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Efficient Operation of On-farm Reservoir for Crops Requiring Five Numbers of Irrigation

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ABSTRACT
The world water day is an occasion to reflect on the great importance of water for the existence of humanity. Without water, there is no life. Therefore, there is no greater challenge facing humankind than the challenge of harnessing and using water wisely and efficiently especially in agriculture sector, which uses major quantity of fresh water and also wastes considerable amount of water due to use of less efficient techniques of irrigation. The present study deals with improvement in water irrigation efficiency of crops requiring Five numbers of irrigations with the use and efficient operation of on-farm reservoir (OFR). The study suggests that out of different manners of use of OFR, there is one particular manner, which yields maximum water irrigation efficiency.

Keywords: On-farm reservoir, Irrigation efficiency, Operation of OFR and Efficient path.

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I. INTRODUCTION

Water is a natural resource of a region whose availability is limited by its topography and climate. Out of so many demands of water, the most outstanding demand in India as per FAO(2003) is for agriculture which consumes about 86% of all the water withdrawals. The other areas like domestic use, industrial and other demands require about 8%, 5% and 1% respectively. A major portion of valuable irrigation water is lost to the atmosphere through evaporation and to the ground through seepage loss during its conveyance from source to the field. This leads to poor irrigation efficiency (Danny et al., 1997). It is therefore necessary to devise efficient techniques, which can yield higher water irrigation efficiency. Though certain amount of water loss can be saved by means of adopting better irrigation methods and reducing the conveyance distance, however, due to prohibitive initial cost and practical constrains in developing countries, their use is restricted and may not be feasible. It is, therefore, important that water efficiency should be improved so that considerable amount of fresh water can be saved.

II. RESEARCH METHODOLOGY

If the capacity of OFR is assumed to be two times the excess runoff, then there can be possibility of filling of remaining capacity of OFR through direct withdrawal of water. Thus, in addition to agricultural needs during each irrigation, if the farmer aspires to conserve water in OFR through direct withdrawal of water in OFR as shown in Fig. 1, the network of supplemental use of OFR water with different rotations of irrigations of crop becomes complex.

