

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 6, Issue 10, October 2017

Improved Irrigation Efficiency through Management of Water in On-Farm Reservoir

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ABSTRACT: During watering of the crops in the farm through canal flows or direct pumping of ground water, a huge quantity of water is wasted due to poor irrigation practices. This wastage can be minimized by storing excess water of field in on-farm reservoir (OFR) during each irrigation. This stored water of OFR can be used as supplemental irrigation with the usual irrigation of the crop. The study suggests that the use of stored water of OFR invariably increases water irrigation efficiency. The stored water also ensures assured water supply during crop stress.

KEYWORDS: On-farm reservoir, Irrigation efficiency, Storage, Watering of crops, supplemental irrigation.

I. INTRODUCTION

In an environment of growing scarcity and competition for water, every nation's goals are to increase the productivity of water, protect the environment, and alleviate poverty. If agricultural, industrial production and livelihoods are to be sustained at current levels, the water available to various sectors will have to be used more productively. In developing countries including India, the agricultural sector uses water less efficiently than needed. Ironically, food production requires about three quarter of overall demand as per report of FAO (2003) hence huge quantity of water goes unproductively. The agricultural water needs are met either directly through rainfall or canal networks. The productivity of rain-fed areas are quite low as compared to irrigated areas. A lot of literature is available on the enhanced productivity of land and water in rain-fed areas through water harvesting in on-farm reservoirs (OFR) and supplemental irrigation (Panda et al., 2001). OFR irrigation system is economically viable (Panigrahi B et al., 2006). However, the use of OFR has been limited to rain-fed areas only. Very little literature is available on the OFR system of storage and supplemental irrigation except a few Singh & Ojha (2003) as well as Singh & Ojha (2005). Hitherto OFR has been used to harvest water from rainfall runoff.

A major portion of irrigation water is lost to the atmosphere through evaporation and to the ground due to seepage and percolation losses in the farm as a result of excess irrigation, since, in irrigated areas most of the farmers flood their crop land, whenever the water is supplied through canal network. This leads to poor irrigation efficiency (Danny et al., 1997). Objective of this paper is to show that use of OFR in storing the surface runoff through cropped field and withdrawal of extra water from the supply source during first and following irrigations along with the supplemental irrigation leads to saving of water irrespective various frequencies of single crop and mixed crops.

II. ON-FARM RESERVOIR

On-farm reservoir captures surface runoff water during any watering of the crop from cropped farm and receives supply from the water sources such as canal network and stores it within the cultivated area into some type of reservoir. This

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stored water of OFR is used subsequently with other irrigations as supplemental irrigation. Here, Supplemental irrigation (SI) is defined as the application of a certain amount of water available in OFR to the crop with usual supply to provide sufficient water for plant growth to increase and stabilize yields. Further, it is assumed that the water productivity (i.e., the ratio of economic yield of a crop and the total amount of water consumed) by this method is unaffected.

The sustainability of the various types of OFR is found to depend largely upon the timing and the amount of water to be stored, crop type, cropping pattern, soil type and depth, land topography, climatic conditions and local socioeconomic factors, these systems tend to be very site-specific. Before designing on-farm reservoir, proper estimation of water yield from the cropped field and the water requirement of the crop in the field should be assessed and for an optimum design the demand should match with the availability as reported by Panigrahi, and Panda (2003).

Sizing of an OFR for supplemental irrigation has generally been based on rule of thumb values due to limited information on the stochastic nature of storage availability and irrigation requirements of rainfed crops at critical growth stages in sub-humid regions. These estimates tend to be conservative, resulting in either larger or smaller sizes than required. A larger OFR may meet the irrigation demand of crops at all times but may not be economical. On the other hand, a smaller size OFR may not meet the irrigation requirement of crops during the critical growth stage and thereby affect yield seriously. Hence, there is a need to determine the optimum size of an OFR that can harvest and reuse the precious water in farming. The optimum size of an OFR must take into account the economics of supplemental irrigation that leads to increase in crop yield. Irrigation management practices, crop parameters, soil physical properties, and hydrologic characteristics of the cropped field yielding runoff to the OFR must also be considered along with the economics of supplemental irrigation.

