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OPTIMAL IRRIGATION ALLOCATION OF WATER FOR THE COMMAND AREA OF AN IRRIGATION PROJECT

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Abstract

This study is focused on creating a process for optimizing water allocation to different crops at different times so that the yield reaches its greatest value accepting the help of root growth model (RGM) and Relative yield to determine the best way to distribute crop water from an irrigation reservoir using a root growth model and stochastic dynamic programming. The water depth for maintaining the soil moisture above the critical moisture limit by using root growth model and stochastic dynamic programming (SDP) finding is cropping for onion, gram, potato, vegetable, and wheat 440mm, 350mm, 250mm, 215mm, and 360mm respectively. On the application of soil moisture balance study and root growth model, the percentage saving of water for different crops i.e. onion, gram, potato, vegetable, and wheat are as 2.20%, 1.70%, 14.97%, 5.70%, and 6.49% respectively. Scheduling of water can be made using weekly water demand considering the root growth model for the command area of the project. The results of the study show that the optimal utilization water can help increase the area for seasonal crops i.e. rabi crop for increasing crop production or gaining maximum yield. Thus for each farmer, profit becomes the key objective that wishes to maximize.

Keywords: Crop Coefficient, Root Growth Model(RGM) , Potential Evapotranspiration, Actual Evapotranspiration, Water Allocation

1. Introduction

India produces most of its food through irrigated agriculture. By 2050, there will be 3.7 billion more people on the planet than there are now (Wallace, 2000), which means that freshwater resources will be under even more stress from the extra food needed to feed future generations. This is because 75% of the freshwater used by humans today is used for agriculture, making it the single largest user. The two main issues that irrigation scheduling addresses are when and how much to water. Once a sufficient water supply is guaranteed, irrigation schedules can be programmed to saturate the crop root zone depth up to the field capacity based on how long it takes the soil to decrease to a critical level. This kind of irrigation that the crop will develop at its maximum rate, given that all other inputs are applied at the best possible rates. Water deficits throughout different seasons of the crop are unavoidable when the available water is insufficient to meet the crop's water demands for that season. The decision of irrigation managers regarding how effectively to distribute water deficits throughout the intra-seasonal periods for a crop becomes crucial.

To optimize profit, reservoir managers and farmers in the semiarid regions of the choral region have completed to choose the best planting pattern and irrigation schedule for each crop-soil condition due to the restricted availability of canal water and little rainfall. The purpose of this specific study is to support farmers and reservoir management in their decision-making. Based on the grouping of canal outlets and priority sequences, a rotational system of canal regulation is implemented in these locations. For a set amount of time, the priority outlets receive a full supply level, while the second priority outlets may receive a half supply level. In these outlets, the length of supply is determined by the area that is planted, not by the amount of water required for the crops. Farmers divide their land among different crops according to the availability of canal water. The reservoir's storage capacity affects the canal discharge as well, but it is not influenced by the need for irrigation at sea level.

In the first stage, the seasonal production for each crop are calculated using an SDP technique to maximize the crop's predicted relative output for a given seasonal water supply. To optimize net benefits from crop-facing variable evapotranspiration demands, Rhenals and Bras (1981) devised a model called stochastic dynamic programming (SDP). The model accounts for the weekly variability in crop evapotranspiration and reservoir water discharge. Several values of seasonal water availability, from zero to the highest practical irrigation need for each crop under consideration, are tested at this specific stage multiple times. With the aid of the sigmoidal root growth model, this depth rises with crop growth and reaches its maximum value by the end of the flowering season for the majority of crops (Borg and Grimes, 1986). Several studies have examined the optimal distribution of water. These include Smith et al. (1992), which found that the Penman-Monteith method consistently estimates evapotranspiration (ETo) and outperforms other methods when compared to lysimeter data; English et al. (1989) proposed that irrigation frequency and deficit irrigation affect wheat yields. (Gorantiwar et al. 2003) suggested employing deficit irrigation in rotational systems to distribute limited water resources. The current regulations for water allocation in semiarid tropical regions, which include deficit irrigation schemes with rotational irrigation systems, are predicated on applying a constant depth of water during irrigation, regardless of the crops' growth phases or the soils they are planted on.To maximize the use of water and land resources as well as irrigation supplies for tertiary units in big irrigation schemes, (Gorantiwar et al., 2005) implemented a multilayer method. According to Paul (1998), the majority of farming scenarios involve growing many crops during a single season. When considering a multi-crop situation, it is important to take into account the distribution of land and water resources. The main drawbacks of the mathematical programming model (MPM) developed by Vedula and Kumar (1996) are its specific rules, lack of information or data monitoring, and process simplification. The best cropping pattern and seasonal distribution of water to various crops are determined by the Root Growth Model (RGM) formulation and with the help of SDP. The land and water to be allotted to each crop at a given time are the decision factors in RGM.

