International Journal of Engineering Innovation & Research
Volume 3, Issue 6, ISSN: 2277 – 5668

Strategies of Deficit Irrigation in Canal Command

R. T. Thokal
Chief Scientist, AICRP on Water Management

P. B. Jadhav
M. Tech (Ag. Engg.) student, College of Agril. Engg. & Tech., Dapoli

M.S. Mane
Professor & Head, Department of Irrigation & Drainage Engg., College of Agril. Engg. & Tech., Dapoli

H.N. Bhange
Assistant Professor, Department of Soil & Water Conservation Engg., College of Agril. Engg. & Tech., Dapoli

S.R.Kale
Associate Professor, Department of Irrigation & Drainage Engg., College of Agril. Engg. & Tech., Dapoli

Abstract: **The objective of this study was to evaluate the AquaCrop model, developed by FAO, for its ability to simulate crop performance under full and deficit irrigation in a humid environment in Konkan region of Maharashtra. Different irrigation (depth of irrigation) scenarios on crop yields grown in the irrigation command and their effects on sustainability and project benefit were also tested in the study. Panchnadi Minor Irrigation Project was selected as a case study. The management scenarios were developed for improving irrigation efficiency and were compared in terms of monetary benefits with present status of irrigation project. The possibility of deficit irrigation was also explored for light texture soil in command area. Project net benefit for 10, 30 and 50 per cent deficit scenarios was Rs. 23.67, 12.20 and -0.74 lakh, respectively. The results suggested that 10 per cent deficit strategy could be beneficial for irrigation command under study. The net water allocation for 10 per cent deficit scenario was 0.31 Mm^3 for the live storage in the reservoir of 1.461 Mm^3. The canal could be run from 1st October to 31st May of the year i.e. for 243 days. The overall efficiency of the lined and unlined sections of canal and unlined field channel under existing condition was observed as 75, 52 and 35 per cent, respectively. The total loss from lined and unlined main canal sections and unlined field channels was observed as 0.184, 0.61 and 0.183 Mm^3, respectively. The gross water allocation for 10 per cent deficit irrigation strategy was 1.43 Mm^3.**

Keywords: **AquaCrop Model, Deficit Irrigation, Irrigation Efficiency, Lined and Unlined Canal Sections,Water Allocation**

I. INTRODUCTION

The FAO AquaCrop model predicts crop productivity, water requirement, and water use efficiency under water-limiting conditions (Raes *et al*., 2009). This model has been tested for maize (Hsiao *et al*., 2009; Heng *et al*., 2009), cotton (Farahani *et al*., 2009; Garcia-Via *et al*., 2009), sunflower (Todorovic *et al*., 2009) and quinoa (Geerts *et al*., 2009) under different environmental conditions. Many workers have illustrated that the model could accurately simulate the crop biomass and yield as well as soil water dynamics under full and water deficit irrigation and soil fertility stress conditions. As such the aim of this paper was to evaluate this 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 and water productivity of crops in the command area under humid conditions of Konkan region of Maharashtra State.

II. MATERIALS AND METHODS

A. 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. The growth engine of AquaCrop is water-driven, in that transpiration is calculated first and translated into biomass using a conservative, crop-specific parameter (Geerts *et al*., 2009), the biomass water productivity, normalized for atmospheric evaporative demand and air CO_2 concentration. The normalization is to make AquaCrop applicable to diverse locations and seasons. Simulations are performed on calendar time, in daily time-steps, but can be performed on thermal time. The model uses canopy ground cover instead of leaf area index (LAI) as the basis to calculate transpiration and to separate soil evaporation from transpiration. Crop yield is calculated as the product of above ground dry biomass and harvest index (HI). Starting at flowering, HI increases linearly with time after a lag phase, until near physiological maturity. Other than for the yield, there is no biomass partitioning into the various organ. Crop responses to water deficits are simulated with four modifiers that are functions of fractional available soil water modulated by evaporative demand, based on the differential sensitivity to water stress of four key plant processes: canopy expansion, stomatal control of transpiration, canopy senescence, and HI. The HI can be modified negatively or positively, depending on stress level, timing and stress duration. AquaCrop uses a relatively small number of parameters (explicit and mostly intuitive) and attempts to balance simplicity, accuracy, and robustness. The model is aimed mainly at practitioner-type and end-users such as those working for extension services, consulting engineers, governmental agencies, nongovernmental organizations, and various kinds of farmers associations. It is also designed to fit the need of economists and policy specialists who use simple models for planning and scenario analysis (Steduto *et al*., 2009).

