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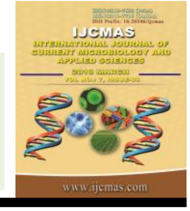

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Profit Maximization of Yield from Different Sizes of OFR

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A B S T R A C T

A Dynamic Programing (DP) model is developed to allocate optimum supplemental irrigation to crop for receives maximum net annual return from the cropped area under land and water availability constraints in the OFR based rainfed agricultural system. The model integrates the dynamics associated with the water released by supplemental irrigation from the OFR to the actual water utilized by the crops at farm level. It also takes into account the non-linear relationship of root growth, soil moisture dynamics for multiple crops and yield response to water deficit at various growth stages of the crops. The DP model is simulated for 5% to 12% field area and economic benefits from the crops takes into accounted for optimum size of OFR. For 10% soil water depletion for rice (from saturation) and mustard (from field capacity) crops, the optimum size of OFR varied from 5.35% to 9.85%. Similarly, for 15% soil water depletion it varied from 5.05% to 9.35%.Relative yield for10% soil water depletion for rice (from saturation) and mustard (from field capacity) crops varied from 0.65 to 0.88 and 0.85 to 0.94. Similarly, for 15% soil water depletion it varied from 0.70 to 0.90 for rice and 0.88 to 0.96 for mustard crop. If only rice crop is grown, the optimum size of OFR for 10% soil water depletion varied from 0.00% to 6.90%, whereas for 15% soil water depletion it varied from 0.00% to 6.70%. Similarly, relative yield for 10% and 15% soil water depletion varied from 0.70 to 0.90 and 0.74 to 0.93, respectively. In low water availability condition, the model performance is very good because it allocate supplemental irrigation at the time when crop has high yield response factor.

Introduction

Rice (*Oryza sativa*), a major crop in rainy season, is the staple food of the people in eastern India and so, it is grown extensively in all types of land topography. Out of 44 million ha of total rice area in the country, the upland rice occupies 7 million ha ofwhich 75% is from eastern India only (Kar *et al.*, 2004). The average yield of rice from this area is very low because of uneven distribution rainfall in crop growing season. Due to this scope of growing a second crop after withdrawal of monsoon is also very much limited due to quick depletion of soil moisture. Verma and Sarma (1990) developed a procedure to design water storage and recycling tank and compute the benefit-cost ratio for a region in northern Punjab. It was observed that the total cost of tank per unit of capacity decreased with increasing tank capacity. Tanks designed on the basis of seasonal runoff and used for pre-sowing irrigation of wheat, were the most beneficial with a benefit-cost ratio ranging from 1.60 to 4.56 for catchment areas varying from 1 to 100 ha. Panigrahi and Panda (2003) reported that an OFR having a depth of 2.0 m covering 12% of the 800 m^2 farm area with a volume of 61 m^3 was optimum for applying supplemental irrigation to rice-mustard cropping system. The yields of rice grain and mustard seed were increased by 39 and 15%, respectively, over rainfed condition due to application of 84 and 45 mm of supplemental irrigation to respective crops. Islam *et al.,* (1998) reported 20% increase in yield of irrigated crop over rainfed (non-irrigated) farm in low rainfall areas of Bangladesh with a benefit-cost-ratio of 1.5.

Arnold and Stockle (1991) developed a simulation model to determine the optimum size of pond and to plan different irrigation strategies for supplemental irrigation systems. A comprehensive basin scale soil and water-resource model is modified to simulate crop yield, supplemental irrigation, and economics. The model is capable of determining the effects of various management strategies on crop production and sediment yield. Mahendrarajah *et al.,* (1992) analyzed the optimization of monsoonal water storage tank for supplemental irrigation under double rice cropping in Sri Lanka. Mujumdar and Ramesh (1998) developed a short-term yearly reservoir operation model for irrigation of multiple crops. Sharma (2002) developed computer software to design water harvesting structure for different agro-climatic regions in India. After economic analysis he found that for Dasuya (Orissa), the benefit-cost ratio were greater than one, up to 40% probability. For Indore (M.P.), the benefit-cost ratio were greater than one, up to 60% probability level and beyond that these were less than one, but for the study site at Kansas (Punjab), the benefit-cost ratio has been just equal to one up to 50% probability. Singh and Panda (2012) developed a linear programming model for the optimal land and water resources allocation in order to maximize net annual returns from an irrigated area located in the Haryana State of India. The water production functions were incorporated in the model to estimate the crop yield under different qualities of irrigation water. The net annual return from the study area has increased by about 26%. The objective of present study is to maximize yield from different sizes of the OFR under single and dual cropping situations.

