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Hydrological Implications of Soil Water Dynamics Under an Alley Cropping System in the Mid Country Intermediate Zone of Sri Lanka

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ABSTRACT. Use of alley cropping (sloping agricultural land technology–SALT) is promoted as a measure to improve the degraded watersheds in the mid country of Sri Lanka. Increase of the extent under alley cropping in the watersheds may affect the hydrology of the area. Soil water status is one of the important parameters that affects the hydrology. A study was conducted over a two–year period from 1995–1996 in an alley cropping system to study the soil water dynamics over the year and its effect on the hydrologic process. The study was conducted in Pallekelle in Kandy district (80^0.39'E 7^0.16'N). Soil water content (SWC) was measured up to 250 cm in the soil profile using a neutron moisture probe in a micro plot (740 m^2) isolated in the field. Rainfall and runoff from the plot and the rainfall was monitored. The results showed that the change of soil water below 30 cm layer was seasonal and influenced only by the rainfall in the months of April, October and November. The SWC at depths below 30 cm reached to peak levels in the month of November during the year. There was a deficit of soil water storage year round. The rainfall in November greatly exceeded the soil water deficit at the beginning of the month. The excess of rainfall over deficit was nearly 100 mm during November. In the remaining months rainfall was very much lower than the soil water deficit experienced at the beginning of each month. The results indicate that the soil water conditions under this climate–soil–vegetation combination do not favour for significant contribution from rainfall to catchment yield except in the month of November.

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INTRODUCTION

Degradation of land and water resources in the country is considered to be a major environmental problem in Sri Lanka at present. Declining trend of soil fertility in the agricultural lands (Nayakekorala, 1998), decreasing trend of dry weather flows and increasing trend of peak flows in rivers (Maddumabandara and Kuruppuarachchi, 1989) and increasing trend of rainfall to runoff ratio in major rivers (NARESA, 1991) are some consequences of this degradation. Degradation of watersheds has been attributed to soil erosion (Nayakekorala and Prasantha, 1996) and change of land use (Maddumabandara and Kuruppuarachchi, 1989) in the catchments. At present attempts are being made to improve the land and water resources in the watersheds through watershed management programs by various organizations (Gamage, 1994).

Main emphasis of these watershed management programs is to increase the vegetative cover in the lands. The alley cropping system (known as hedgerow cropping, avenue cropping or sloping agricultural land technology–SALT) is promoted in many of the programs. This system has been accepted as an appropriate agroforestry technology for small holder farmers throughout the ecologically marginal areas of Sri Lanka (Nanayakkara, 1991). Since 1988 the Mahaweli Authority of Sri Lanka has been working with GTZ to promote use of this system on the steep slopes of the Upper Mahaweli catchment (Mohns and Rajapakse, 1990). In this system, food crops are grown in alleys formed by contour hedgerows of trees or shrubs across the slope. The hedgerow trees transpire additional water from the soil and deplete the soil water storage. Soil water status can greatly influence the hydrology of an area. Temporal and spatial variability of soil water over catchment areas affect surface and subsurface runoff, modulates evaporation and transpiration, determines the extent of ground water recharge, and initiates or sustains feed back between land surface and atmosphere (Geogakakos and Banmer, 1996). Therefore, hydrological consequences of different land use systems are much important especially in the mid country intermediate zone where watersheds of some major reservoirs are located.

The over all objective of this research was to determine the hydrological implications of soil water behavior under an alley cropping system. The specific objectives were to determine the variation of soil water content at various depths in relation to rainfall, identify the periods and degree of water deficit in the soil profile and to analyse the results in terms of their implications on the hydrology of the area.

