IRRIGATION SCHEDULING BASED ON SOIL MOISTURE STUDIES AND CROP YIELD UNDER DEFICIT IRRIGATION

Dr. K Thirupathi Rao[1], Syed Riyaz[2], Dr. G Dineshkumar[3]
[1]Professor, Department of Civil Engineering, Vaagdevi College of Engineering, Telangana, India.
[2]Assistant Professor, Department of Civil Engineering, Vaagdevi College of Engineering, Telangana, India.
[3]Associate Professor, Department of Civil Engineering, Vaagdevi College of Engineering, Telangana, India.

Article History: Received: 05-01-2023 **Revised:** 08-02-2023 **Accepted:** 27-02-2023

ABSTRACT

A critical element in irrigation scheduling is the accurate measurement of the volume of water applied or the depth of application at a predetermined frequency. The problem arises when there is deficit in the availability of water for the desired cropping pattern. A live problem in a distributory of a major irrigation project in the State of Andhra Pradesh in South India has been taken up for the present study. A software "SOMOSIM" (Soil Moisture Simulation) has been developed as a part of the study to determine the frequency and depth of irrigation. This program is then combined with the software B2D developed by Playan et al (1994) to determine the discharge required and corresponding duration to store a design depth of irrigation in a prescribed dimensioned strip of land. The study is carried for different levels of deficits and adopting various cropping patterns prescribed by statutory bodies and funding agencies. Sensitive factors of different crops, suggested by FAO are also taken into consideration for various stages of crop growth in the computation. Necessary data for this study were obtained from the agricultural university, agricultural research station and the agriculture-marketing department. The results of the study indicate a scientific allocation of water under deficit conditions. When the deficit is large and if the crops are very sensitive for shortage of water, such crops may not be grown. Four approaches are used in the study for distribution of water during shortage in water availability.

DOI: 10.48047/ecb/2023.12.Si8.531

Introduction

The main purpose of irrigation is to supply adequate water to meet the crop water requirements. As the plant grows, it exchanges gases with the air for photosynthesis and some water evaporates. Water is taken up from the soil by plant roots to replace this water. The process of water leaving the plant is called transpiration. The combination of transpiration and evaporation is called evapotranspiration (ET) and is considered as the crop water use. Water taken out of the soil must be made up with either rainfall or irrigation, other wise the soil moisture is likely to be reduced to such low levels that the plants have to exert lots of stress to meet their water requirements.

Over the last half-century, significant gains in agriculture production protected the world from devastating food shortages, famine and the threat of mass starvation. Appropriate water management was instrumental in achieving those gains in both rain-fed and irrigated agriculture. A key component in Green Revolution technologies, which was very successfully carried out in India, based on fertilizer application and the use of high yielding varieties, improved water management, etc., helped boost productivity - or output of "crops per drop". From a food grain-importing nation in the sixties to a food grain surplus nation exporting food grains to other nations presently, agricultural productivity in the country has taken a quantum jump. As per the records available from FAO (2003), it is also noticed that the production of food and fibre crops claims the biggest share of freshwater withdrawn from natural sources for human use, or some 70% of global withdrawals.

FAO sees broad scope for policy intervention to help "re-invent" agricultural water management and it recommends a strategic approach to development of available land and water resources in order to meet demand for food products and agriculture commodities, and a broader awareness of the productivity gains that can be achieved through wise water use.

In most of the earlier studies, crop irrigation requirements did not consider limitations of the available water supplies. The design of irrigation schemes did not address situations in which moisture availability is the major constraint on crop yields. However, in arid and semi-arid regions, increasing municipal and industrial demands for water are necessitating major changes in irrigation management and scheduling in order to increase the efficiency of use of water that is allocated to agriculture.

