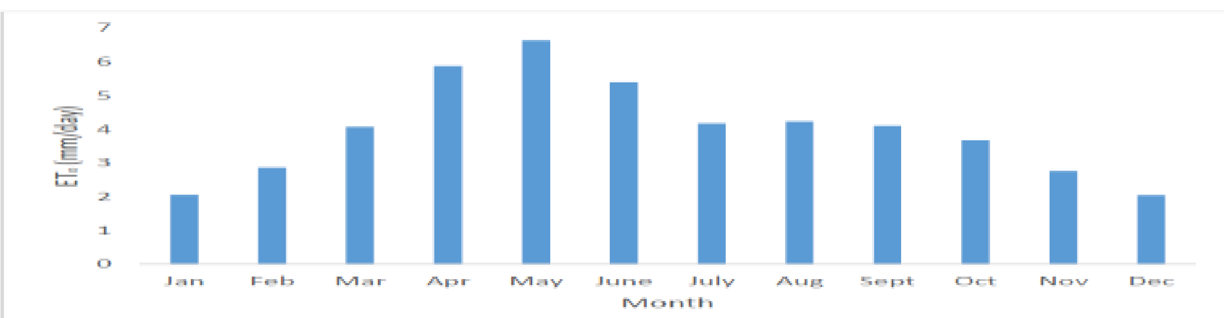

Fig. 2 Monthly Variation of ETo for Patna station

4.1.2 Calculation of Effective Rainfall

Effective rainfall has been calculated based on USDA S.C. Method from CROPWAT for which thirty years monthly average data from 1980 to 2009 is used. The result is as given below:

Fig. 3 Monthly Variation of Effective Rainfall for Patna

4.1.3 ETc Calculation

For different types of maize crop ETc value has been calculated based on reference ET_0 and Kc values. The Fig 4 below indicates that the ETc values for different types of maize vary from 249.10 mm to 610.7 mm during the entire crop growth period. It has also been observed that the ETc value for maize8 is higher and it is lower for maize6.

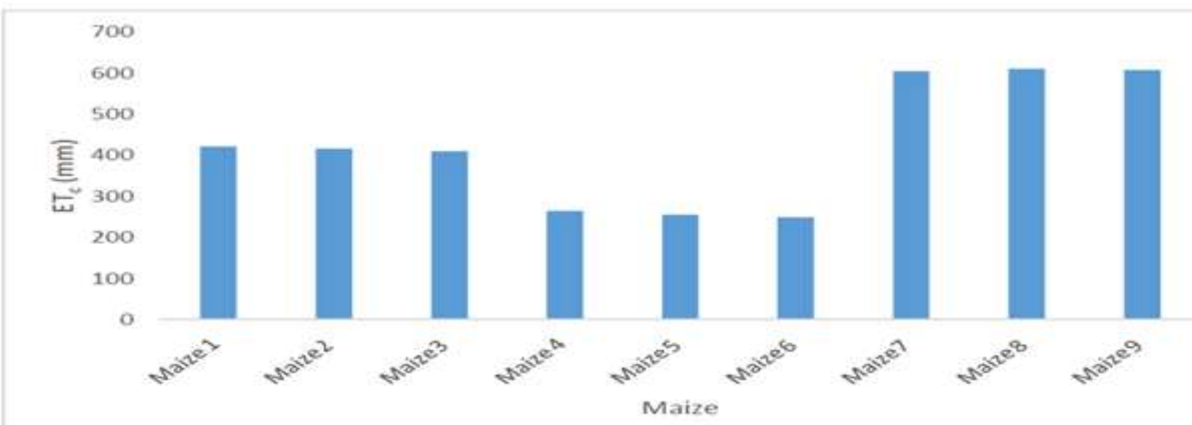

Fig. 4 Value of ETc for Different Types of Maize

4.1.4 Irrigation Water Requirement Computation

It is calculated by abstracting Effective Rainfall (ER) from the value of ETc and for different types of maize crop, it is given below in Fig 5.