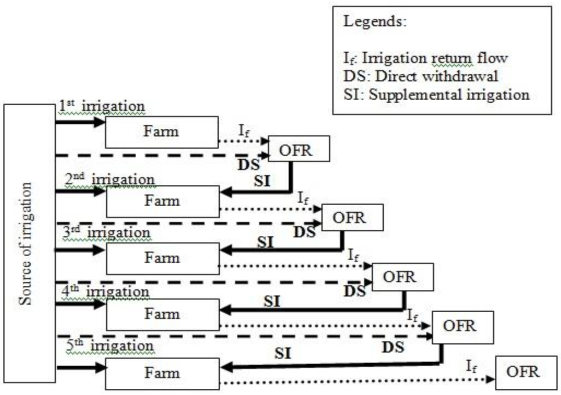

Fig. 1: Flow diagram showing the source of water to OFR and its utilizations

After each rotation of irrigation, the runoff of excess irrigation in the farm will make OFR either partially filled or full, depending on the storage capacity of OFR. The size of OFR depends on the type of crop(s), supplemental irrigation needs, topography and climate of the area (Palmer et al., 1981, Palmer et al., 1982 and Panigrahi and Panda, 2003). Assuming that capacity of OFR is twice the runoff, after 1st rotation of irrigation the OFR will be half filled. However, in addition to agricultural needs during each watering, if the farmer aspires to conserve water in OFR through direct withdrawal of additional water through supply channel to OFR as shown in Fig.1, the network of supplemental use of OFR water with different number of irrigations of crop becomes complex. At the onset of the 2nd rotation of irrigation, the farmer has various options of using stored water of OFR depending on the filled status of OFR. Any amount of water can be withdrawn from OFR depending on the ambition of the farmer. Assuming that a farmer has only three options of withdrawal of water, so that the OFR remains either full/ nearly full, half full/ nearly half full or empty/ nearly empty. After the 2nd rotation of irrigation, the OFR will have different filled status depending upon the adapted withdrawal manner of water by the farmer from OFR. Similarly, after the 3rd and 4th rotations of irrigation, there can be various possibilities corresponding to half filled or completely filled or empty status of OFR. On the onset of the 5th and the last irrigation, farmer would have to, in any case, empty OFR, otherwise stored water would be wasted, without any utility. Thus a network can be drawn considering these possibilities as shown in Fig.2. for a crop requiring five number of irrigations , which is self-explanatory. In Fig.2, columns 'i', 'k' and 'l' together, 'n' and 'o' together and 'q' and 'r' together as well as 's' represent status of OFR after 1st , 2nd , 3rd , 4th and 5th rotations of irrigation, respectively. Here, columns 'l', 'o' and 'r' correspond to direct filling of OFR through supply channel. Columns 'j', 'm', 'p' and 's' indicate options of withdrawal of water. The number of possible strategies for this frequency crop is ninety seven.

Once the network of various strategies is drawn, the problem is, thus, to identify the most efficient strategy or path of operation, which would lead to maximum saving of water. The most efficient strategy of operation is identified and explained with the help of an illustrative example.

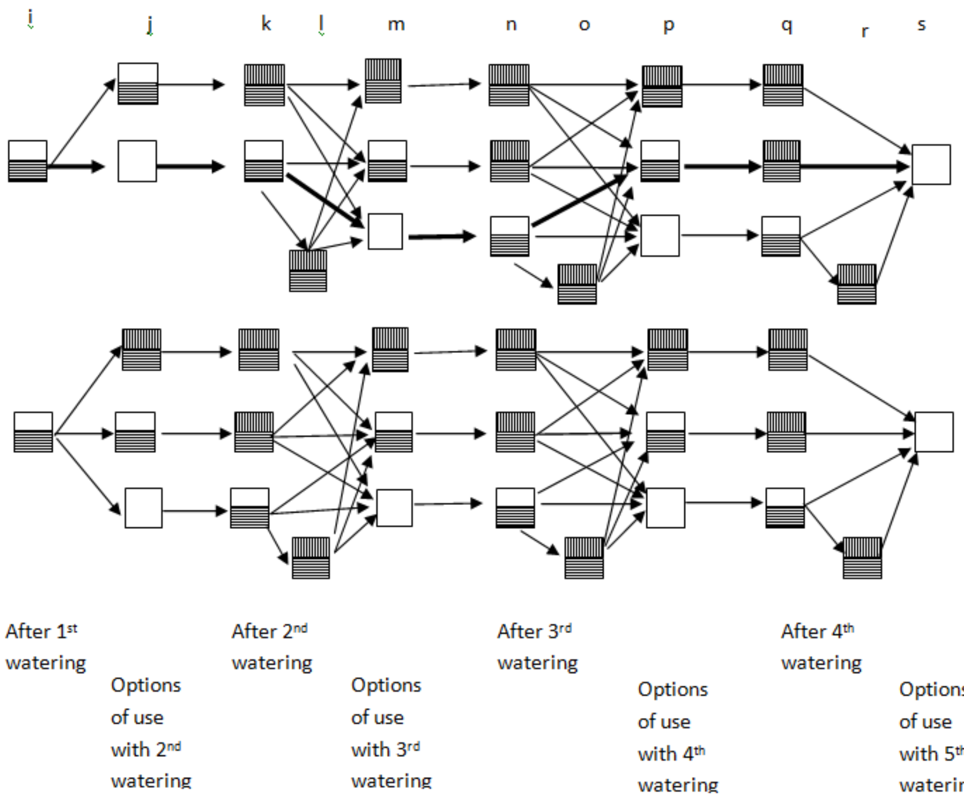

Fig. 2: Network for a crop of five number of irrigations

III. ILLUSTRATIVE EXAMPLE

Consider a farm having a lined OFR at the end corner of the field as shown in Fig. 3(a) and 3(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 crops grown require 50 cm of water in 5 numbers of irrigation. 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. It is also assumed that during entire crop period, there is no rainfall and application efficiency of OFR is 100%.