B. Model calibration and validation

Evaluation of model involves a comparison between independent field measurements (data) and output created by the model. Graphical techniques provide a visual comparison of simulated and measured constituent data and a first overview of model performance (ASCE, 1999) and are essential to appropriate model evaluation (Legates and McCabe, 1999). It is generally recommended that both graphical techniques and quantitative statistics be used in model evaluation. Thus the model was evaluated using graphical slope and y-intercept method standard regression method, dimensionless quantitative statistics by determining Nash-Sutcliffe efficiency (NSE) and error index method by calculating RMSE-observations standard deviation ratio (RSR). The observed data of crop yield and water application for the different crops were taken from the published researches on different crops like banana (Anonymous, 2011), watermelon, okra, chilli and tomato (Hall, 1980, Panigrahi *et al.*, 2010) were simulated with AquaCrop model.

The Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970), normalized RMSE (Loague and Green, 1991) and RSR (Legates and McCabe, 1999) were calculated using following equations.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean} \right)^2} \right] \quad \ldots (1)$$

$$RMSE = \sqrt{\left[\sum_{i=1}^{n} \frac{\left(Y_i^{sim} - Y_i^{obs} \right)}{n} \right]} \quad \ldots (2)$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2} \right]}{\left[\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean} \right)^2} \right]} \quad \ldots (3)$$

NSE ranges between -∞ and 1.0 (inclusive 1), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values $\leq$ 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. RMSE values of 0 indicate a perfect fit. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation to a large positive value. The lower RSR, lower the RMSE, and better the model simulation performance.

C. Model application

The existing cropping pattern was taken from Maharashtra State 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 was not available and it is general practice by Irrigation Department to release water considering irrigation depth as 90mm.

D. Effect of deficit irrigation on crop yield

The crop growth model relates the actual and maximum evapotranspiration or transpiration and maximum crop yield to actual crop yield. Therefore 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. However, the yield is not only a function of total stress applied but also the crop stage during which the stress is applied. The yields are estimated with the help of stress offered during individual crop growth period by stage wise crop growth models. Several stage wise crop growth models are available in the literature.

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. Many authors have proposed semi empirical water production function that relates crop yields to the amount of evapotranspiration. It has been pointed out that an important factor in water management is the timing of soil moisture stress imposed on a crop in relation to its physiological stage of growth.

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 Stewart formula (Stewart *et al.*, 1976) as given in equation 4.

$$\frac{Y_a}{Y_m} = 1 - \sum_{s=1}^{ni} k_{yi} \left[\frac{ET_{mi} - ET_{ai}}{ET_{mi}} \right] \quad \ldots (4)$$

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.

III. RESULTS AND DISCUSSION

A. Calibration for crop yields

The observed yield data and water application data for using slope and y-intercept method are presented in Fig. 1.1, while the quantitative statistics were worked out for both parameters and are shown in Fig. 1.2. The results show 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.

