

Deficit Irrigation for Sugarcane in Kunigal command area

R.Shreedhar & Nithya B.K.

ABSTRACT

Managing water for agriculture includes a spectrum of options, from producing under fully irrigated to rainfed conditions, to supporting livestock, forestry, fisheries, and to interacting with ecosystems. However, allocation of water for agriculture through irrigation is decreasing steadily. Growing population, food security, municipal and industrial growth among others are contributing factors behind today's water scarcity, but the main reasons for water problems are lack of commitment and targeted investment, insufficient human capacity, ineffective institutions and poor governance (IWMI, 2007). Innovations are needed to increase the water use efficiency (WUE). Irrigation technologies and irrigation scheduling may be adapted for more effective and rational uses of limited supplies of water. Deficit irrigation is one of the methods designed to ensure the optimal use of allocated water. It maximizes WUE for better yields per unit of irrigation water applied through exposing the crop to a certain level of water stress either during a particular period or throughout the growing season. All this will be done to meet the specific objective that any income loss through yield reduction will be insignificant compared with the benefits gained from diverting the saved water to irrigate other crops for which water is insufficient under traditional irrigation practiced. This paper is going to review sugarcane yield responses to deficit irrigation at Kunigal command area in Karnataka state, India. The development of irrigation schedules under deficit irrigation and evaluation of current irrigation practices were done by a crop growth simulation computer programme Cropwat 8.0 developed by FAO. From the simulations, it was evident that deficit irrigation incurs some yield reductions in proportional to water stress magnitudes, but it saves substantial amounts of water. The recommended deficit irrigation practice was to spread the stress uniformly across the whole cycle.

Index terms: Deficit irrigation, Full irrigation, Water stress, Crop water requirement, reference evapo-transpiration, and crop evapo-transpiration.

1.0 INTRODUCTION

The primary objective of irrigation is to apply water to maintain crop evapo-transpiration (ETA) when precipitation is insufficient. Earlier, crop irrigation requirements did not consider limitations of the available water supplies. There is scope for increasing the water productivity in many cash crops and there is sufficient information for adopting the best deficit irrigation strategy for many situations. In growing

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industrial and municipal demands for water are necessitating major changes in irrigation management and scheduling in order to increase the efficiency of use of water allocated to agriculture. The measures like tillage practices, crop rotation, mulching can reduce the demand for irrigation. The design of irrigation schemes does not consider situations in which moisture availability is the major constraint on crop yields. Another option in which plants are exposed to certain levels of water stress which is known as deficit irrigation. There is scope for increasing the water productivity in many cash crops and there is sufficient information for adopting the best deficit irrigation strategy for many situations.

CROPWAT [1] is a practical tool to help agrometeorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation. Ali Abdzad Gohari [2] adopted the CROPWAT model to appropriately estimate the yield reduction caused by water stress and climatic impacts. The simulation results analysis suggest that in both conditions rainfed and irrigated the largest yield reduction occurred in the stage three (developmental stage). Kirda [3] concluded that the proper application of deficit irrigation practices can generate significant savings in allocation of water in irrigation. Among field crops, groundnut, banana, vegetables, common bean and sugarcane show proportionately less yield reduction obtained under various levels of reduced evapotranspiration. Dhanapal et al [4] conducted that the proper application of deficit irrigation practices can generate significant savings in irrigation water allocation. Among field crops, groundnut, soybean, common bean and sugarcane show proportionately less yield reduction. Li and Barker [5] introduce the research on practices to increase water productivity for paddy irrigation in China and summarize the experience on implementation of the alternate wetting and drying (AWD) irrigation technique. Considerable benefits have been realized from the adoption of AWD. However, farmers must be persuaded through demonstration and training that yields can be maintained with application of less water. A study was carried out by Nithya et al [6] to determine the crop water requirement of some selected crops for the command area in Kunigal taluk. These crops include rice, pulses, groundnut, sugarcane and millet (ragi). Crop water requirement for each of the crops was determined using 30-year climatic data in CROPWAT. Reference crop evapotranspiration (ET_o) was determined using the FAO Penman Monteith method. Shreedhar et al [7] carried out research to review the crop yield responses of major crops to deficit irrigation in Kunigal command area. A study was carried out by Shreedhar et al [8] to develop optimum cropping pattern for Markandeya command area with the constraints of available resources like water usage and also labour, fertilizers, seeds, etc., and ultimately getting maximum net benefits using linear programming model [8].