MATERIALS AND METHODS

The experiment was conducted during October, 1994 to December 1996 at Pallekelle, Kandy, Sri Lanka (80°.39'E 7°.16'N). A plot of 740 m^2 was isolated in a land with 9% slope using an earth bund (covered with grass) of about 30 cm high. In the land there were hedgerows established about 2 years before. The rows were of different tree species namely *Gliricidia sepium, Cassia spectabills, Tithonia diversifolia, Caliandra calothyrsus* and Guinea–B (*Panicum maximum*) grass. They were approximately spaced at 6 m apart. The hedges were of double rows spaced at 40 cm. The hedgerows were maintained as a soil conservation measure and were pruned when they were grown to shade the ground. Eighteen aluminum neutron probe access tubes were installed up to the decomposing bedrock (250 cm) to measure soil water using a neutron moisture meter. The details of the hedgerow spacing, types of tree species in each row, and distribution of access tubes are shown in Figure 1. Access tubes were installed on the hedgerow, and 1.5 and 3 m away from the row. The neutron counts were taken at 30 cm depth intervals starting from 30 cm depth. The readings were made approximately at weekly intervals. However, additional readings were taken following heavy rains. Gravimetric samples were taken for soil moisture determination at 10 cm depth. The probe was calibrated for the site. Rainfall was recorded using a non–recording rain gauge. Eggplant (*Solanum melongena*) was planted in the plots in early part of October in each year. The land was left fallow during June to October. The loppings of hedgerows were used as a mulch in the plot. Undecomposed plant debris was put in between the two plant rows of the hedge. Runoff from the plot was measured using a collecting tank constructed at the lower end of the plot.

A soil pit dug out side the experimental plot was used to sample the soil for determination of physical characteristics of different horizons. Soil samples from different horizons were used to determine soil texture, soil water characteristic curves (SWCC) and the bulk density. Soil texture was determined by pipette method (Gee and Bauder, 1986), soil water characteristics curve by pressure plate apparatus, and the bulk density by core sample method. Using the SWCC, field capacity (FC) and the permanent wilting point (PWP) were determined as the moisture contents at 10 and 1500 kpa, respectively. Sum of water content at FC in all depths up to 250 cm was considered as the total soil water storage for that profile. Any amount below this level, based on observation, was considered to be the soil moisture deficit.

The vegetation of the experimental site comprised of hedgerow plant species (described before), eggplant crop and some broad leaf and grassy

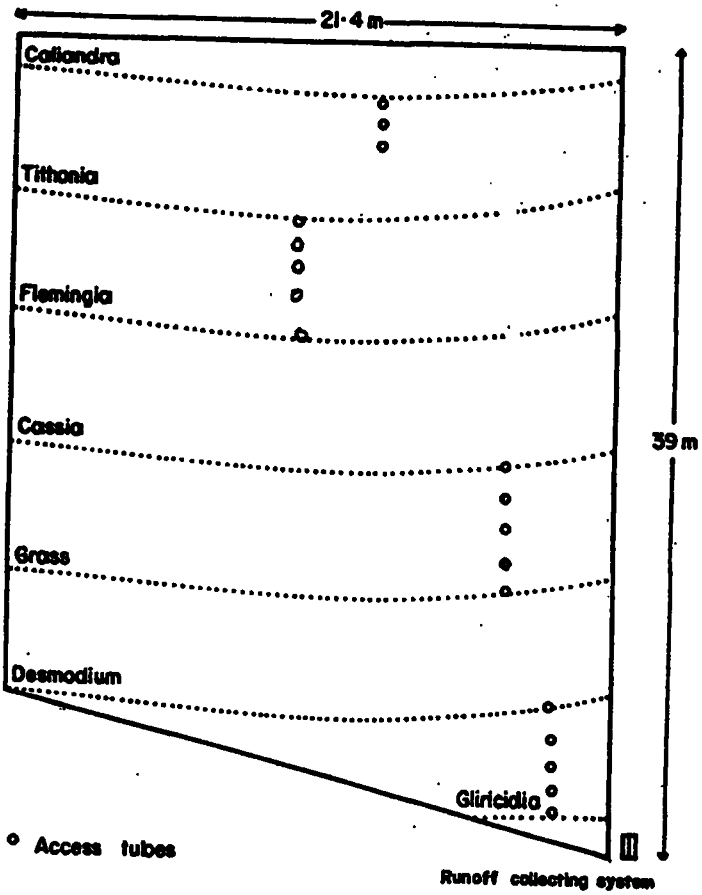

Figure 1. **Field plan of the experimental site.**

weeds, which were common in the area. Eggplant was transplanted in mid October at a spacing of 90 cm × 90 cm each year beginning from 1994. The field was maintained free of weeds during October to May each year. Thereafter, it was left fallow. The hedgerows were pruned 3 times a year when they were over grown to cover the field. The dates of pruning were 13th January, 18th June and 29th November in 1995. In 1996 the dates were 25th in January and May and 16th in November.

