Novateur Publication's
International Journal of Innovation in Engineering, Research and Technology [IJIERT]
ICITDCEME'15 Conference Proceedings
ISSN No - 2394-3696

DSS-IWM: A FARM LEVEL DECISION SUPPORT SYSTEM FOR IRRIGATION WATER MANAGEMENT

S. A. Kadam
Assistant Professor Department Of Irrigation And Drainage Engineering
Mahatma Phule Krishi Vidyapeeth, Rahuri-413 722

M. A. Tamboli
Vishwabharati Academy's College Of Engineering, Ahmednagar
Savitribai Phule Pune University, Pune

S. D. Gorantiwar
Professor And Head
Department Of Irrigation And Drainage Engineering
Mahatma Phule Krishi Vidyapeeth, Rahuri-413 722

P. C. Jayapal
Sr. Software Engineer, Bangalore.

IJIERT-ICITDCEME'15

ABSTRACT
A farm level irrigation water management decision support system (DSS-IWM) was developed based on Soil Water Balance-Crop Yield Benefit (SWAB-CRYB) model, crop penology model, root growth model, crop yield response function, soil parameters, weather data and irrigation management strategies. The DSS-IWM needs four input data files related to crop, soil, climate and irrigation strategies. In DSS-IWM Penman-Monteith method was used to estimate crop water requirement considering daily crop coefficients. Soil water balance was carried out to obtain actual crop evapotranspiration (ETa), using linear root growth model. Actual crop yield was estimated with crop yield response models incorporating crop growth stages and response of water stress to each crop growth stage. Economic model was developed to estimate net benefits from farms. DSS-IWM enables the estimation of soil moisture in the root zone, actual evapotranspiration and return flow to the groundwater due to irrigation in terms of deep percolation, crop yield and net benefits by simulating the different processes responsible for soil water balance in the root zone. The DSS-IWM can be used for evaluation of effect of certain irrigation plan on crop yield reduction. A case study of wheat crop irrigation water management by DSS-IWM showed its practical value and benefits. It could be an objective oriented and practical irrigation water management decision-making tool.
KEY WORDS: Farm level, Irrigation water management, Decision support, Soil water balance and Model

INTRODUCTION
The decision support system (DSS) is essential for enabling the decision makers/policy makers to take appropriate decisions by screening various possibilities for making optimum and sustainable management of irrigation water. The definitions of DSS provided in the literature range from that any computer based system that supports decision making to the other extreme where a DSS is considered to be a system which has modelling capabilities and is used by decision makers to solve unstructured problems (Walsh, 1993., Kersten and Micalowski, 1996., Ewing et al. 1997 and Reitsma, 1996). A more general definition is given by Densham and Goodchild (1989) as 'computer based simulation models designed to enable the user to explore the consequences of potential management options'. A DSS supports technological and managerial decision making by assisting in the organization of knowledge about ill-structured, semi-structured or unstructured issues.

There are many mathematical programming and optimization techniques like Linear programming model, Dynamic programming model, Goal programming, Hierarchical programming, Simulated programming and Genetic algorithm which optimize certain objectives defined by users/decision makers (Galgale, 2006). The objectives can be structured and unstructured problems. A structured problem is one which can be broken down into a series of well-defined steps. The structured problem can be solved by the optimization techniques. An unstructured problem requires the use of intuition, reasoning and memory. An unstructured problem can be solved by Decision support system. Here irrigation water management is found to be structured problem and solved by decision support system. Hence taking a new step of solving structured problem in irrigation water management using the Decision Support System, the decision support system for efficient irrigation management at the farm level is developed based on the Soil Water Balance and Crop Yield Benefit model developed to produce the best results.