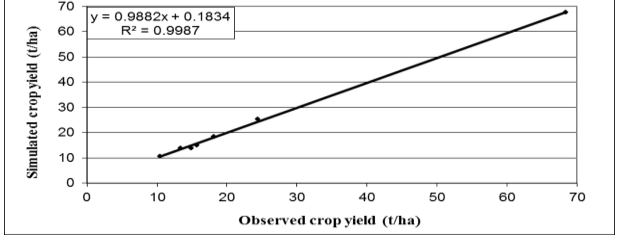

Fig. 1.1. Crop yield calibration using slope and y-intercept method

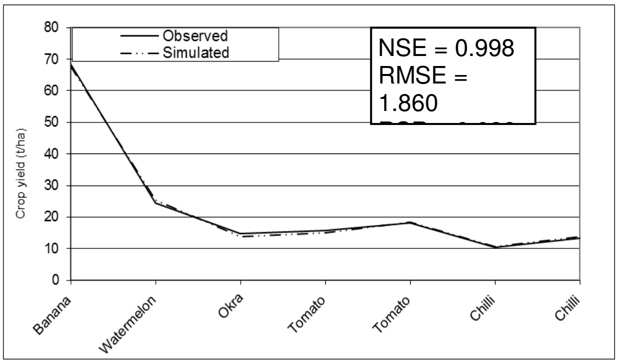

Fig. 1.2. Crop yield calibration using quantitative statistical methods

B. *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 command areas. 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 under water scarce situations.

Thus the study was mainly concentrated on the application of water to crops during *rabi* and summer seasons. The moisture status as influenced by water application for the different seasonal and annual crops is described in the following sections. The effect of deficit irrigation on the soil moisture availability in the root zone and the yield of crop were assessed. For the assessment of soil moisture status, the results from output file (.Wable) of AquaCrop model were retrieved.

C. *Effect of deficit irrigation on moisture status in the root zone of crop*

The scenarios were developed for groundnut crop during *rabi* season for the water application of 90, 70 and 50 mm totaling water application as 630, 490 and 350 mm respectively. Total seven irrigations were applied to groundnut out of which first six irrigations were 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. 1.3(a) to Fig.1.3(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 is obvious 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).

When 90mm depth was applied to groundnut, more loss of water was observed and moisture content in soil was more than field capacity for 3 to 4 days after irrigation. Soil moisture content after each irrigation reveals that water application of 70 mm could save water after 4th irrigation because it just reaches above the field capacity after irrigation, whereas in case of water application with 50mm irrigation depth may cause stress after 4th irrigation as the moisture content does not reach to field capacity after irrigation.

No moisture stress was observed for water application depth of 90mm, however, mild stress was observed during 75-85 and 95-105 days in case of 70 mm application depth. 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. Lenka and Misra (1973) noted productive efficiency of flowers to vary with availability of water and the percentage of unproductive flowers that did not peg to form pods increased with delayed irrigation.

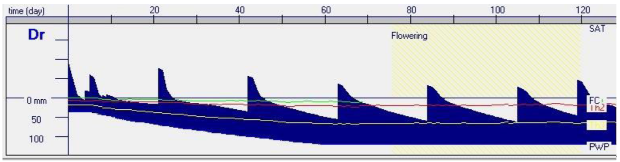

Fig. 1.3(a). Soil water depletion in root zone (Dr) of groundnut over growing period (days) at 90mm water application by surface irrigation

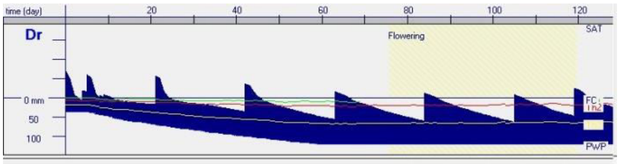

Fig. 1.3(b). Soil water depletion in root zone (Dr) of groundnut over growing period (days) at 70mm water application by surface irrigation

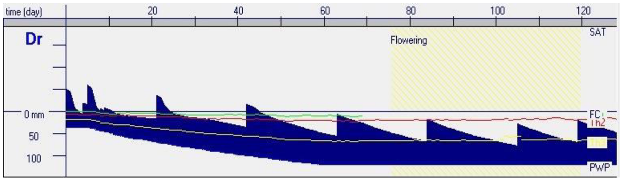

Fig. 1.3(c). Soil water depletion in root zone (Dr) of groundnut over growing period (days) at 50mm water application by surface irrigation