2.0 FULL IRRIGATION

Full irrigation refers to the systematic application of water to the soil so as to fully satisfy the Crop Water Requirement (CWR). Full irrigation has the potential to provide higher yields than rainfed agriculture and deficit irrigation, but water requirements are also higher. Over the recent decades, it was obtained that the yields that can be obtained from irrigation are more than double that yields that can be obtained from rainfed agriculture (FAO, 2002). Due to the high demand of water for full irrigation coupled with increasing water scarcity, implementation of water saving methods is required. There are also other several reasons why conventional irrigation cannot continue to grow as fast as it has over the past few decades. Among others are, environmental costs of conventional irrigation are high (waterlogging, salinization), less water available and inaccessibility and affordability of irrigation infrastructures (FAO, 2002).

3.0 DEFICIT IRRIGATION

At present and more so in the future, irrigated agriculture will take place under water scarcity. Insufficient water supply for irrigation will be the norm rather than the exception. Irrigation management will shift from emphasizing production per unit area towards maximizing the production per unit of water consumed, i.e. the water productivity (Neumann, 2006). To cope with scarce supplies, deficit irrigation can be implemented. Deficit irrigation is defined as the deliberate application of water below full crop water requirements (crop evapotranspiration) such that a certain degree of water stress is allowed during the less sensitive crop growth stages that have little impact on yield. This is done in order to achieve a specific objective, which is usually to increase the water use efficiency. By so doing, deficit irrigation assists in conserving limited water resources. As a result of allowable water stress, biomass and yield of crop produced under deficit irrigation are lower than under full irrigation conditions. The gains obtained by diverting the saved water to irrigate other valuable crops and/ or by expanding the area cropped using the same total water volumes can compensate the reduction in income due to the lower yields expected under deficit irrigation conditions.

4.0 WATER USE EFFICIENCY (WUE)

Generally speaking, Water Use Efficiency (WUE) is defined as the ratio between the actual volume of water used by a crop for a specific purpose and the volume extracted or derived from a supply source for that same purpose (FAO, 1975). In this same vein, the definition of WUE can be narrowed to be the ratio between the volume of water used by plants throughout the evapotranspiration process and the volume that reaches the irrigation plots (Palacios, 1981). In accordance with the definition proposed by the International Irrigation and Drainage Committee (Burman et al., 1981), efficiency in the use of water for irrigation may be separated into three components: storage efficiency, conveyance efficiency and

irrigation efficiency. WUE can also synonymously express as the ratio of dry matter or harvested portion of the crop produced per unit of water consumed by that same plant that is water productivity.

5.0 MATERIALS AND METHODS

5.1 STUDY AREA

The study area Kunigal as shown in figure 1.0 is situated about 35 km south of Tumkur on the Bangalore-Hassan road, and 75 km from Bangalore city. Kunigal is located at latitude of 12.45°N and longitude of 76.20°E. It has an average elevation of 726 m. The Annual average rainfall of the kunigal is 593.0 mm. Tumkur district falls under agriculture zone 4 (Central dry zone), zone 5(Eastern dry zone) and zone 6 (Southern dry zone). The Zone 4 consists of 6 taluks namely Chikkanayakanahali, Tiptur, Koratagere, Sira, Madhugiri and Pavagada. The Zone 5 consists of Gubbi and Tumakuru taluks and the Zone 6 consists of Kunigal and Turuvekere taluks. The south west monsoon starts normally from 1st week of June and peak precipitation will occur during September.

Very near to this place at Marconahalli, a dam has been built across the Shimsha River forming the biggest reservoir in the district. Marchonahally Dam, (Markonahalli Reservoir) has been the life-saving water source for irrigating over 6,000 hectares of land spread over villages around Kunigal. It is located around 50 km from Tumkur town. Markonahalli dam is said to be a unique water resource management project as the reservoir has automatic siphon spillways, considered to be an efficient flood control system requiring no manual operations.

