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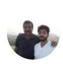

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EVALUATION OF AQUACROP MODEL FOR IRRIGATION PLANNING IN COMMAND AREA UNDER CHANGING CLIMATE

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ABSTRACT

A study was conducted to evaluate AquaCrop model for its ability to simulate crop performance under full and deficit water conditions in a humid environment in Konkan region of Maharashtra. The study dealt with the effect of different scenarios of irrigation (10, 30 and 50 per cent deficit) on crop yields grown in the irrigation command and their effects on crop yield sustainability and overall benefit. The net benefit for 10, 30 and 50 per cent deficit strategies was Rs. 23.67, 12.20 and -0.74 lakh, respectively. It was observed that 10 per cent deficit strategy was more beneficial in light soils.

Key words: AquaCrop model, Deficit irrigation, Net benefit, Soil water depletion, Water stress

In arid areas, crop production depends almost entirely on irrigation which is critical to improve water use efficiency in semiarid regions (Musick *et al*., 1994). Even in sub humid regions, irrigation is increasingly adopted to prevent decline in yield or harvest quality due to short term droughts (Evett *et al*., 2003). Defining optimum strategies in planning and management of available water resources in the agricultural sector is becoming a national and global priority (Smith, 2000). Various studies have shown that one of the promising irrigation strategies might be deficit irrigation, whereby less water than required is applied during the crop growth period. Although this inevitably results in crop water stress and yield depression, high yield can still be obtained by supplying the required amount of irrigation water during sensitive crop growth stages, and by restricting the water stress to tolerant growth stages.

Examining yield response to different water applications in field and/or controlled environments is laborious and expensive. Also its application on a larger area is more tedious as well as time consuming. Considering such limitations, modeling can be a useful tool to study and develop appealing deficit irrigation strategies (Blum, 2009). The FAO AquaCrop model predicts crop productivity, water requirement, and water use efficiency under water-limiting conditions (Raes *et al*., 2009). Hence, the aim of this paper was to evaluate AquaCrop model under full and deficit irrigation to different crops grown in the irrigation command and to apply it for simulating the effects of different irrigation scenarios on yield of crops in the command area under humid conditions of Konkan region of Maharashtra State.

MATERIALS AND METHODS

Study area

The location map of Panchnadi Minor Irrigation Project is shown in Fig. 1. The command area is located at $73^0 10'$ E longitude and $17^0 37'$ N latitude. Total storage, active or live storage and dead storage of tank is 1.738 Mm^3, 1.461 Mm^3 and 0.277 Mm^3, respectively. The right bank and left bank canal of distribution system covers the length of 2.91 km and 1.32 km while area under irrigation is 71 ha and 20 ha, respectively. The proposed total area under irrigation of tank is 114 ha. The proposed cropping pattern consists of 28.5 ha (25%) under plantation crops, 62.7 ha (55%) under vegetables, pulses and groundnut and 22.8 ha (20%) under *rabi* paddy. The area under existing cropping pattern is 30.70 per cent compared to the proposed cropping pattern. The existing area under arecanut, coconut, mango, *rabi* paddy, and vegetables is 96.4, 60, 30, 5 and 53.33 per cent, respectively, of proposed area.

The data indicate that the water management strategies are very essential so as to cope up with the shortage in the reservoir storage. Also when the reservoir is filled to its full capacity, these strategies may be beneficial to increase the area under irrigation. The existing cropping pattern was taken from the Irrigation Department, Dapoli. The project benefit for existing cropping pattern was calculated for 90 mm irrigation depth because the data of release rate and irrigation depth were not available.

The meteorological data were collected for 26 years (1985-2010) from the observatory located at Department of Agronomy, College of Agriculture, Dr. B.S.K.K.V., Dapoli. The data included ambient temperature, relative humidity, bright sunshine hours, wind speed, pan evaporation, rainfall, and the location specific data like longitude, latitude and altitude. The reference evapotranspiration (ETo) values were estimated by Penman Monteith (FAO-56) method (Allen *et al.* 1998). Major part of the irrigation command is occupied by sandy clay soil (70.03 per cent sand, 18 per cent silt and 11.97 per cent clay) soil followed by sandy clay loam (55.22 per cent sand, 18.75 per cent silt and 26.025 per cent clay) soil.