III. WATER BALANCE MODEL OF THE OFR

Let us use the following notations and equations for the convenience. These are: C = Storage capacity of OFR, C_p = Percolation coefficient, d = Total depth of crop water requirement, DP_f = Deep percolation loss from field, Ev_f = Evaporation loss from field, EV_{ofr} = Evaporation loss from surface of the OFR, f = No. of irrigations of the crop, I_c = Net Inflow to the OFR through supply channel, I_f = Inflow to the OFR from field as surface runoff, K_f = Percentage of water loss from field, K_{ofr} = Percentage of water loss from OFR through evaporation, NS = Net storage in OFR, O_f = Outflow or withdrawal from the OFR into field to supplemental irrigation needs, R_c = Runoff coefficient, TWR = Total water required for the particular crop, WR = Water required by the crop in any particular watering, WS = Sum of total water supply through supply channel and in the field in any particular watering, WS_c = Water supply through supply channel to the OFR in any particular watering, WS_f = Water supply in the field in any particular watering, η_c = Water conveyance efficiency of supply channel, η_f = Water conveyance efficiency of field and η_{ofr} = Water application efficiency of OFR. In terms of these notations, the following relationships hold good.

$$WR = \frac{TWR}{f} \quad (1)$$

$$WS_c = \frac{\text{Amount of water added to OFR}}{\eta_c} \quad (2)$$

$$WS_f = \frac{TWR}{\eta_f \cdot f} = \frac{WR}{\eta_f} \quad (3)$$

$$DP_f = C_p \cdot (WS_f - WR) \quad (4)$$

$$(5)$$

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$$EV_f = K_f \cdot (WS_f - WR)$$

$$I_f = R_c \cdot (WS_f - WR)$$

Water balance model of the OFR was run by considering all the inflow and outflow components of the OFR. The inflows are the direct supply in the OFR and surface runoff from the field coming to the OFR and the outflows are evaporation, seepage and percolation and supplemental irrigation supplied to crops in the field. The various components of the OFR water balance model are:

$$S_i - S_{i-1} = NS_i = I_{fi} + P_i - EV_{fi} - SI_i - DP_{fi} \tag{6}$$

where S_i is the OFR water storage at state i , m^3 ; I_{fi} the volume of surface runoff coming from the field to the OFR, m^3 ; P_i the volume of direct rainfall in the OFR, m^3 ; EV_{fi} the volume of water lost as evaporation from the OFR, m^3 ; SI_i the volume of water used as supplemental irrigation in the cropped field, m^3 ; DP_{fi} the volume of water lost as seepage and percolation from the OFR storage, m^3 and i is the time index taken as 1 day in the study. If A_{farm} is the field area given as:

$$A_{farm} = FA - A_{ofr} \tag{7}$$

where, FA is the farm area and A_{ofr} is the area of the OFR. The value of surface runoff coming from field to the OFR on any day is estimated by knowing the depth of water drained to the OFR.

IV. METHODOLOGY

After each application of irrigation, it is likely that a considerable amount of water may be lost as surface runoff or may be localized in some pockets to be infiltrated and wasted beyond the root zone depth. To trap such a quantum of water, which is otherwise destined to be of no use to the irrigation, use of OFR for storing this water after the each irrigation is in-fact an important step. In addition to collection of such surface runoff in OFR, the water can also be stored from direct withdrawal of water from source of supply through supply channels. Thus, OFR may be filled partially or fully depending upon its capacity, amount of water available at source and aspiration of the farmer. At the onset of the subsequent irrigation, the farmer may use stored water of OFR as supplemental irrigation along with water withdrawn from source for subsequent irrigation and so on till the required number of irrigations for the grown crop or crops. This has been explained with help of flow diagram as shown in Fig. 1.