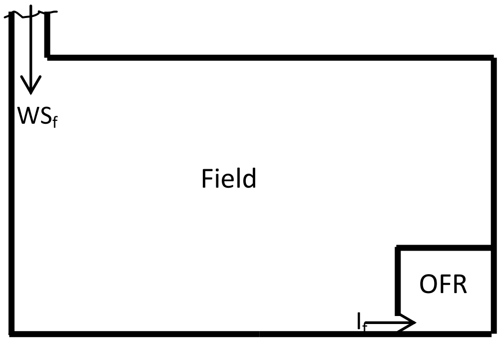

Fig. 3.a Plan of field and lined OFR

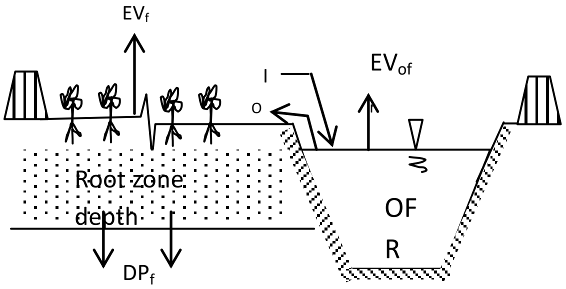

Fig. 3.b Cross-section of lined OFR with flow details

LIST OF NOTATIONS

Let us use the following notations and equations for the convenience, as shown in Fig. 3.(b).

DP_f = Deep percolation loss from field in m^3

EV_f = Evaporation loss from field in m^3

EV_{ofr} = Evaporation loss from surface of the OFR in m^3

I_f = Inflow to the OFR from field as irrigation return flow in m^3

O_f = Outflow or withdrawal from the OFR into field to supplement irrigation needs in m^3

WS_f = Water supply in the field in any particular irrigation in m^3

C = Storage capacity of OFR in m^3

C_p = Percolation coefficient

d = Total depth of crop water requirement in m

f = No. of irrigations of the crop

K_f = Coefficient of water loss from field

K_{ofr} = Coefficient of water loss from OFR through evaporation

NS = Net storage in OFR in m^3

R_c = irrigation return flow coefficient

TWR = Total water required for the particular crop in m^3

WR = Water required by the crop in any particular irrigation in m^3

η_f = Water application efficiency of the system. In terms of these notations, the following relationships hold good.

WR

$$= \frac{TWR}{f} \qquad (1)$$

$$WS_f = \frac{TWR}{\eta_f . f} = \frac{WR}{\eta_f} \qquad (2)$$

$$DP_f = C_p.(WS_f - WR) \qquad (3)$$

$$EV_f = K_f.(WS_f - WR) \qquad (4)$$

$$I_f = R_c.(WS_f - WR) \qquad (5)$$

Water balance model of the OFR was run by considering all the inflow and outflow components of the OFR. The inflow is irrigation return flow 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:

$$S_i - S_{i-1} = NS_i = I_{fi} + P_i - EV_{ofri} - SI_i - DP_{ofri} \qquad (6)$$

Where:

S_i is the OFR water storage at stage i, m^3

I_{fi} the volume of irrigation return flow from the field to the OFR, m^3

P_i the volume of direct rainfall in the OFR, m^3

EV_{ofri} 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_{ofri} the volume of water lost as seepage and percolation from the OFR storage, m^3

i is the time index taken as the time interval between two consecutive irrigations.