The objectives of the present work are for the agricultural management system to tackle the issues of crop water allocation, crop productivity maximization, and profit maximization. Determining the ideal water allocation for every crop is the aim of this study. Low irrigation frequencies did not further diminish yields under deficit irrigation; the maximum yields were obtained with a relatively lengthy irrigation interval of week-wise.

2. Study Area

Choral River a tributary of River Narmada originates from Vindhyan ranges and flows through Indore and Khargone districts. The Choral reservoir is located in Rampuriya village under Mhow Tehsil of Indore district. The latitudes and longitudes of the study area are 75°46’N and 22°25’E respectively. Water requirements of each stage differ as the growth rate differs from one stage to the other.

3. Methodology

3.1 Model Formulation

For all of the crops cultivated in the research region, the model is designed to provide the best irrigation schedule and water allocation. The present study's intricacies are too numerous to take into account in a single-level method. For example, the "curse of dimensionality" will prevent the problem from being solved as stated if a single stochastic optimisation technique, such as SDP, is applied. The multilevel strategy produces the best results. The fundamental components of the multilevel technique consist of two parts: (1) an RGM for the overall depth of water allocation for all crops, and (2) an SDP solution for the weekly intra-seasonal allocation for an only crop. The schematic representation of the entire process is displayed in Fig. 1.

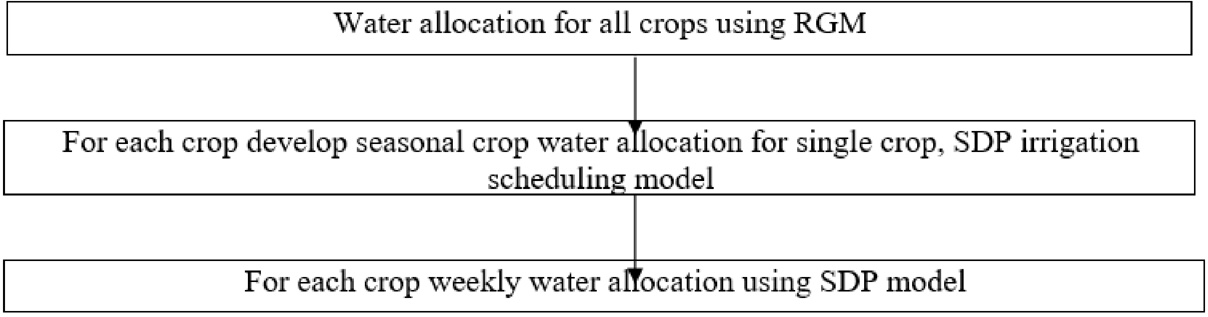

Fig. 1- Schematic of Multilevel Break-up Procedure

A crop's development and output are significantly influenced by the amount of water given to during irrigation seasons. Every crop receives the appropriate quantity of water for maximum growth and output. Applying the appropriate amount of water to crops to meet their needs is crucial when there is an adequate supply of water. In instances where crop growth phases are interrupted by insufficient water availability, the real transpiration rate will decrease below the maximum rate. Main the reason we chose this study area: under this situation, water stress will develop in the crop and negatively impact crop growth and yield. Furthermore, this study used models RGM and SDP for the allocation of water according to the utility of the crop to gain maximum production. Using these acquired data, the required parameters of the Penman-Monteith method i.e. ET0 have been calculated. Using the Food Agricultural Organization (FAO)-56 value of Kc has been calculated. Based on these computations, an assessment of ETc by the Penman-Monteith method & net irrigation requirement at the Canal head has also been calculated. For calculation of the maximum yield methodology proposed by “Food Agricultural Organization FAO 33” has been used. Optimal allocation of water for agricultural management has become very essential nowadays, particularly in the Indian agricultural context. The root growth model as it incorporates the depth of water with the crop growth has an edge over the other models and has been used in the present study for the optimal allocation of water for agricultural management in an irrigation project. Firstly we evapotranspiration rate from a reference surface evapotranspiration value (ETo) with the use the meteorological data (i.e. wind speed, maximum temperature, minimum temperature, relative humidity, Sunshine hour, and Radiation)or used all parameters to calculate the ETo. Further to calculate the potential evapotranspiration (PET) for each crop and calculate the root growth depth. Further calculation of the actual evapotranspiration (AET) in each fortnight wise, soil moisture balance for the root zone depths in the different periods. This study collects to need for further calculations of all data i.e. meteorological data (Min temp, Max temp, Humidity, Wind Speed, Sunshine & Radiation), depletion factor, and crop coefficient (Kc) from the sources.