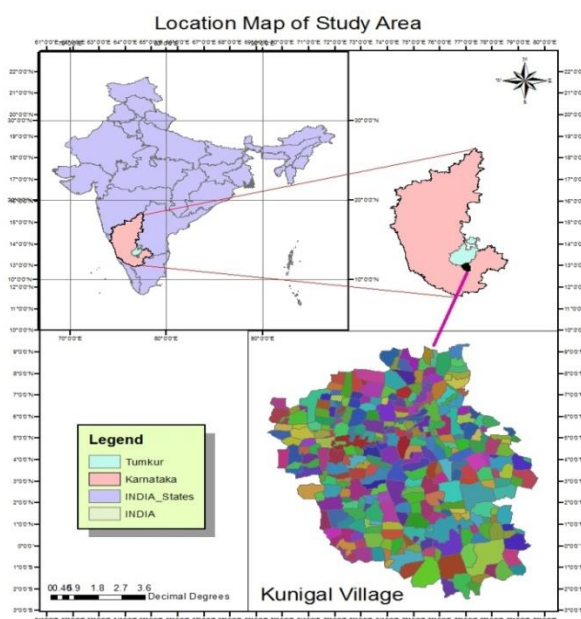


Figure -1: Location map of study area

5.2 CROPWAT 8.0

CROPWAT 8.0 is a computer program for irrigation planning and management, developed by the Land and Water Development Division of FAO. Its basic functions include the calculation of reference evapotranspiration (ET_o), Crop Water Requirements (CWR), and scheme irrigation requirements. Through a daily water balance, the user can simulate various water supply conditions, estimate yield reductions, and irrigation and rainfall efficiencies. Typical applications of the water balance include the development of irrigation schedules for various crops and various irrigation methods, the evaluation of irrigation practices, as well as rainfed production and deficit irrigation conditions.

Procedures for calculation of the CWR and irrigation requirements are mainly based on methodologies presented in FAO Irrigation and Drainage Papers No. 24 "Crop Water Requirements" and No. 33 "Yield response to water". There are two new versions of the CROPWAT; one is CROPWAT 7.0, which overcomes many shortcomings of the first 5.7 version. Currently there is also another new updated version CROPWAT 8.0 awaiting to be published by the end of year.

All versions use the same FAO Penman-Monteith method for calculating the reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations. Assumptions are made that the crop is well protected against diseases, pests, weeds infestation and wild animals' destruction together with occurrences of natural disasters like hailstorms and the effects of poor drainage, salinity and so forth.

5.3 REFERENCE EVAPOTRANSPIRATION (ET_o)

Reference evapotranspiration (ET_o) refers to evapotranspiration rate from a hypothetical reference grass crop, not short of water. It can only be affected by climatic parameters; consequently it is a climatic parameter and can be computed from weather data (FAO, 1998). ET_o shows the evaporating power of the atmosphere at a specific location and it does not consider the crop characteristics and soil factors. According to FAO indications, Penman Monteith equation is the sole recommendable method used to calculate ET_o (FAO, 1998). It closely approximates grass ET_o at the location evaluated, is physically based and explicitly incorporates both physiological and aerodynamic parameters, meaning to say it varies with the physiological behavior of the reference grass crop and

the climatic conditions of the specific area studied. Penman Monteith equation uses the air temperature, air humidity, wind speed, solar radiation and sunshine hours to compute the reference evapotranspiration.