The DSS-IWM enables the estimation of soil moisture in the root zone, actual evapotranspiration; return flow (deep percolation) to the groundwater due to irrigation, crop yield and net benefits. The estimation of the moisture content in the root zone and yield need the appropriate representation of the system related to crop, soil and climate. Therefore, in this study the SWAB-CRYB simulation model developed by Gorantiwar (1995) and Gorantiwar and Smout (2003) and the modSWAB-CRYB model (Gorantiwar, 1995 and Palkar, 2011) that makes use of NDVI value derived from spectroradiometer and remote sensing data for the estimation of crop coefficient were used for developing DSS-IWM at farm level.

SYSTEM DESIGN AND PRINCIPLE

A well equipped DSS-IWM is developed in this study for efficient irrigation management at the farm level. The decision support system is based on the SWAB CRYB model developed by Gorantiwar (1995) and Gorantiwar and Smout (2003). The DSS-IWM system is developed by using Visual Basic.NET 2010 and run on the Windows platforms. The procedure and methodology followed for the development of the DSS-IWM are described in Fig. 1. While developing the DSS-IWM following options of the SWAB-CRYB model are not used.

1. Separation of actual soil evaporation and actual transpiration from actual crop evapotranspiration
2. Layer wise heterogeneity in soil
3. The division of entire root zone depth into different sections called as extraction layers to consider root lengthwise moisture extraction patterns
4. Pre-sowing irrigation

In DSS-IWM, all the important processes involved in the simulation are considered from SWAB-CRYB model. In DSS-IWM, Penman-Monteith method was used to estimate crop water requirement considering daily crop coefficients. Crop evapotranspiration values were estimated by determining crop coefficient values using FAO tabulated Kc, daily Kc, Kc from polynomial equation and Kc-NDVI relationships developed in this study. Soil water balance was carried out to obtain actual crop evapotranspiration (ETa), using linear root growth model. Actual crop yield was estimated with Stewart, et al. (1976) and Stewart and Hagan (1973) crop growth model incorporating crop growth stages and response of water stress to each crop growth stage. Economic model was developed to estimate net benefits from farms. This DSS-IWM enables the estimation of soil moisture in the root zone, actual evapotranspiration and return flow to the groundwater due to irrigation in terms of deep percolation, crop yield and net benefits. The DSS-IWM needs four input data files related to crop, soil, climate and irrigation strategies. The DSS-IWM provides the detailed output of daily values of different parameters (reference crop evapotranspiration, maximum crop evaporation, crop coefficient, normalized difference vegetation index, root zone depth, moisture content in soil root zone etc., and the yield and cost related parameters) by simulating the different processes responsible for soil water balance in the root zone. The DSS-IWM can be used for screening different irrigation strategies.