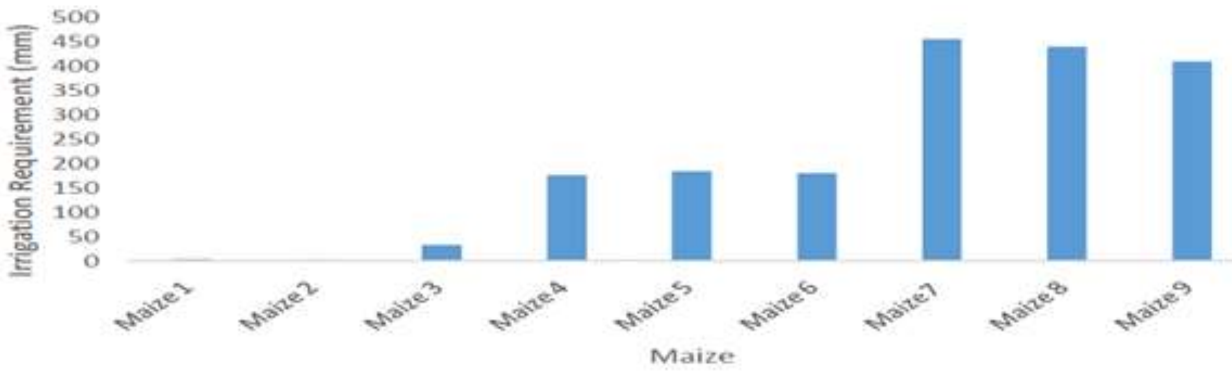

Fig. 5 Irrigation Requirements for Different Types of Maize

4.1.5 Management Criteria for Irrigation Schedule

Irrigation scheduling has been developed by considering five management scenarios for the irrigation water to be supplied to the crop. These five scenarios are as:

Scenario-1: "Irrigate at famers defined interval of 14 days and refill the soil up to field capacity"

Scenario-2: "Irrigate at famers defined interval of 14 days and applying 75 mm fixed depth of water"

Scenario-3: "Irrigate at critical depletion level and refill the soil up to field capacity"

Scenario-4: "Irrigate at critical depletion level and applying 75 mm fixed depth of water"

Scenario-5: "Applying no irrigation water, i.e. Rainfed"

Irrigation scheduling for different maize and for different scenarios has been obtained by CROPWAT model and a chart has been prepared for comparative studies, the results of which are given below:

Table 3 Appraisal under different Scenarios for Maize1

Contents	**Scenarios**				
	1	**2**	**3**	**4**	**5**
Efficiency of Irrigation Schedule (%)	100.0	15.8	-	-	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	0.0
Efficiency of Rainfall (%)	35.5	35.5	45.5	45.5	45.5
Yield Reduction (%)	0.0	0.0	0.0	0.0	0.0

Table 4 Appraisal under different Scenarios for Maize2

Contents	**Scenarios**				
	1	**2**	**3**	**4**	**5**
Efficiency of Irrigation Schedule (%)	100.0	18.6	-	-	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	0.0
Efficiency of Rainfall (%)	35.6	35.6	46.5	46.5	46.5
Yield Reduction (%)	0.0	0.0	0.0	0.0	0.0

Table 5 Appraisal under different Scenarios for Maize3

Contents	Scenarios				
	1	2	3	4	5
Efficiency of Irrigation Schedule (%)	100.0	18.3	-	-	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	0.0
Efficiency of Rainfall (%)	36.3	36.3	46.2	46.2	46.2
Yield Reduction (%)	0.0	0.0	0.0	0.0	0.0

Table 6 Appraisal under different Scenarios for Maize4

Contents	Scenarios				
	1	2	3	4	5
Efficiency of Irrigation Schedule (%)	100.0	33.9	100	100	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	13.0
Efficiency of Rainfall (%)	92.5	90.2	99.1	100.0	100.0
Yield Reduction (%)	0.0	0.0	0.0	0.0	16.4

Table 7 Appraisal under different Scenarios for Maize5

Contents	Scenarios				
	1	2	3	4	5
Efficiency of Irrigation Schedule (%)	100.0	35.8	100	100	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	18.3
Efficiency of Rainfall (%)	92.5	90.2	100.0	100.0	100.0
Yield Reduction (%)	0.0	0.0	0.0	0.0	22.8

Table 8 Appraisal under different Scenarios for Maize6

Contents	Scenarios				
	1	2	3	4	5
Efficiency of Irrigation Schedule (%)	100.0	34.7	100	100	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	16.6
Efficiency of Rainfall (%)	92.2	92.2	98.7	100.0	100.0
Yield Reduction (%)	0.0	0.0	0.0	0.0	21.8

Table 9 Appraisal under different Scenario for Maize7

Contents	Scenarios				
	1	2	3	4	5
Efficiency of Irrigation Schedule (%)	100.0	78.0	100	100	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	51.7
Efficiency of Rainfall (%)	68.8	78.4	95.3	100.0	100.0
Yield Reduction (%)	0.0	0.0	0.0	0.0	64.8

