Agropedology 2010, 20 (2), 165-174

Crop water balance model for suggesting suitable crops on major soils of Cauvery delta of Tiruvarur district, Tamil Nadu

P. KANNAN, S. NATARAJAN, R. SIVASAMY, R. KUMARAPERUMAL AND D. MUTHUMANICKAM

Remote Sensing and GIS centre, Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore- 641 003, India

Abstract : A semi-detailed reconnaissance soil survey was conducted based on the image interpretation of IRS-1D PAN merged LISS III satellite data. Sixteen representative pedons were identified representing major physiographic units in the area. The soils were characterized as deep to very deep, yellowish brown to red, excessive to poorly drained, slightly acidic to slightly alkaline, sandy to clayey in texture, low in organic carbon and low to high in cation exchange capacity. The length of growing period of the area varies from 158 to 182. The water balance study indicated that *rabi* rice cultivation is ensured with 100 per cent Water Requirement Satisfaction Index (WRSI) without any moisture constraints in the pedons. But other crops, such as, *kharif* rice, black gram, sesame, cotton and groundnut were supported with an average of 35, 44, 57, 47 and 49 per cent WRSI, respectively. At the flowering and pod filling stages, the crops suffer from moisture stress in all the soils. The results indicated that soils of Alathur, Nannilam and Kalathur were relatively highly suitable for *kharif* rice, black gram, sesame cultivation due to relatively high WRSI indices (58,53 and 52 per cent) whereas the soils of Alathur and Nannilam were found to be best suited for cotton and groundnut cultivation.

Additional key words : *Water Requirement Satisfaction Index (WRSI), available water holding capacity*

Introduction

The effect of water shortage on crop production is exacerbated by the mismatches between resources availability and demands (Tesfaye and Walker 2004). In view of scarce water supplies, it is imperative to optimize water use in the field by proper interpretation of water balance components in the field, to minimize unproductive water losses (Singh 2005). In this context, understanding the crop water requirement, use and consumption is a pre-requisite for better management and conservation of agricultural water especially in an arid and a semi-arid climate (Schumacher *et al.* 2009).

The Cauvery delta zone constitutes 9.3 per cent of the net sown area in Tamil Nadu state. This delta is agriculturally important and comprises Thanjavur, Thiruvarur and Nagapattinam districts. Tiruvarur is one among the districts that contributes maximum to paddy and pulse production. In recent years, due to the problem of inter-state water sharing and monsoon failure, continuing rice cultivation in this delta has become uncertain. This uncertainty slows down economic prosperity and threatens the livelihood of small and marginal farmers as well as agricultural

labourers in this region. A change from the traditional cropping in this delta, which is a fragile agricultural ecosystem, is imminent. Thus, there is a need for scientific data on natural resources, weather data, water availability and crop water demand which must form the basis for addressing the alternate cropping plan and water management in this region. With this background, the present investigation was undertaken with the objectives to carry out interpretation of physiography using remote sensing and GIS techniques and characterize and classify the soils. The water balance models for different crops grown in the study area were computed to suggest suitable crop plan.

Materials and methods

Study area

The study was conducted in Tiruvarur district of Cauvery Delta zone which is bounded on the north by Cuddalore district, south by Palk Strait, east by Nagapattinam district and west by Thanjavur district. The area lies between 10°20'32.69" and 11°07'57.77" N latitude and between 79°15'02.29" and 79°45'38.24" E longitude. The climate of the study area is moist sub-humid that receives a mean annual rainfall of 1201 mm and mean annual temperature is 31.17°C. The LGP varies from 158 to 182 days.

Soil resource inventory

Geocoded IRS-1D PAN merged LISS III satellite data were visually interpreted. Twenty two image interpretation units (IIU) were recognized during the visual interpretation. Soil profile studied were studied in each image interpretation unit of the sample strips and 22 IIU were converged into 16 representative pedons. Horizon-wise soil samples were collected and analyzed. The particle-size distribution was done by International Pipette Method (Piper 1966). Organic carbon by Walkley and Black, (1934), Calcium carbonate (Piper 1966) and the exchangeable cations were determined as per method outlined by Black (1965).The soils were classified according to keys to Soil Taxonomy (Soil Survey Staff 2006).