3.2 Soil Moisture Balance

In the research area, there is little rainfall. Bunds surround the land as well, preventing runoff from this little rainfall. The soil's moisture balance equation can be expressed as follows, taking into account the general mass balance equation and ignoring the runoff from the field.

$$\mathrm{SM}_{t+1}\,\mathrm{Z}_{t+1} = \mathrm{SM}_{t+1}\,\mathrm{Z}_{t} + \mathrm{x}_{t} + \mathrm{S}_{0}(\mathrm{Z}_{t+1} - \mathrm{Z}_{t}) - \mathrm{AET}_{t} \qquad (1)$$

Where,

Z_t and Z_{t+1} = root zone depths in the periods t and t+1 respectively (cm);
x_t =water allocation in period t (mm)
S_0 = initial soil moisturecontent (mm/cm)
SM_t = soil moisture content in depth units per unit root depth in period t (mm/cm)

3.3 Potential Evapotranspiration

The potential evapotranspiration is given by

$$\mathrm{PET} = \mathrm{K}_{\mathrm{C}} \times \mathrm{ET}_{0} \qquad (2)$$

Where,
PET = Potential evapotranspiration
K_c = Crop coefficient
ET_O = Reference crop evapotranspiration

Whether there is enough water available in the root zone or if the crop will experience stress from a water deficiency determines the actual evapotranspiration potential rate.

3.4 Root Growth Model

The effective depth of root penetration into the soil determines the depth of the active soil reservoir, from which the crop takes water. This depth rises with crop growth and reaches its maximum value by the end of the flowering period for the majority of crops. In this investigation, a root growth model (Borg and Grimes 1986) is applied:

$$Z_t = Z_{max}\left(0.5 + 0.5\sin[3.03(\frac{t}{t_{max}}\right) - 1.47]) \quad (3)$$

Where,
Z_t = depth of effective root zone at time t after sowing (cm)
t_{max} = time for the full development of root zone (days)
Z_{max} = maximum possible depth of effective root zone (cm)

2.4 Actual Evapotranspiraton

The effective depth of root penetration into the soil determines the depth of the active soil reservoir, from which the crop takes water. This depth rises with crop growth and reaches its maximum value by the end of the flowering period for the majority of crops. In this investigation, a root growth model (Borg and Grimes 1986) is applied:

AET,

$$0; SM_t < WP_t \quad (4)$$

$$\frac{PETt(SMt-WP)}{(1-p)(FC-WP)}; \mathrm{WP} < SMt \le (1-\mathrm{p})(\mathrm{FC}-\mathrm{WP})$$

$$PET_t; SM_t \ge (1-p)(FC-WP)$$

Where,
SM_t = soil moisture content in depth units per unit root depth in period *t* (mm/cm),
FC= field capacity (mm/cm)
WP = wilting point (mm/cm), *p* = crop water depletion fraction

Actual crop evapotranspiration depends on the evaporative demand of the atmosphere, the crop growth stage, and the available soil moisture in the root zone. The ET_o value i.e. the value of evapotranspiration for the project area for each month has been worked out using Penman Monteith method by using CROPWAT Software.

3.5 The Relative Yield Ratio and The Objective Function

The relative yield for each crop is expressed as:

$$R_t^*(x_t\,, AET_t) = 1 - [K_t(1 - \left(\frac{AET}{PET}\right) t] \quad (5)$$

Where,
$R^*(x_t, AET_t)$ = relative yield corresponding to x_t irrigation depth and the given AET
x_t = water allocation in period *t* (mm); *t* = index for period

In the present study for each of the crops for each fortnight the maximum relative yield ratio is taken as the objective function for individual season. The overall objective function used in the present study for the complete growth season of a crop is the product of all the relative yield ratios as given by (Rao et al., 1990).

$$\frac{Y_a}{Y_{max}} = \prod_{t=1}^{NP}\left[1 - k_t\left(1 - \frac{AET}{PET}\right) t\right] \quad (6)$$

Where,
Y_a = Actual yield obtained (100 kg/ha);

Y_{max} = maximum obtainable yield (100 kg/ha);
k_t = yield stress sensitivity factorfor period *t*
AET = actual evapotranspiration (mm);
PET =potential evapotranspiration (mm);
t = period index; and NP = total number of periods for the crop

4. Result & Discussion

This study used all data i.e. meteorological data, depletion factor, and crop coefficient (Kc) from the sources. We calculate or develop all meteorological data for the calculation of Monthly ET0 Penman-Monteith. We took all the metrological data and then prepared it every month by taking the average of daily data as per the requirement of the cropwat model.