If A_{field} is the field area given as:

$A_{field} = FA - A_{ofr}$

Where: FA is the farm area

A_{ofr} is the area of the OFR, the value of total water required (TWR) for any crop is estimated by multiplying depth of water required (d) by the crop with $A_{field.}$

With $C_p = 0.25$, $K_f = 0.25$, $R_c = 0.50$, and $K_{ofr} = 0.1$, and using the data given in the illustrative example and invoking Eqs.(1), (2), (3), (4), (5) and (6), we get various quantities during first irrigation event at node "i" as :

WR = 1000.00 m^3
WS_f = 1333.33 m^3
EV_{ofr} = 33.33 m^3
I_f = 166.67 m^3
I_c = 166.67 m^3
WS_c = 185.19 m^3
O_f = 0
$C = 2 \times I_f$ = 333.33 m^3 (Assuming that the maximum storage capacity if OFR = 2 I_f = C i.e after two irrigation events OFR is full provided there is no evaporation loss).

Using the same equations, procedure and the network drawn for a crop requiring five irrigations as shown in Fig. 2, the calculations for saving in water against the respective paths have been produced in Tables 1. The number of possible strategies for a crop of five numbers of irrigations is ninety seven. It is further verified that the most efficient path or strategy for a crop of five numbers of irrigations also remains unaffected by change in the of values of various parameters, such as d, η_f, η_c, R_c and K_{ofr}.