Table-1: Long-term average monthly reference evapotranspiration of Kunigal command area

Country: India		Station: Kunigal		Altitude: 726 m		Lat: 12.45°N		Long: 76.2° E	
Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad (MJ/m ² /day)	ET _o (mm/day)		
January	16.0	32.0	50	164	5.0	14.5	4.28		
February	17.0	34.0	45	72	5.0	15.6	3.70		
March	19.0	37.0	64	72	4.0	15.2	3.79		
April	21.0	38.0	68	69	4.0	15.7	3.99		
May	22.0	37.0	64	69	6.0	18.6	4.58		
June	20.0	33.0	69	95	10.0	24.2	5.29		
July	20.0	31.0	64	69	10.0	24.3	4.98		
August	20.0	30.0	77	69	8.0	21.6	4.38		
September	20.0	32.0	80	69	5.0	16.8	3.66		
October	20.0	32.0	80	69	4.0	14.4	3.26		
November	18.0	30.0	77	69	5.0	14.7	3.11		
December	16.0	31.0	33	69	5.0	14.1	3.28		
Average	19.1	33.1	64	80	5.9	17.5	4.03		

6.0 RESULTS AND DISCUSSION

6.1 IRRIGATION REQUIREMENT

Sugarcane life cycle can be divided into four growth stages, which are distinguished physically and physiologically from each other, hence, respond differently to water stress. Each stage has its own duration and its own irrigation requirement (Table-2). The figure does not include the soil moisture variation over the crop cycle.

Table-2: Irrigation requirement for the whole cycle and each growth stage of sugarcane

Growth stage	Duration (days)	Irrigation requirement (mm)
Initial	30	31.7
Development	60	168.7
Mid-season	180	526.8
Late	95	135.6
Total	365	862.8

The middle stage requires more than 60% water when the crop is at grand growth stage, which end up in the first yield formation phase. Yield formation will continue until early phases of the late stage.

6.2 RAINFED AND FULL IRRIGATION CONDITIONS

Under rainfed conditions, yield reduction is 40.1%. In actual conditions, farmers do not grow sugarcane under rainfed conditions, as this yield reduction is considered excessive and unacceptable by farmers (Table-2). The yield reduction is strongly linked to low rainfall received. The cane is suffering water stress almost through out the whole cycle (Figure-2).

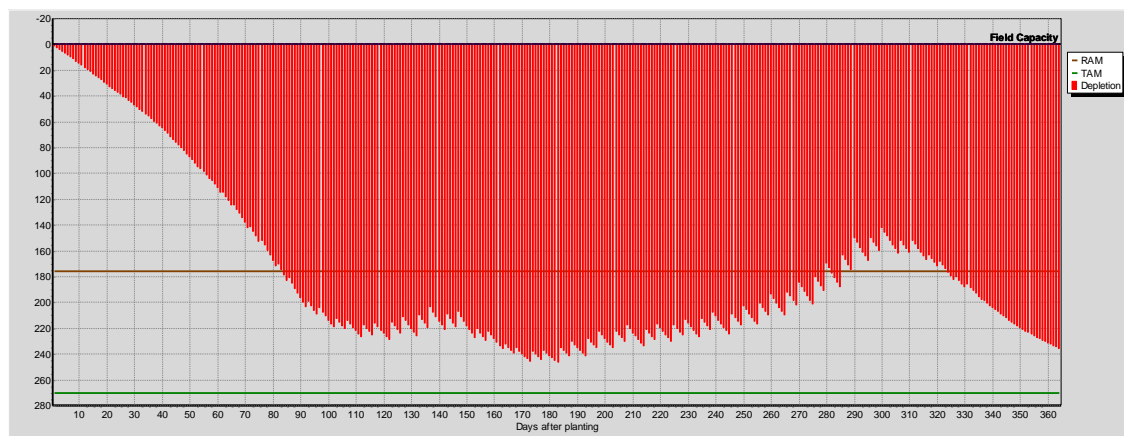


Figure-2: Soil water depletion at Kunigal command area under rain-fed conditions resulting from CROPWAT 8.0 simulations.

Figure-2 shows that on the greater percentage of the life cycle the cane will be depleting the soil moisture below the Readily Available Moisture (RAM) level leaving the crop exposed to water stress, hence inducing yield reduction compared to no stress conditions. Under full irrigation, the crop will be supplied with enough water to meet its water requirements and will not suffer water stress (Figure-3). Full irrigation can maximize yield as indicated by zero percent yield reduction (Table-2).