RESULTS AND DISCUSSION

Soil physical characteristics

Soil at the experimental site was Reddish Brown Latosolic (de Alwis and Panabokke, 1972) which is classified as Rhodudults according to soil taxonomy (USDA, 1975). The soil was 250 cm deep down to the decomposing bedrock. Four major horizons were identified and were designated as A, Bt1, Bt2, and C. Depths of these horizons were 0–20, 20–75, 75–105 and >105 cm, respectively. Some important physical characteristics of each horizon are given in Table 1. The texture of the horizons ranged from sandy loam and sand. According to the data on field capacity (FC) and permanent wilting point (PWP) presented in Table 1, the 250 cm profile can hold 342 mm of water when wetted up to the FC level. This is considered as the profile storage capacity (PSC). Similarly at the PWP the profile can hold 143 mm of water. Accordingly, the profile had 199 mm of available water capacity (AWC).

Table 1. **Selected physical characteristics in different horizons of the soil profile at the experimental site.**

Horizon		A	Bt1	Bt2	C
Depth (cm)		0–20	20–75	75–105	>105
Bulk density (Mg m^{-3})		1.48	1.56	1.44	1.48
Texture	% sand	82.00	81.00	76.00	90.00
	% silt	12.00	12.00	15.00	7.00
	% clay	6.00	7.00	9.00	3.00
Field capacity (cm cm^{-1})		0.30	0.17	0.10	0.11
Permanent wilting point (cm cm^{-1})		0.17	0.08	0.03	0.04
Water storage capacity (cm)*		6.00	9.40	3.10	15.70

* This row gives the total water that is stored in the soil horizon when it is filled up to field capacity.

Climatic conditions during the experimental period

The soil water behavior is dependent on the climate. Rainfall and the ambient temperature are two important climatic variables that can have direct impact on the soil water content (SWC). The mean ambient temperature varied between 24–28°C over the year during the experimental period. The lowest temperature was experienced in December–January while the highest was experienced in August–September. Comparison of two year data with that of 10 year average data (1986–1995) obtained at the meteorological station at Kundasale (which is located within 2 km radius from the experimental site) clearly showed that the mean rainfall in the two years of experimental period was about 14% less than that of the 10 year average rainfall. The distribution also deviated from the long-term pattern. The mean monthly temperature and duration of sunshine showed a slight increase.

Soil water dynamics in different depths over the year

Soil water content at different depths in the profile changed with time as influenced by the rainfall and water uptake by the vegetation (Figure 2). The results show the effect of daily and seasonal rainfall on SWC in each soil layer. Change of SWC with time in different depths followed a similar pattern in the two years of the study. The change of SWC with time in 10 cm depth was highly variable. This high variability could be attributed to quick response of the SWC to the rainfall. However, as the depth increased, the variability of SWC was reduced. The change at 60 cm and below was very smooth and seasonal. At these depths, SWC gradually increased with time starting from end of September with increasing rainfall in the *Maha* season (longer rainy season). The SWC came to peak level in late November to mid December period.

The level of rise of SWC was depended on the cumulative rainfall received. After the peak rainfall period in *Maha*, SWC at these depths declined until the end of March irrespective of the rainfall received during the period. The rainfall in January, February and March did not affect the SWC at depths below 30 cm. With the rainfall in April, the SWC increased again until end of April and continued to decrease gradually until *Maha* rains commenced in late September. The rainfall during May to October also could not influence the SWC below 30 cm depth. It has to be noted that the depth of influence of rainfall on SWC depend on the amount of cumulative rainfall