1. Methodology

The methodology developed is divided in to three parts. In the first part, the crop growth stage wise water requirements are calculated by using soil moisture simulation technique; under water availability is not a constraint condition by using SOMOSIM (SOil MOisture SIMulation) software. To use this program data file consists of date, Avg. Temperature, Rel. Humidity, Sunshine, Wind Velocity and Rainfall required. Also requires Field Capacity, Optimum Moisture Content, and Name of the crop, crop growth stage and Crop coefficient as inputs. In the second part, for any available water (less than or equal to maximum water requirement), single crop optimization model is developed to maximize relative yield for available water. In the third part, four models are developed for multi crop water allocations when available water is in shortage. For this purpose, a new software WADS (Water Allocation During Shortage) has been developed.

To schedule irrigation for most efficient use of water and to optimize production, it is desirable to frequently determine the soil water conditions throughout the root zone of the crop being grown. The Potential Evapotranspiration (PET) and Actual Evapotranspiration (AET) are calculated using Christiansen's equation since relevant data were available from the local agriculture research station.

A typical output of SOMOSIM program is shown in Table 1. By using SOMOSIM, PET is calculated followed by estimated schedules of irrigation, considering daily soil moisture levels in the soil up to root zone depth. The irrigation scheduling is calculated for three cropping patterns, sample calculation is presented in Table 2

Table: 1 Typical Output from SOMOSIM

Date	AET(mm)	SMC_1(mm)	SMC_2 (mm)	Irrigation required or not	Irrigation Depth (mm)
01/06/2003	4.526	60.750	56.224	Yes	20.250
02/06/2003	4.551	56.224	51.674	No	
03/06/2003	4.603	51.674	47.071	No	
04/06/2003	4.078	47.071	42.993	No	
05/06/2003	4.405	42.993	60.750	Yes	20.250

.

Table: 2 Scheduling of Irrigation

Name of the crop (season shown in brackets)	Crop growth stage	Period of growth	Watering dates	Depth of irrigation in mm.
Sorghum (Kharif)	Initial Crop develop Mid season Late season	16th June to 5th July 6th July to 15th Aug. 16th Aug. to 25th Sep. 26th Sep. to 25th Oct.	16/6, 23/6/03 6/7/03 16/8, 8/9/03 26/9, 20/10	20.25 48.94 91.63 101.25

Groundnut (Rabi)	Initial	16th Oct. to 5th Nov.	16/10/03	20.25
	Crop develop	6th Nov to 15th Dec.	6/11,14/11,23/11, 2/12, 12/12	32.62
	Mid season	16th Dec. to 25th Jan.	16/12, 1/1,14/1	61.09
	Late season	26th Jan. to 15th Feb.	26/1/04	67.50
Cotton (Two season)	Initial	1st July to 31st July	1/7/03	20.25
	Crop develop	1st Aug to 5th Oct.	1/8, 9/9/03	69.99
	Mid season	6th Oct to 5th Dec.	6/10,11/11,30/11	107.55
	Late season	6th Dec to 31st Jan.	6/12, 6/1/04	108.00

Irrigation Scheduling when Availability of Water is a Constraint

There are some crucial stages in the life cycle of a crop when the plant is critically in need of water. Supplying less quantity of water or allowing water stress beyond a certain limit during these stages can cause a definite slow down the growth processes of the plants, which, in turn will affect the yield.

If available moisture is not a constraint, the evapotranspiration will be equal to ETR (same as PET), which ensures maximum yield. However, at the time of deficit, if the value of ETP (actual evapotranspiration provided is less than that is required, the situation leads to deficiency in the yield. Research has been carried out to study the yield in terms of deficit of ETR. The water production function used in the present research work is that developed by Doorenbose and Kassam (1979) and adopted by Rao et al (1990). The various equations used in the study are:-

$$Y_a/Y_m = ((1- K_y\,(1- ETP / ETR))_i)_j$$

Where:

Y_a = Actual crop yield; Y_m = Maximum crop yield

K_y = Sensitivity factor for the growth stage of the crops, values available

ETP = Evapotranspiration that can be provided according to the availability of water.