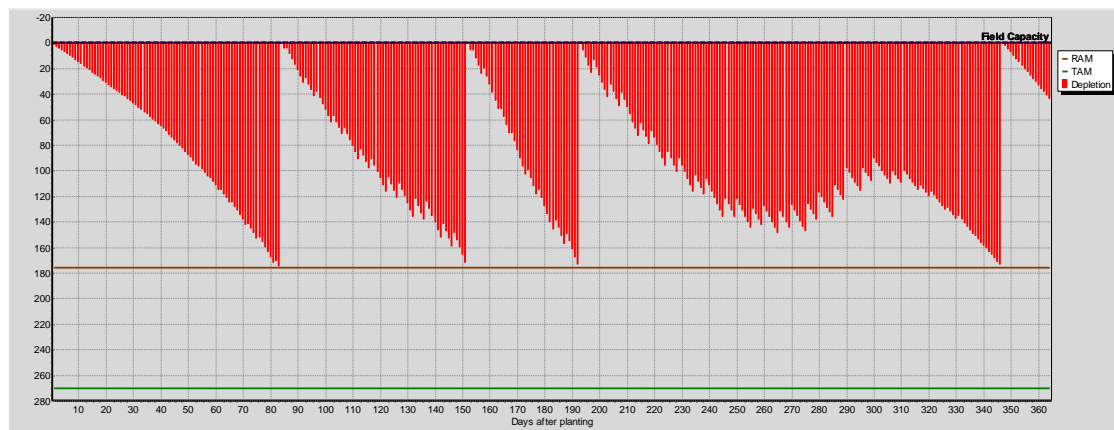


Figure-3: Soil water depletion at Kunigal command area under full irrigation conditions resulting from CROPWAT 8.0 simulations.

Table-3: Comparison of yield reduction under rainfed and full irrigation conditions, resulting from CROPWAT 8.0 simulations

Condition	Yield reduction (%)	Actual water used by crop ET _a (mm)	Potential water used by crop ET _c (mm)	Total Gross Irrigation (mm)
Rainfed	40.1	993.6	1493.2	0.0
Full irrigation	0	1493.2	1493.2	1019.6

6.3 DEFICIT IRRIGATION SCHEDULING

In order to successfully meet the objective of deficit irrigation practice of eliminating irrigations that have little impact on yield, there is need to know the level of actual crop evapotranspiration deficiency allowable that can cause acceptable reduction in crop yields. The water stress that can be simulated by CROPWAT either can be distributed uniformly over the entire life cycle or can be concentrated on one specific phase of the crop cycle (FAO, 1986).

6.4 WATER STRESS UNIFORMLY SPREAD OVER THE CROP CYCLE

By using CROPWAT, water deficit of different magnitudes occurring continuously over the total growing period was simulated (Table-4). This was done by selecting the option, irrigate below or above critical depletion, from the irrigation-timing window.

Table-4: Yield reductions obtained over different water deficits uniformly spread over the crop cycle

% above critical depletion	Yield reduction (%)	Actual water used by crop ET _a (mm)	Total Gross Irrigation (mm)
0	0	1493.2	1019.6
10	0.4	1488.1	833.2
20	4.5	1436.8	908.6
30	11.8	1346.9	655.1
40	21.3	1228.7	351.4
50	40.1	993.6	0

The simulations were carried out allowing irrigation at above critical soil moisture depletion of RAM. Irrigation at 100% depletion of RAM was the benchmark, which had no effect of yield reduction. This means that irrigation water is applied whenever the entire RAM has been depleted such that the crop will never be exposed to water stress. Different water deficit magnitudes were used (Tab.4), thus depletion was allowed to go beyond the RAM level also known as critical depletion point. By so doing, the crop suffered some stress that ultimately leads to yield reduction. These different deficits were spread

uniformly over the entire cycle. The simulations were done at intervals of 10% exceedance of the critical depletion (100%) and indicated that the higher the degree of exceedance, the greater is the yield reduction. Irrigating at 100% of critical moisture depletion renders no yield reduction and requires more water use (Table-4). This is full irrigation condition. In contrary, irrigation at 150% of critical moisture depletion, though it utilizes much less water it incurs high yield reduction of 40.1%. The yield reduction increases linearly with the decrease in water used by the cane under conditions of water stress uniformly spread over the whole crop cycle (Figure-4).