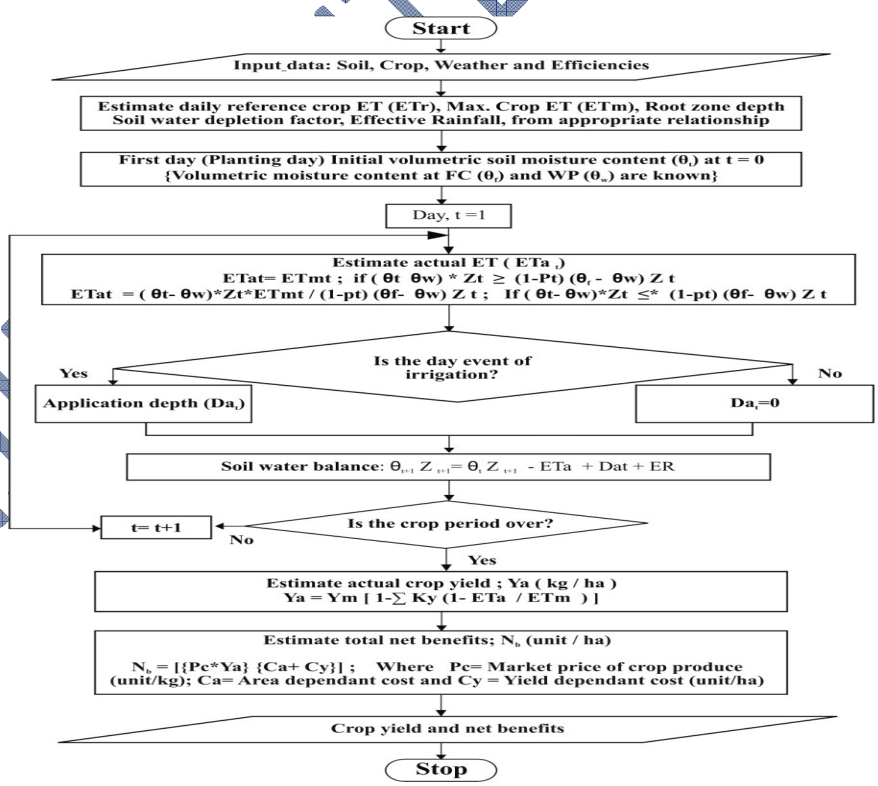

Figure 1 Flow chart of SWAB-CRYB model (Gorantiwar, 1995 and Gorantiwar and Smout, 2005)

MAIN FUNCTIONS

DSS-IWM is designed for all season crops (Kharif, Rabi, Summer, Perennial) to provide a practical decision tool for irrigation water management. The main functions includes: (1) crop module to input crop phenology, (2) soil module to input soil characteristics and parameters data, (3) weather module to estimate reference crop evapotranspiration during crop growth period, (4) Irrigation module to evaluate crop water requirements and to make irrigation plans based on historical and real time weather data, (5) simulation module to simulate daily change of soil moisture content in the root zone, (6) crop yield- benefit module to estimate crop yield and net benefits.

MAIN FUNCTION MODULES

DSS-IWM combines environmental conditions like climate and soil with crop growth characteristics as a whole, and was established through soil water balance model, crop phenology model, root growth model, crop yield response model and irrigation decision making model.

SOIL WATER BALANCE MODULE

Soil water balance model can reflect the dynamics of soil water content in the root zone and can be expressed as flow equation as;

$$RFe_{t-1} + ID_t = ETa_{t-1} + DP_t \pm \Delta\theta_t$$

Where,

RFe_t = effective Rainfall in mm for t th day (mm)

ID_t = depth of irrigation on t th day (mm)

ETa_t = actual evapotranspiration on t th day (mm/day)

DP_t = deep percolation losses on t th day (mm)

$\Delta\theta_t$ = change in soil moisture storage from (t-1) th day (mm)

INITIAL SOIL WATER DEPELTION

The initial soil moisture is assumed at field capacity, 50 % available moisture and wilting point for the planting in rainy (kharif), winter (rabi) and summer (hot weather) seasons, respectively when pre-sowing irrigation is not performed. If the pre-sowing irrigation is performed, the soil moisture contents before pre-sowing irrigation is assumed at wilting point or according to the input in the model. The initial soil moisture is computed by carrying out a water balance over the period from pre-sowing irrigation to first crop irrigation. The depth of presowing irrigation is either given or computed in the model so that soil moisture content at the presowing irrigation is brought to field capacity and by adjusting it for application efficiency and minimum and maximum possible irrigation depth.

MAXIMUM CROP EVAPOTRANSPIRATION

The maximum crop evapotranspiration (ETm) is computed by equation

$$ETm_t = Kc_t \times ETr_t$$

Where,

ETm_t = maximum crop evapotranspiration on t^{th} day (mm)

Kc_t = crop coefficient on t^{th} day

ETr_t = reference crop evapotranspiration on t^{th} day (mm)

SOIL WATER DEPLETION FACTOR

The value of p_t depends upon crop, magnitude of maximum crop evapotranspiration and soil. The p_t values can be computed by the by equation;

$$p_t = p_2 - [(p_2 - p_1) / (ETm_1 - ETm_2)] (ETm_1 - ETm_t)$$

Where,

ETm_1 = maximum value of ETm (mm/d)