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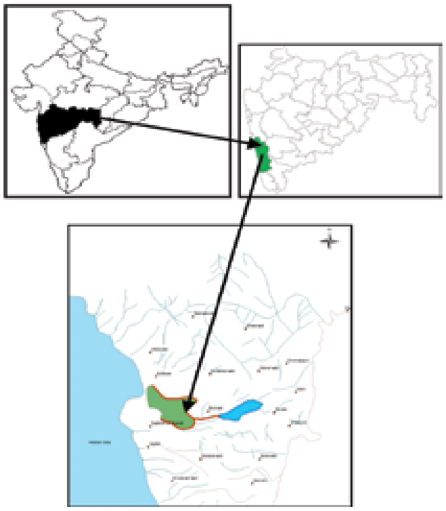

Fig. 1. Location map of study area

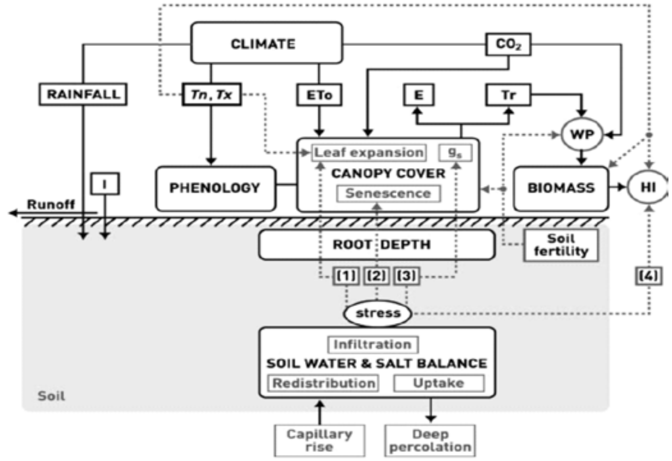

Fig. 2. Functional relationship between different components of AquaCrop Model

Model description

The FAO crop model, AquaCrop (Steduto *et al*., 2009), simulates attainable yields of major herbaceous crops as a function of water consumption under rainfed, supplemental, deficit and full irrigation conditions. Climate file is one of the inputs of the AquaCrop which includes the rainfall, reference evapotranspiration (ETo), temperature and CO_2 concentration. Fig. 2 shows functional relationship between different components of AquaCrop Model.

Model calibration and validation

The model was evaluated using graphical slope and y-intercept method standard regression method, dimensionless quantitative statistics by determining Nash-Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970), and error index method by calculating RMSE-observations (Loague and Green, 1991), standard deviation ratio (RSR) (Legates and McCabe, 1999). The observed data of crop yield and water application for the different crops were taken from the published researches on different crops like banana, watermelon, okra, chilli and tomato and these were simulated with AquaCrop model.

Effect of deficit irrigation on crop yield

The purpose of the model is to estimate the crop yield from the output such as actual evapotranspiration or transpiration obtained from the soil water balance equation as influenced by the different amount of irrigation water applied at different instants of time. The relative difference or ratio between maximum crop evapotranspiration and actual evapotranspiration indicates the degree of stress. Stress influences the yield provided other inputs are applied uniformly. The crop growth model thus relates the stress with yield and yields are estimated with the help of stress offered during individual crop growth period by stage wise crop growth models. The response of crop yield to water supply is quantified using the yield response factor k_y, which relates relative yield decrease to relative evapotranspiration deficit. Crop yields and net profits were calculated for irrigation depth applied at 90 mm, 70 mm and 50 mm water application per irrigation. The yield response factors of seasonal crops were taken from the standard literature as well as publications. The complexity of crop responses to water deficits led to the use of empirical production functions as the most practical option to assess crop yield response to water. The deficit irrigation was planned by using the crop growth model given by Stewart formula (Stewart *et al*., 1976) as given in equation 1.

$$\frac{Y_a}{Y_m} = 1 - \sum_{s=1}^{ni} k_{yi} \left[\frac{ET_{mi} - ET_{ai}}{ET_{mi}}\right] \quad \ldots (1)$$

Where, Y_a is actual crop yield [t/ha], Y_m is potential crop yield [t/ha], k_{yi} is Yield reduction coefficient for stage I and ET_{ai}, ET_{mi} are actual & potential crop evapotranspiration [mm/day] for stage i.