Table 10 Appraisal under different Scenarios for Maize8

Contents	Scenarios				
	1	**2**	**3**	**4**	**5**
Efficiency of Irrigation Schedule (%)	100.0	74.0	100	100	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	48.8
Efficiency of Rainfall (%)	66.8	78.6	100.0	100.0	100.0
Yield Reduction (%)	0.0	0.0	0.0	0.0	62.1

Table 11 Appraisal under different Scenarios for Maize9

Contents	Scenarios				
	1	**2**	**3**	**4**	**5**
Efficiency of Irrigation Schedule (%)	100.0	70.6	100	100	-
Deficiency of Irrigation Schedule (%)	0.0	0.0	0.0	0.0	43.7
Efficiency of Rainfall (%)	60.3	60.6	76.4	97.5	100.0
Yield Reduction (%)	0.0	0.0	0.0	0.0	55.5

V. DISCUSSION ON RESULTS

It has been observed from Fig 5 that three varieties of maize such as maize1, 2 and 3 require minimum quantity of irrigation water, whereas mize7, 8 and 9 require maximum amount. Hence, in the command area, varieties of maize1, 2 and 3 should be preferred. An irrigation scheduling is generally considered better which utilizes maximum rainfall water and minimum irrigation water. From the studies of the comparative chart, it has been inferred that scenarios-1 and 3 are best suited for almost all varieties of maize under irrigated condition as its efficiency of irrigation scheduling and rainfall efficiency is maximum. As in India, scenario-3 is not practiced, hence under irrigated condition; scenario-1 is best suited, i.e. irrigation water should be applied at an interval of 14 days till the moisture level in the soil approaches to its field capacity. Irrigation scheduling for varieties of maize1, maize2 and maize3 is depicted below in Fig 6:

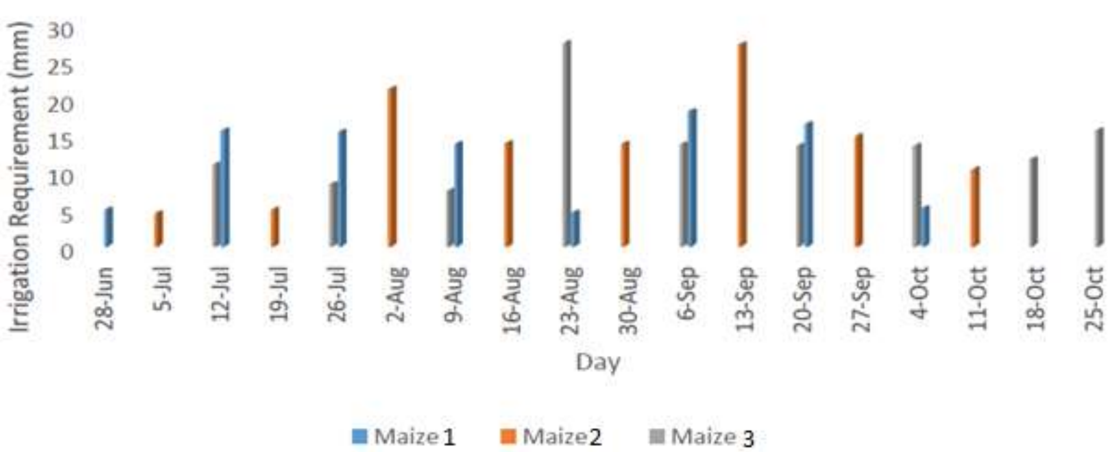

Fig. 6 Irrigation Scheduling under Scenario-1for Maize1, Maize2 and Maize3

It has also been found from the studies of comparative chart that all the varieties of maize under rainfed condition have certain yield reduction except for maize1, 2 and 3 which have nil values. It has maximum value as 64.8% for maize7.

VI. CONCLUSION AND RECOMMENDATIONS

On the basis of above studies and results obtained, the inferences are as follows:

- In the command area, the varieties of maize1, 2 and 3 require minimum quantity of irrigation water in comparison to the other varieties, even though, ETc values for maize 4, 5 and 6 have less value. This may be due to the rainfall occurred during the growth period of maize1, 2 and 3.
- Maximum amount of irrigation water is required for the varieties of maize7, 8 and 9.
- Scenarios-1 and 3 of irrigation scheduling are best suited for almost all varieties of maize under irrigated condition.
- Under rainfed condition, all varieties of maize have certain yield reduction except for maize1, 2 and 3 which have nil values. It has maximum value as 64.8% for maize7.

Hence, in the command area of Hajipur Distributary, it is recommended to grow the varieties of maize1, 2 and 3 as per the scenario-1, i.e. irrigation water should be applied at an interval of 14 days till the moisture level in the soil approaches to its field capacity.

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