Materials and Methods

Study area

The site selected for the present study is the experimental farm of the Agricultural and Food Engineering Department of Indian Institute of Technology, Kharagpur in West Bengal state, India. It is located at Latitude 22^{o}19'N, Longitude 87^{o}19'E and altitude 48 m above the mean sea level. The total field area is select as 800 m^2 (including OFR area and crop area). Mean annual rainfall of the study area is about 1500 mm, of which about 80% is received during monsoon season in between June and September. Maximum and minimum relative humidity (RH) during *kharif* and *rabi* season crops were nearly 98.2% and 51.9%, respectively. The average wind velocity was 2.17 km/h and 1.0 km/h, respectively. Water holding capacity of the sandy loam soil in the experimental site is very low. It dries up quickly after cessation of rainfall. Field capacity, wilting point, saturation soil moisture, and pore connectivity index of the soil are 20%, 9%, 36%, and 0.25, respectively.

Field water balance module

Daily field water balance simulation modeling was done to estimate the supplemental irrigation (SI) requirement of *kharif* crops and surface runoff (SR) generated from the cropped field.

For simplicity in modeling, rice plots were considered as leveled fields. Soil, crop and daily weather data were used as input to run the water balance model.

The inflow components of the model are direct rainfall (R) and SI from the lined/unlined OFR and outflow components are the actual crop evapotranspiration (AET), seepage & percolation (SP) and SR diverted to the OFR.

Considering the effective root zone as a single layer, the general water balance model under unsaturated conditions can be expressed as (Panigrahi and Panda, 2003; Panigrahi *et al.*, 2005):

$$\mathrm{SMC_i = SMC_{i-1} + R_i + SI_i - AET_i - SP_i - SR_i} \quad (1)$$

Where, SMC = soil water content in the crop root zone (mm); R = rainfall (mm); SR = surface runoff (mm); SI = supplemental irrigation (mm); AET = actual evapotranspiration (mm); SP = seepage and percolation losses (mm) and i = time index taken as days after sowing.

If SMC is more than saturation moisture content (SAT), then ponding will occur in the field.

Under the ponding phase, the water balance in rice field can be expressed as (Panigrahi *et al.*, 2001):

$$D_i = D_{i-1} + R_i + SI_i - AET_i - SP_i - SR_i \quad (2)$$

Where, *D* is the ponding depth in rice field, mm.

Supplemental irrigation

In the present study, 10 and 15% depletion from saturation moisture content (*SAT*) and field capacity (*FC*) for rice and non-rice crop, respectively, was considered for supplemental irrigation (*SI*) from the OFR. Irrigation was allowed to be continued till *SAT* for rice and *FC* for non-rice crop was reached.

SI for rice crop

$$SI_i = 0, if\, SMC_i > X\%\, of\, SAT;\; Else\, SI_i = (SAT - SMC_i) \quad (3)$$

SI for non-rice crop

$$SI_i = 0, if\, SMC_i > Y\%\, of\, FC;\; Else\, SI_i = (FC - SMC_i) \quad (4)$$

Where, *X* = soil moisture depletion from *SAT*, %; *Y* = soil moisture depletion from *FC*, %;

Water balance module of the OFR

The capacity of any OFR must be sufficient to store all the excess rainfall generated from the cropped fields. In the present study, the top width, height, free board and berm width of the embankment were fixed at 30, 30, 15 and 30 cm respectively, the side slope was taken as 1:1 and the depth of the OFR was taken as 2.4 m.