RESULTS AND DISCUSSION

Calibration for crop yields

The observed yield data and water application data for using slope and y-intercept method are given in Fig. 3, while the quantitative statistics were worked out for both parameters and are shown in Fig. 4. The results showed that the model performed very well for simulating the crop yields for water applied. The calculated slope of straight line, NSE, RMSE and RSR were 0.9882, 0.998, 1.86 and 0.038 for water deficit irrigation, respectively.

Assessment of deficit irrigation

The soil in command area is sandy loam and sandy clay loam having the field capacity in the range of 22 to 32 per cent and can be classified as light soils. The irrigation interval was kept as 28, 21 and 14 days during monsoon, winter and summer seasons, as regularly adapted in the command area.

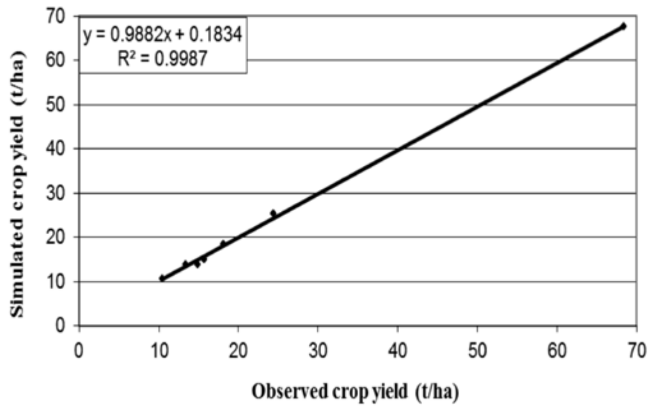

Fig. 3. Crop yield calibration using slope and y-intercept method

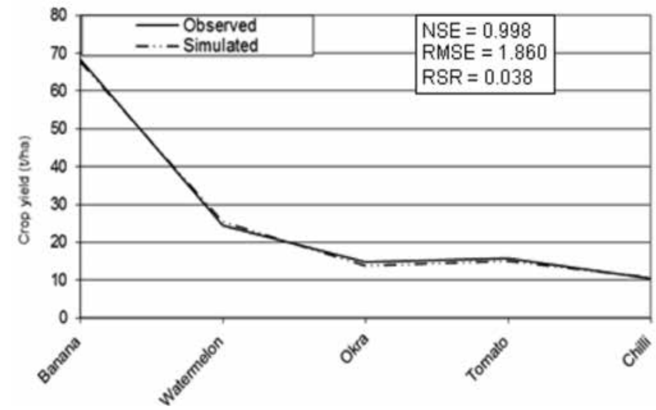

Fig. 4. Crop yield calibration using quantitative statistical methods

During monsoon season mainly monocropping system with paddy is generally adapted in command area. The irrigation during monsoon season may be useful as protective irrigation. Thus the study was mainly concentrated on the application of water to crops during *rabi* and summer seasons. The effect of deficit irrigation on the soil moisture availability in the root zone and the yield of crop were assessed.

Effect of deficit irrigation on moisture status in root zone

The scenarios were developed for groundnut crop during *rabi* season for the water application of 90, 70 and 50 mm, the total water application as 630, 490 and 350 mm respectively. Total seven irrigations were applied to groundnut out of which first six irrigations applied at an interval of 21 days and only one irrigation was delivered at an interval of 14 days during crop season. The soil moisture status in the crop root zone for each application depth is given in Fig. 5(a) to Fig. 5(c).

In the initial crop period, after the first irrigation, the amount of precipitation was 127 mm, from 4 to 10 days after planting. This rainfall raised soil moisture content in root zone up to second irrigation. Thus, the effect of depth of irrigation on soil moisture status before second irrigation was nullified and the same moisture status was observed in all depths of application. The trend of peaks of soil moisture was decreasing up to 70 days due to increase in metabolic activities of plant. After 70 days the peaks were nearly constant up to next two irrigations (up to 110 days). This may be due to the reduction in metabolic activities of the crop. This happens when the crop attains the maturity stage. The increase in peak of soil moisture at the last irrigation might be due to lesser irrigation interval (14 days).