4.1 Effect of time on crop coefficient

The crop coefficient (Kc) an important factor for evaluating crop evapotranspiration, is defined as the ratio of actual crop evapotranspiration(AET) to reference crop evapotranspiration (ETo). The crop coefficient changes for four stages Initial crop, development crop, mid-season crop, and late-season crops.

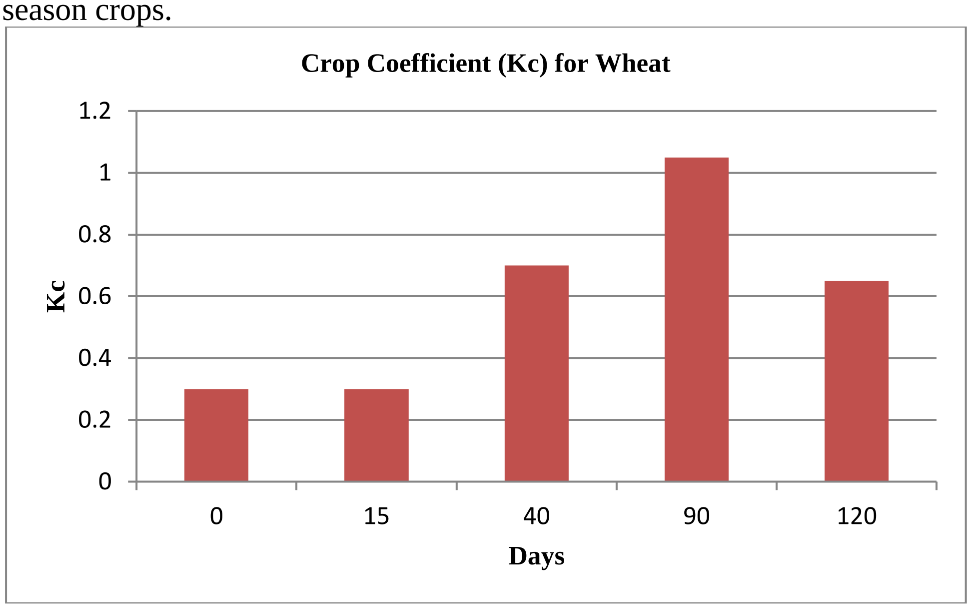

Figure 2: Crop coefficient day wise for wheat crop

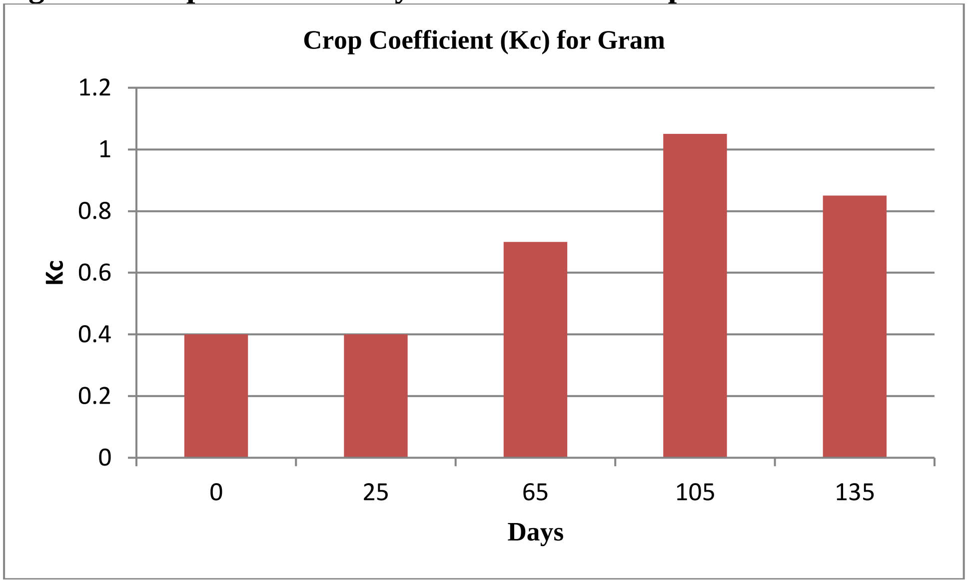

Figure 3: Crop coefficient day wise for gram crop

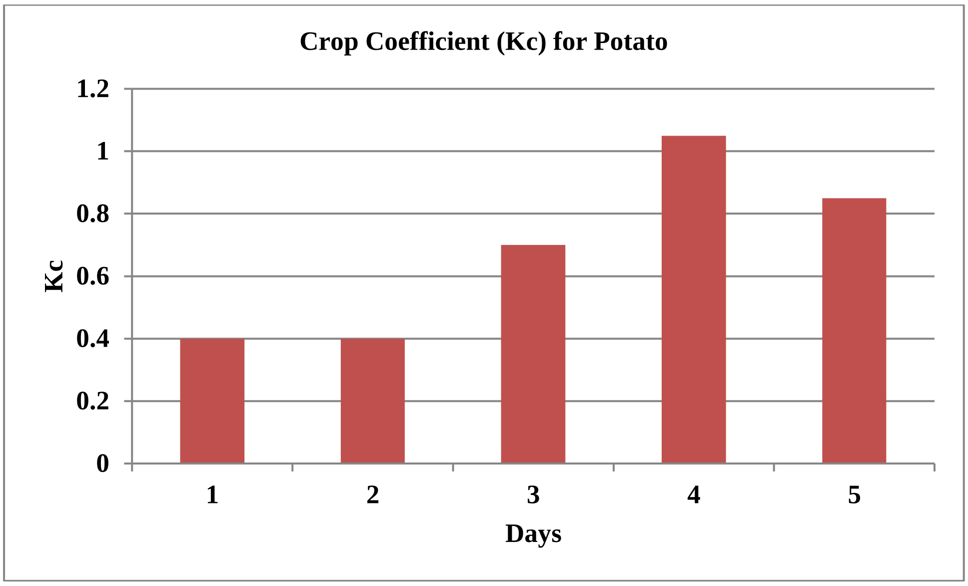

Figure 4: Crop coefficient day wise for Potato crop