ETm_2 = minimum value of ETm (mm/d)

p_1 = p value corresponding to ETm_1

p_2 = p value corresponding to ETm_2

ACTUAL CROP EVAPOTRANSPIRATION

The calculation method of actual crop evapotranspiration is adopted from Doorenbos and Kassam (1986). The actual crop evapotranspiration equals to maximum evapotranspiration until the readily available soil water (fraction of available soil water) has been depleted. Beyond this depletion, actual evapotranspiration becomes increasingly smaller than maximum crop evapotranspiration until the next application of water and its magnitude depends on remaining soil water content and maximum crop transpiration. The mathematical representation is given by the equation,

$$ETa_t = ETm_t$$

$$\text{If } (\theta_t^R - \theta_w^R) Z_t \geq (1-p_t) (\theta_f^R - \theta_w^R) Z_t$$

$$ETa_t = [(\theta_t^R - \theta_w^R)\, Z_t\, ETm_t] / [(1-p_t)(\theta_f^R - \theta_w^R)\, Z_t]$$

$$\text{If } (\theta_t^R - \theta_w^R)\, Z_t < (1-p_t)(\theta_f^R - \theta_w^R)\, Z_t$$

Where,

θ_t^R = volumetric Soil moisture content in root zone depth on t^{th} day (cm/m)

θ_w^R = volumetric soil moisture content in root zone depth on t^{th} day at wilting point (cm/m)

θ_f^R = volumetric soil moisture content in the root zone depth on t^{th} day at field capacity (cm/m)

Zt = depth of root zone on t^{th} day (mm)

p_t = soil water depletion factor on t^{th} day

EFFECTIVE RAINFALL

The effective rainfall is the part of total annual, seasonal or periodical rainfall that actually added to the crop root zone layer soil moisture. It is computed by using equation proposed by (Dastane, 1974).

$$RFe_t = (1-\alpha)\, RF_t$$

Where,

RFe_t = effective rainfall amount on t^{th} day (mm)

RF_t = total rainfall amount on t^{th} day (mm)

α = runoff coefficient

DEEP PERCOLATION

The water in excess of field capacity of the soil is considered as deep percolation.

CROP PHENOLOGY MODULE

The crop phonology module contains the information crop name, sowing date, harvesting date, crop period, root growth model, crop coefficient model and yield response models required to simulate the soil moisture content in the root zone, computation of crop water requirement and estimation of the yield and net benefits.

CROP ROOT GROWTH MODULE

The root growth model is used to calculate soil water content in the root zone. The planting depth is considered as the minimum crop rooting depth. The linear and sigmodial root growth (Brog and Grimes, 1987) functions are used for the development of DSS-IWM based on minimum and maximum rooting depth and days to attain the maximum rooting depth.

Linear root growth function (Fereres et al., 1981)

$$Zt = Zo + (Zm - Zo)\,(t / tm)$$

Sigmoidal model root growth function (Subbaiah and Rao, 1993)

$$Z_t = Zo + (Zm - Zo)\,[0.5\sin(3.03t / tm - 1.47)]$$

Where,

Z_t = depth of root zone on t^{th} day (mm)

Zm = maximum depth of root zone during crop growth period (mm)

Zo = initial depth of root zone (depth of sowing) (mm)

tm = the day at which crop attains Zm since sowing

t = the day on which root growth is to be calculated (day)

CROP COEFFICIENT MODULE

The daily values of crop coefficient specified for different crop growth stages or crop coefficient represented by the equation can be used. If the stage wise crop coefficient values are used, the daily crop coefficient values are obtained by interpolation by using the method described by Doorenbos and Pruitt (1984).

KC_T EQUATION

The daily values of crop coefficient can be obtained by using the polynomial equations of following form developed for the crop coefficient.

$$Kc_t = a_0 + a_1(t/T) + a_2(t/T)^2 + \ldots\ldots\ldots + a_n(t/T)^n$$

Where,

Kc_t = crop coefficient on t^{th} day

T = total crop period (days)

t = days since sowing or planting

n = order of equation

$a_0, a_1, a_2, \ldots\ldots\ldots, a_n$ = coefficients of the equation

KC-NDVI RELATIONSHIPS

The different types Kc-NDVI of relationships are used to calculate the daily crop coefficient values by using following equations.