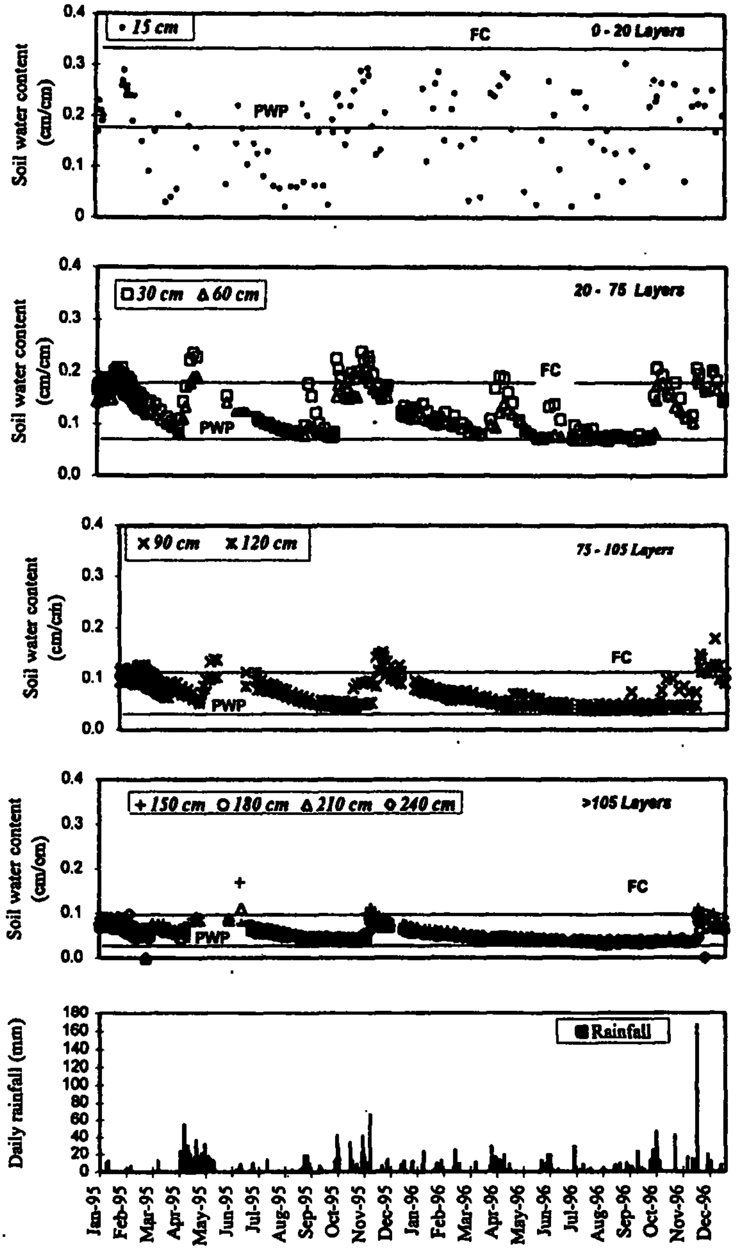

Figure 2. Change of soil water content at different depths in relation to rainfall distribution in 1995/96 under an alley cropping system in mid country intermediate zone of Sri Lanka.

during the period considered. For example, rainfall of 263 mm in April 1995 increased the SWC in all depths up to 250 cm. However, 184 mm of rainfall in April in 1996 could increase the SWC only in depths above 90 cm (Figure 2).

The FC and PWP are marked in Figure 1 for various soil horizons. Therefore, depletion of SWC at different depths in relation to soil water constants can be observed from these results. The data showed that during the months with low rainfall such as February, March, July, August and September, the SWC in depths below 60 cm reached the level of PWP. The SWC at 10 and 30 cm depths also reached this level depending on the rainfall. The SWC at depths above 180 cm reached FC during peak rainfall period namely, mid November to Mid December, but not the depths of 210 and 240 cm. The Figure 2 clearly illustrates that the change of SWC at depths below 60 cm continued to be seasonal. The SWC at these depths were increased only by the *Yala* season (short season rainfall) rains in April and *Maha* rains in October and November. Rainfall in other months changed the SWC only in soil above 60 cm.