Table 1: Saving of water

Strategy No.	Strategy of operation	WS with OFR (m^3)	WS without OFR (m^3)	Net Saving (m^3)	Saving(%)
1	i1j1k1m1n1p1q1s1	6400.00	6666.7	266.67	4.00
2	i1j1k1m1n1p2q2s1	6346.67	6666.7	320.00	4.80
3	i1j1k1m1n1p3q3s1	6373.33	6666.7	293.33	4.40
4	i1j1k1m1n1p3q3r1s1	6466.67	6666.7	200.00	3.00
5	i1j1k1m2n2p1q1s1	6280.00	6666.7	386.67	5.80
6	i1j1k1m2n2p2q2s1	6286.40	6666.7	380.27	5.70
7	i1j1k1m2n2p3q3s1	6304.53	6666.7	362.13	5.43
8	i1j1k1m2n2p3q3r1s1	6384.59	6666.7	282.08	4.23
9	i1j1k1m3n3p2q2s1	6263.47	6666.7	403.20	6.05
10	i1j1k1m3n3p3q3s1	6270.93	6666.7	395.73	5.94
11	i1j1k1m3n3p3q3r1s1	6328.59	6666.7	338.08	5.07
12	i1j1k1m3n3o1p1q1s1	6478.51	6666.7	188.16	2.82
13	i1j1k1m3n3o1p2q2s1	6425.18	6666.7	241.49	3.62
14	i1j1k1m3n3o1p3q3s1	6451.84	6666.7	214.82	3.22
15	i1j1k1m3n3o1p3q3r1s1	6545.18	6666.7	121.49	1.82
16	i1j2k2m2n2p1q1s1	6266.67	6666.7	400.00	6.00
17	i1j2k2m2n2p2q2s1	6261.87	6666.7	404.80	6.07
18	i1j2k2m2n2p3q3s1	6281.60	6666.7	385.07	5.78
19	i1j2k2m2n2p3q3r1s1	6364.14	6666.7	302.52	4.54
20	i1j2k2m3n3p2q2s1	6238.93	6666.7	427.73	6.42
21	i1j2k2m3n3p3q3s1	6259.20	6666.7	407.47	6.11
22	i1j2k2m3n3p3q3r1s1	6326.81	6666.7	339.86	5.10
23	i1j2k2m3n3o1p1q1s1	6416.29	6666.7	250.38	3.76
24	i1j2k2m3n3o1p2q2s1	6362.96	6666.7	303.71	4.56
25	i1j2k2m3n3o1p3q3s1	6389.62	6666.7	277.04	4.16
26	i1j2k2m3n3o1p3q3r1s1	6482.96	6666.7	183.71	2.76
27	i1j2k2l1m1n1p1q1s1	6525.92	6666.7	140.74	2.11
28	i1j2k2l1m1n1p2q2s1	6472.59	6666.7	194.08	2.91
29	i1j2k2l1m1n1p3q3s1	6499.26	6666.7	167.41	2.51
30	i1j2k2l1m1n1p3q3r1s1	6592.59	6666.7	74.08	1.11
31	i1j2k2l1m2n2p1q1s1	6392.59	6666.7	274.08	4.11
32	i1j2k2l1m2n2p2q2s1	6395.26	6666.7	271.41	4.07
33	i1j2k2l1m2n2p3q3s1	6413.92	6666.7	252.74	3.79
34	i1j2k2l1m2n2p3q3r1s1	6494.81	6666.7	171.85	2.58
35	i1j2k2l1m3n3p2q2s1	6371.26	6666.7	295.41	4.43
36	i1j2k2l1m3n3p3q3s1	6376.59	6666.7	290.08	4.35
37	i1j2k2l1m3n3p3q3r1s1	6432.59	6666.7	234.08	3.51
38	i1j2k2l1m3n3o1p1q1s1	6604.43	6666.7	62.23	0.93
39	i1j2k2l1m3n3o1p2q2s1	6551.10	6666.7	115.57	1.73
40	i1j2k2l1m3n3o1p3q3s1	6577.77	6666.7	88.90	1.33
41	i1j2k2l1m3n3o1p3q3r1s1	6671.10	6666.7	-4.43	-0.07
42	i2j3k3m4n4p4q4s2	6585.19	6666.7	81.48	1.22
43	i2j3k3m4n4p5q5s2	6531.85	6666.7	134.81	2.02
44	i2j3k3m4n4p6q6s2	6558.52	6666.7	108.15	1.62
45	i2j3k3m4n4p6q6r2s2	6651.85	6666.7	14.81	0.22
46	i2j3k3m5n5p4q4s2	6451.85	6666.7	214.81	3.22
47	i2j3k3m5n5p5q5s2	6455.59	6666.7	211.08	3.17