Linear : $Kc_t = a\,(NDVI_t) + b$

IJIERT-ICITDCEME'15

Exponential : $Kc_t = ae^{b(NDVI_t)}$

Logarithmic : $Kc_t = a\ln(NDVI_t)+b$

Power : $Kc_t = a(NDVI_t)^b$

Polynomial : $Kc_t = a(NDVI_t)^2+b\,(NDVI_t)+c$

Where,

Kct = Crop coefficient on t^{th} day

$NDVI_t$ = Normalized Difference Vegetative Index on t^{th} day

a, b, c = Coefficient of equations

YIELD RESPONSE MODULE

The crop growth model relates the actual and maximum evapotranspiration and maximum crop yield to actual crop yield. The Stewart, et al. (1976) and Stewart and Hagan (1973) yield response models are used for estimating actual yields and the impact of different irrigation strategies on actual crop yield.

(1) Stewart, et al. (1976): Crop production function in additive form (ET as measure of water stress)

$$\frac{Ya}{Ym} = 1 - \sum_{s=1}^{ns} Ky_s\left(\frac{ETm_s - ETa_s}{ETm_s}\right)$$

(2) Stewart and Hagan (1972): Crop production function in additive form (ET as measure of water stress)

$$\frac{Ya}{Ym} = 1 - \sum_{s=1}^{ns} Ky_s\left(1 - \frac{ETa_s}{ETm_s}\right)$$

Where,

Ya	=	actual crop yield, Kg/ha
Ym	=	potential crop yield, Kg/ha
s	=	subscript for crop growth stage
Ky_S	=	yield response factor of s^{th} stage
ns	=	number of stages
ETm_S	=	maximum crop ET of s^{th} stage (mm)
ETa_S	=	actual crop ET of s^{th} stage (mm)
ETm	=	maximum crop ET of entire crop growth period (mm)
Tm_S	=	maximum crop T of s^{th} stage (mm)
Ta_S	=	actual crop T of s^{th} stage (mm)

SOIL MODULE

Soil module consists of the "Soil data" regarding soil type, depth of soil, moisture content of the soil at field capacity and moisture content of the soil at wilting point in per cent and computation of initial soil moisture content.

WEATHER MODULE

Weather module consists of information of "Weather data" viz. minimum temperature, maximum temperature, minimum relative humidity, maximum relative humidity, sunshine hours and wind speed required to calculate reference crop evapotranspiration using Penman-Monteith method. The reference crop evapotranspiration is estimated by Penman-Monteith Method (Allen et al., 1998) as;

$$ET_{rt} = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)}$$

Where,

ET_{rt} = Potential evapotranspiration on t^{th} day (mm day-1)

Rn_t = Net radiation at the crop surface on t^{th} day (MJ m-2 day-1)

G_t = Soil heat flux density on t^{th} day (MJ m-2 day-1)

T_t = Mean daily air temperature at 2 m height on t^{th} day (°C)

$u2_t$ = Wind speed at 2 m height on t^{th} day (m s-1)

es_t = Saturation vapour pressure on t^{th} day (kPa)

ea_t = Actual vapour pressure on t^{th} day (kPa)

es_t - ea_t = Saturation vapour pressure deficit on t^{th} day (kPa)

Δ_t = Slope vapour pressure curve on t^{th} day (kPa °C-1)

γ_t = Psychrometric constant on t^{th} day (kPa °C-1)

IJIERT-ICITDCEME'15

ISSN No - 2394-3696

IRRIGATION STRATEGIES MODULE

The irrigation strategies module contains the information on total number of farms and sub-farms, name, number of crops grown, soil type, total area, efficiencies, irrigation method and irrigation strategies. The application efficiency of 75 % was considered for all the crops on all the soils and for all irrigations. The value of runoff coefficient for computing effective rainfall was assumed as 0.70 for all crop-soil combinations. The maximum and minimum possible values of irrigation depth were assumed as 150 and 50 mm respectively for all crops grown on all soils, though a scheduled irrigation could be missed by giving an application of 0 mm. Fixed date fixed depth, fixed date variable depth and variable date variable depth (adequate irrigation and deficit irrigation) irrigation strategies were used to simulate moisture content in root zone.