Soil water dynamics during dry and wet periods

Variation of SWC during *Yala* and *Maha* rainy periods of 1995 and 1996 is illustrated in Figure 3. Only the periods where SWC continuously increased have been considered (four periods are considered). Figures 3A and 3C show the behaviour of SWC during *Yala* rains in 1995 and 1996, respectively. The Figures 3B and 3D show the behaviour during *Maha* rains of the same years. The water storage of profile at the beginning of the rainy periods in A, B, C and D were 156, 151, 143 and 130 mm, respectively. These SWC's were raised to 308, 358, 215, and 347 mm by rainfall of 228, 286, 181 and 275 mm, respectively. Change of soil water storage accounted for 72–79% of the rainfall in the two *Maha* seasons while it was 40–66% in the two *Yala* seasons. The water storage capacity of the profile was 342 mm. The results indicate that the cumulative rainfall of 275 and 286 mm during the two *Maha* seasons raised the soil water storage up to PSC (the full capacity) of the profile. However, the soil water distribution in the profile (Figure 3) shows that all soil layers did not attain FC level. The SWC of layers between 30–120 cm were raised above the FC level while those below and above this limit remained lower than the FC level. This can be seen when SWC at each depth is compared with that at FC level as illustrated in Figure 3. As an example, in the Figure 3C, the rainfall of 181 mm within a month failed to make an appreciable change of SWC below 120 cm depth.

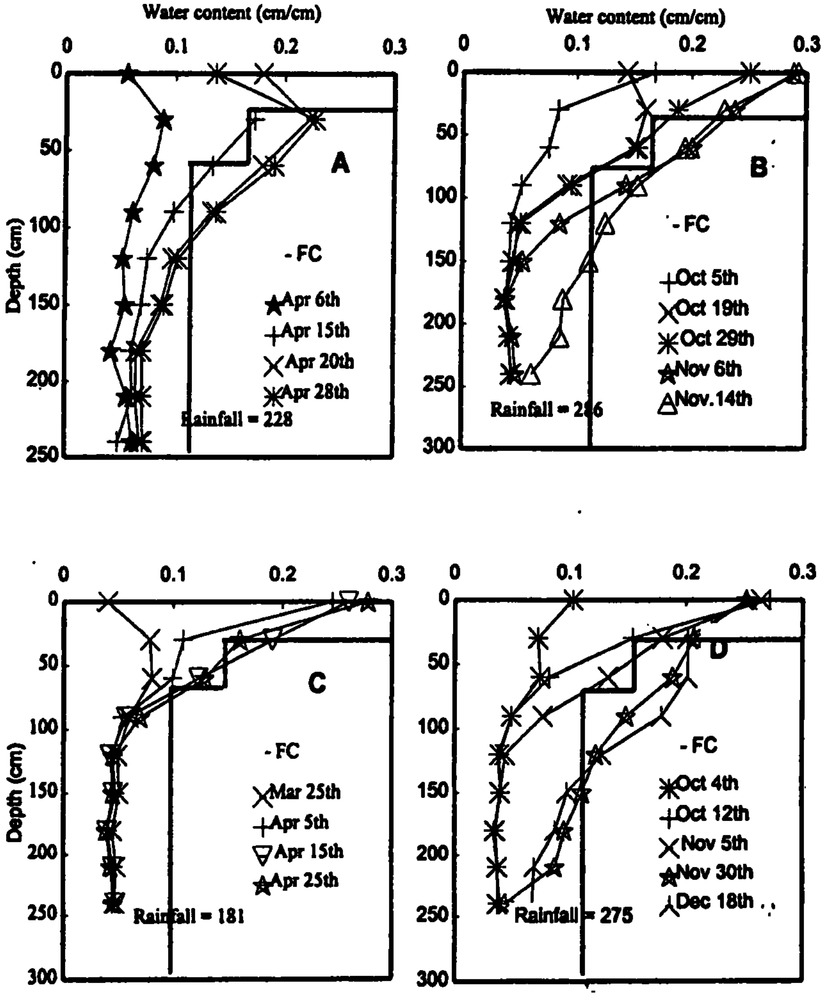

Figure 3. Change of soil water content at different depths during four wet periods in 1995 (A, B) and 1996 (C, D).

The soil water contents and their distribution in the profile during rainy periods is very important from the hydrological point of view. Saturation of subsurface soil layers may initiate two types of run off processes *i.e.* overland run off or subsurface run off. The over land run off from the plot was monitored in this study. Over land run off was negligible and was produced only in the months of January, April and November in 1995. It amounted to 1.4, 2.1 and 1.6 mm, respectively, in these months. There was no run off produced in 1996. This indicates that if there were any run off from the plot it would have been subsurface run off.