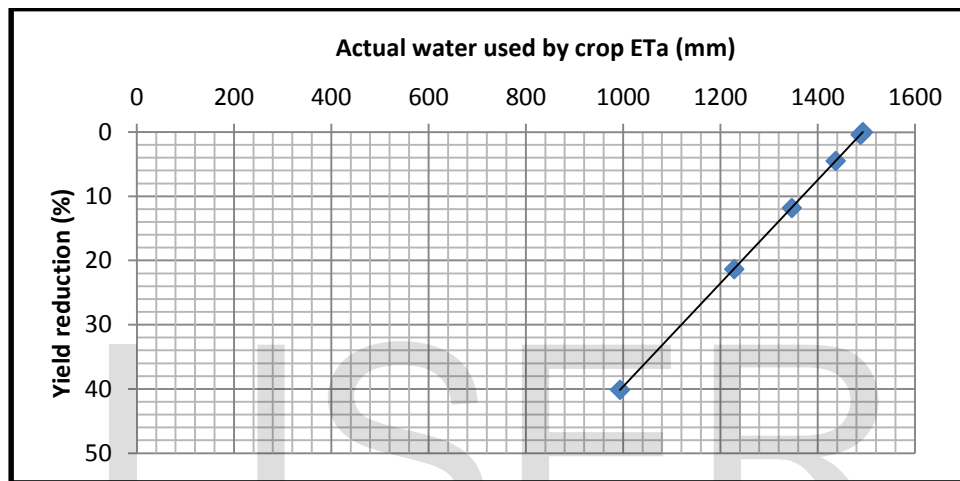


Figure-4: Yield reduction versus ETa for water stress uniformly spread over the whole cycle.

6.5 WATER PRODUCTIVITY

Deficit irrigation aims at maximizing water productivity (WP) that is maximizing the yield produced per unit of water. WP can be calculated using different methods and in this case study the method used was:

$$WP = Y / ET_a$$

Where: Y is yield (ton/ha)

ET_a is Actual crop evapotranspiration (mm/cycle)

The maximum yield attainable in Karnataka under optimum water and fertilization conditions is 120 ton/ha. In this case, simulations were done and it was found that distributing water stress evenly across the whole life cycle of different magnitudes it leads to different yield responses (Tab.3). Using the maximum agronomically attainable yield of 120t/ha at Kunigal command area, corresponding actual yields were calculated in order to find the water productivity (Figure-5).

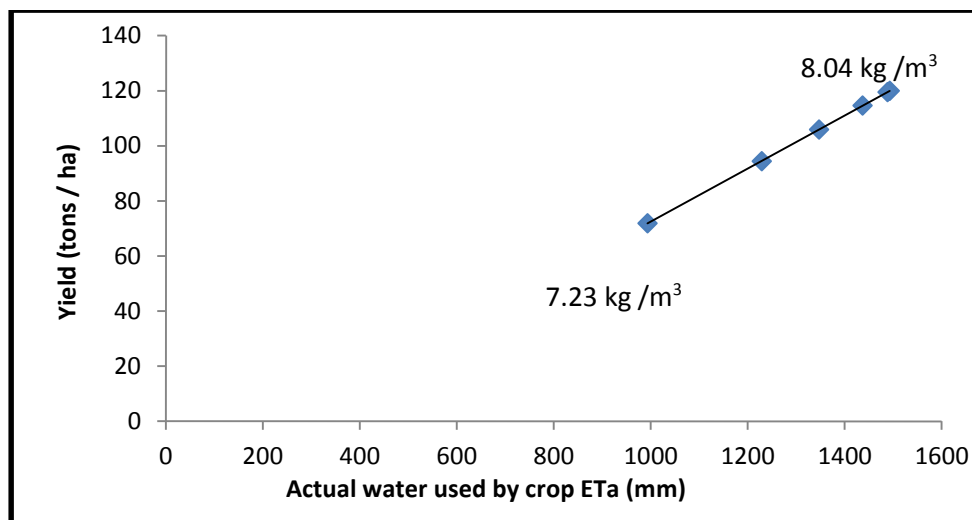


Figure-5: Water productivity of sugarcane at different water deficit magnitudes uniformly spread over the whole cycle.