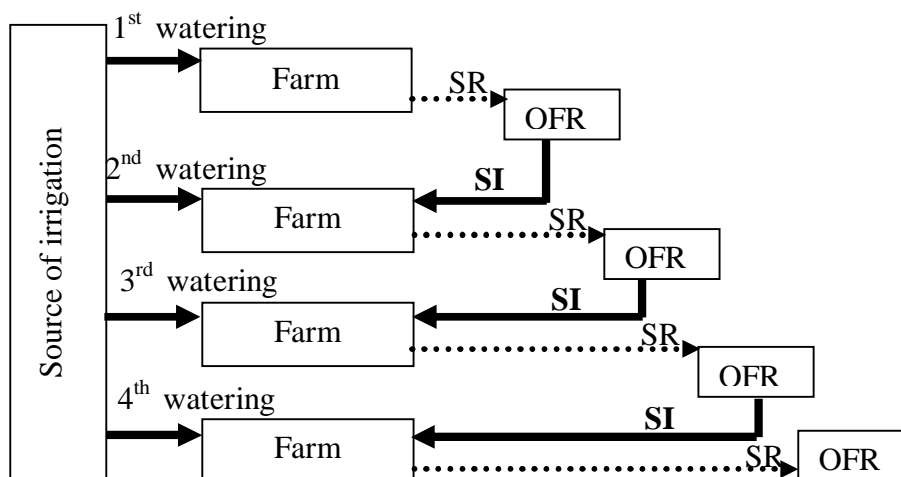


Fig. 1: Flow diagram showing the storage of water in OFR and its utilizations

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The use of water in aforesaid manner leads to saving of water as compared to case when there is no storage of water in the farm. The whole hypothesis is based on the premise that yield of crop is not affected due to loss of field area in adjusting the OFR (Panda et al., 2003). The saving of water can be explained with the help of an illustrative example.

V. ILLUSTRATIVE EXAMPLE

Consider a farm having a lined OFR at the end corner of the field as shown in Fig. 2(a) and 2(b). The OFR can be filled by agricultural runoff collection from the field and directly through the supply channel. Let the total area of the field be 1 hectare excluding the surface area of OFR. It is assumed that the crop grown requires 40 cm of irrigation in 4 turns.. It is given that water application efficiencies through field and supply channel are 75% and 90 %, respectively. The respective coefficients due to evaporation, deep percolation and runoff are assumed as 0.25, 0.25 and 0.50, respectively. It is also assumed that during entire crop period, there is no rainfall and application efficiency of OFR is 100%.

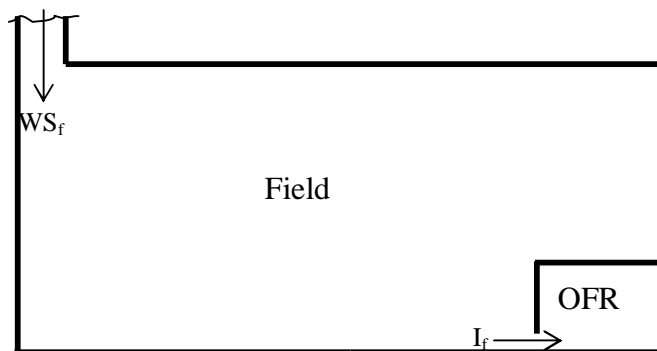


Fig. 2a: Plan of field and lined OFR

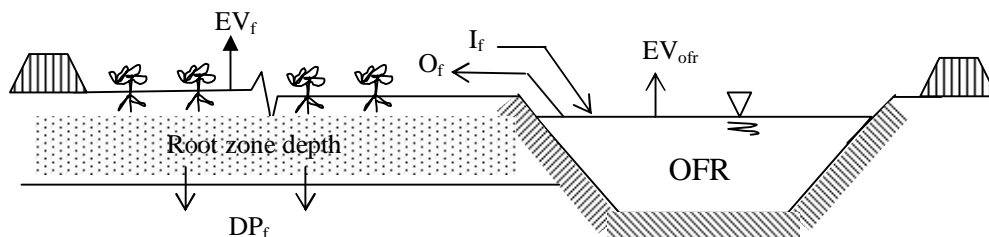


Fig. 2b: Cross-section of lined OFR with flow details

SOLUTION: The solution is based on the following assumptions :

- i) Water is supplied to the field from the source in adequate quantity as and when the crop requires water right from growing stage to the maturity period.
- ii) There is a reservoir in the field of the capacity equal to Surface runoff from the field.

