Root zone water balance modeling of horticultural crops in bunded fields under rainfed conditions

Raneesh. K .Y.[#1]

[#]Research Associate, K C A E T, Tavanur, Malppuram, Kerala.

[1]kyraneesh@yahoo.co.in

***Abstract* — A study was made to develop a simple conceptual daily root zone water balance model applicable to drylands enclosed by bunded fields having deep water table conditions. The soil moisture contents predicted from the model for different months were similar to that of the observed values both under control and treatmental plots while 45cm root zone depth was considered. The soil moisture contents were always higher in treatmental plots than in control plots both in observed and predicted values. The model predicted soil moisture relatively better during dry periods compared to moist periods prevailing after the receipt of the rainfall. This might be due to the moisture redistribution process in the soil after the receipt of the infiltrated rainwater, which was not considered in the model. The model predicted low values than the observed runoff in the treatment and control plots.**

***Keywords* — bunded fields; conceptual model; dryland agriculture; horticultural crops; root zone water balance.**

I. Introduction

Water is the major critical resource in the semi-arid tropics and one of the key constraints to sustainable agriculture. Agricultural systems in semi-arid tropics are strongly affected by climatological variability. Timing and frequency of rainfall events, conditioned by the inter-annual large-scale-ocean-atmosphere circulation features strongly influence the dryland cropping system. Dryland agriculture will maintain an important role in growth of food production in future. A study was made to develop a simple conceptual daily root zone water balance model applicable to drylands enclosed by bunded fields having deep water table conditions. The model was based on a conceptual understanding of the results of the crop response to available soil water. The study conducted in two locations, viz. Thondamuthur and Chettipalayam in Coimbatore district of Tamil Nadu characterized by low annual mean rainfall and very deep water table. The soils were of sandy clay loam and sandy loam texture respectively. Mango and Guava were the field crops grown by the farmers in the respective locations. The in-situ moisture conservation treatments viz. V-Catchments, Crescent bunds, Compartmental bunds and Scattered trenches were laid for the purpose of soil moisture conservation.

II. Materials and Methods

The model was based on empirically established results of crop response to available soil water (Doorenbos and Kassam, 1979). It was tested by application to the conditions of case study areas in two fields in order to evaluate its use for quantifying water balance components like root zone soil moisture, runoff, etc. and the design of microcatchments. The sites selected for the research study were located at Thondamuthur and Chettipalayam, in Coimbatore district of Tamil Nadu, India. Thondamuthur lies to the western part of Coimbatore near to the Western Ghats. It has a sandy clay loam soil type. The area has a mean monthly minimum temperature of 21^{o}C and a maximum of 31^{o}C. The mean annual rainfall is 628.15mm. The water table was very deep (70-90m). Here, a farmer field with dryland Mango plantation was selected for the study. The root zone depth of the Mango crop was 120cm. The area of the field was 2.2 hectares, bunded from all sides. The crop grown here was 11 years old. The field was left dry and it depended on rainfall for water.

The soil moisture in the root zone on any day was computed as the difference between the soil moisture and the Actual Evapotranspiration (AET) of the just previous day. For subsequent days, the water balance reflected in terms of soil moisture in the root zone was given by the difference between the sum total of infiltrated volume of water, supplemental applied water if any, the previous day root zone soil moisture content and the sum total of outflow components. The outflow components included deep percolation and Actual Evapotranspiration (AET) on that day. The deep percolation was compared from the difference between the inflow and the moisture storage at the root zone. When the rainfall intensity was less than the average infiltration rate of soil, the basic infiltration rate or average infiltration rate or the maximum infiltration rate of the soil depending upon the soil moisture condition was taken for the purpose of calculating infiltrated volume of water. In this condition, the duration of the storm was taken as the infiltration time and the infiltrated volume was obtained by the product of the corresponding infiltration rate conceded and the duration of the storm. When the rainfall intensity was more than the average infiltration rate of soil, the runoff was produced, as the difference between total rainfall and the cumulated infiltration volume, calculated by the Kostiakov-Lewis equation. Here the average time of infiltration was taken as the sum of the duration of rainfall and the average time of infiltration of ponding water stored in the micro-catchments. The inputs of the model included initial soil moisture contents, basic and maximum infiltration rates of soils, Potential Evapotranspiration (PET), Field Capacity (FC) and Permanent Wilting Point (PWP) applied to normal field crops, soil moisture depletion factor ‘p’, average intensity and duration of rainfall, Kostiakov’s parameters for the defined soil textures and supplemental irrigation, if any. The outputs of the model were daily soil moisture contents, Actual Evapotranspiration (AET) and deep percolation.