ETR = Evapotranspiration required for maximum yield

i = Growth stage: j = Crop

If ETP = ETR, the yield is maximum. ETR = PET * $K_{c.}$

$K_{c.}$ = Crop coefficient.

If the available water is in deficit in the canal, then this deficit water should be distributed among all the crops that are being cultivated under the command area of the canal, based on yield consideration and survival of the crop. The deficit limit for a particular crop should be defined, i.e., the upper limit of the deficit should not affect survival of the crop and the lower limit is zero. The maximum deficit limit in any stage of the growth is restricted to 50%, when the soil moisture deficit exceeds 50%, the moisture content in root zone is assumed to fall below wilting coefficient. The crop yield response factors for Kharif and Rabi seasons given by Doorenbos and Kassam (1979) are used in this study.

Evapotranspiration required for maximum yield (ETR) is calculated by using **SOMOSIM** software. Actual evapotranspiration that can be provided according to the availability of water (ETP) is calculated on the basis of deficit and yield considerations. For this purpose, a new software **WADS** (**W**ater **A**llocation **D**uring **S**hortage) has been developed.

The maximum yield and income from different crops are collected from Deputy Director, Agriculture Deportment and Market Yard, Warangal and the details of cost of cultivation are collected from Deputy Director, Agriculture Deportment, Warangal.

Single crop optimization

If the available water is a constraint (less than maximum water requirement) in a crop season, initially individual crop out of group of the crops is considered to maximize the relative yield for any shortage of available water. For this purpose, a single crop optimization model is developed to maximize relative yield.

The primary objective of this step is to allocate available water for a single crop in different crop growth stages with considering crop yield response factor to get maximum relative yield of a single crop. The objective function is the maximization of relative yield of a single crop.

$$R = \text{Maximize} \prod_{i=1}^{ns} \left(1 - K_{yi}\left(1 - ETP_i / ETR_i\right)\right)$$

Subject to ETP_i > or = 0.5 * ETR_i

Where

R = Relative yield; i = 1 to number stages (ns)

K_{yi} = Sensitivity factor at i^{th} stage of the crop

ETP_i = Water is provided for crop evapotranspiration at i^{th} stage of the crop

ETR_i = Evapotranspiration required for maximum yield at i^{th} stage of the crop

The above equation is used to calculate stage-wise relative yield. The constraint of the maximization is that the survival ETP should be at least 50% of ETR at every stage of the growth to survival of the crop.

The stage wise relative yield is calculated as

$$R_i = (1- K_{yi} (1- ETP_i / ETR_i)$$

R_i = Relative yield at i^{th} stage of the crop

The net relative yield of the crop

$$R = \prod_{i=1}^{ns} R_i$$

For survival condition the relative yield is

$$R_s = \prod_{i=1}^{ns} R_{is}$$

$$R_{is} = 1- K_{yi} (0.5)$$

Where

$$ETP_i / ETR_i = 0.5$$

Total survival depth of water in all stages is

$$\mathbf{ETP_s = \sum_{i=1}^{ns} 0.5 * ETR_i}$$

$$\mathbf{Total\ ETR = \sum_{i=1}^{ns} ETR_i}$$

If 'x' depth units of water available more than the survival depth required in all stages, this 'x' varies from 0.5 x total ETR to total ETR. This depth of water should be allocated among the crop growth stages, such that to get maximum relative yield. Let C_i = 1- K_{yi} (0.5). If these x units are added in last stage then the relative yield is

$$R (x) = \prod^{ns-1} C_i * (1- K_{y\,ns} (1- ((ETR_{ns} / 2) +x) / ETR_{ns}))$$

i=1

$$R(x) = \prod_{i=1}^{ns-1} C_i * (1- K_{y\,ns} (1- (0.5) - x / ETR_{ns}))$$

$$R(x) = \prod_{i=1}^{ns-1} C_i * (1- K_{y\,ns} (0.5 - x / ETR_{ns}))$$

$$R(x) = \prod_{i=1}^{ns-1} C_i * ((1- K_{y\,ns}\, 0.5) + (x * K_{y\,ns} / ETR_{ns}))$$

As an example: Let x = one unit.