At full irrigation, there is high water productivity of 8.04kg/m^3 . Under water deficit conditions, WP decreases with increase in deficit magnitude but less water is required for irrigation.

6.6 WATER STRESS CONCENTRATED OVER ONE PHASE OF CROP CYCLE

Crop response to water deficit can also vary as a function of the phase of the crop cycle during which the stress occurs. From the simulations carried out sugarcane proved that it responds differently to different levels of water deficit (Table-5, Figure-6).

Table-5: Yield reductions incurred at different growth stages at various water deficits

Growth stage	10% ET_c reduction			20% ET_c reduction			30% ET_c reduction			40% ET_c reduction		
	Yield red. (%)	Eta (mm)	Total GIR (mm)	Yield red. (%)	Eta (mm)	Total GIR (mm)	Yield red. (%)	Eta (mm)	Total GIR (mm)	Yield red. (%)	Eta (mm)	Total GIR (mm)
Initial	0.9	1482.4	850.4	0.9	1482.4	850.4	0.9	1482.4	850.4	0.9	1482.4	850.4
Dev.	0.9	1481.7	854.2	0.9	1481.7	854.2	0.9	1481.7	854.2	0.9	1481.7	854.2
Mid	5.1	1429.7	914.1	10.7	1359.4	600.3	21	1231.8	550.7	21	1231.8	550.7
Late	0.9	1482.4	850.4	0.9	1482.4	850.4	0.9	1482.4	850.4	0.9	1482.4	850.4

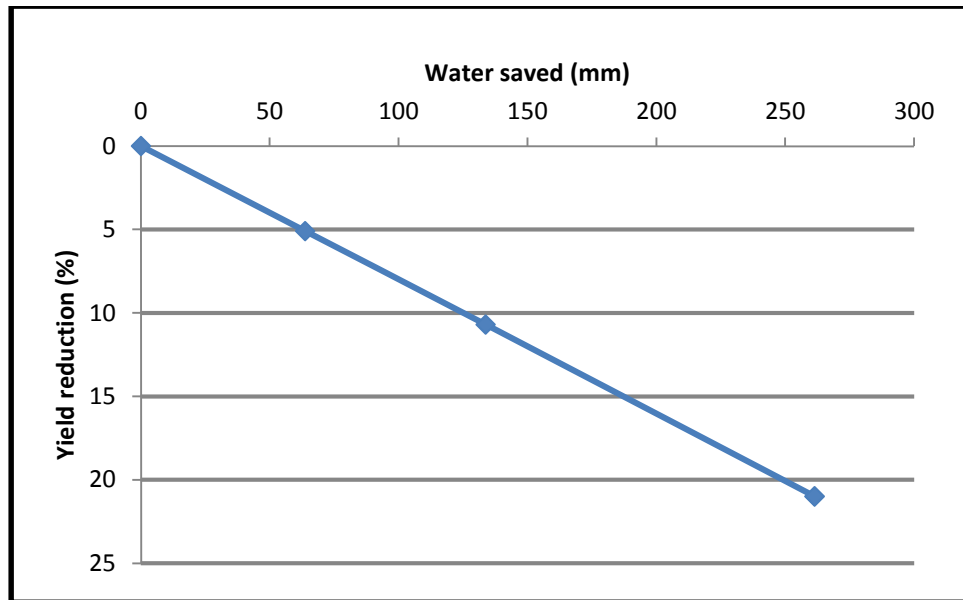


Fig. 6: Yield reduction versus water saved as compared to FI for the water stress concentrated over mid-season stage

At initial, development and late season stages, there is negligible yield reduction. Compared to full irrigation (FI), there is rather no water saved when stressing in these three stages. The ET_c for FI is about 1493.2 mm compared to 1482.4 mm and 1481.7 mm for initial and development stages respectively. In order to save some substantial amounts of water, the stress should be induced over the mid-season stage. If the farmers accept high yield reduction, they can stress at mid-season stage as it saves more water than stressing at other stages. The linearity of yield reduction versus water saved as shown in Fig.6 is due to the K_y approach derived on the assumption that the relationship between relative yield and relative evapotranspiration is linear and is valid for water deficits of up to about 50% of the crop water requirement.