III. RESULTS AND DISCUSSIONS

The model was run for the entire root zone depth of the selected crops, Mango and Guava and also a part of the root zone depth of these crops (45 cm of root zone) for test verifying with the field observed data like soil moisture and runoff on specific days of different months of the study period. The comparison between soil moisture for model and observed values in Thondamuthur and Chettipalayam fields for different treatments and in the control plot are shown in figures 1 to 10. The simple daily root zone water balance model with minimum input data predicted the outputs like soil moisture and runoff reasonably well. The soil moisture contents predicted from the model for different months was similar as that of the observed values both under control and treatmental plots while 45 cm root zone depth was considered. The soil moisture contents were always higher in treatmental plot than in control plot both in observed and predicted values. The model predicted soil moisture relatively better during dry times compared to moist periods prevailing after the receipt of the rainfall. This might be due to the moisture redistribution process in the soil after the receipt of the infiltrated rain water which was not considered in the model. The prediction pattern of soil moisture of the two types of soil namely sandy clay loam and sandy loam was the same where two different crops, Mango and Guava were considered. Predicted and observed runoff was also in close agreement as revealed from the statistical analysis for a sandy clay loam soil underlain by a less pervious soil layer. But in a sandy loam texture of Chettipalayam field there was a wider variation between the predicted and observed runoff.

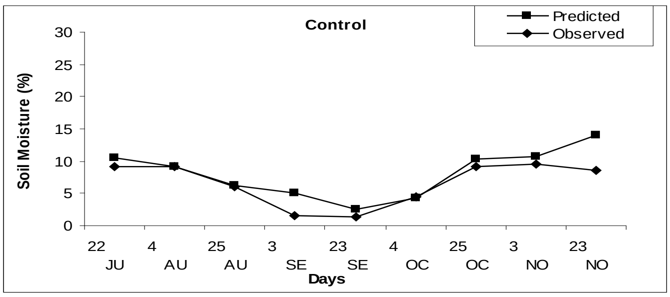

Fig 1. Comparison of soil moisture for model and observed values in Control plot in Thondamuthur field

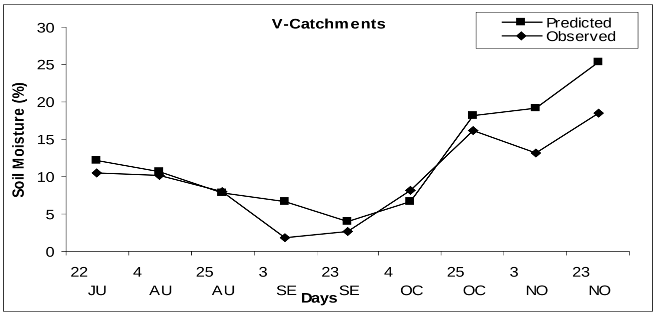

Fig 2. Comparison of soil moisture for model and observed values in V- Catchments in Thondamuthur field

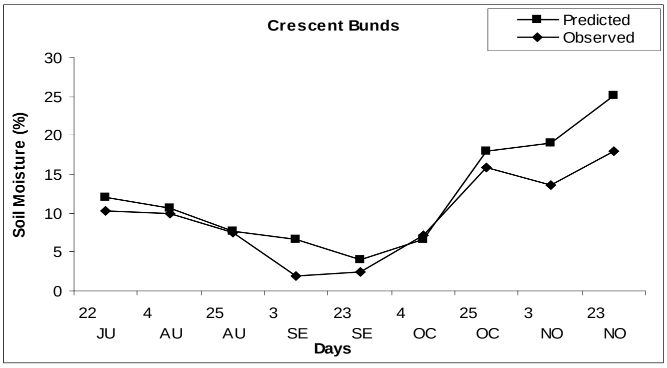

Fig 3. Comparison of soil moisture for model and observed values in Crescent bunds in Thondamuthur field

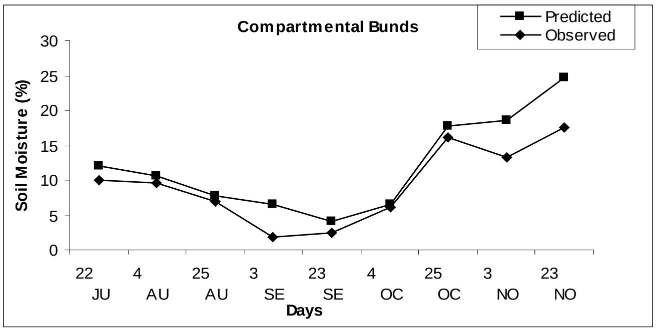

Fig 4. Comparison of soil moisture for model and observed values in Compartmental bunds in Thondamuthur field