The volume of water stored in an OFR on any day can be found out by the information on previous day's storage and various inflow and outflow components of the OFR. The inflow components include the surface runoff coming from the cropped field and the direct rainfall, whereas evaporation, supplemental irrigation, seepage and percolation are the outflow components of the OFR (Panigrahi *et al.*, 2007).

$$FV_i = FV_{i-1} + VR_i + VQ_i - VE_i - VSI_i - VSP_i \quad (5)$$

where, *FV*= final volume of water in the OFR, m^3;*VR* = volume of direct rainfall in the OFR $(= R_i \times A_{OFR})$, m^3; *VQ* = volume of surface runoff coming from the field to the OFR $(= SR_i \times A_{crop})$, m^3;*VE* = volume of water lost as evaporation from the OFR, m^3; *VSI* = volume of water used as supplemental irrigation in the cropped field $\left(= \frac{SI_i \times A_{crop}}{\eta}\right)$, m^3; *VSP*= volume of water lost as seepage and percolation from the OFR storage, m^3;A_{OFR} = surface area of the OFR, m^2; A_{crop}= area of crop field equal to $(A_{Farm} - A_{OFR})$, m^2, in which A_{Farm} is the area of the farm, m^2; η is the irrigation system efficiency, fraction; and *i* = time index, considered as one day.

Economic analysis

In any economic analysis, all cash flows must be evaluated at some reference time. A present worth analysis is an economics tool. It helps converting all the cash flows (inflows and outflows) over the life span of the project, using appropriate factors to account for interest and inflation, into an equivalent present value at the beginning. It is also a widely adopted method (Palmer *et al.*, 1981; Verma and Sharma, 1990; Islam *et al.*, 1998) to study the economics of water harvesting and recycling reservoirs.

An economic analysis is often associated with preparing a balance sheet of fixed and variable costs in a system against the amount of return.

While the fixed cost consists of the initial one time investment in the system, the variable cost includes the parameters those demand investment every year or at some recurrence interval during the life span of the project.

Irrigation cost

Supplemental irrigations to crops during the rainy season are provided with hiring irrigation pumps and conveyance pipes. The operation is accomplished with hiring pump set and sprinkler unit for crops during winter season. Hiring charges of the pump set with conveyance pipes or sprinkler unit in the locality in Kharagpur, West Bengal have been taken into account to calculate the irrigation cost on an annual basis for the farm. One kerosene run 3 hp centrifugal pump is hired at the rate of Rs. 120 hr^{-1} for the purpose.

Production cost of crops

The production cost of crops includes the cost of all the agricultural inputs, including labor wage, except irrigation cost in the present study. The production cost of all the crops, excluding irrigation cost, is shown in Table 1.

Present worth analysis

Cash flow in the OFR irrigation system is divided into (a) cash inflow; and (b) cash outflow. The cash inflow includes annual returns from irrigation and cash outflow includes initial investment and variable costs in the system. Annual cash inflows and outflows throughout the life period of the system are converted to their present worth using interest and inflation rate prevailing at the beginning of the system.

Cash outflow

$$PW_{co} = I_{nv} + PW_v \quad (6)$$

Where, PW_{co} = present worth of cash outflow (Rs); I_{nv} = initial investment (Rs); and PW_v= present worth of total variable cost (Rs).

Since, the initial investment is made at the beginning of the project so, the present worth of initial investment is equal to the initial investment itself. Annual variable costs likely to be incurred each year are converted to their present worth values and are assumed flowing at the beginning of the project.

$$PW_{av} = \sum_{t=1}^{n} A_{nr}(1+f)^{t-1}(1+r)^{-t}$$
$$A_{nr} = A_{irrigated} - A_{rainfed} \quad (7)$$

Where, A_{nr} = net annual return from the OFR system (Rs); PW_{av} = present worth of net return from the system (Rs); $A_{irrigated}$ = return from the OFR system with the provision of SI (Rs); and $A_{rainfed}$ = return from rainfed system without SI (Rs).

Net profit due to supplemental irrigation

Net profit, an economic index, is used to test whether the cost involved in the intervention of the OFR is acceptable or not.