48	i2j3k3m5n5p6q6s2	6471.05	6666.7	195.61	2.93
49	i2j3k3m5n5p6q6r2s2	6554.07	6666.7	112.59	1.69
50	i2j3k3m6n6p5q5s2	6421.99	6666.7	244.68	3.67
51	i2j3k3m6n6p6q6s2	6440.12	6666.7	226.55	3.40
52	i2j3k3m6n6p6q6r2s2	6491.85	6666.7	174.81	2.62
53	i2j3k3m6n6o2p4q4s2	6663.70	6666.7	2.97	0.04
54	i2j3k3m5n5o2p5q5s2	6610.36	6666.7	56.30	0.84
55	i2j3k3m6n6o2p6q6s2	6637.03	6666.7	29.64	0.44
56	i2j3k3m6n6o2p6q6r2s2	6730.36	6666.7	-63.70	-0.96
57	i2j4k4m4n4p4q4s2	6451.85	6666.7	214.81	3.22
58	i2j4k4m4n4p5q5s2	6398.52	6666.7	268.15	4.02
59	i2j4k4m4n4p6q6s2	6425.19	6666.7	241.48	3.62
60	i2j4k4m4n4p6q6r2s2	6518.52	6666.7	148.15	2.22
61	i2j4k4m5n5p4q4s2	6318.52	6666.7	348.15	5.22
62	i2j4k4m5n5p5q5s2	6343.59	6666.7	323.08	4.85
63	i2j4k4m5n5p6q6s2	6359.05	6666.7	307.61	4.61
64	i2j4k4m5n5p6q6r2s2	6434.96	6666.7	231.70	3.48
65	i2j4k4m6n6p5q5s2	6351.59	6666.7	315.08	4.73
66	i2j4k4m6n6p6q6s2	6363.32	6666.7	303.35	4.55
67	i2j4k4m6n6p6q6r2s2	6424.30	6666.7	242.37	3.64
68	i2j4k4m6n6o2p4q4s2	6554.07	6666.7	112.59	1.69
69	i2j4k4m5n5o2p5q5s2	6500.74	6666.7	165.93	2.49
70	i2j4k4m6n6o2p6q6s2	6527.41	6666.7	139.26	2.09
71	i2j4k4m6n6o2p6q6r2s2	6620.74	6666.7	45.93	0.69
72	i2j5k5m5n5p4q4s2	6328.12	6666.7	338.55	5.08
73	i2j5k5m5n5p5q5s2	6343.59	6666.7	323.08	4.85
74	i2j5k5m5n5p6q6s2	6359.05	6666.7	307.61	4.61
75	i2j5k5m5n5p6q6r2s2	6434.96	6666.7	231.70	3.48
76	i2j5k5m6n6p5q5s2	6327.05	6666.7	339.61	5.09
77	i2j5k5m6n6p6q6s2	6351.59	6666.7	315.08	4.73
78	i2j5k5m6n6p6q6r2s2	6422.52	6666.7	244.15	3.66
79	i2j5k5m6n6o2p4q4s2	6491.85	6666.7	174.81	2.62
80	i2j5k5m5n5o2p5q5s2	6438.52	6666.7	228.15	3.42
81	i2j5k5m6n6o2p6q6s2	6465.19	6666.7	201.48	3.02
82	i2j5k5m6n6o2p6q6r2s2	6558.52	6666.7	108.15	1.62
83	i2j5k5l2m4n4p4q4s2	6651.85	6666.7	14.81	0.22
84	i2j5k5l2m4n4p5q5s2	6598.52	6666.7	68.15	1.02
85	i2j5k5l2m4n4p6q6s2	6625.19	6666.7	41.48	0.62
86	i2j5k5l2m4n4p6q6r2s2	6718.52	6666.7	-51.85	-0.78
87	i2j5k5l2m5n5p4q4s2	6518.52	6666.7	148.15	2.22
88	i2j5k5l2m5n5p5q5s2	6522.25	6666.7	144.41	2.17
89	i2j5k5l2m5n5p6q6s2	6537.72	6666.7	128.95	1.93
90	i2j5k5l2m5n5p6q6r2s2	6620.74	6666.7	45.93	0.69
91	i2j5k5l2m6n6p5q5s2	6488.65	6666.7	178.01	2.67
92	i2j5k5l2m6n6p6q6s2	6506.79	6666.7	159.88	2.40
93	i2j5k5l2m6n6p6q6r2s2	6558.52	6666.7	108.15	1.62
94	i2j5k5l2m6n6o2p4q4s2	6730.36	6666.7	-63.70	-0.96
95	i2j5k5l2m5n5o2p5q5s2	6677.03	6666.7	-10.36	-0.16
96	i2j5k5l2m6n6o2p6q6s2	6703.70	6666.7	-37.03	-0.56
97	i2j5k5l2m6n6o2p6q6r2s2	6797.03	6666.7	-130.36	-1.96