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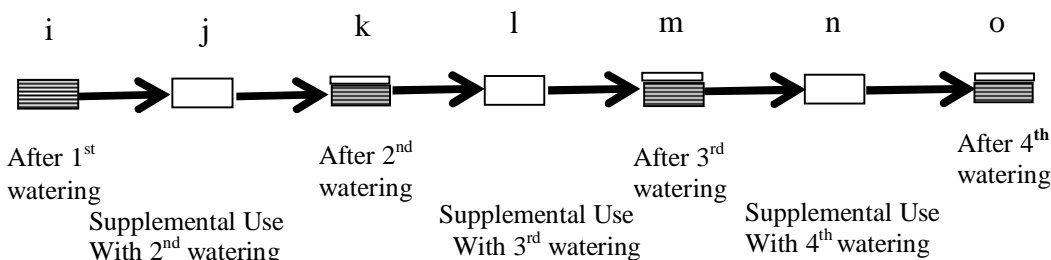


Fig. 3 Supplemental Use of OFR water with four frequency crop

The methodology as explained earlier is applied here to show the water saving. To understand more explicitly a network is drawn as shown in the figure 3. Invoking the equations (1) to (7) the savings of water have been directly given in the following tables (1) to (3).

Table 1: Saving of water for single crop in the field

S. No.	Crop water requirement (cm)	Frequencies of the crop	Water used without OFR (m ³)	Water used with OFR (m ³)	Water saving (%)
1	30	3	4000.00	3786.67	5.33
2	40	4	5333.33	5018.06	5.90
3	50	5	6666.67	6259.13	6.11
4	60	6	8000.00	7496.78	6.29
5	70	7	9333.33	8735.08	6.40

Table 2: Saving of water for mixed crop in the field

S. No.	Crop water requirement (cm) Maximum of two crops	Frequencies of the crop With equal areas	Water used without OFR (m ³)	Water used with OFR (m ³)	Water saving (%)
1	40	3+4	4666.67	4352.00	6.74
2	50	3+5	5333.33	4992.55	6.39
3	60	3+6	6000.00	5603.00	6.62
4	70	3+7	6666.67	6225.49	6.62
5	50	4+5	6000.00	5592.53	6.79
6	60	4+6	6666.67	6229.65	6.55
7	70	4+7	7333.33	6841.47	6.71
8	60	5+6	7333.33	6829.67	6.87
9	70	5+7	8000.00	7468.16	6.65
10	70	6+7	8666.67	8068.16	6.90

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Table 3a: Saving of water for mixed crop in the field with unequal areas (40 % for lower and 60 % for higher frequency crop)

S. No.	Crop water requirement (cm) Maximum of two crops	Frequencies of the crop With unequal areas (say 40% & 60%)	Water used without OFR (m ³)	Water used with OFR (m ³)	Water saving (%)
1	40	3+4	4800.00	4485.32	6.55
2	50	3+5	5600.00	5245.86	6.32
3	60	3+6	6400.00	5981.64	6.54
4	70	3+7	7200.00	6727.33	6.56
5	50	4+5	6133.33	5725.86	6.64
6	60	4+6	6933.33	6482.98	6.50
7	70	4+7	7733.33	7220.13	6.37
8	60	5+6	7466.66	6962.98	6.75
9	70	5+7	8266.66	7721.47	6.59
10	70	6+7	8800.00	8201.46	6.80

Table 3b: Saving of water for mixed crop in the field with unequal areas (40 % for higher and 60 % for lower frequency crop)