Weekly rainfall probability analysis

The weekly rainfall data were analysed for 30, 50 and 75 per cent probability level by following simple probability analysis method and 50 per cent probability level available quantum of rainfall data were used. As per Sarkar and Biswas (1988), the area receiving assured weekly rainfall (>400 mm), 50 per cent probability was taken for further water balance modeling.

Water holding capacity

Available water capacity (AWC) was calculated by pressure plate method (Richards 1954). Moisture storage capacity of the soils was worked out for 1m-depth and soil moisture control section (SMCS). As the crops can utilize water from in and around root zone, effective root zone depth of 30 cm was taken for rice and groundnut. For other crops, such as blackgram, greengram, sesame and cotton, 60 cm depth were taken for soil moisture storage calculation and it was used for crop water balance modeling.

Crop water balance model

The average weekly PET values were calculated for the area using the pan evaporation method.

$$PET = K_P \times E_{pan}$$

Where, E_{pan} = Evaporation (mm) from the open pan evaporimeter, K_P = Pan Coefficient (0.7)

WRSI was determined by method described by Frere and Popov (1979) as the running total of the weekly water deficits that are expressed as a percentage of the total crop water requirement for the entire season (TWR)

$$WRS1 = WRSI_{(w-1)} + (ASM_{(w)}/TWR) \times 100$$

$$ASM_{(w)} = ASM_{(w-1)} + ER_{(w)} - Crop\ ET_{(w)}$$

Where, ASM = Available Soil Moisture (mm),
ER = Effective rainfall (mm),
w = Running index of the week

WRSI is initially 100 per cent and remains at this value until there is water deficit, when it is decreased by the percentage deficit as a fraction of the seasonal water requirement. Water requirement satisfaction

index was calculated for *kharif and rabi* rice, black gram, sesame, groundnut and cotton.

Results and Discussion

Soil resource

Sixteen soil series were identified in the study area. The major soil series is Kalathur, covering 31076.80 ha (13.51 %) of the area, followed by the Kizh Nemmeli series (22538.11ha; 9.80 %), Alathur series (18543.33 ha; 8.06 %), Nannilam series (18110.82 ha; 7.87 %), Vedaranyam series (15431.34 ha; 6.71 %) and Kalacheri (12546.44 ha; 5.45 %). The other soil series cover less than 5 per cent of the area.

The soil physical and chemical properties are presented in table 1 and 2, respectively. Brief description of major soil series and their classification are given below -

Rainfall analysis

The weekly analysis of rainfall data (1996-2005)

Table 1. Important soil physical properties

Horizons	Depth (cm)	Colour	Texture	Clay (%)	Silt (%)	Sand (%)	BD (Dry)	AWC (%) w/w
Pedon 1: Alathur (Fine, smectitic, isohyperthermic Udic Haplusterts)								
Ap	0-20	10YR4/2	sc	36.9	15.8	47.3	1.34	14.9
Bss1	20-70	10YR5/2	c	41.9	27.9	30.1	1.29	17.6
Bss2	70-90	10YR5/1	c	42.7	23.0	34.4	1.30	15.6
Bss3	90-142+	10YR6/1	c	43.0	22.0	35.0	1.31	13.2
Pedon 2: Nannilam (Fine, smectitic, isohyperthermic Chromic Haplusterts)								
Ap	0-18	10YR4/3	c	42.1	23.1	34.9	1.29	15.4
Bw	18-36	10YR3/3	c	44.7	22.0	33.4	1.28	13.5
Bss1	36-51	10YR3/2	c	46.2	18.2	33.3	1.31	12.8
Bss2	51-102+	10YR3/2	c	48.7	17.8	33.3	1.30	13.9
Pedon 3: Kalathur (Fine, smectitic, isohyperthermic Udic Haplusterts)								
Ap	0-20	10YR3/2	scl	29.7	23.7	46.6	1.34	12.0
Bss1	20-65	10YR3/2	c	40.9	20.0	39.1	1.30	14.8
Bss2	65-148+	10YR3/2	c	45.9	14.7	39.5	1.30	13.7
Pedon 4: Vedaranyam (Fine, mixed, isohyperthermic Udic Haplustepts)								
Ap	0-15	10YR7/3	scl	30.6	4.3	65.2	1.38	9.8
Bw1	15-29	10YR7/3	c	47.1	16.2	36.6	1.23	13.1
Bw2	29-54	10YR5/1	c	49.3	15.7	35.1	1.26	13.5
Bw3	54-87	10YR5/1	c	49.9	16.5	33.6	1.25	10.1
Bw4	87-128+	10YR5/1	c	52.5	8.6	38.8	1.23	11.7
Pedon 5: Kalcheri (Coarse- loamy, mixed, isohyperthermic Typic Ustifluvents)								
Ap	0-20	7.5YR5/4	ls	8.2	7.3	84.5	1.62	7.4
C1	20-45	5YR4/4	ls	9.4	7.5	83.1	1.60	4.6
2C2	45-71	5YR4/6	sl	12.9	8.7	78.5	1.58	5.4
3C3	71-130+	5YR5/4	ls	7.9	6.5	85.6	1.61	5.0
Pedon 6: Kizh Nemmeli (Fine, mixed, isohyperthermic Ultic Paleustalfs)								
Ap	0-18	7.5YR5/6	scl	29.7	23.7	46.6	1.45	11.0
Bt1	18-38	7.5YR5/6	cl	35.2	21.1	43.7	1.46	12.6
Bt2	38-65	5YR5/6	c	42.9	18.0	39.1	1.34	13.8
Bt3	65-86	5YR5/6	c	46.9	14.7	39.5	1.36	13.7
Bt4	86-116+	5YR5/6	c	50.2	15.4	34.4	1.37	13.6