In the present study, the net profit due to supplemental irrigation (SI) from the OFR has been computed by taking the differential return between irrigated and rainfed conditions. A negative net profit suggests rejection of the OFR irrigation system.

$$NP = PW_{nr} - PW_{co} \quad (8)$$

Where, NP = net profit due to SI from the OFR over rainfed situation, Rs.

Results and Discussion

The developed on-farm reservoir (OFR) operation model for irrigating crops (decision variable) is solved using dynamic programming technique by utilization the harvested water in the OFR (state variable) to maximize the relative crop yield (objective function). Finally, the optimum sizing of the OFR is determined by considering maximum return from the field. The model considers rice in *kharif* season and mustard in *rabi* season. However, if there is a competition among the crops for limited water available in the OFR, the allocation of irrigation water to crops will depend on crop growth stages, sensitivity to water stress, and its effect on final yield. In the study area, water deficiency exists mainly in *rabi* season, since the *kharif* crop receives a good amount of rainfall in monsoon season.

Crop data

The major crops grown during *kharif* and *rabi* seasons are rice and mustard, respectively. The crop parameters are presented in Table 2.

Determination of OFR by net profit analysis

Economic analysis of OFR sizes from 5% to 12% was carried out for 30 years from 1985-2014 and their results (2014) are presented in Table 3.

It was found that the initial investment, present worth of cash outflows and net return are increasing with the increase in the size of the OFR. The initial investment that includes cost of earthwork and lining is Rs.11809.

When the size of the OFR increases from 5%to 12% of the field area, the cost gradually increases to Rs.28208. Similarly, the present worth of cash outflows increased from Rs.21683 to Rs.45943 when the size of lined OFR increased from 5 to 12% of the field.

Pertaining to present worth of net return from the farm with provision of SI, it was observed to be increasing from Rs.31010 to Rs.63341as the OFR size increases from 5 to 12%. However, it may be noticed that the net profit is highest when the OFR size is 9% of the field area (Rs. 19739).

Table.1 Production cost of crops, their minimum support prices (MSP) and local market prices of by-products

Crop	Cost of production (Rs ha^{-1})	MSP of grain/seed (Rs/100kg)	Local market price of by-products (Rs/100kg)
Rice	9540	745	40
Mustard	4160	1735	20

Source: Dept. of Agriculture and Economics, minimum support price for 2003-14 season, Govt. of India

Table.2 Crop parameters for rice and mustard

Crop parameters	Rice	Mustard
Standard week of sowing	26th	43rd
Crop duration (day)	99	70
Length of crop growth stages (day)	25, 20, 30, 24	9, 16, 30, 15
Crop coefficient at different stages (k_c)	1.0, 1.15, 1.11, 1.0	0.34, 0.61, 0.88, 0.82
Yield response factors at differentstages (k_y)	1.1, 1.1, 2.4, 0.33	0.3, 0.6, 0.6, 0.3
Maximum root depth (cm)	45	100
Maximum Yield (100kg/ha)	17.4	8.1

Table.3 Economics of various sizes of lined OFR irrigation system for 800 m^2 upland farm area in 2014

OFR size (%)	Initial investment (Rs)	Present worth of total variable cost (Rs)	Present worth cash outflow (Rs)	Present worth of net return due to SI (Rs)	Net profit (Rs)
5	11809	9874	21683	31010	9327
5.5	12899	10438	23337	33613	10276
6	14000	10936	24936	36210	11274
6.5	15113	11548	26661	37879	11218
7	16234	12140	28374	42406	14032
7.5	17365	12727	30092	44724	14632
8	18703	13268	31971	47483	15512
8.5	19847	13880	33727	51969	18242
9	20998	14420	35418	55157	19739
9.5	22154	14933	37087	56699	19612
10	23516	15462	38978	58582	19604
10.5	24682	16038	40720	60113	19393
11	25853	16587	42440	61603	19163
11.5	27029	17137	44166	62575	18409
12	28208	17735	45943	63341	17398

Table.4 The optimal size of OFR in different probability of exceedance level, different cropping scenario and different soil water depletion factor