Then the relative yield

$$R(1) = \prod_{i=1}^{ns-1} C_i * (1- K_{y\,ns} (0.5) + K_{y\,ns} / ETR_{ns})$$

Then the above equation becomes

$$R(1) = \prod_{i=1}^{ns-1} C_i * (1- K_{y\,ns} (0.5)) + (\prod_{i=1}^{ns-1} C_i * K_{y\,ns} / ETR_{ns})$$

$$R(1) = \prod_{i=1}^{ns} C_i + (\prod_{i=1}^{ns-1} C_i * K_{y\,ns} / ETR_{ns})$$

Let $K_{yi} / ETR_i = M_i$

$$R(1) = \prod_{i=1}^{ns} C_i + \prod_{i=1}^{ns-1} C_i * [M_{ns}]$$

The general form of the equation is

$$R(1) = \prod_{i=1}^{ns} C_i + \prod_{\substack{i=1 \\ i \neq k}}^{ns} C_i * M_k \qquad [\text{ k = 1 to ns, crop growth stages}]$$

If the number of crop growth stages (ns) is four and the one unit of water is added in fourth stage (k = 4) then the relative yield is,

$$R = \prod_{i=1}^{4} C_i + \prod_{\substack{I=1 \\ i \neq 4}}^{4} C_i * M_4$$

If this one unit of water is added in third stage then the relative yield is, (k = 3)

$$R = \prod_{i=1}^{4} C_i + \prod_{\substack{i=1 \\ i \neq 3}}^{4} C_i * M_3$$

If this one unit of water is added in second stage then the relative yield is, (k = 2)

$$R = \prod_{i=1}^{4} C_i + \prod_{\substack{i=1 \\ i \neq 2}}^{4} C_i * M_2$$

If this one unit of water is added in first stage then the relative yield is, (k = 1)

$$R = \prod_{i=1}^{4} C_i + \prod_{\substack{i=1 \\ \mathbf{i \neq 4}}}^{4} C_i * M_1$$

In all the above equations the first term is constant, only second term is variable. So, the second terms are calculated for all the stages and arranged in descending order. Because the maximum value of the second term of any crop growth stage, if water provided in that stage up to maximum water requirement in that stage gives maximum crop relative yield. Then this 'x' depth units of water should be allocated in all growth stages of the crop to get

maximum relative yield. The following conditions must be followed, while water allocating for a crop in different stages.

If x < or = ETR/2 of first in the order then total x is allotted to that stage, otherwise
If x - ETR / 2(of first in the order) = x1 < or = ETR / 2 of second in the order then total x1 is allotted to that stage, other wise

If x1 - ETR / 2(of second in the order) = x2 < or = ETR / 2 of third in the order then total x2 is allotted to that stage, other wise

x2 - ETR / 2(of third in the order) allocated to fourth in order stage.

After allocating the water the total ETP can be calculated by using the equasion,

$$\text{Total ETP} = \sum_{i=1}^{ns} ETP_i$$

This total ETP varies from 0.5 x total ETR to total ETR

Multi-crop Optimization

When limited water supply is available for a particular command area, proper irrigation scheduling is required to increase crop production. The available water is a constraint (less than maximum water requirement) in a crop season or crop growth stage wise. Now a group of crops are considered to maximize the profits or equalize the relative yield for any shortage of available water.