S. No.	Crop water requirement (cm) Maximum of two crops	Frequencies of the crop With unequal areas (say 40% & 60%)	Water used without OFR (m ³)	Water used with OFR (m ³)	Water saving (%)
1	40	3+4	4533.33	4218.66	6.94
2	50	3+5	5066.66	4739.19	6.46
3	60	3+6	5600.00	5224.30	6.71
4	70	3+7	6133.33	5723.58	6.68
5	50	4+5	5866.66	5459.19	6.94
6	60	4+6	6400.00	5976.31	6.62
7	70	4+7	6933.33	6462.79	6.79
8	60	5+6	7200.00	6696.31	7.00
9	70	5+7	7733.33	7214.79	6.70
10	70	6+7	8533.33	7934.79	7.01

It can be seen from the Tables 3.3a and 3.3b that the as the frequency of crop increases the saving of water increases. To study the effect of various parameter taken in the illustrative example, the parameters were changed one by one keeping other constants and the effects on saving of water has been reported in the subsequent sections.

EFFECT OF CHANGE OF RUNOFF COEFFICIENT R_c

Fig. 4 (a), (b) and (c) shows a graphical plot of variation of water saving with R_c . It can be seen that the as the R_c increases, the saving of water increases.

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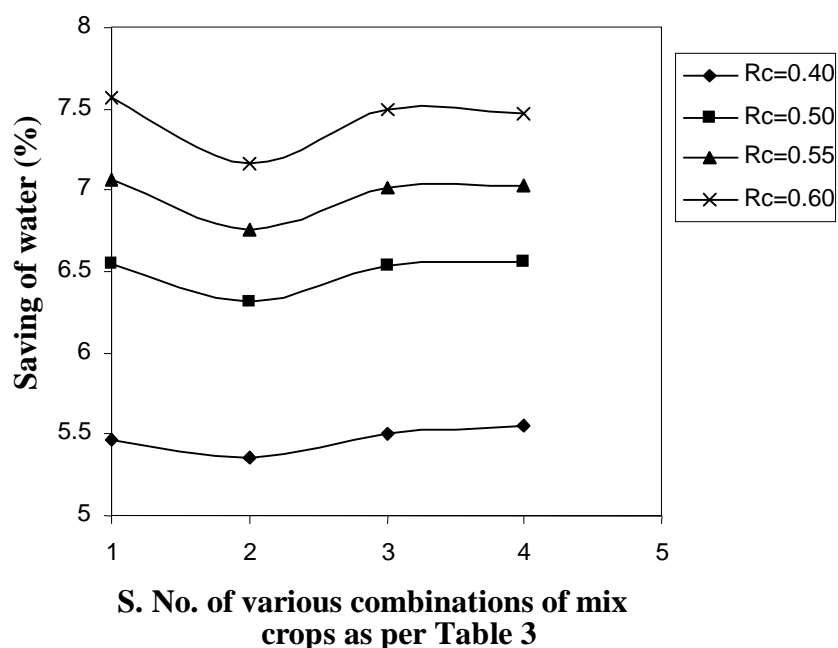


Fig. 4(c) Variation of water saving with R_c

EFFECT OF CHANGE OF WATER CONVEYANCE EFFICIENCY OF FIELD H_f

Fig. 5 (a), (b) and (c) shows a graphical plot of variation of water saving with η_f for various frequencies of irrigation. It can be seen that the as the η_f increases, the saving of water decreases.