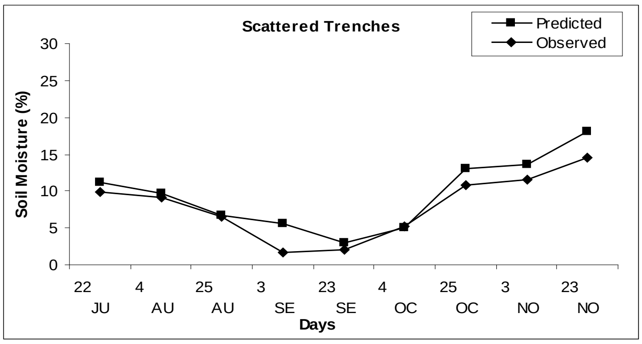

Fig 5. Comparison of soil moisture for model and observed values in Scattered trenches in Thondamuthur field

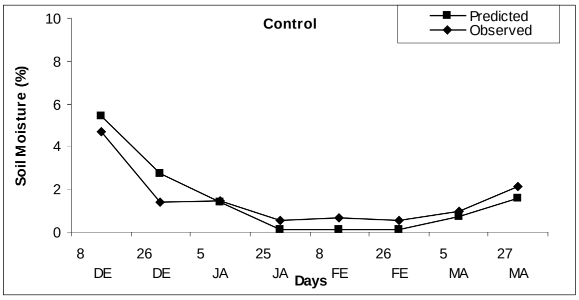

Fig 6. Comparison of soil moisture for model and observed values in Control plot in Chettipalaym field

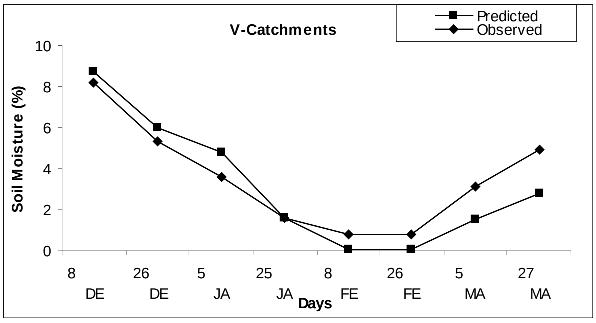

Fig 7. Comparison of soil moisture for model and observed values in V-Catchments in Chettipalaym field

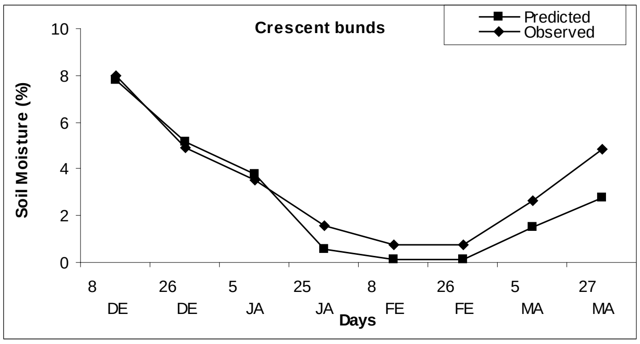

Fig 8. Comparison of soil moisture for model and observed values in Crescent bunds in Chettipalaym field

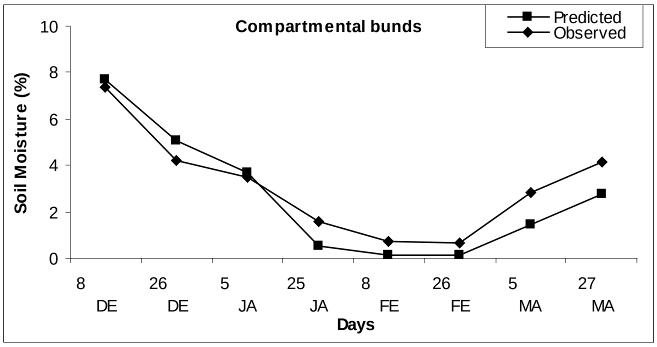

Fig 9. Comparison of soil moisture for model and observed values in Compartmental bunds in Chettipalaym field

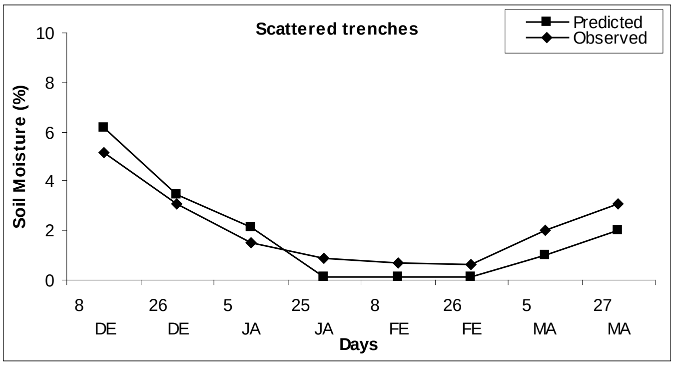

Fig 10. Comparison of soil moisture for model and observed values in Scattered trenches in Chettipalaym field.