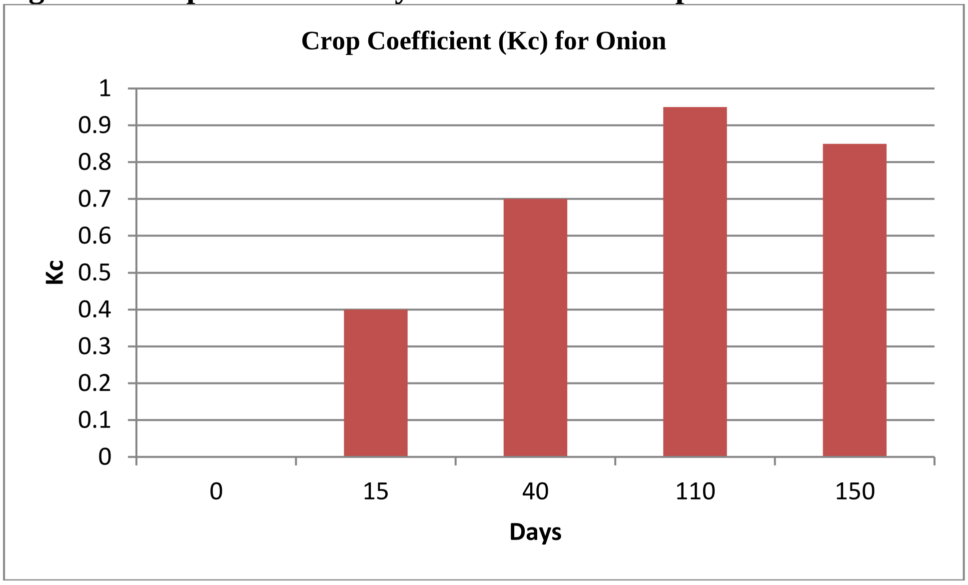

Figure 5: Crop coefficient day wise for Onion crop

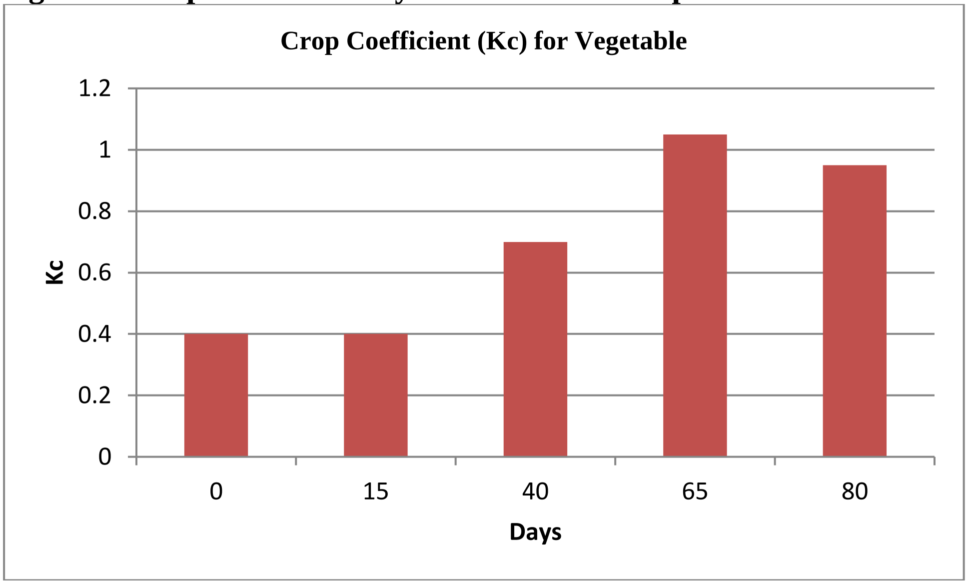

Figure 6: Crop coefficient day wise for Vegetable

4.2 Effect of time on root growth model

Firstly calculate the ETo using monthly average data, potential evapotranspiration is calculated with the help of crop coefficient and evapotranspiration. Root zone depth computes the maximum feasible depth of the effective root zone, the duration in days that the root zone will fully develop, and the depth of the root zone at time t after planting. Deep