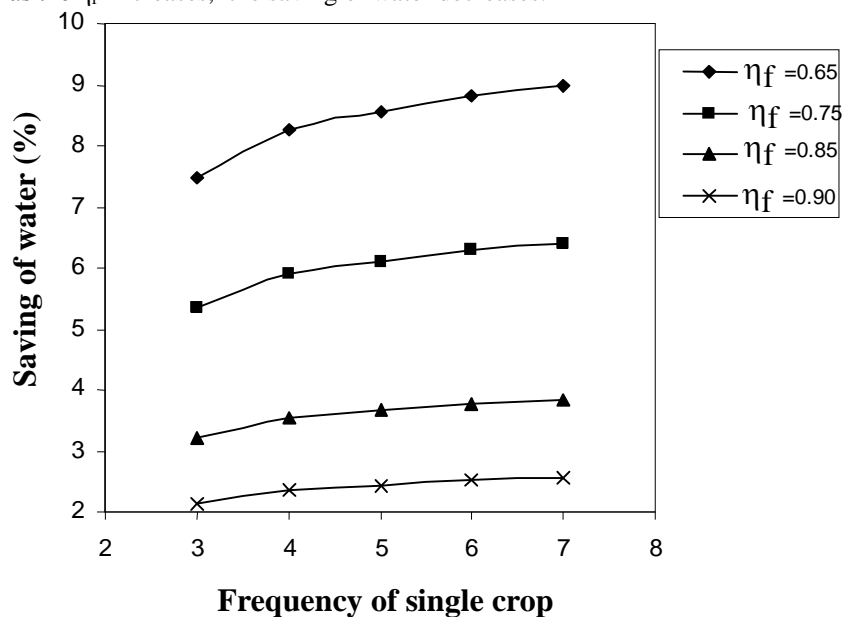


Fig. 5(a) Variation of water saving with η_f

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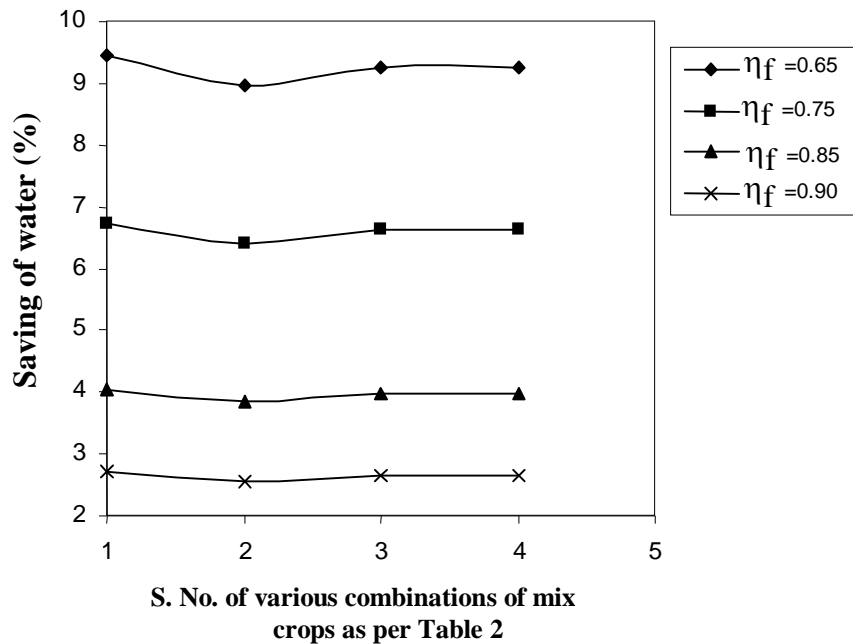