Table 2. Important soil chemical properties

Horizons	Depth (cm)	pH 1:2.5	EC dSm^{-1}	Organic C (gkg-1)	Free CaCO3 (%)	CEC $cmol(p^+)kg^{-1}$	Exchangeable cation $cmol\ (P^+)\ kg^{-1}$				BS %
							Ca	Mg	Na	K	
Pedon 1: Alathur (Fine, smectitic, isohyperthermic Udic Haplusterts)											
Ap	0-20	6.7	0.2	4.7	0.74	35.4	15.9	12.8	1.1	0.55	85.7
Bss1	20-70	8.4	0.16	3.9	0.86	32.1	12.7	10.8	2.5	0.34	82.1
Bss2	70-90	8.6	0.22	2.5	0.98	28.9	14.2	8.8	2.2	0.33	88.4
Bss3	90-142+	8.7	0.22	2.4	0.62	27.9	14.3	10.3	1.0	0.20	92.4
Pedon 2: Nannilam (Fine, smectitic, isohyperthermic Chromic Haplusterts)											
Ap	0-18	6.7	0.12	9.3	0.62	39.1	16.3	13.9	1.2	0.37	81.1
Bw1	18-36	7.9	0.11	8.3	0.74	35.9	13.9	11.9	1.5	0.33	76.9
Bss1	36-51	8.3	0.11	6.8	0.8	31.8	11.9	12.9	1.3	0.25	82.8
Bss2	51-102+	8.7	0.08	5.6	0.8	31.4	12.9	14.3	1.3	0.20	91.4
Pedon 3: Kalathur (Fine, smectitic, isohyperthermic Udic Haplusterts)											
Ap	0-20	8.0	0.6	13.3	0	36.0	14.3	13.8	3.2	0.43	87.9
Bss1	20-65	8.1	0.39	13.3	0	31.7	13.8	9.9	3.8	0.31	87.6
Bss2	65-148+	8.2	0.42	8.1	0	27.6	9.9	12.5	4.0	0.30	96.6
Pedon 4: Vedaranyam (Fine, mixed,isohyperthermic Udic Haplustepts)											
Ap	0-15	7.8	0.48	1.8	6.3	20.6	7.2	8.6	3.2	0.64	95.4
Bw1	15-29	8.2	0.53	2.8	8.9	19.2	7.0	4.5	3.2	0.82	81.0
Bw2	29-54	8.2	0.76	2.3	10.6	34.6	13.8	6.5	4.6	1.32	75.7
Bw3	54-87	8.0	1.04	2.1	9.8	45.7	16.5	5.6	4.6	1.03	60.6
Bw4	87-128+	8.1	1.12	1.9	9.6	42.4	12.6	8.5	4.7	0.98	63.0
Pedon 5: Kalcheri (Coarse-loamy, mixed, isohyperthermic Typic Ustifluvents)											
Ap	0-20	7.1	0.05	1.7	0	8.6	4.1	2.8	0.3	0.17	85.1
C1	20-45	7.4	0.05	1.1	0	9.7	4.2	2.7	0.4	0.13	76.6
2C2	45-71	7.2	0.06	0.9	0	10.5	4.5	3.2	0.5	0.13	79.3
3C3	71-130+	7.4	0.1	0.8	0	7.9	3.1	1.9	0.2	0.1	67.1
Pedon 6: Kizh Nemmeli (Fine, mixed, isohyperthermic Ultic Paleustalfs)											
Ap	0-18	7.4	0.29	8.3	0	14.1	3.1	1.9	0.8	0.43	44.0
Bt1	18-38	7.7	0.32	6.8	0	14.7	3.4	2.1	0.9	0.57	47.4
Bt2	38-65	7.9	0.35	5.9	0	15.7	3.7	2.3	1.2	0.50	49.0
Bt3	65-86	8.1	0.39	4.4	0	14.6	3.5	2.4	1.1	0.59	51.9
Bt4	86-116+	8.1	0.42	4.1	0	14.5	3.4	2.3	0.9	0.41	48.3