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. Work cited by Reddy (1988) suggests that the period of maximum sensitivity to drought occurs between 50-80 days after sowing. Balasubramanian and Yayock (1981) observed that the adverse effect of moisture deficit was more severe on pod and kernel yield than the production of Haulm and total dry matter. Though the crop is reputed as drought tolerant, the available information on most sensitive of different phenol phases to moisture is contradictory. Flowering and pegging stages were considered as most sensitive ones (Reddy, 1976 and Doorenbos and Pruitt, 1979). Roy *et al.* (1988) observed that the period of late flowering and pod formation was most sensitive to moisture. They further reported that moisture stress during the late flowering and pod formation and filling reduced yields more than stress in early, full flowering, late flowering and pod formation stages. Majority reports reveal that pod development stage is the most sensitive to moisture (Meisner, 1991 and Ramachandrappa *et al.*, 1992) during which the demand of photosynthetic products for active sinks (pods) is higher.

D. 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. For this evaluation, the daily maximum and actual evapotranspiration data for different depths of application were retrieved from the output file (.Wable) of AquaCrop. The potential and actual yields and per cent reduction in yield of different crops with respect to different irrigation depths is given in Table I.

Table I. 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

The data from Table I 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, 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) stated that the deficit irrigation should always be coupled with increase in the irrigation frequency.

E. Effect of deficit irrigation on water use efficiency of crops

The water use efficiency denotes the production of crops per unit of water applied. It is expressed as the weight of crop produce per unit depth of water over a unit area i.e. Kg/ ha-cm. The water use efficiency of crops for existing cropping pattern irrigated with different application depths is given in Table II.

The water use efficiency of brinjal, chilli, okra and cucumber was highest in 10 per cent deficit than 30 and 50 per cent deficit. Hence 10 per cent deficit was suitable for these crops to achieve highest yield and WUE, but these results are in the contradiction with the results by Mao *et al*. (2003) reported on their study on the effect of deficit irrigation on yield and water use of cucumber in China that WUE decreased with increase of irrigation water applied from stem fruiting to the end. This might be due to increased irrigation interval. These results are in conformity with the results for chilli obtained by Ismail and Ozava (2009) who concluded that the proper irrigation interval (3 days) encouraged the root development in lower soil layers at the early growth stages and was a practical tool to increase water use efficiency and to save more water.

The reverse trend of WUE i.e. with the increase in deficit irrigation water use efficiency was increased observed for groundnut, watermelon and beans. This means one can go for groundnut cultivation with 50 per cent deficit under the water scarce conditions however about 8 per cent groundnut yield has to be sacrificed as against 10 per deficit. Watermelon can be cultivated under water scarce condition with 50 per cent deficit however about 30 per cent yield reduction can be observed as against 10 per cent deficit. In this case the WUE can be enhanced up to 438.7 to 352.8 kg/ha-cm. i.e. WUE can be enhanced by 20 per cent with 50 per cent deficit as against 10 per cent deficit. Similar trend was also observed in case of beans. The results from Table II indicated that the deficit irrigation up to 30 per cent can be beneficial for the cultivation of brinjal and tomato as against 10 per cent deficit. However with the water saving of 20 per cent the yield 22 and 14 per cent can be reduced for brinjal and tomato respectively.

The banana also can be grown with deficit irrigation however the results of WUE as against viz-a-viz banana yield. The above discussion indicated that the crops like brinjal, tomato, groundnut, beans, 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. Greets and Raes (2009) indicated that the deficit irrigation is successful in increasing in water productivity for various crops without causing severe yield reductions. Nevertheless, a certain minimum amount of seasonal moisture must be guaranteed. They also concluded that the minimum moisture content can be attained by reducing irrigation interval less than 10 days in case of light soils. The deficit irrigation requires precise knowledge of crop response to drought stress. In developing and optimizing the deficit irrigation strategies, field research should therefore be combined with crop water productivity modeling.