Fig. 5(b) Variation of water saving with η_f

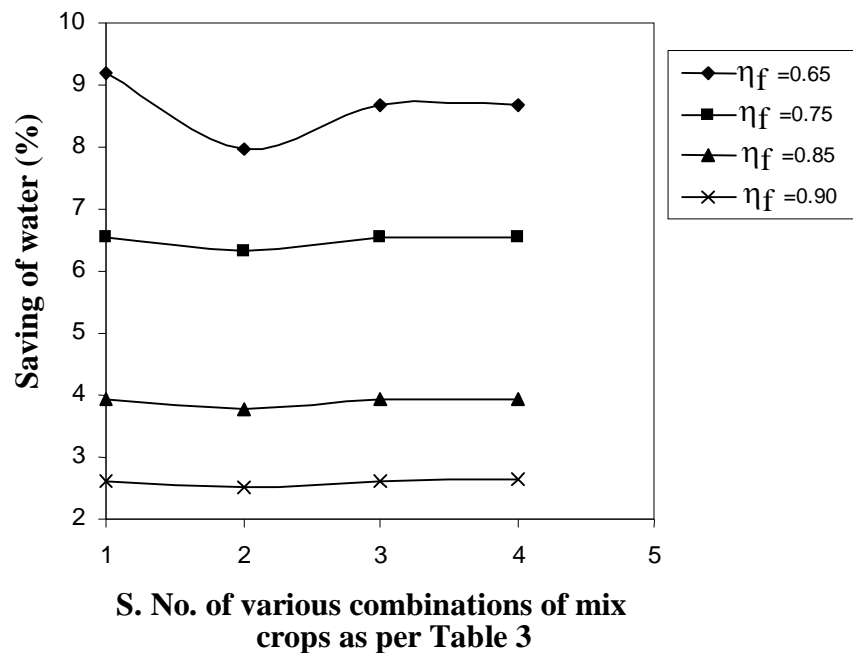


Fig. 5(c) Variation of water saving with η_f

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EFFECT OF CHANGE OF EVAPORATION COEFFICIENT, K_{OFR}

Fig. 6 (a), (b) and (c) shows a graphical plot of variation of water saving with K_{OFR} for various frequencies of irrigation. It can be seen that the as the K_{OFR} increases, the saving of water decreases.