CROP YIELD AND BENEFIT MODULE

The net benefits are estimated by calculating total cost and total benefits. The total cost is summation of the cost of cultivation including all resources and operations and water related costs which include cost of water and cost of water application. Total benefits are computed with the help of actual crop and fodder yield estimated for the given irrigation strategy and the market value of the produce. Net benefits are derived from main produce and bi-produce and estimated as total benefit minus total cost.

GRAPHICAL REPRESENTSTION OF SOIL WATER IN THE ROOT ZONE

The results of the DSS-IWM can be represented as graphical plots of variations in moisture content of root zone over crop growth period, reference crop evapotranspiration, maximum evapotranspiration, actual evapotranspiration, crop coefficient and depth of irrigation over the crop growth period.

CASE STUDY FOR WHEAT CROP

To know the applicability of the developed DSS-IWM in irrigation water management, it was applied to Rabi wheat cultivated on clay soil considering variable date and fixed depth irrigation strategy. The DSS-IWM was used to simulate the daily soil moisture content in the root zone and to evaluate the effect of different irrigation strategies on yield reduction. The DSS-IWM was applied for knowing the influence of these irrigation strategies on yield and total benefits of crop when grown on specific soil. It is considered that the wheat crop is sown on November 27, 2012 and harvested on March 26, 2013. The total crop growth period is 120 days. The field capacity, wilting point and depth of soil were considered as 43 %, 17 % and 2500 mm, respectively. The weather parameters data for the year 2012 and 2013 is considered for the calculation of reference crop evapotranspiration during the crop growth period. Linear root growth model is used to simulate daily root zone depth considering minimum rooting depth as 50 mm, maximum rooting depth as 150 mm and days to attain maximum rooting depth as 50. The Stewarts yield response model is used for the estimation of crop yield and net benefits. The DSS was run by varying the irrigation intervals from 14 days to 35 days with 70 mm depth of irrigation per irrigation for wheat crop. The result obtained is presented in Table 1. The graphs showing variation of soil moisture content in the root zone over the crop growth period are shown in Figures 1.

It is seen from the graphs that the soil moisture content is always above the allowable depletion level over the crop period when irrigation interval is 14 days. It is seen from the figures that the moisture content in the root zone drops below the allowable soil moisture content for the irrigation intervals of 21, 28 and 35 days. As the soil moisture content drops below allowable soil moisture content for 21, 28 and 35 days interval, the crop is subjected to stress. The degree of stress increases with increase in irrigation interval resulting in more reduction in yield. The reduction in yields is 0, 2.67, 11.13 and 16.08 % at 14, 21, 28 and 35 days interval. Thus, there is more reduction in yield when crop is subjected to more stress i.e. with greater irrigation interval (Tables 1). As there is no stress for irrigation depth of 70 mm applied at 14 days interval, there is no reduction in yield. The yields and net benefits are found increased with decrease in irrigation interval. Thus the increase in interval beyond a certain limit causes the moisture content in soil to drop below the allowable depletion level resulting in reduction in yields. On the other hand as irrigation interval decreases from 35 to 14 days, total depth of irrigation decreases from 473 to 210 mm. Thus with the DSS-IWM it is possible to take the decision of appropriate irrigation interval for specified irrigation depth for obtaining expected yield.