Table II. Water use efficiency of crops under deficit irrigation strategies

Crop	**Yield (t/ha)**			**Irrigation water delivered (mm)**			**Water use efficiency (kg/ha-cm)**		
	10 per cent deficit	**30 per cent deficit**	**50 per cent deficit**	**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	19.84	15.37	8.82	540	420	300	367.4	366.0	294.1
Chilli	10.99	8.07	5.47	540	420	300	203.52	192.1	182.3
Okra	11.12	8.40	5.09	540	420	300	205.93	200.0	169.5
Groundnut	2.66	2.65	2.45	630	490	350	42.3	54.2	70.1
Cucumber	16.70	11.43	6.58	630	490	350	265.08	233.2	188.1
Watermelon	25.4	21.95	17.55	720	560	400	352.78	391.9	438.7
Beans	10.53	10.14	7.85	450	350	250	234.0	289.9	314.2
Tomato	15.43	13.25	6.35	630	490	350	244.92	270.3	181.3
Banana	76.01	57.40	43.78	1170	980	700	649.66	630.77	673.39
Paddy	0.99	0.50	0.097	630	490	350	15.71	10.20	2.77

F. Crop 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 in Appendix . 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 (thousand Rs/ha) from different crops of existing cropping pattern for deficit irrigation strategies is given in Table III. Form the Table III 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 was decreased by 1/5th and 1/2 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 the 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 the groundnut can be cultivated with irrigation up to the deficit of 30 per cent. The reduced 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.

Table III. Net benefits (thousand Rs/ha) 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

G. Project 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. According to Speer *et al.* (2009) 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. They also concluded that about 3 per cent yield reduction was caused per 10 per cent reduction in irrigation application. Joseph and Jose (2004) reported that the coconut yield increased by 20-30 per cent due to irrigation. They also revealed that the coconut tree yielded 5300 nuts/ha with the application of 520 mm irrigation. The optimum irrigation requirement of coconut is reported to be 1200 mm as a general rule for which about 14000 nuts/ha yield can be achieved (Anonymous, 1996). Anonymous (2012) reported that about 2/3 of the potential coconut production is generally lost due to either poor nut setting or immature nut fall as a result of 50 per cent water deficit conditions. The project net benefit from existing cropping pattern for deficit irrigation strategies is given in Table IV. 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 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, beans resulted 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 64 per cent total net benefit for this outlet.

Table IV. Project 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**
	Groundnut	0.5	0.11	0.11	0.08
	Paddy	0.5	-0.18	-0.26	-0.32

2	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**

H. Water allocation

The live storage capacity of reservoir is 1.461 Mm^3. The main aim of the study is to retain the water for the whole year for the project sustainable benefit. The results from the previous section indicated that the 10 per cent deficit resulted in highest net benefit for the present irrigation strategies in the command area as compared to other deficit irrigation levels under study. Thus the net water allocation was also calculated for the crops of existing cropping pattern and is given in Table V.

Table V. Net water applied (Mm^3) for 10 per cent deficit strategy

Crop	**Area (ha)**	**Net water applied for 10 per cent deficit (Mm^3)**
Bean	1.4	0.006
Cucumber	1.2	0.008
Tomato	1.9	0.012
Brinjal	2.5	0.014
Watermelon	3.1	0.022

Chilli	1.8	0.010
Okra	1.9	0.010
Groundnut	2.2	0.014
Banana	1	0.013
Paddy	1	0.006
Total	**17**	**0.115**
Mango	3	0.030
Arecanut	11	0.129
Coconut	3	0.035
Total	**17**	**0.194**
Grand Total	**35**	**0.309**

Then gross water allocation (Mm^3) was calculated by adding net water allocation and total losses from reservoir and canal network under different outlet is given in Table VI. The gross water allocation for 10 per cent deficit irrigation strategy was 1.43 Mm^3 and it was 29, 31, 20, 10 and 9 per cent of total allocation for 1st, 2nd, 3rd, 4th and 5th outlet respectively, hence it was highest for 2nd outlet followed by 1st, 3rd, 4th and 5th outlet. The gross water allocation for the command area was worked out so that the water allocation plan can be prepared accordingly.