percolation, or the movement of water downward through the soil profile below a plant's effective rooting zone, as well as rainfall, water allocation, and initial soil moisture content are used to determine the soil moisture balance. The SDP model's weekly canal release and evapotranspiration. For every week that corresponds to all canal release levels and real evapotranspiration, the relative yield is calculated. The goal of SDP is to maximize relative yields' expected value.

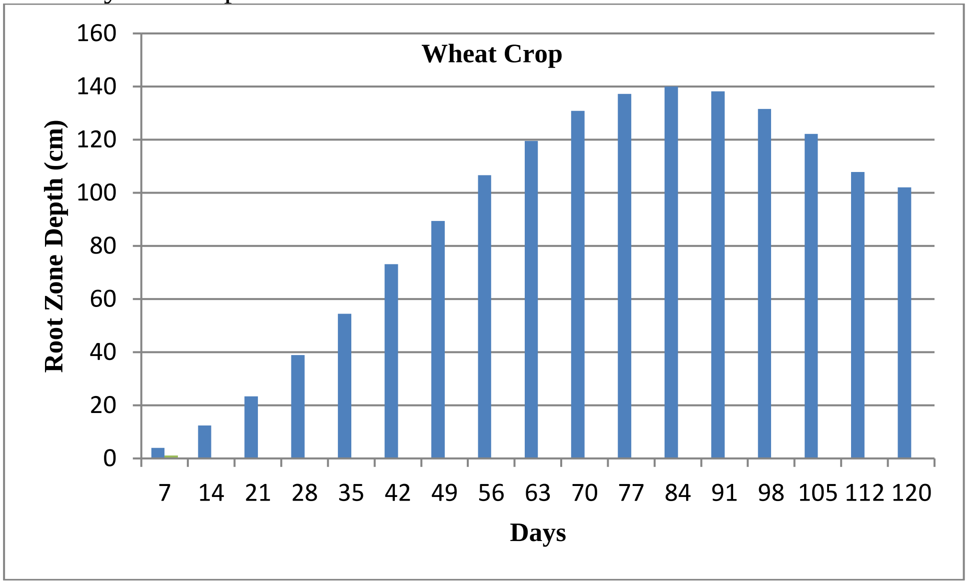

Figure 7: Depth of effective root zone at different time interval after showing for wheat crop