of study area indicated that, 75 per cent probability of getting rainfall was absolutely zero except in 24, 36, 39, 40 to 47 Meteorological Standard Weeks (MSW). The chance of getting more than 15 mm rainfall was observed in 43rd and 45th standard weeks. At 50 per cent probability, the rainfall amount was zero from 1 to 15, 17, 20, 23, 25 to 27, 29, 30 and 52 MSW. More than 20 mm was noticed for the Standard Weeks 40, 42 to 45, 48 and 49. Rainfall amount of more than 50 mm was observed in the standard weeks of 47. At 30 per cent probability of getting rainfall was absolutely zero for the standard weeks from 2 to 4, 6 to 13, 15, 17 and 30. The rainfall amount of 20 to 50 mm was observed in 19, 24, 31, 32, 36, 37, 40, 41, 45 and 48 standard weeks. Rainfall amount of more than 50 mm was observed in the standard weeks 39, 42 to 44 and 49 (Fig. 1).

The graphical representation of the weekly

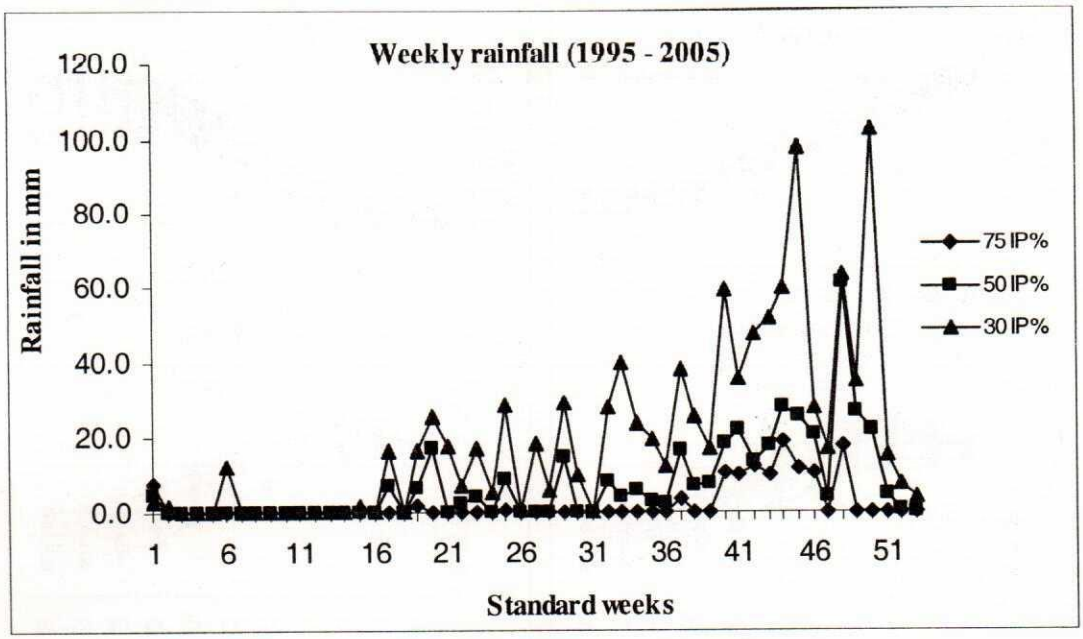

Fig. 1. Weekly rainfall probability of Tiruvarur district

rainfall data clearly showed two peaks, one from 13 to 24 standard week and the second peak from 28 to 49 standard week. The rainfall amount was found to be high during 39th to 49th standard week. At 30, 50 and 75 per cent probability levels, 49th standard week recorded 102.7 mm, 22.2 mm and 0.0 mm, respectively. At 50 per cent probability, the rainfall amount was more than 39 mm in 47th standard week. Rainfall more than 20 mm was observed in the standard week 40, 43, 44, 45, 47, 48 and 49. Minimum 20 to 25 mm of rainfall is required for sowing of crops. Based on the 50 per cent probability, *rabi* sowing of crops can be taken 39th standard week.

Soil moisture availability period

Based on the important climatic data such as rainfall, potential evapo-transpiration and temperature the entire study area was classified as 140 days length of growing period (LGP) (Table 3) It means the area supports crop growth by supplying moisture up to 140 days. The soil moisture availability and the length of growing period for individual pedon of Tiruvarur district was computed using available soil moisture present in the soil moisture control section (SMCS) and 1m soil depth. Seven different soil textures namely, sand (30-90 cm), loamy sand (30-90 cm), sandy loam (30-90 cm), sandy clay loam (20-60 cm), sandy clay (20-60 cm), clay loam (10-30 cm) and clay (10-30 cm) of different depth moisture supplying capacity was used to extent the LGP. Soil moisture supplied from SMCS increase the LGP 6 to 10 days but in the case of 1m soil depth, the LGP is 18 to 42 days. The length of growing period is 146 to 150 days for all the pedons with moisture supplied from SMCS but in the case of 1m depth, moisture supply can extend the length of growing period from 158 to 182 days. The extent of length of growing period was in an average of 25 days more in 1 m depth of soil than the soil moisture control section due to the greater retention of water in the 1 m deeper layers. Based on the LGP, we can choose short or long duration crop and single or double crop.

Water holding capacity

The available water content varied from 5.6 per cent in pedon 5 to 16.6 per cent in pedon 1. The low available moisture content at any tension in pedon 1 with depth suggests the need for frequent irrigation in these soils during early stages of crop growth. As the stage of crop growth advances, the roots would