The model predicted low values than the observed runoff in all the treatments and control. Tables 1 and 2 show the values of run off from both the fields respectively. The predicted runoff values while considering the 45cm or the entire root zone depth for the operation period of the model were the same. Deep percolation values at 45cm root zone depth for different treatments were always more than the control. However, there was no deep percolation when the model was run for the entire root zone depth. The predicted AET values per day were varying depending upon the PET and soil moisture conditions prevailed during the prediction period. The V-catchments produced low runoff compared to other treatments for all the five days of the model run due to better runoff control. Scarcity moisture days below permanent wilting point specified for normal crops were in the order of 25% (38 days out of 150 days) considered during the monsoon season at 45cm depth of the Thondamuthur field. Hence there was a possibility to grow shallow rooted crops like pulses, cereals and other leguminous crops with one or two supplemental irrigations. But when the entire root zone depth of 1.2m was considered, the scarcity days below permanent wilting point were in the order of 80% of the total period considered. The duration in days of soil moisture scarcity in both the fields are shown in tables 3 and 4 respectively. However the horticultural trees like Mango could withstand without permanent wilting even under low moisture conditions. The redefining of permanent wilting point of moisture for this type of trees was the need of the hour. In Chettipalayam field, the model predicted more percentage of soil moisture scarcity days than the Thondamuthur field due to the receipt of less quantum of rainfall during the period coupled with the soil and crop characteristics.

TABLE.I

Runoff volumes for Thondamuthur field

Treatment	Predicted runoff (m^3)	Observed runoff (m^3)
Control	14.30	12.35
V Catchments	11.21	11.13
Crescent bunds	11.29	11.21
Compartmental bunds	11.30	11.12
Scattered trenches	13.19	11.56

TABLE.II
Runoff volumes **for Chettipalayam field**

Treatment	Predicted runoff (m3)	Observed runoff (m3)
Control	3.71	7.56
V Catchments	3.13	7.01
Crescent bunds	3.14	7.23
Compartmental bunds	3.16	7.32
Scattered trenches	3.52	7.42

TABLE.III
Duration (days) of the scarcity soil moisture in Thondamuthur field

Treatment	45cm depth	Entire root zone depth
Control	54	123
V Catchments	32	64
Crescent bunds	33	65
Compartmental bunds	33	65
Scattered trenches	43	123
Total study period	**150 days**	

TABLE.IV
Duration (days) of the scarcity soil moisture in Chettipalayam field

Treatment	45cm depth	Entire root zone depth
Control	100	103
V Catchments	76	98
Crescent bunds	83	98
Compartmental bunds	83	98
Scattered trenches	95	100
Total study period	**120 days**	

IV. CONCLUSIONS

The simple daily root zone water balance model with minimum input data predicts the outputs like soil moisture, runoff reasonably well. The soil moisture contents predicted from the model for different months was similar as that of the observed values both under control and treatmental plots while 45 cm root zone depth was considered. The soil moisture contents were always higher in treatmental plot than in control plot both in observed and predicted values. Both the observed and predicted values of soil moisture were in descending order of V-Catchments, Crescent bunds, Compartmental bunds, Scattered trenches and the lowest in Control. The model predicted soil moisture relatively better during dry times compared to moist periods prevailing after the receipt of the rainfall. This might be due to the moisture redistribution process in the soil after the receipt of the infiltrated rain water, which was not considered in the model. Predicted and observed runoff was in close agreement as revealed from the statistical analysis for a sandy clay loam soil underlain by a less pervious soil layer. But in a sandy loam texture of Chettipalayam field there was a wider variation between the predicted and observed runoff. The model predicted low values than the observed runoff in all the treatments and control. The predicted runoff values while considering the 45cm or the entire root zone depth for the operation of the model were the same. Deep percolation values at 45cm root zone depth for different treatments were always more than the control. However, there was no deep percolation when the model was worked for the entire root zone depth.Scarcity moisture days below permanent wilting point were in the order of 25% (38 days out of 150 days) considered during the monsoon season at 45cm depth of the Thondamuthur field. Hence there was a possibility to grow shallow rooted crops like pulses, cereals and other leguminous crops with one or two supplemental irrigations, provided there was a compatibility of crops.

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