7.0 CONCLUSIONS

The proper practice of deficit irrigation can generate significant savings in irrigation water allocation, though it entails yield reductions (Fig.4&6). In as much as deficit irrigation assists in conserving limited water resources available for irrigation, the practice however requires precise knowledge of yield response to water function and of the economic risk. From the simulations carried out, it is conclusive that decrease in yield is proportionally greater with the increase in water deficit for the water stress uniformly distributed over the whole crop cycle (Tab.4). By stressing the cane at either initial or development stage, insignificant yield reductions of 0.9% are incurred but the water saved is negligible (Fig.6). In contrary, inducing stress at either mid-season stage, though the yield reductions are much greater, there will be substantial amounts of water that can be saved. Comparing the two deficit practices, it is better to spread

the stress uniformly across the growth cycle for it saves more water (Fig.4 & 6). However, economic analysis needs to be carried out in order to find out the exact deficit magnitude, which saves more water and simultaneously entails acceptable yield reduction percentage by farmers. Farmers in Kunigal command area can profitably use the saved water to expand the area cropped or irrigate other valuable crops using the same total water volumes. Though these conclusions ought to be credible, they must be taken with caution since CROPWAT is just a simplification of reality and can be applied within some limited boundaries, meaning that a degree of error is supposed to be accepted. According to CROPWAT indications, the crop under simulation is supposed to be well protected against diseases, pests, and weeds. Therefore, in reality the farmers can incur more or less yield reductions than those simulated by CROPWAT depending on their agronomic managerial practices. These practices involve pests, diseases, weeds management, and soil fertility management.

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References

- [1] Food and Agriculture Organization (FAO) CROPWAT: A Computer Program for Irrigation Planning and Management, by M. Smith. FAO Irrigation and Drainage Paper No. 46. Rome, (1992).
- [2] Ali Abdzad Gohari, "Simulation of Peanut (*Arachis hypogaea* L.) with Cropwat model in Irrigation Condition and Rainfed". *Sci. Agri.*, 2 (3), 54-59, (2013).
- [3] Kirda, C., "Deficit irrigation scheduling based on plant growth stages showing water stress tolerance", *Water Reports*, ISSN 1020-1203, Food and agriculture Organization of the United Nations, Rome, Adana, Turkey, pp 3-10, Volume 22, (2002)
- [4] R. Dhanapal H.P. Maheswarappa, P. Subramanian and Ajayakumar Upadyay, "Influence of Drip Irrigation on Growth and Yield of Cod X Wet Coconut", *CORD*, Volume 19, (No. 2), (2003).
- [5] Yuanhua Li, Randolph Barker, "Increasing water productivity for paddy irrigation in China", 2(4), pp 187-193, (2004).
- [6] Nithya B.K., Shreedhar R., Dr. Shivapur A.V., "Water Requirements of Selected Crops in Kunigal Command Area", *I-manager's Journal of Civil Engineering* - (eISSN 2249-0779, pISSN 2231-1068), 5(2), pp 24-30, (2015).

[7] Shreedhar .R., Dr. Shivapur A.V., Nithya B.K., “Deficit Irrigation management of Major Crops in Kunigal Command Area”, International Journal of Scientific & Engineering Research, Volume 6, Issue 9, September-2015, ISSN 2229-5518, pp 170-185

[8] Shreedhar .R., Chandrashekrayya G Hiremath, Girish G Shetty, “Optimization of cropping pattern using linear programming model for Markandeya command area”, International Journal of Scientific & Engineering Research, Volume 6, Issue 9, September-2015, ISSN 2229-5518, pp 1311-1326

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