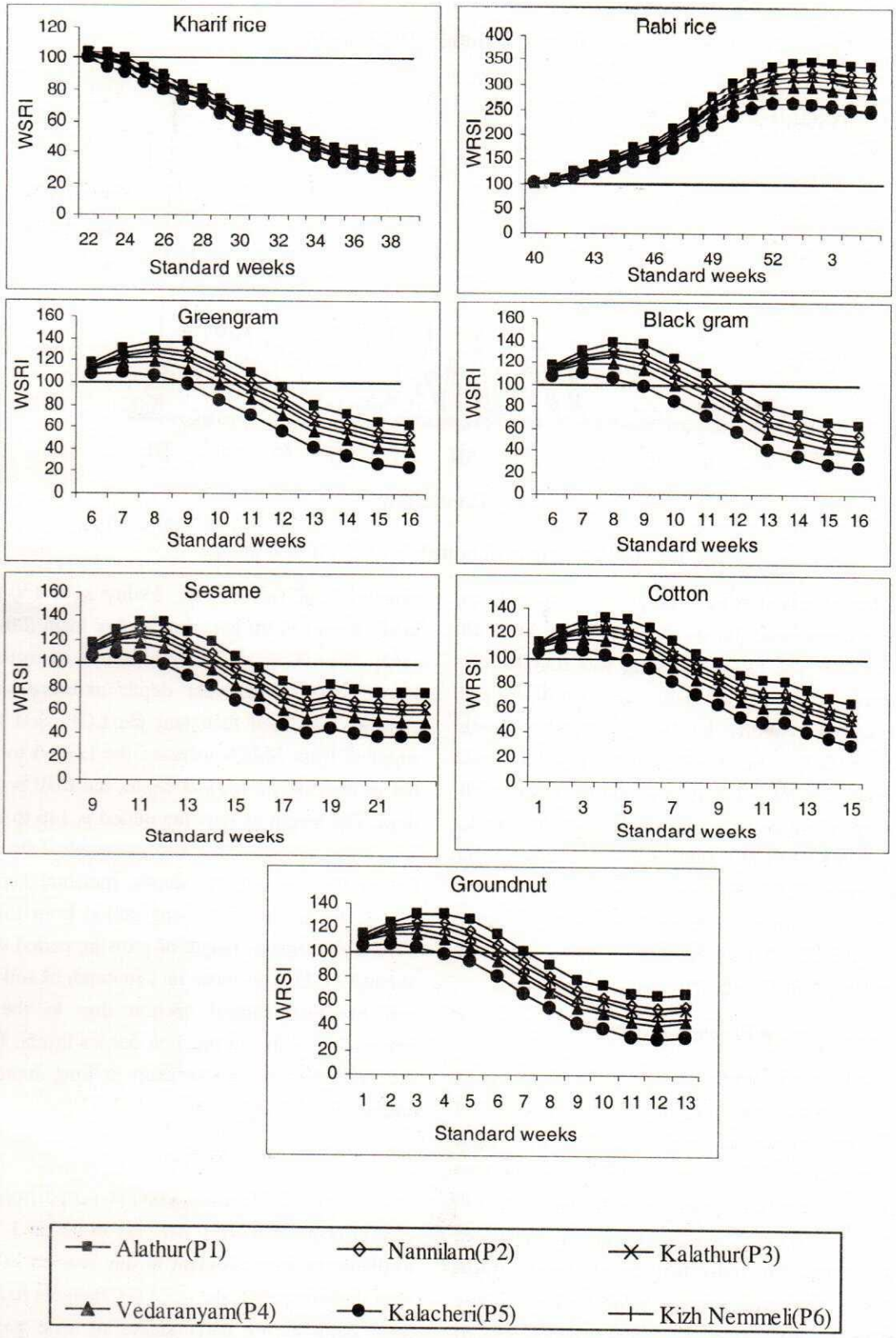

Fig. 2. Water requirement satisfaction index (WRSI) for different crops

Table 3. Soil moisture availability period in Tiruvarur district

Pedon	Thickness (cm)	BD (Mg m^{-3})	AWC (%) w/w	AWC (mm cm^{-1})	Volumetric water content (mm cm^{-3})	Control section			1 m depth		
						80% of AWC	Days*	LGP	80% of AWC	Days*	LGP
P1	20	1.34	14.9	1.99	39.87						
	50	1.29	17.6	2.27	113.50						
	20	1.30	15.6	2.03	40.57						
	52	1.31	13.2	1.73	89.89	34.1	9	149	169.0	42	182
P2	18	1.29	15.4	1.99	35.77						
	18	1.28	13.5	1.73	31.10						
	15	1.31	12.8	1.68	25.16						
	51	1.30	13.9	1.81	92.21	34.7	9	149	144.5	36	176
P3	20	1.34	12.0	1.61	32.21						
	45	1.30	14.8	1.91	86.08						
	83	1.31	13.7	1.80	149.16	29.4	7	147	144.9	36	176
P4	15	1.38	9.8	1.35	20.28						
	14	1.23	13.1	1.62	22.64						
	25	1.26	13.5	1.70	42.45						
	33	1.25	10.1	1.26	41.66						
	41	1.23	11.7	1.44	59.22	24.9	6	146	116.6	29	169
P5	20	1.62	7.4	1.21	24.13						
	25	1.60	4.6	0.73	18.24						
	26	1.58	5.4	0.86	22.27						
	59	1.61	5.0	0.80	47.12	23.6	6	146	70.2	18	158
P6	18	1.45	11.0	1.60	28.76						
	20	1.46	12.6	1.84	36.89						
	27	1.34	13.8	1.84	49.63						
	21	1.36	13.7	1.87	39.18						
	30	1.37	13.6	1.86	55.77	27.7	7	147	144.4	36	176

Note - 140 days were the moist period for the Tiruvarur district as computed from the climatalogical data

** Number of days met from the stored soil moisture*

naturally extend deeper and utilize the available moisture there in and hence irrigation be scheduled at wider intervals depending upon the crop stage and vegetative matter. The scheduling of irrigation is mostly decided by texture and clay mineralogy (Bharambe *et al.* 2003). During the times of heavy rain, the excess water is likely to be lost through surface run-off. There is a possibility for storing the surplus water. Thus the moisture retaining power of the different soil series provide an opportunity for planning water harvesting in developing a tract as suggested by Peer-Mohamed (1988).