Table VI. Outlet wise gross water allocation (Mm^3)

Outlet	Net water allocation (Mm^3)	Total loss (Mm^3)	Gross water allocation (Mm^3)
1	0.07	0.35	0.42
2	0.07	0.37	0.44
3	0.04	0.25	0.28
4	0.07	0.08	0.15
5	0.06	0.07	0.13
Total	**0.31**	**1.12**	**1.43**

IV. CONCLUSIONS

The present irrigation schedule adapted in the command area may not be suitable for the existing cropping pattern. With this irrigation schedule, actual yield reduction of crops was 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.

REFERENCES

[1] Anonymous, 1996. Package of practices recommendations for crops. Kerala Agricultural University. Trissur.

[2] Anonymous, 2011. Report on Benchmarking of Irrigation Systems in Maharashtra State 2009-10. Water Resources Department, Government of Maharashtra, India.

[3] Anonymous, 2012. Effect of water deficit (drought) on growth/productivity of coconut. Coconut Cultivation Board. Battaramulla, Sri Lanka.

[4] ASCE. 1993. Criteria for evaluation of watershed models. Journal of Irrigation and Drainage Engineering. 119(3): 429-442.

[5] Balasubramanian, V. and J. Y. Yayock. 1981. Effect of gypsum and moisture stress on growth and pod filling of groundnut plant. Plant and Soil. 62: 209-210.

[6] Doorenbos, J. and A. H. Kassam. 1979. Yield response to water. Irrigation and Drainage Paper 33. FAO, Rome, Italy, 193.

[7] English, M. and S. N. Raja. 1996. Perspectives on deficit irrigation. Journal of Agricultural Water Management. 32:1-14.

[8] Farahani, H. J., Izzi, G., Oweis, T.Y. 2009. Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton. Agronomy Journal. 101: 469-476.

[9] Garcia-Via, M., Ferres, E., Mateos, L., Orgaz, F. and Steduto, P. 2009. Deficit irrigation optimization of cotton with AquaCrop. Agronomy Journal. 101: 477-487.

[10] Greets, S. and Raes, D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agricultural Water Management. 96: 1275-1284.

[11] Geerts, S., Raes, D., Garcia, M., Miranda, R., Cusicanqui, J.A., Taboada, C., Mendoza, J., Huanca, R., Mamani, A., Condori, O., Mamani, J., Morales, B., Osco, V. and Steduto, P. 2009. Simulating yield response of Quinoa to water availability with AquaCrop. Agronomy Journal. 101: 499-508.

[12] Hall, T. J. 1980. Resistace at the *Tm-2* locus in the tomato to tomato mosaic virus. Euphytica. 29: 189-197.

[13] Heng, L.K., Asseng, S., Mejahed, K. And Rusan, M. 2007. Optimizing wheat productivity in two rain fed environments of the west Asia-North Africa using a simulation model. European Journal of Agronomy. 26: 121-129.

[14] Hsiao, T.C., Heng, T.C., Steduto, O., Rojas-Lara, B., Raes, D. and Fereres, E. 2009. AquaCrop-the FAO crop model to simulate yield response to water III. Parameterization and testing for maize. Agronomy Journal. 101: 448-459.

[15] Ismail, S. M. and Ozava, K. 2009. Effect of irrigation interval on growth characteristics plant water stress tolerance and water use efficiency for chile pepper. 13th International Water Technology Conference, IWTC 13, Hurghada, Egypt. 545-557.