The mild moisture stress was observed during 75-85 and 95-105 days when the irrigation was applied at 90 mm depth. Similar trend was observed in case of 70 mm application depth; however the moisture stress in root zone was moderate. In case of 50 mm water application depth, the soil moisture reached below the threshold value three (Th3) prior to 5th and 6th irrigation, this indicates the severe water stress to crop during these periods during which the peg initiation to pod development stages of the crop growth fall. The severe moisture stress during these stages may cause the drastic reduction in yield of groundnut. Pimpanit *et al*. (1988) investigated effects of stopping irrigation at different crop growth stages on yield of groundnut and reported that drought stress during pegging and early pod formation stages would cause greatest yield reduction.

Effect of deficit irrigation on crop yield

The water delivered to the crop was about 10, 30 and 50 per cent less than that of the maximum water requirement for the depths of 90, 70 and 50 mm respectively. The actual yield of crops was estimated using Stewart equation for different application depths and effect of reduction in depth of application on yield was evaluated.

The potential yields of different crops were taken from the published researches. The data from Table 1 indicated that the per cent yield reduction was highest for *rabi* paddy followed by cucumber, banana, chilli, okra, tomato, watermelon, bean and groundnut when the water application depth to crop was 90 mm. The crop yields reduced when the depth of water application was reduced to 70 mm and ultimately 50 mm. The highest reduction in yield of paddy (78 per cent) was obvious because it requires the anaerobic condition during its growth period and with 90 mm depth, its water need was not sufficient. Similarly, reduction in yield of cucumber, banana, chilli, okra and tomato was in the range of 11 to 33 per cent and indicated that these crops were under water stress even with 90 mm application depth. The moisture stress was in the development and maturity stages of the respective crops, when the irrigation interval was of 21 and 14 days respectively. This indicated that the irrigation interval during these stages is more.

The critical analysis of results of reduction in yield of crops indicated that very less reduction (0.80 per cent) was observed in brinjal with 90 mm application depth. However, when water application for brinjal was reduced from 90 mm,

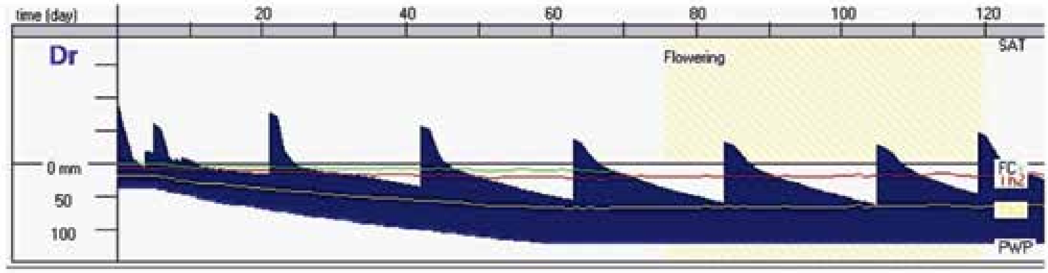

Fig. 5(a). Soil water depletion in root zone (Dr) of groundnut over growing period (days) at 90 mm water application by surface irrigation

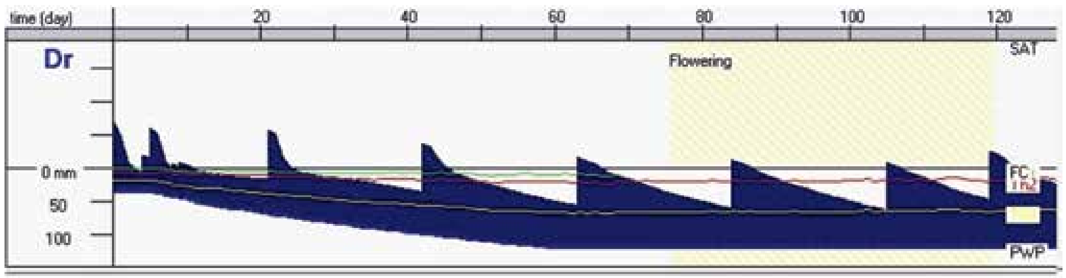

Fig. 5(b). Soil water depletion in root zone (Dr) of groundnut over growing period (days) at 70 mm water application by surface irrigation