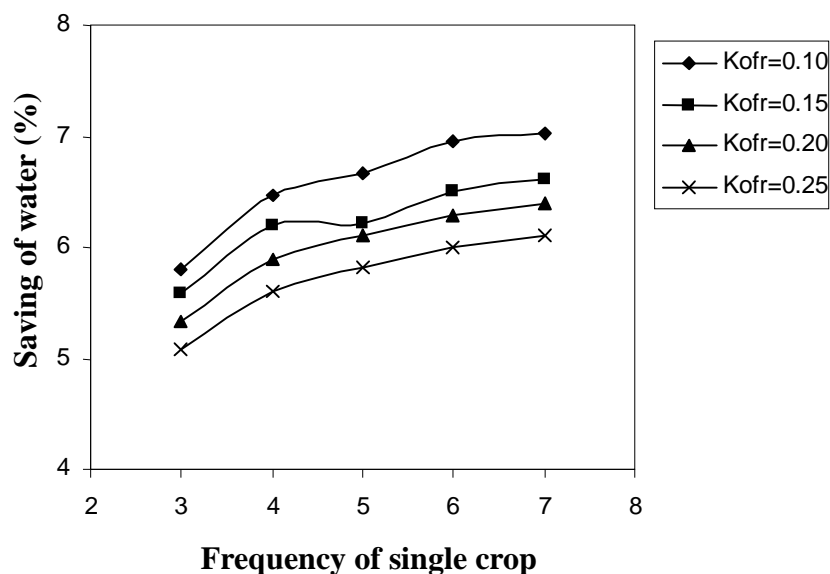


Fig. 6(a) Variation of water saving with K_{OFR}

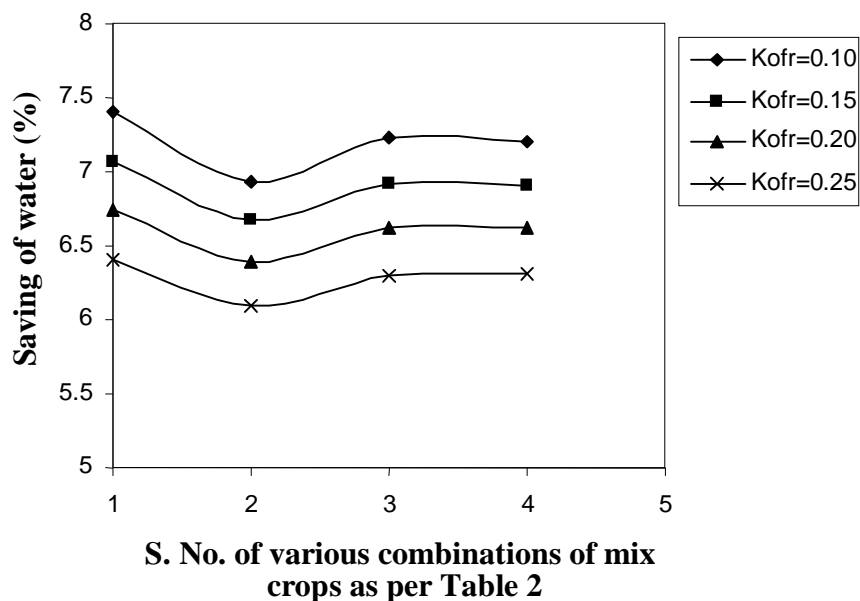


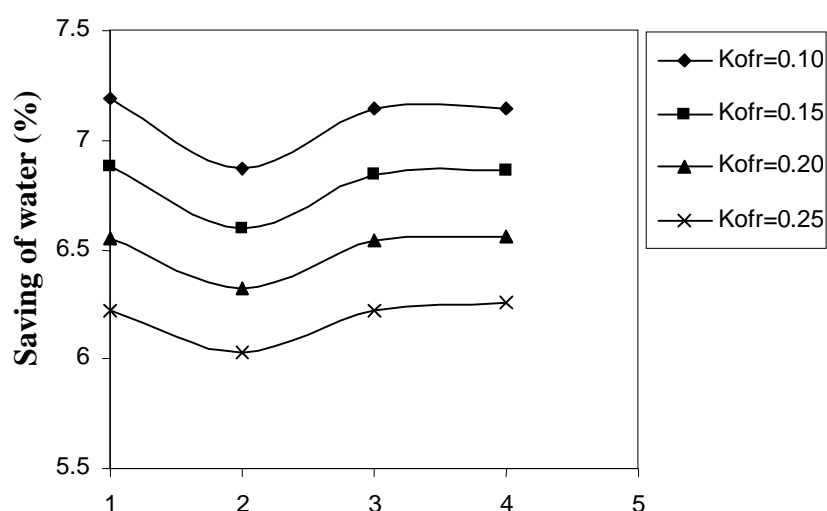
Fig. 6(b) Variation of water saving with K_{OFR}

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**S. No. of various combinations of mix
crops as per Table 3**

Fig. 6(c) Variation of water saving with K_{ofr}

VI. RESULTS AND DISCUSSION

From the results of water saving for a single crop as well as mixed crops reported in Tables 1 to 3, it can be summarized that the storage of excess agricultural runoff in lined OFR leads to better water application efficiency. This is because the excess water of each irrigation is utilized rather than allowing it to be wasted as surface runoff.

The efficiency of water use in irrigation by flooding is less, because the travel time of water is longer at the farthest point of the farm, and water must stand for a longer time and water percolates to the lowest point of root zone depth at the farthest point. In this manner a considerable amount of water is lost to the atmosphere and deep percolation below the root zone depth. If an OFR system is used, there is a flexibility in the application of water at a point as the concerned pipe can be placed at any desired point on the farm as water is secured from OFR, leading to considerable reduction in water loss due to evaporation and deep percolation, and hence improved efficiency of water use. It is true that OFR adds to the cost of pumping and loss of certain farm area, but it has been reported that the benefit-cost ratio is higher due to timely irrigation of crop, especially at the critical stage of crop growth. Thus, a small investment in OFR and pumping of water is beneficial in the long run due to higher crop yield and water saving at the farm level. This also helps with increased availability of water in canal networks. Hence, this will lead to more efficient use of water and controlling the excessive rate of decline of ground water, and thus reducing the pumping cost of ground water.

VII. CONCLUSIONS

The following conclusions are drawn from this study:

- (1) The use of an OFR for supplemental irrigation leads to improved irrigation efficiency for both single and multiple crops. The water use efficiency is higher for multiple crops as compared to a single crop.
- (2) The water use efficiency is sensitive to the values of various parameters, such as η_f , K_{ofr} , R_c , etc.
- (3) From the results obtained for different crops, it is surmised that the use of OFR will be beneficial for any type of crop in any climate.
- (4) The use of lined OFR always leads to improved irrigation efficiency irrespective of the manner of operation of stored water.

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