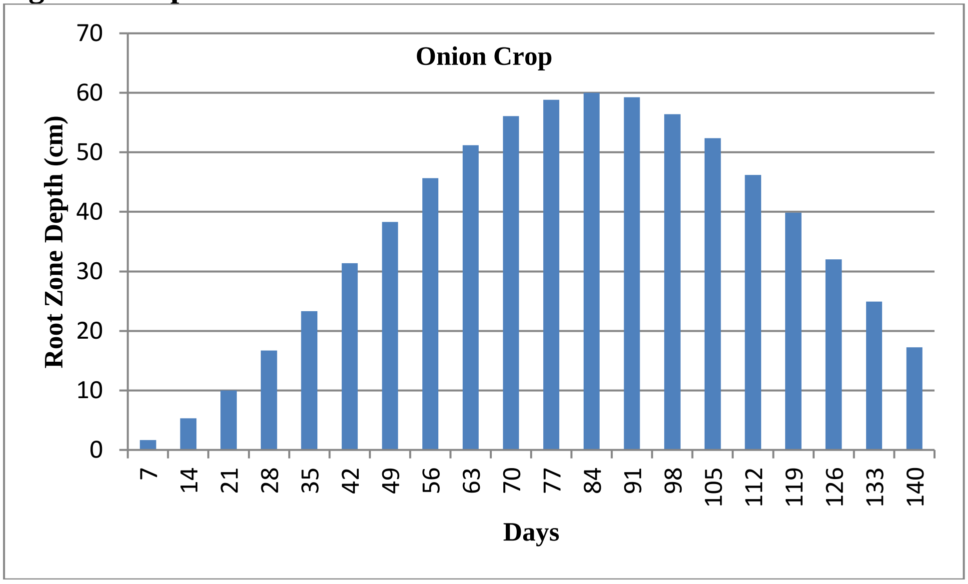

Figure 8: Depth of effective root zone at different time interval after showing for onion

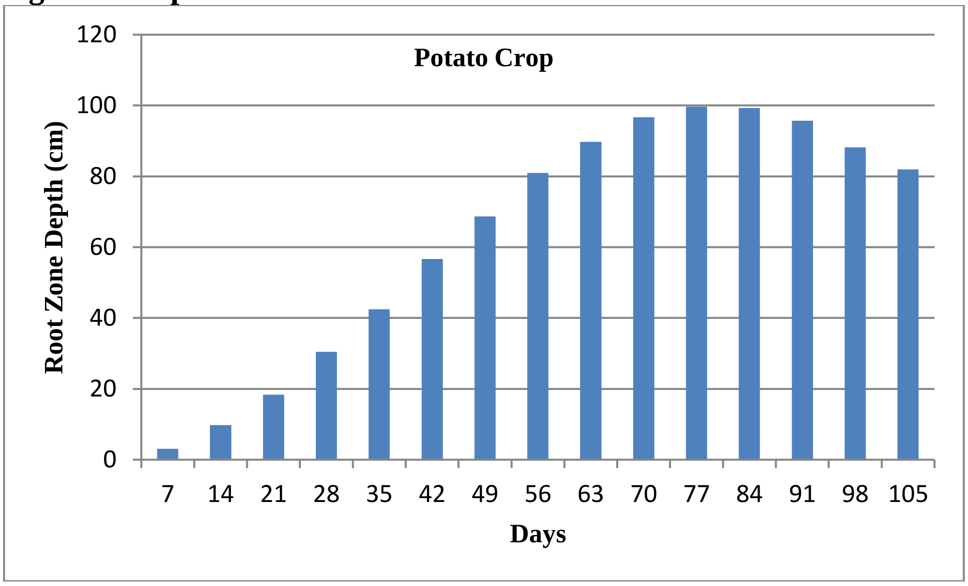

Figure 9: Depth of effective root zone at different time interval after showing for Potato

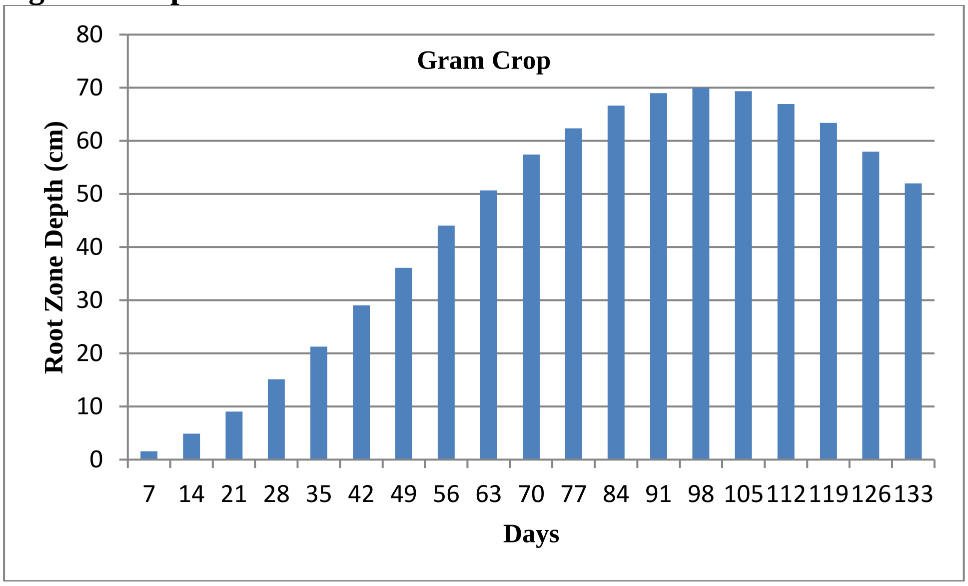

Figure 10: Depth of effective root zone at different time interval after showing for gram crop