Probability of exceedance (%)	OFR size (%)			
	Rice -Mustard (10%)	Rice -Mustard (15%)	Rice (10%)	Rice (15%)
5	9.68	9.30	6.57	6.21
10	9.40	9.02	6.39	6.05
15	9.23	8.84	6.27	5.95
20	9.09	8.69	6.18	5.86
25	8.97	8.57	6.10	5.79
30	8.86	8.46	6.03	5.72
35	8.77	8.36	5.96	5.65
40	8.68	8.27	5.89	5.59
45	8.59	8.09	5.83	5.52
50	8.51	8.13	5.76	5.45

Fig.1 Variations in the OFR size, relative yield of rice (10% soil moisture depletion from saturation), and mustard (10% soil moisture depletion from field capacity) to maximize net annual return during 1985 – 2014

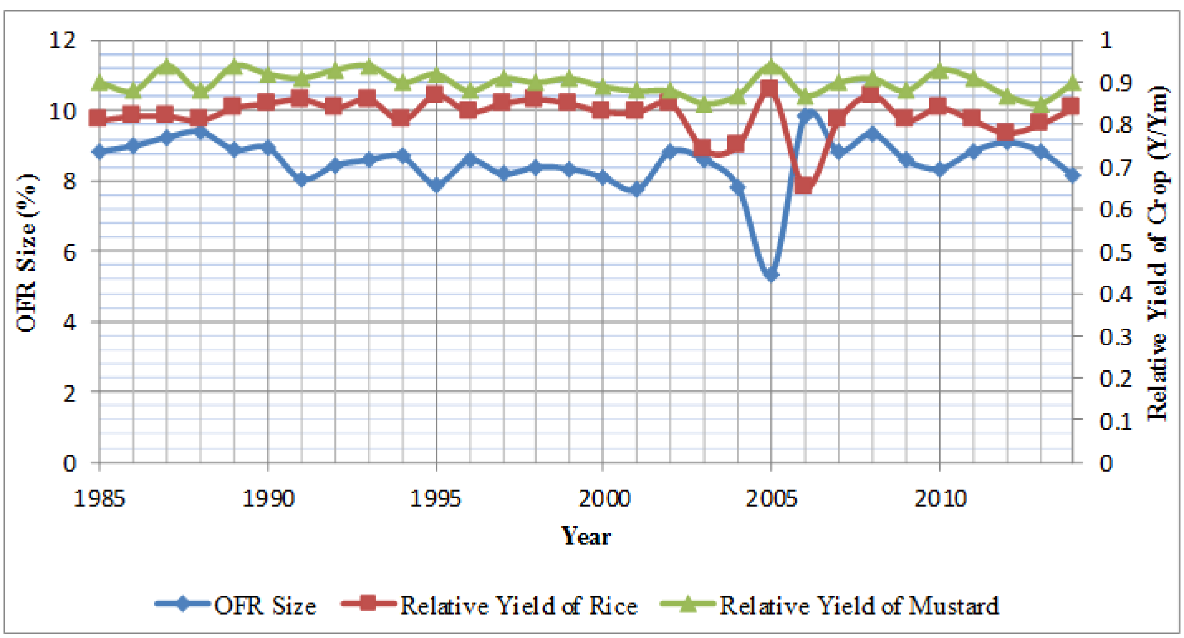


Fig.2 Variations in the OFR size, relative yield of rice (15% soil moisture depletion from saturation), and mustard (15% soil moisture depletion from field capacity) to maximize net annual return during 1985 – 2014