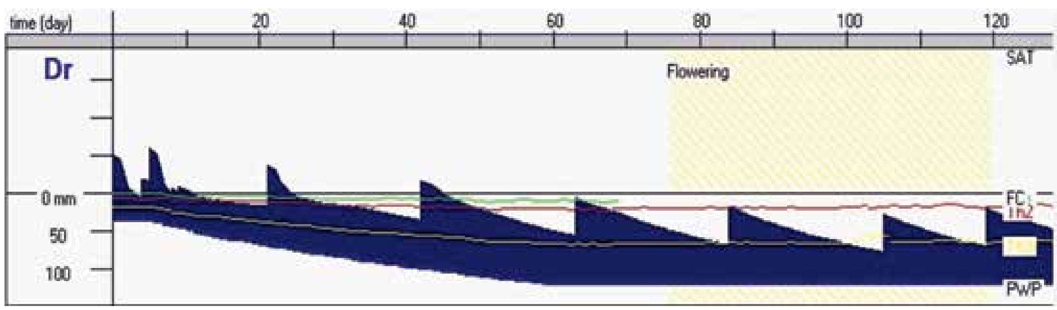

Fig. 5(c). Soil water depletion in root zone (Dr) of groundnut over growing period (days) at 50 mm water application by surface irrigation

Table 1. Potential and actual yields and per cent yield reduction of seasonal and annual crops under deficit irrigation strategies

Crop	Potential yield (t/ha)	Actual yield (t/ha)			Per cent reduction in yield		
		10 per cent deficit	30 per cent deficit	50 per cent deficit	10 per cent deficit	30 per cent deficit	50 per cent deficit
Brinjal	20	19.84	15.37	8.82	0.80	23.15	55.90
Chilli	15	10.99	8.07	5.47	26.73	46.20	63.53
Okra	15	11.12	8.4	5.09	25.86	44.00	66.07
Groundnut	3	2.66	2.65	2.45	11.33	11.67	18.33
Cucumber	25	16.70	11.43	6.58	33.20	54.28	73.68
Watermelon	30	25.4	21.95	17.55	15.33	26.83	41.50
Bean	12	10.53	10.14	7.85	12.25	15.50	34.58
Tomato	20	15.43	13.25	6.35	22.85	33.75	68.25
Banana	110	76.01	57.4	43.78	30.91	47.82	60.2
Paddy	4.5	0.99	0.50	0.097	78.00	88.88	97.84

Table 2. Net benefit for existing cropping pattern for deficit irrigation strategies

Crop	Net benefit (thousand Rs/ha)		
	10 per cent deficit	30 per cent deficit	50 per cent deficit
Brinjal	66.38	21.91	-43.34
Chilli	70.15	14.65	-34.68
Okra	49.30	8.72	-40.73
Groundnut	21.72	22.68	16.86
Cucumber	66.14	3.13	-54.72
Watermelon	77.04	52.92	22.19
Beans	31.77	26.26	15.77
Tomato	14.19	-5.19	-67.09
Banana	236.44	143.68	75.84
Paddy	-2.351	-27.6	-31.52

the yield was drastically reduced. The moisture status results also indicated the same trend. The actual yield of paddy, groundnut, bean, chilli, okra and cucumber was ranged from 2 to15 t/ha, for brinjal and watermelon it was about 20 and 25 t/ha. The highest yield was obtained from the banana about 76 t/ha when the irrigation application was 90 mm.

The results indicated that the present irrigation scheduling adapted in the command area may not be suitable for the existing cropping pattern. With this irrigation schedules the actual yield reductions in the crops more than 10 per cent except brinjal and also the yield of paddy could not be attained due to less frequency in water application. Thus this concluded that the irrigation frequency should be increased because the command area has the light textured soils. English and Raja (1996) reported that the deficit irrigation should always be coupled with increase in the irrigation frequency.