Four models are developed for multi crop allocations during limited water availability. They are

- **Distribution of deficit to maximize profit among all the crops**
- **Distribution of deficit to achieve equal relative yield among the number of crops.**
- **Stage wise distribution of deficit to maximize profit among all the crops**
- **Stage wise distribution of deficit to achieve equal relative yield.**

First two methods for season wise water shortage, one for maximize yield and other for equalize yield and other two methods for crop growth stage wise water shortage, one for maximize yield and other for equalize yield. The above methods are discussed in the following sections. A user-friendly computer program may be more helpful for practical field application. A program named **WADS** (**W**ater **A**llocation **D**uring **S**hortage) has been developed in the present study and applied to the study area.

Distribution of Deficit to Maximize Profit among All the Crops

Using the objective function maximizes the profit

$$\text{Profit} = \text{Maximize} \sum^{nc} A_j \times B_j \times R_j$$

j=1

Subject to R_j > or = R_{js}

Where

j = 1……… to number of crops (nc); A_j = Area of cultivation of the j^{th} crop in Hectares

B_j = Benefit of the j^{th} crop in Rs. Per Ha.; R_j = Relative yield of the j^{th} crop

R_{js} = Survival relative yield of the j^{th} crop

For survival condition the profit

$$\text{Profit} = \sum_{j=1}^{nc} A_j \times B_j \times R_{js}$$

Survival water required may be calculated

$$W_s = \sum_{j=1}^{nc} A_j \times (0.5 \times \text{Total ETR})_j$$

Maximum water required may be calculated

$$W_{max} = \sum_{j=1}^{nc} A_j \times (\text{Total ETR})_j$$

$$\text{Total ETR} = \sum_{i=1}^{ns} ETR_i$$

If Y Ha-m water is available to allocate

Balance water = Y - W_s this should not be negative

This balance water is allocated among all the crops to maximize profit

$$\text{Profit} = \sum_{j=1}^{nc} A_j \times B_j \times R_j$$

$$R_j = \prod_{i=1}^{ns} (1- K_{yi} (1- ETP_i / ETR_i))_j$$

$$Profit = \sum_{j=1}^{nc} A_j \, x \, B_j \, x \left[\prod_{i=1}^{ns} (1- K_{yi} (1- ETP_i / ETR_i))\right]_j$$

Out of the balance water first 0.1 Ha-m is converted in to depth of water in mm for each crop (0.1 * 1000 / A_j in Ha.) this depth is added to survival ETP of each crop and profits are calculated for all the crops, which crop is giving more benefit this water is allocated to that crop and that crop's ETP becomes ETP_{sur} + this depth. Similarly increment of 0.1 Ha-m is allocated till available water. Fig. 1 shows operation menu of **WADS** software for multicrop optimization to get maximum profits. Similar calculations made for remaining three methods, a sample results presented in Table 3