[16] Joseph, K. and Jose, K. I. 2004. Performance of irrigation levels on the performance of component crops in coconut based cropping system. Indian Journal of Agriculture Research, 38(3): 231-234.

[17] Legates, D.R. and McCabe, G.J. 1999. Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation. Water Resource Research. 35(1): 233-241.

[18] Lenka, D. and M. Misra. 1973. Response of groundnut (*Arachis hypogaea* L.) to irrigation. Indian Journal of Agronomy. 18: 492-497.

[19] Loague, K. and Green, R.E. 1991. Statistical and graphical methods for evaluating solute transport models: overview and application. Journal of Contaminant Hydrology. 7: 51-73.

[20] Mao, X., X. W. Mengyuliu, C. Liu, Z. Hou and J. Cshi. 2003. Effects of deficit irrigation on yield and water use of cucumber in north China plain. Journal of Agricultural Water Management. 61: 219-228.

[21] Meisner, C. A. 1991. Peanut roots shoot and yield under water stress. Dissertation of Abstract in International Biological Science and Engineering. 52(1): 38-48.

[22] Nash, J. E. and Sutcliffe, J.V. 1970. River flow forecasting through conceptual models: Part I. A discussion of principles. Journal of Hydrology. 10(3): 282-290.

[23] Panigrahi, D., Mohanty, P. K., Acharya, M. and Senapati, P. C. 2010. Optimal utilization of national resources for agricultural sustainability in rainfed hill plateaus of Orissa. Agricultural Water Management. 97: 7.

[24] Pimpanit, P., V. Luckaewma and N. Kansrang. 1988. Study on the effects of stopping irrigation at different growth stages on yield of groundnut. P 408-410 in proceeding of the Sixth Thailand National Groundnut meeting for 1986, Songkhla, Thailand. 18-20 March 1987.

[25] Raes, D., Steduto, P., Hsiao, T.C. and Fereres, E. 2009. AquaCrop-the FAO crop model to simulate yield response to water. Reference Manual Annexes. www.fao.org/nr/water/aquacrop.html.

[26] Ramachandrappa, B. K., Kulakarni, K. R. and Nanjappa, H. V. 1992. Stress day index for scheduling irrigation for summer groundnut (*Arachis hypogaea* L.) Indian Journal of Agronomy. 37: 276-279.

[27] Reddy, C. R. 1988. Studies on yield response to water in groundnut (*Arachis hypogaea* L.) Ph. D Thesis, Andhra Pradesh Agricultural University, Hyderabad.

[28] Reddy, G. H. S. 1976. Management of Irrigation water. Ph. D Thesis. Andhra Pradesh Agricultural University, Hyderabad.

[29] Roy, R. C., Stonehouse, D. P., Francois, B. and Brown, D. M. 1988. Peanut responses to imposed – drought conditions in Southern Ontario. Peanut Science. 15: 85-89.

[30] Speer, W., Ongprasert, S., Hegele, M., Wunsche, J. N. and Muller, J. 2009. Yield and fruit development in mango (*Mangifera indica* L. cv. Chok Anan) under different irrigation regimes. Agricultural Water Management, 4: 574-584.

[31] Steduto, P., Hsiao, T.C., Raes, D. And Fereres, E. 2009. AquaCrop-the FAO model to simulate yield response to water. I. Concepts and underlying principles. Agronomy Journal. 101: 426-437.

[32] Stewart, J.L.; Hagen, R.M. and Pruit, W.O. 1976. Water production functions and predicted irrigation programs for principal crops as required for water resources planning and increased water use efficiency. Univ. of California. Department of Land, Air and Water Resources, Davis, and USDI/Br, Denver, Co.

[33] Todorovic, M., Albrizo, R., Zivotic, L., Ali saab, M., Stockle, C. and Steduto, P. 2009. Assessment of AquaCrop, CropSyst and WOFOST models in the simulation of sunflower growth under different water regimes. Agronomy Journal. 101: 509-521.