Water balance model for irrigated crops

Rainfall received during the cropping period is of paramount importance for sustaining the crop production because soil moisture is the key source, which meets the evapo-transpiration requirement of the crops (Suraj Bhan *et al.* 1995). Availability of soil moisture for crops depend on the amount and distribution of rainfall, water retention characteristics of soil and crop characteristics such as duration, rooting depth etc. The WRSI of different crops is graphically exhibited in figure 2.

Kharif rice

The crop has duration of 4 months and sowing is taken up during 2nd week of June in the area. The crop is prone to water stress during entire growth period. Soil water holding capacity was higher in all the pedons except P5, but low rainfall during the south-west monsoon in the area led all the pedons to experience water deficit during the entire crop period. The 100 per cent of the crop water requirement is satisfied upto 2 weeks and at last week, an average 35 per cent of water requirement has been satisfied by rainfall. In pedon 5, the available water holding capacity was 90 mm and the deficit was noticed throughout the crop duration and WRSI was found to be 29.4 per cent. In fine-textured soils (P1, P2 and P3), WRSI was found to be more than 35 per cent. The WRSI varied from 29.4 per cent in coarse loamy to 38.7 per cent in clay soils. The overall WRSI of *Kharif* rice was 34.7 per cent for entire area, which directly indicates the need for supplemental irrigation to overcome the water stress at panicle initiation and flowering stage.

Rabi rice

The active growing period started from october 1st week and terminated in January last week. The water balance study showed that in P1, P2 and P3, the AWC was more than 150 mm and WRSI was found to be 100 per cent. Pedons (P1, P2 and P3) showed the water deficit of 29, 33 and 35 mm, respectively at last three weeks of crop growth period. Remaining pedons, the AWC was more than 130 mm, which was satisfied the total requirement of the crop. This was evident from the data of WRSI at the harvest stage. The water stress was observed at terminal stage of *rabi* rice in entire Tiruvarur district but it had not affected the rice production.

The availability of sufficient water at different critical stages such as tillering, panicle initiation, flowering and maturity stage enhanced the *rabi* rice production in the area. Most of the pedons in area had fine texture with reasonable clay content which directly correlated with more available soil moisture, which in turn avoided the water stress at critical stages of rice. Higher rainfall during the north-east monsoon sustained the rice production without any moisture constraint. So, *rabi* season rice cultivation is recommended in all the soil series of Tiruvarur district without any constraint.

Blackgram and greengram

Black gram is grown using residual moisture after harvesting of rice crop. The growing period starts from first week of February (6th standard week). The deficit is observed in all the pedons. But in clay soils (P1 and P3), residual moisture maintained the WRSI at 100 per cent up to 11th standard week. The WRSI for the different soil types indicated that, in general, 44.0 per cent of the total water requirement by the crop was satisfied till harvest. The WRSI varied from 23.2 per cent in coarse loamy to 61.9 per cent in clay soils due to the variation in AWC of the soils. The study

indicated that among the different pedons, Alathur and Nannilam pedons was found to be more suitable for blackgram and greengram cultivation.

Sesame

The crop is raised during first week of March (9th standard week). Since there is no rainfall from 9th to 16th weeks, the deficit was observed after the 3rd week of sowing and it continued up to 11th week after sowing. The deficit was observed in all the pedons. But in clay soils (P1, P2, P3 and P6), higher AWC sustained the WRSI at 100 per cent up to 6th week after sowing. The WRSI for these soil types indicated that around 57 per cent of the total water requirement by the crop was satisfied till harvest. The WRSI varied from 37.3 per cent in coarse loamy to 74.7 per cent in clay soils due to the variation in AWC of these soils. The deficit amount varied from 124 mm to 143 mm depending on the soil texture and the available water holding capacity. Providing irrigation in the later stages of the crop can minimize the risk of crop failure. From this study, it was found that Alathur, Nannilam and Kalathur soil series association were more suitable for sesame cultivation.