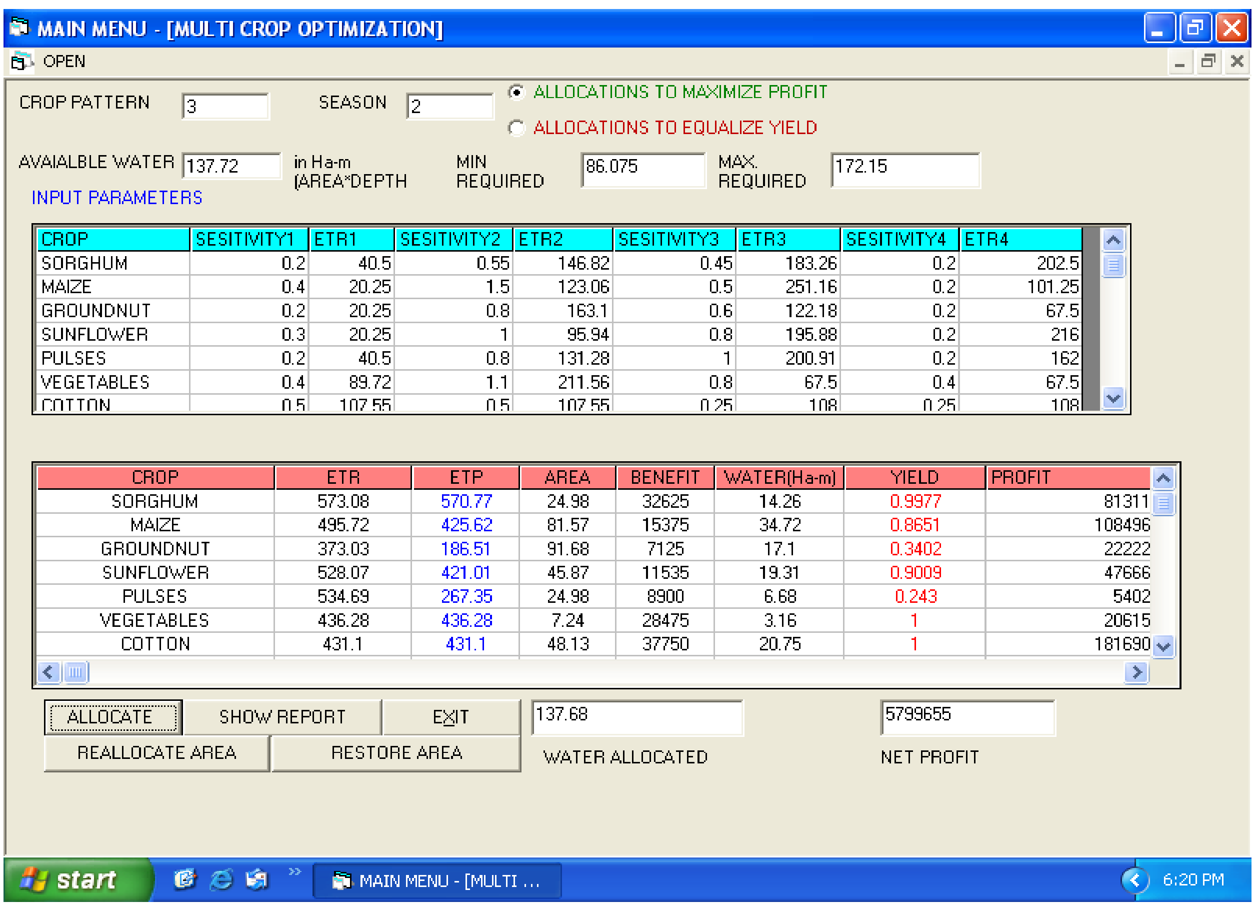

Fig. 1 Operation Menu of the WADS for Multi Crop Optimization (Maximize Profits) during Crop Season wise Water Shortage

Table 3 Multi-Crop Stage Wise Optimisation for Crop Pattern 3 and Season 2 (Fourth method)

CROP PATTERN: **3** SEASON: **2**METHOD: **EQUALIZE YIELD**

MIN. WATER REQUIRED: **86.07** Ha-m. MAX. WATER REQUIRED: **172.15** Ha-m.

	I	II	III	IV
STAGE WISE DEFICIT IN %:	20.00	20.00	20.00	20.00

SN	CROP	Dia1 %	R1	Dia2 %	R2	Dia3 %	R3	Dia4 %	R4	R TOTAL	PROFIT In Rs.
1	Sorghum	30.03	0.94	29.30	0.84	21.41	0.90	22.36	0.96	0.6822	555982
2	Maize	15.01	0.94	10.74	0.84	19.27	0.90	22.36	0.96	0.6822	855586
3	Groundnut	30.03	0.94	20.14	0.84	16.06	0.90	22.36	0.96	0.6822	445633
4	Sunflower	20.02	0.94	16.11	0.84	12.04	0.90	22.36	0.96	0.6822	360964
5	Pulses	30.03	0.94	20.14	0.84	9.63	0.90	22.36	0.96	0.6822	151670
6	Vegetables	15.01	0.94	14.65	0.84	12.04	0.90	11.18	0.96	0.6822	140644
7	Cotton	12.01	0.94	32.23	0.84	38.54	0.90	17.89	0.96	0.6822	1239512
8	Chillies	8.58	0.94	23.02	0.84	24.09	0.90	11.18	0.96	0.6822	538063
9	Turmeric	7.51	0.94	20.14	0.84	19.27	0.90	8.94	0.96	0.6822	229831