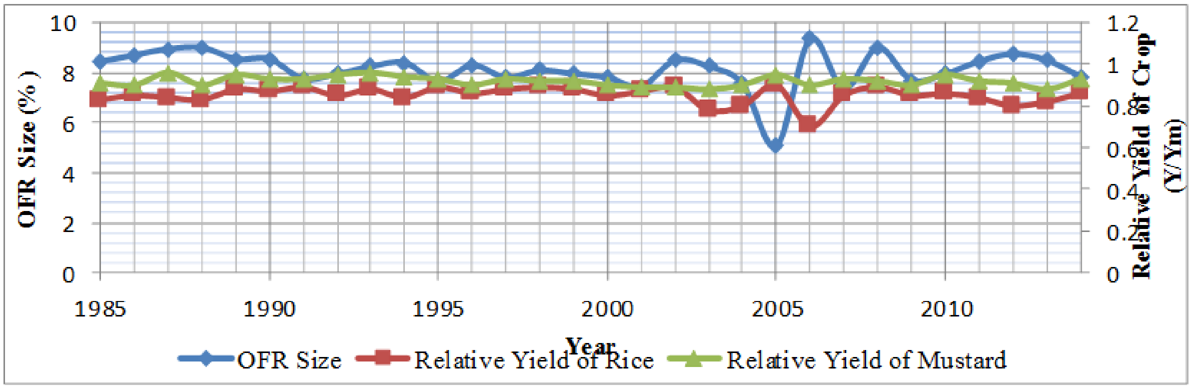


Fig.3 Variations in the OFR size and relative yield of rice at 10% soil moisture depletion from saturation to maximize net seasonal return during 1985 – 2014

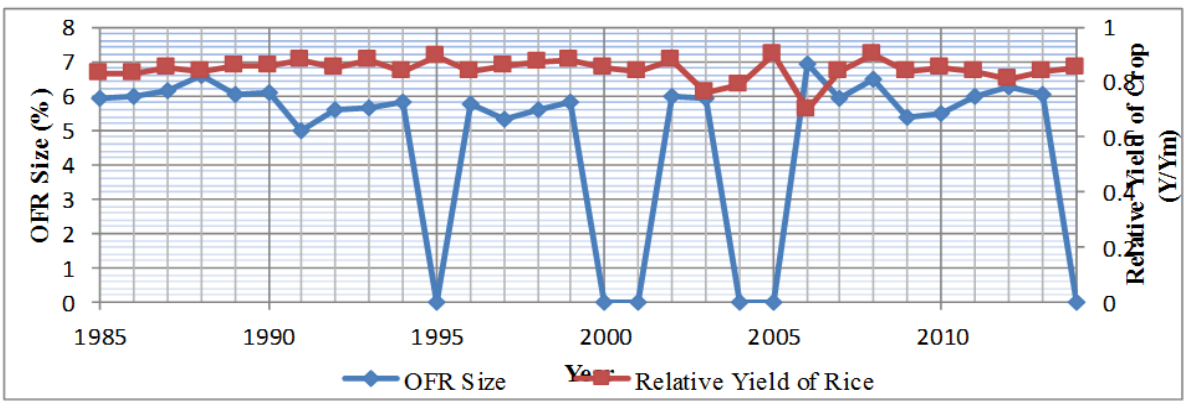
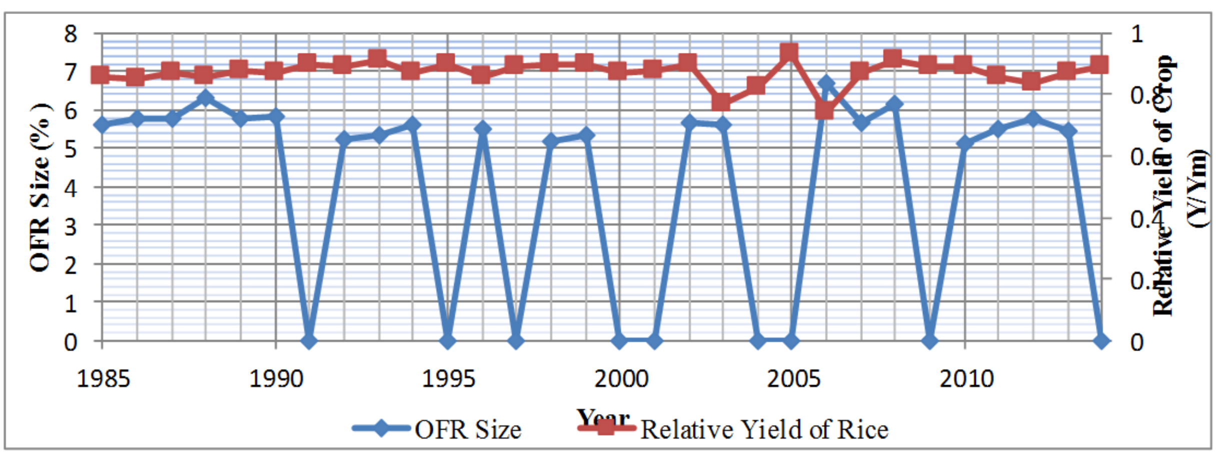