Benefits of existing cropping pattern for deficit irrigation strategies

The net benefit of each crop was derived from the cost of cultivation and total benefit from the respective crops. The scheme calculation of cost of cultivation of the crops in existing cropping pattern is iterated. While calculating the net benefit of crops the cost of water was also taken into consideration so as to view the effect of cost of water under deficit irrigation strategies.

The net benefit from different crops of existing cropping pattern for deficit irrigation strategies is given in Table 2. The net benefit for all the vegetables was negative with 50 per cent deficit. It was also observed that about 2/3rd of the net benefit were decreased for watermelon and banana with 50 per cent deficit as compared to 10 per cent deficit. However, the net benefit for groundnut and beans decreased by 1/5th and ½, respectively, when crop was irrigated with 50 per cent deficit as compared to 10 per cent deficit. The deficit irrigation for paddy cultivation was not found beneficial, however it can be beneficial if the irrigation frequency is increased. It is seen that the net benefit for all the vegetables in the existing cropping pattern was decreased by at least 2/3rd in case of 30 per cent deficit as that of the 10 per cent deficit. Thus, it can be concluded that for extracting more benefits from the vegetables in the command area, the vegetables should be irrigated with maximum of 10 per cent deficit. Among all the crops of existing cropping pattern in the command area, groundnut can be cultivated with irrigation up to the deficit of 30 per cent. The decreasing trend of net benefit from watermelon, beans and banana was observed when these crops were irrigated with 30 per cent deficit as compared to 10 per cent deficit however the least reduction of 17 per cent was observed in beans while this reduction was extended to 31 and 40 per cent in watermelon and banana respectively with this strategy.

The results of net benefits from the crops indicated that the 10 per cent deficit of the maximum requirement can be allowed to extract the reasonable net benefits from the crops except groundnut and paddy. The deficit irrigation up to 30 per cent can be extended to groundnut for its beneficial cultivation. The deficit irrigation was not found beneficial for paddy cultivation. The highest benefit was obtained from banana followed by watermelon, chilli, brinjal, cucumber, okra, bean, groundnut, tomato for 10 per cent deficit irrigation strategy.

Net benefit of existing cropping pattern for different deficit strategies

The yields of plantation crops like mango, coconut and arecanut for deficit under study were worked out from the available literatures. Accordingly the water requirements and net benefits for these crops were also worked out. Accordingly the average yield of mango was 83.35 kg/tree and 66.1 kg/tree under 100 per cent evapotranspiration and no irrigation treatment. Only 20.82 per cent yield reduction in mango under rainfed condition compared to full irrigation was observed. Joseph and Jose (2004) reported that the coconut yield increased by 20-30 per cent due to irrigation. The project net

Table 3. Net benefit from existing cropping pattern for deficit irrigation strategies