TOTAL WATER ALLOCATED In Ha-m. = 137.72; **TOTAL PROFIT In Rs.** = 4517885

Water allocation and profits, the comparison of profit in Rupees per unit water and reduction of profit in % for two approaches (Maximize Profit and Equalize Yield) for season wise and stage wise calculations for different cropping patterns have also been computed for existing areas cropping patterns CP-1, CP-2 and CP-3 and crop seasons 1 and 2 for 5%, 10%, 15% and 20% deficit water in the canal.

Using the developed methodology water allocation is calculated for the study area and all the three cropping patterns. Water is allocated by using four methods in each crop growth stage for different crops in three cropping patterns and two crop seasons for 5%, 10%, 15% and 20% shortage of the water in the canal. The depth of irrigation can be revised; a sample revised irrigation scheduling is presented in Table 5.

Table: 5.71 Revised Scheduling of Irrigation for CP-3 for 20% Shortage of Water in the Canal (First Method)

Name of the crop (season shown in brackets)	Period of growth	Watering dates	Depth of irrigation (mm)	Depth of Deficit (mm)	Revised depth of Irrigation (mm)
Sorghum (Kharif)	16th June to 5th July 6th July to 15th Aug. 16th Aug. to 25th Sep 26th Sep. to 25th Oct.	16/6,23/6/03 6/7/03 16/8, 8/9/03 26/9, 20/10	20.25 48.94 91.63 101.25	00.00 00.00 00.00 00.30	20.25 48.94 91.63 100.95
Groundnut (Rabi)	16th Oct. to 5th Nov. 6th Nov to 15th Dec. 16th Dec. to 25th Jan 26th Jan. to 15th Feb.	16/10/03 6/11,14/11,23/11,2/12, 12/12 16/12, 1/1,14/1 26/1/04	20.25 32.62 61.09 67.50	10.12 16.31 30.54 33.75	10.13 16.31 30.55 33.75
Cotton (Two season)	1st July to 31st July 1st Aug to 5th Oct. 6th Oct to 5th Dec. 6th Dec to 31st Jan.	1/7/03 1/8, 9/9/03 6/10,11/11,30/11 6/12, 6/1/04	20.25 69.99 107.55 108.00	00.00 00.00 00.00 00.00	20.25 69.99 107.55 108.00

Conclusions

- Four methods are developed for multi crop allocations during deficit water conditions. In the present study deficit up to 20% in the canal water for maximizing profits to the farmers as well as to achieve equal relative yield are adopted.
- For first and third methods, an increasing trend is observed for the profit per unit water with increasing deficit.
- For the fourth method, profit per unit water decreases with increasing deficit.
- At this stage of the study nothing can be said about in the second method and this needs further investigations.
- An approach has been developed for maximizing profit and equalizing relative yield for crop season wise and crop stage wise shortage of water. It was observed that the difference in profits for various percentage of deficit in the canal (5%, 10%, 15% & 20%) is very insignificant, the lowest value (5%) being 1.84% and the highest value (20%) being 21.3%. this indicates that the two objectives of maximizing profit and equalizing relative yield do not make much difference in the profit per unit water for the farmer.
- For the three recommended cropping patterns and for maximum permissible deficit (20% in the present study) the reduction in profit varies from 7.15% to 9.28% for equal yield conditions when compared to maximum profit condition for season wise studies. For the stage wise studies, the reduction in profit varied from 15.62% to 21.3%.