Fig.4 Variations in the OFR size and relative yield of rice at 15% soil moisture depletion from saturation to maximize net seasonal return during 1985 – 2014



Determination of OFR size under different soil water depletion factor for rice – mustard in different years

The model was run to calculate OFR size under rice-mustard cropping sequence in 800 m^2 field areas and OFR depth was maintained as 2.5 m. In case of rice crop, 10% and 15% soil water depletion from saturation was considered.

Whereas for mustard crop, 10% and 15% soil water depletion from field capacity was considered (Figure 1 and 2). Represents the variation of optimum size of OFR area (%) and relative yield of rice and mustard crops in different years.

In case of 10% soil water depletion for rice and mustard crops, optimum OFR size varies from 5.35% to 9.85%, relative yield of rice varies from 0.65 to 0.88 and relative yield of mustard varies from 0.85 to 0.94.

In case of 15% soil water depletion for rice and mustard crops, optimum OFR size varies from 5.05% to 9.35%, relative yield of rice varies from 0.70 to 0.90 and relative yield of mustard varies from 0.88 to 0.96. The OFR size was higher and relative yield of rice and mustard was low in case of 10% depletion than in 15% depletion.

Determination of OFR size under different soil water depletion factor for rice

The model was run to calculate OFR size under rice crop 10% and 15% soil water depletion from saturation was considered. Figure 3 and 4 represent the variation of optimum size OFR area (%) and relative yield of rice crop in different years. In case of 10% soil water depletion from saturation for rice crop, optimum OFR size varies from 0.0% to 6.90%, relative yield of rice varies from 0.70 to 0.90. In case of 15% soil water depletion from saturation, optimum OFR size varies from 0.0% to 6.7% and relative yield varies from 0.74 to 0.93. The OFR size was higher and relative yield of rice crop was low in case of 10% depletion than in 15% depletion.

Determination of OFR size in different probability of exceedance level in different cropping scenario

Optimum sizes of OFR (30 years) were fitted to lognormal probability distribution function (FLOOD software developed by Goutam Kumar Dey and Prof. S. N. Panda.

Determined OFR size at different probability of exceedance (PE) levels from 5% to 50% is illustrated in Table 4. It was observed that the OFR size is maximum when PE value is less and OFR size is gradually decreasing with the increase in value of PE in all cropping scenario.

For 10% soil water depletion for rice (from saturation) and mustard (from field capacity) crops, the optimum size of OFR varied from 5.35% to 9.85%. Similarly, for 15% soil water depletion it varied from 5.05% to 9.35%.Relative yield for 10% soil water depletion for rice (from saturation) and mustard (from field capacity) crops varied from 0.65 to 0.88 and 0.85 to 0.94.

Similarly, for 15% soil water depletion it varied from 0.70 to 0.90 for rice and 0.88 to 0.96 for mustard crop. If only rice crop is grown, the optimum size of OFR for 10% soil water depletion varied from 0.00% to 6.90%, whereas for 15% soil water depletion it varied from 0.00% to 6.70%.

Similarly, relative yield for 10% and 15% soil water depletion varied from 0.70 to 0.90 and 0.74 to 0.93, respectively. For 5% to 50% probability of exceedance level, the optimum size of OFR for 10% soil water depletion for rice (from saturation) and mustard (from field capacity) crops varied from 9.68% to 8.51%. Similarly, for 15% soil water depletion it varied from 9.30% to 8.13%. If only rice crop is grown and 5% to 50% probability of exceedance level is considered, the optimum size of OFR for 10% and 15% soil water depletion level varied from 6.57% to 5.76% and 6.21% to 5.45%. In low water availability condition, the model performance is very good because it allocate supplemental irrigation at the time when crop has high yield response factor. If a year from a particular size of OFR the return of the crop is less than the return came from no OFR condition then it show no OFR required at that year.

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