Table 1: Seasonal irrigation depth (TDI, mm), potential yield (Ym, kg/ha), actual crop yield (Ya, kg/ha), net benefits (NB, Rs.) and reduction in yield (RY, %) for 14, 21, 28 and 35 days interval and 70 mm irrigation depth for wheat

Irrigation strategy	Ym	Ya	NB	TDI	RY
rigation interval of 14 days and 70 mm depth of irrigation	4000	4000	8017	473	0.00
rigation interval of 21 days and 70 mm depth of irrigation	4000	3893	6500	315	2.67
rigation interval of 28 days and 70 mm depth of irrigation	4000	3555	3.00	266	11.13
rigation interval of 35 days and 70 mm depth of irrigation	4000	3357	-3720	210	16.08

CONCLUSIONS AND DISCUSSIONS

The DSS-IWM was developed based on SWAB-CRYB model, crop phenology model, root growth model, crop yield response model and different irrigation strategies. The DSS-IWM could be used to simulation of soil moisture content in the

IJIERT-ICITDCEME'15

root zone and evaluation of the effect of certain irrigation strategy on crop yield and yield reduction. In general the DSS-IWM developed is useful for evaluating irrigation strategies for different crops grown on different soils at farm scale. The results of the DSS would provide guidelines to select the appropriate irrigation strategy depending in the land and water availability.

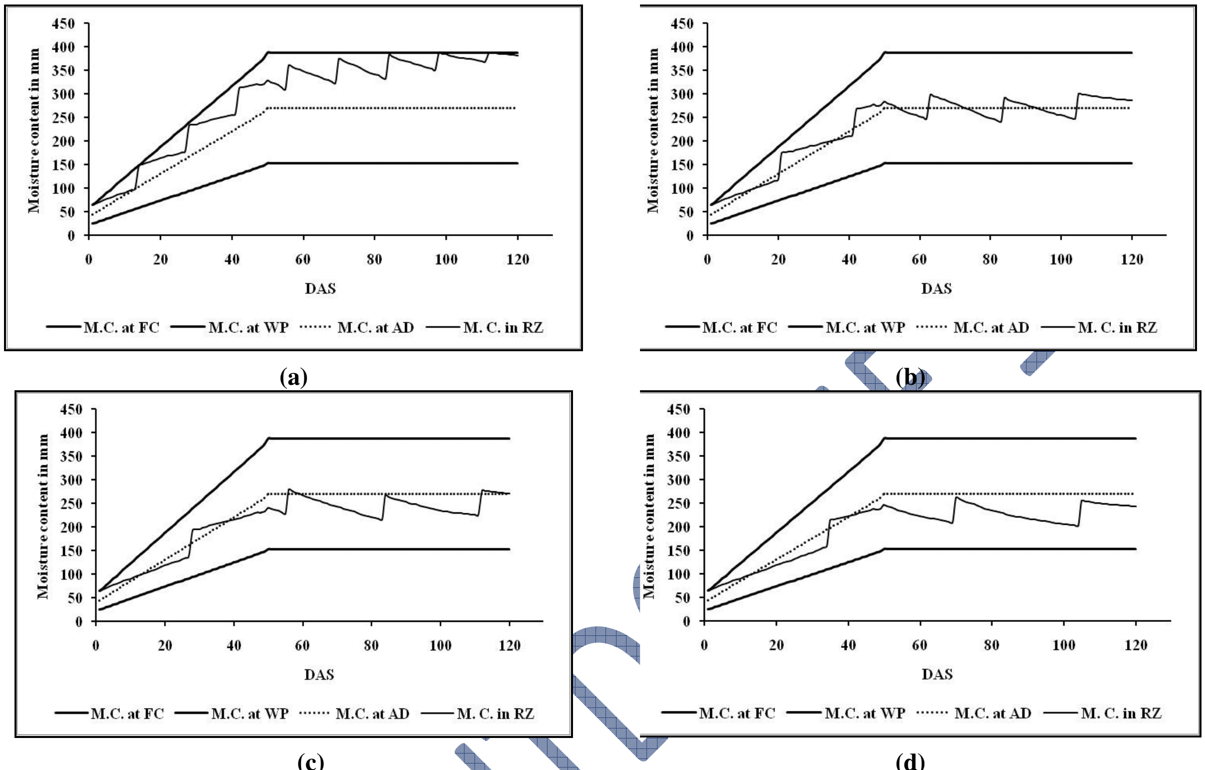

Figure 1. Variations in moisture content of root zone of wheat at (a) 14 days interval and 70 mm depth (b) 21 days interval and 70 mm depth, (c) 28 days interval and 70 mm depth and (d) 35 days interval and 70 mm depth