References

- Bhaskar Rao K. and S. Ramaseshan (1978), "Digital simulation of watersheds", Technical Report, Department of Civil Engineering IIT Kanpur.
- Bishop A.A. and A.K. Long (1983), "Irrigation water delivery for equity between users", *Journal of Irrigation and Drainage Engineering,* ASCE, Vol. 109, No.4, pp.349-356.
- Bos M G, D.H. Murray-Rust, D.J. Merry, H.G. Johnson and W.B. Snellen (1994), "Methodologies for assessing performance of irrigation and drainage management", *Irrigation and Drainage Systems*, Vol.7, pp..231 – 261.
- Doorenbos, J. and A, H, Kassam, "Yield Response to Water", FAO Irrigation and Drainage, Rome Italy, 1979.
- Goodwin I. and A.M. Boland (2000) "Scheduling deficit irrigation of fruit trees for optimizing water use efficiency", *Deficit Irrigation Practices – Water Reports- 22" FAO Corporate Document Repository.*
- Hajilal M.S, N. H. Rao and P.B.S.Sarma (1998). "Planning intraseasonal water requirements in irrigation projects", *Agricultural water Management* Vol. 37, pp. 163 – 182.
- Hajilal M.S, N.H Rao and P.B.S Sarma (1998)."Real time operation of reservoir based canal irrigation systems" *Agricultural Water Management* Vol. 38, pp103 -122.
- Hal Werner "Measuring soil moisture for irrigation water management" http://www.agbiopubs.sdstate.edu/articles/Fs876.
- Hill, R.W. and R.G. Allen (1996). "Simple irrigation scheduling calendars." *Journal of Irrigation and Drainage Engineering,* ASCE, Vol. 122, No.2, pp.107 – 111.
- Kerry Harrison and Anthony Tyson "Irrigation scheduling methods" http://www.engr.uga.edu/service/extension/publications/b974-cd.

- Kirda C. (2000) "Deficit irrigation scheduling based on plant growth stages showing water stress tolerance", *Deficit Irrigation Practices – Water Reports- 22" FAO Corporate Document Repository*.
- Michael A. M. (1992), "Irrigation Theory and Practice", Vikas Publishing House, New Delhi.
- Playan, E., W. R. Walker and G. P. Merkley (1994) "Two dimensional simulation of basin irrigation." *Journal of Irrigation and Drainage Engineering*, ASCE, Vol. 120 No. 5, pp. 857-870.
- Rafael L., R.L. Bras and J.R. Cordova (1981). "Intraseasonal water allocation in deficit irrigation." *Water Resources Research*, vol. 17, No. 4. pp. 866 – 874.
- Rao, N. H. and P.B.S.Sarma (1990). "Optimal multicrop allocation of seasonal and intraseasonal irrigation water." *Water Resources Research*, Vol. 26, No. 4. pp.551 – 559.
- Robert W. Hill and G. Allen Richard (1996), "Simple irrigation scheduling calendars", *Journal of Irrigation and Drainage Engineering*, ASCE, Vol. 122, No.2, pp.107-111.
- Smart, G.M. (1983), "Drought analysis and soil moisture predication", *Journal of Irrigation and Drainage Engineering*, ASCE, Vol. 109, No.2, pp. 251-261.
- Umamahesh, N. V., (1994), "Optimal Planning and Operation of Irrigation Reservoirs under Multi-crop Environment," Ph.D. thesis submitted to Kakatiya University, Warangal.
- Vedula S. and Mujumdar P. P. (2005) "Water Resources Systems" Tata McGraw-Hill Publishing Company Limited, New Delhi.
- Wambeke (2000) Department of crop and soil sciences cornel university, Ithaca, NY USA "The Newhall Simulation Model for estimating soil moisture & temperature regimes".
- Walker W. R. "Guidelines for Designing and Evaluating Surface Irrigation Systems" FAO Irrigation and Drainage Paper 45, Rome Italy, 1989.
- Walter L. Trimmer (1990) "Applying partial irrigation in Pakistan", *Journal of Irrigation and Drainage Engineering*, ASCE, Vol. 116, No.3, pp. 342-353.