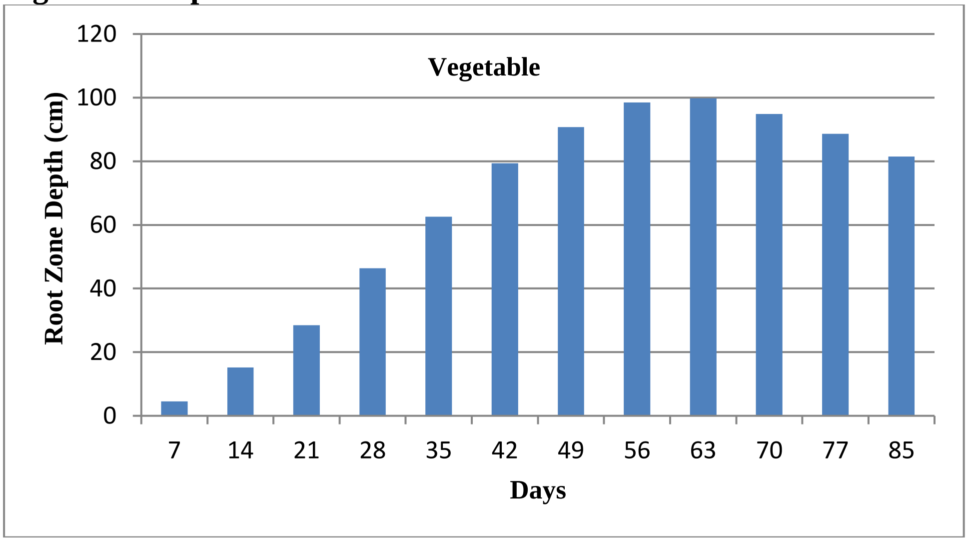

Figure 11: Depth of effective root zone at different time interval after showing for vegetable

By using the soil moisture balance study and the root growth model, the required water depth is calculated for maintaining the soil moisture above the critical moisture limit. The detailed calculations every week for each of the crops. The main criterion for keeping the soil moisture close to the critical limit was adopted to maintain the relative yield ratios equal to 1. The final results or main findings of the model application for the water allocated to crop at the field Onion, Gram, Potato, Vegetable, and Wheat water allocated to crop at the field are 440mm, 350mm, 250mm, 215mm, and 360mm respectively. Further, we have a comparison of crop water requirement by conventional method and RGM are findings 2.20%, 1.70%, 14.97%, 5.70%, and 6.49% of water savings and gain maximum yield of each crop.

It is estimated that the farmer provides water to the field in a limited manner, due to which sometimes the crop gets more water and at other times it gets less water. Therefore, with the help of the root growth model and stochastic dynamic programming, we watered all the crops according to the requirement of a certain amount of field capacity and we gave water to all the crops and got maximum production or maximum yield.

As per the literature, various research for maximum yield for different crops like cotton, maize, wheat, sunflower, sugar beet, etc. using different methods or models like cropwat model, linear programming and many other methods have been used. Therefore we have been stochastic dynamic programming and root growth model and get better results than other models for different crops and gain maximum yield with the help of these models.

5. Conclusion

The main findings are the water depth for maintaining the soil moisture above the critical moisture limit by using soil moisture balance and root growth model is 440 mm for crop onion, 350 mm for gram, 250 mm for potato, 215 mm for vegetable, and 360 mm for wheat, which is less than the water depth required as calculated by conventional method for irrigation supply for crop. On the application of soil moisture balance study and root growth model, the percentage saving of water for different crops i.e. onion, gram, potato, vegetable, and wheat are as 2.20%, 1.70%, 14.97%, 5.70%, and 6.49% respectively. For the potato crop, the maximum percentage saving of water concerning the other crops is obtained. The saved water can be used for irrigation of additional land, which will result in an increase in the overall production of crops under the project.

Scheduling of water can be made using the weekly water demand considering the Root Growth model for the command area of the project. Similarly, we can do water allocation for other crops with the help of using this model. So that water can be saved and farmers can produce more and more crops and similar studies can be conducted for other irrigation projects. Presently we have done it for five crops in the rabi season but the farmer can do the same for more crops in both seasons like the rabi and kharif season. With the help of this model, farmers will produce maximum production of crops and save water.

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