REFERENCES

[1]Allen, R. G., L. S. Periera., D. Raes and M. Smith. 1998. Crop evapotranspiration: Guideline for computing crop requirements. FAO Irrigation and Drainage Paper No. 56. Food and Agricultural Organization of the United Nations, Rome, Italy, pp.293.

[2]Dastane, N. G. 1974. Effective rainfall. FAO Irrigation and Drainage Paper No. 25. Food and Agricultural Organization of the United Nations, Rome, Italy.

[3]Densham, P. J. and M. F. Goodchild. 1989. Spatial decision support system: a research agency. In GIS/LIS’89 Proceeding Volume 2, American Congress on Surveying and Mapping, Bethesda, MD.

[4]Doorenbos, J. and A. H. Kassam. 1986. Yield response to water. FAO Irrigation and Drainage Paper No. 33. Food and Agricultural Organization of the United Nations, Rome, Italy. pp.193.

[5]Doorenbos, J. and W. O. Pruitt. 1984. Guideline for predicting crop water requirements. FAO Irrigation and Drainage Paper No. 24. Food and Agricultural Organization of the United Nations, Rome, Italy. pp.193.

[6]Draper, A.J. 2001. Implicit Stochastic Optimization with Limited Foresight for Reservoir Systems. Ph.D. thesis, Engineering, University of California, Davis.

[7]Fereres, E., W.O. Pruitt., J.A. Beutel., D.W. Hemderson., E. Holzapfel., H. Schulbach and K. Uriu. 1981. Evapotranspiration and drip irrigation scheduling, En: Drip Irrigation Management. Fereres E. Tech. Ed., Division of Agricultural Sciences, University of California. pp.8-13.

[8]Gorantiwar, S.D. 1995. Model for planning and operation of heterogeneous irrigation scheme in semi-arid regions under rotational water supply. An unpublished Ph.D. thesis submitted to Loughbourgh University of Technology, Loughbourgh, UK. pp.483.

[9]Gorantiwar, S.D. and I. K. Smout. 1995. Optimizing the use of water in multi crop-soil irrigation scheme. Proceeding of the Congress-International Association for Hydraulic Research. Vol. (4): 386-391.

[10]Kersten, G.E. and W. Micalowski. 1996. The DSS phenomena: design, functions and management. In Expert Group Workshop on: Decision Support Systems for Sustainable Development, UNU/IIST-IRDC.

[11]Palkar H. M. 2011. Development of NDVI based Decision Support System for Irrigation Water Management. M. Tech. thesis submitted to Mahatma Phule Krishi Vidyapeeth, Rahuri.

[12]Reitsma, R.F. 1996b. Structure and support of water-resource management and decision-making. Journal of Hydrology. 177:253-268.

[13]Stewart, J. I. and R. M. Hagan. 1973. Functions to predict effects of crop water deficits. ASAE Journal of Irrigation and Drainage Engineering. 99(IR4):421-439.

[14]Stewart, J.I., R.M. Hagan and W.O. Pruitt. 1976. Production functions and predicted irrigation program for principle crops required for water resources planning and increased water use efficiency. U. S. Dept. of Interior, Bureau of Reclamation, Washington, D. C., USA.

[15]Subbaiah, R. and K.A. Rao. 1993. Root growth simulation model under specified environment. Journal of Irrigation and Drainage Engineering.119(5): 898-904.

IJERT-ICITDCEME'15