Outlet	Crops	ICA under outlet (ha)	Project net benefit (Rs. in lakh) for different deficit strategies		
			10 per cent deficit	30 per cent deficit	50 per cent deficit
1	Beans	0.2	0.06	0.05	0.03
	Cucumber	0.2	0.13	0.01	-0.11
	Watermelon	0.4	0.31	0.21	0.09
	Tomato	0.3	0.04	-0.02	-0.20
	Brinjal	0.4	0.27	0.09	-0.17
	Chilli	0.2	0.14	0.03	-0.07
	Okra	0.3	0.15	0.03	-0.12
	Arecanut	5	4.48	2.28	0.08
	Total	7	5.58	2.68	-0.47
2	Groundnut	0.5	0.11	0.11	0.08
	Paddy	0.5	-0.18	-0.26	-0.32
	Beans	0.2	0.06	0.05	0.03
	Cucumber	0.5	0.33	0.02	-0.27
	Watermelon	0.5	0.39	0.26	0.11
	Tomato	0.4	0.06	-0.02	-0.27
	Brinjal	0.5	0.33	0.11	-0.22
	Chilli	0.4	0.28	0.06	-0.14
	Okra	0.5	0.25	0.04	-0.20
	Arecanut	2.5	2.24	1.14	0.04
	Coconut	0.5	0.06	-0.05	-0.15
	Mango	1	1.07	1.04	1.00
	Total	8	4.99	2.51	-0.30
3	Groundnut	0.5	0.11	0.11	0.08
	Watermelon	0.7	0.54	0.37	0.16
	Tomato	0.2	0.03	-0.01	-0.13
	Brinjal	0.4	0.27	0.09	-0.17
	Chilli	0.3	0.21	0.04	-0.10
	Okra	0.4	0.20	0.03	-0.16
	Banana	1	2.36	1.44	0.76
	Arecanut	0.5	0.45	0.23	0.01
	Coconut	0.5	0.06	-0.05	-0.15
	Total	4.5	4.23	2.26	0.28
4	Groundnut	0.7	0.15	0.16	0.12
	Paddy	0.5	-0.18	-0.26	-0.32
	Cucumber	0.5	0.33	0.02	-0.27
	Watermelon	0.5	0.39	0.26	0.11
	Beans	0.5	0.16	0.13	0.08
	Tomato	0.5	0.07	-0.03	-0.34
	Brinjal	0.5	0.33	0.11	-0.22
	Chilli	0.6	0.42	0.09	-0.21
	Okra	0.2	0.10	0.02	-0.08
	Arecanut	2	1.79	0.91	0.03
	Mango	2	2.14	2.07	2.01
	Total	8.5	5.70	3.49	0.92
5	Groundnut	0.5	0.11	0.11	0.08
	Beans	0.5	0.16	0.13	0.08
	Watermelon	1	0.77	0.53	0.22
	Tomato	0.5	0.07	-0.03	-0.34
	Brinjal	0.7	0.46	0.15	-0.30
	Chilli	0.3	0.21	0.04	-0.10
	Okra	0.5	0.25	0.04	-0.20
	Arecanut	1	0.90	0.46	0.02
	Coconut	2	0.26	-0.18	-0.62
	Total	7	3.18	1.26	-1.16
	Grand total	35	23.67	12.20	-0.74

benefit from existing cropping pattern for deficit irrigation strategies is given in Table 3. Project net benefit comprises the net benefit of each crop under existing cropping pattern. The project net benefit was found to be Rs. 23.67 lakh with 10 per cent deficit followed by 30 per cent deficit (Rs. 12.20 lakh) and 50 per cent deficit (Rs. -0.74 lakh). The project net benefit for 30 and 50 per cent deficit irrigation was very less as compared to that of 10 per cent deficit.

The seasonal crops comprising 78 per cent of the total area under the outlet 3 having the highest area for banana followed by watermelon, groundnut, brinjal, okra, chilli, tomato resulted in 94 per cent of the total net benefit for this outlet. The seasonal crops comprising 53 per cent area of the total area under the outlet 4, having the highest area for groundnut, chilli followed by paddy, cucumber, watermelon, and beans resulted in 31 per cent of the total net benefit for this outlet. The seasonal crops comprising 57 per cent area of the total area under the outlet 5, having the highest area for watermelon followed by brinjal, groundnut, bean, tomato, okra, chilli resulted in 64 per cent total net benefit for this outlet.

It can be concluded from the study that the present irrigation scheduling adapted in the command area may not be suitable for the existing cropping pattern. With this irrigation schedule, the actual yield reduction in the crops more than 10 per cent except brinjal and also the yield of paddy could not be attained due to less frequency in water application. Thus, it is concluded that the irrigation frequency should be increased because the command area has the light textured soils. For extracting the more benefits from the vegetables in the command area, the vegetables should be irrigated with maximum of 10 per cent deficit. The crops like brinjal, tomato, groundnut, beans, and watermelon can be grown with maximum 30 per cent deficit, the crops like chilli, okra, cucumber and banana can be irrigated with maximum 10 per cent deficit. The net benefits from the crops indicated that the 10 per cent deficit of the maximum requirement can be allowed to extract the reasonable net benefits from the crops except groundnut and paddy. The highest benefit was obtained from banana followed by watermelon, chilli, brinjal, cucumber, okra, bean, groundnut, tomato for 10 per cent deficit irrigation strategy.

Authors' contribution

Conceptualization of research work and designing of experiments (RTT, PBJ, SDG, SAK); Execution of field/ lab experiments and data collection (PBJ); Analysis of data and interpretation (PBJ, RTT, SDG, SAK); Preparation of manuscript (PBJ, RTT, SDG,SAK).

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