AUTHORS PROFILE

Name: **RAJESH TULSHIRAM THOKAL**
Present Designation: Chief Scientist, All India Co-ordinated Research Project on Water Management, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri
Date of Birth: 25/06/1966
e-mail ID: rtt1966@yahoo.com
Qualification: Ph.D. (Irrigation Water Management Engineering)
Experience: 24 years
Areas of specialization: Irrigation & Drainage Engineering, Remote Sensing and GIS, Water Management, land reclamation

Publications:

Research papers:	38
Technical papers:	30
Extension articles:	10
Technical bulletins:	01
Books:	08
M. Tech (Agril. Engg.) students guided:	04
Advisory Committee Member:	08
Ph.D. Advisory Committee Member	02
Recommendations for farmers:	08

Prizes/Awards/Honours:

1. Tenant of UNDP Fellowship for M.Tech studies during 1988-1990
Subject Prize Award in Agricultural Engineering conferred by Institution of Engineers (India), Kolkata to Mr. R. T. Thokal and Mr. D.M. Mahale for the paper entitled "Influence of Meteorological Variables on Weekly, Monthly and Seasonal Pan Evaporation under Humid Climatic Conditions of Dapoli" published in the Journal of the Institution of Engineers (India) Vol.:88:12-17. This award was conferred in 23rd Indian Engineering Congress held at Warangal on December 12, 2008.

Miss. Pradnya Balkrishna Jadhav did her B. Tech (Agricultural Engineering) from Mahatma Phule Krishi Vidyapeth, Rahuri(Maharashtra) and M. Tech (Agricultural Engineering) with specialization in Irrigation & Drainage Engineering from Dr. B.S. Konkan Krishi Vidyapith, Dapoli (Maharashtra). Presently she is doing Ph.D. from department of Irrigation & Drainage Engineering in Mahatma Phule Krishi Vidyapeth, Rahuri(Maharashtra).

Dr. M.S.Mane completed Bachelors (1990) and Masters degree (1992) in Agricultural Engineering from Mahatma Phule Krishi Vidyapeth, Rahuri (Maharashtra). His Specialization for Masters was on Irrigation & Drainage Engineering also completed Ph.D. from IARI, New Delhi in Soil & Water Conservation Engineering. He is having total 20 years of experience in research, education and extension. He has written number of research papers in internationally abstracted papers and received three awards for the best papers out of them. Presently he is working as Professor & Head, Department of Irrigation & Drainage Engineering, College of Agril. Engineering and Technology, Dapoli(M.S.)

Shri. Harshalkumar Namdeorao Bhange (b. 1St May, 1976) completed Bachelors in Agricultural Engineering from Dr. PDKV, Akola, MS, India in 1997 and Masters Degree in Agricultural Engineering with specialization in Soil Water Engineering and Management, IGKVV, Raipur, CG, India in 2000. He is Member of Institution of engineers (India), Indian Society of Agricultural Engineering, Indian Association of Hydrologists Association of Agrometeorologists. Presently working as Assistant Professor (SWCE), College of Agricultural Engineering and Technology, Dapoli, Dist Ratnagiri, MS, India. He is working in the field of watershed development, surface rainwater harvesting, since last 13 years, that includes teaching, research and extension. He has contributed in 12 state level recommendations.

Prof. S.R. Kale did his post-graduation in Water Resource Development from IIT, Roorkee. He has rendered his services In Kukadi command as developed engineer followed by field research in water resource management in Dr. B.S. Konkan Krishi Vidyapith, Dapoli (Maharashtra). He has his credit three books, about twenty research papers and more than fifty popular articles on rain water harvesting, micro irrigation system and resource development.He was also actively involved in design and execution of list irrigation and drip irrigation for orchards crops like mango, cashew and coconut in Konkan region.Presently he is working as associate professor in Faculty of Agriculture Engineering.