The strategy of operation of OFR for a crop requiring five numbers of irrigations for maximum water saving is given in Table 2.

Table 2: Strategy of operation of OFR for five frequency crop

Stage of watering	Operation required
After 1st irrigation	Conserve excess irrigation return flow in OFR
With 2nd irrigation	Use entire OFR water as supplemental irrigation
After 2nd irrigation	Conserve excess irrigation return flow in OFR
With 3rd irrigation	Do not use OFR water

After 3rd irrigation	Conserve excess irrigation return flow in OFR along with the previous storage
With 4th irrigation	Use entire OFR water as supplemental irrigation
After 4th irrigation	Conserve excess runoff in OFR along with the previous storage
With 5th irrigation	Use entire OFR water as supplemental irrigation

Effect of change of parameters on the most efficient path

To study the effect of change of various parameters such as d, $\eta_f, \eta_c, \eta_{ofr}$, R_c and K_{ofr} on most efficient path the same procedure was used. The results of the effect of change of d , η_{ofr} and R_c have been graphically represented in **Fig. 4(a)-(c).** It can be seen that irrespective of the value of these parameters chosen the critical path remains the same. Thus, whatever is value of these parameters, the critical path is always the same as highlighted by bold arrows in Fig.2.

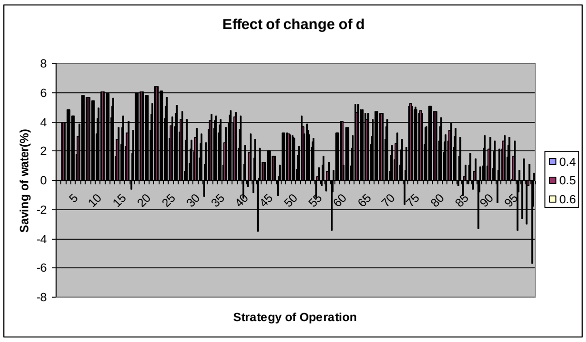

Fig. 4 a: Effect of change of depth d on saving of water

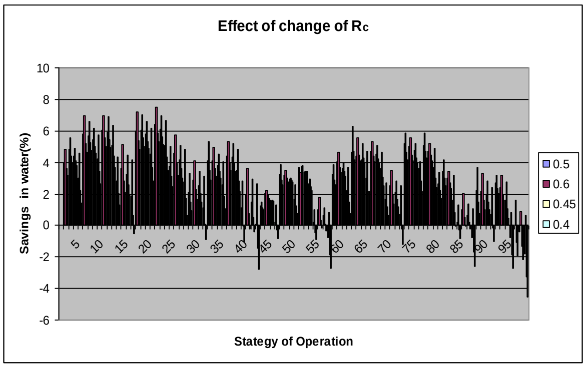

Fig. 4 b: Effect of change of Runoff coefficient R_c on saving of water

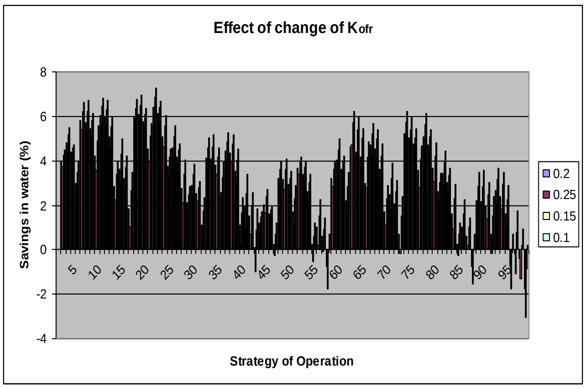

Fig. 4 c: Effect of change of Evaporation coefficient K_{ofr} on saving of water

IV. DISCUSSION

From the illustrative example, it is, therefore, appreciated that, use of lined OFR and storage of irrigation return flow and its subsequent use leads to better water application efficiency. This is due to the fact that excess irrigation return flow water of each rotation of irrigation is being utilized rather than being allowed to be wasted as surface runoff loss. The proposed methodology does reveal that use of OFR leads to better water application efficiency. However, OFR water must be utilized in a particular fashion so that the irrigation efficiency is maximum.

V. CONCLUSIONS

If the farmer aspires to conserve water in OFR through direct withdrawal of water to OFR in addition to agricultural needs during each irrigation, operation sequence of OFR is investigated for supplemental irrigation use in case of crops requiring five numbers of irrigations. Based upon the experiments shown herewith, use of OFR water as supplemental irrigation leads to improved irrigation efficiency. It is expected that the farmers and stake holders of water would encourage the use of OFR to achieve to improved irrigation efficiency.

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