Groundnut

The groundnut is an important oil seed crop. The growing period starts from 2nd week of February (7th standard week) and terminates on 2nd week of May (19th standard week). There was no rainfall received from 7th to 19th week. So the moisture deficit was observed in all the pedons. But in clay soils (P1, P2 and P3), residual moisture sustained the WRSI at 100 per cent up to 6th week after sowing. The WRSI for the different soils indicated that an average of 48.5 per cent of the total water requirement of the crop was satisfied by rainfall. The overall comparison indicated that coarse loamy soils (P5) recorded more deficits and WRSI was found to be very low (30.6 %) and providing irrigation in the later stages of the crop can minimize the risk of crop failure. The study showed that the soil pedons namely Alathur, Nannilam and Kizh Nemmeli were suitable for groundnut cultivation.

Cotton

The water balance study showed that there was no rainfall from 4th week after sowing. The deficit was observed in the last 10 weeks. Hence, there is a possibility for the reduction in the yield due to water stress. But in clay soils (P1, P2 and P3) , higher AWC sustained the WRSI at 100 per cent upto 7th week after sowing. The WRSI for the different soils indicated that around 47.3 per cent of the total water requirement by the crop was satisfied till harvest. The over all comparison indicated that the coarse loamy soils (P5) recorded more deficits and WRSI was found to be very low (30.1 %). Among the different Pedons, Alathur and Nannilam Melaiyur pedons were more suitable for cotton cultivation.

The techniques for soil moisture conservation and effective utilization been suggested as follows

- *In-situ* moisture conservation measures should be taken in early and higher rainfall stages for effective conservation of water to meet the needs of water stress at later stage.
- Soil moisture stress can be minimized by irrigation at most vulnerable critical stages and seed filling stages.
- Capturing the benefits of the initial monsoon rainfall through manipulation of sowing time would be of immense use in extending the moisture availability period for crop growth.
- Growing of short duration crops may be recommended during pre rainy season because its water requirement is low and permit earlier harvest.

References

Bharambe, P.R., Sondge, V.D., Oza, S.R., Jadhav, G.S. and Shelke, D.K. (2003). Soil water balance components and water use efficiency of different crop sequence grown on Vertisols. *Journal of the Indian Society of Soil Science* **51** , 95-98.

Black, C.A., Evans, D.D., Ensminger, L.E., White, J.L., Clark, F.E. (1965). Methods of soil analysis. Part-I. American Society of Agronomy. Inc. (Pb) .Madison.Wisconsin. USA.547-567 pp.

Frere, M.and Popov, G. (1979).Agrometerological crop monitoring and forecasting. Plant production and protection paper: 17, Food and Agriculture Organization, Rome, Italy.64 pp.

Peer-Mohamed, M. (1988). Pedology and resources of Cholavandan basin soils in Periyar-Vaigai command area, Tamil Nadu. Ph.D., Thesis, Tamil Nadu Agricultural University, Coimbatore.

Piper, C.S. (1966). Soil and plant analysis. Inter Science publication. Inc. New York. 368 pp.

Richards, L.A. (1954). Diagnosis and improvement of saline and alkali soils. USDA Handbook, 60, USDA, Washington. D.C., USA.

Sarkar, R. P. and Biswas, B. C. (1988). A new approach to agro-climatic classification to find out crop potential. *Mausam* **39,** 343- 358.

Schumacher, J., Luedeling, E., Gebauer, J., Saied, A., El-Siddig, K. and Buerkert, A. (2009). Spatial expansion and water requirements of urban agriculture in Khartoum, Sudan. *Journal of Arid Environment* **10**, 1016-1019

Singh, K.B. (2005). Field evaluation of soil water balance model. *Journal of the Indian Society of Soil Science* **53 (3),** 288-295.

Soil Survey Staff. (2006). Keys to Soil Taxonomy, Tenth edition, United States Department of Agriculture, Natural Resources Conservation Service, Washington, D.C. USA.

Suraj Bhan, Uttam, S.K and Radhey Shyam (1995). Effect of moisture conservation practices and nitrogen levels on yield, water use and root development of rainfed sorghum. *Indian Journal of Soil conservation* **23,** 24-29.

Tesfaye, K and Walker, S. (2004). Matching of crop and environment for optimal water use: the case of Ethiopia. *Physics and Chemistry of Earth* **29**, 1061-1067.

Walkley, A.J. and Black, C.A. (1934). An estimation of the digestion method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37,** 29-38.

Received : April 2008 *Accepted : December 2010*