The soil water depletion during two different dry periods is shown in Figure 4. In both periods the SWC at all depths remained above PWP levels. The data clearly indicate that the water depletion from layers above 120 cm is greater than that from the layers below 120 cm depth. During dry period A (Figure 4), 78 mm of water from soil above 120 mm depth and 24 mm from soil below 120 cm depth were depleted. During the dry period B, estimations revealed that 86 mm of water was depleted from layers above 120 cm depth while the depletion from layers below was only 4 mm. At the end of both dry periods, the SWC in depths above 90 cm reached PWP levels. The SWC below 90 cm was also depleted to very low levels but remained above PWP levels. Probably the vegetation survived with the water supplied from these depths. The data on dry period B (Figure 4) showed that by the end of May the soil water content in the profile had depleted to very low levels. This was also indicated by the results presented in Figure 2. This dry period in the region generally extends until end of September. During this

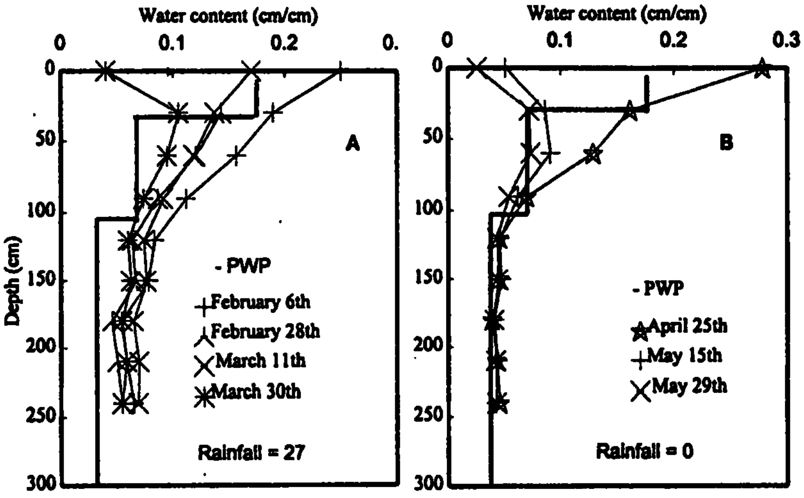

Figure 4. **Change of soil water content at different depths during two dry periods : 1995 (A) and 1996 (B).**

period the vegetation may subject to severe water stress. The dry period from February to March follows the April rains and the profile will be replenished soon and may not affect the vegetation seriously.

Change of soil water storage (SWS) with time

The soil water storage is the sum of water in all depths of the profile at a given time. The change of soil water storage in the profile with time is shown in Figure 5. The results also indicate the distribution of rainfall during the period thus, the effects of rainfall on change of soil water storage could be observed.

Two peaks of soil water storage was observed in a year (Figure 5). These two peaks corresponded with the two rainy seasons namely April (*Yala*) and October–November (*Maha*). The October–November peak was higher than that in April. Similarly, two periods of lowest soil water storage were also observed in March and September and reached the PWP capacity of the profile (PWPC) which is 142 mm. During both years the water storage in the profile at the end of *Maha* rains reached the profile storage capacity (PSC). However, this does not indicate that all the soil layers were filled up to FC level. It was shown before that the soil layers between 30–120 cm were at above FC while the layers below remained lower than the FC level.

The results clearly indicate the effects of rainfall on soil water storage (Figure 5). The storage increased immediately following rains in April, October and November. Similarly, the storage declined soon after the end of rains. The soil profile reached the highest storage of about 370 mm at the end of November in both years. This water content was in excess of the profile capacity of 342 mm. In both years the storage remained at the peak level only for a very short period of time. The rains of dry months namely, February, March, July, August and September did not influence the soil water storage considerably. The storage remained far below when compared to the PSC indicating that the soil profile was at water deficit during most of the time of the year.

Soil water deficit and rainfall

Soil water deficit (SWD) at the start of each month and the monthly rainfall for 1995 and 1996 are given in Table 2. The lowest deficit was shown at the beginning of December in both years and was 53 and 19 mm,

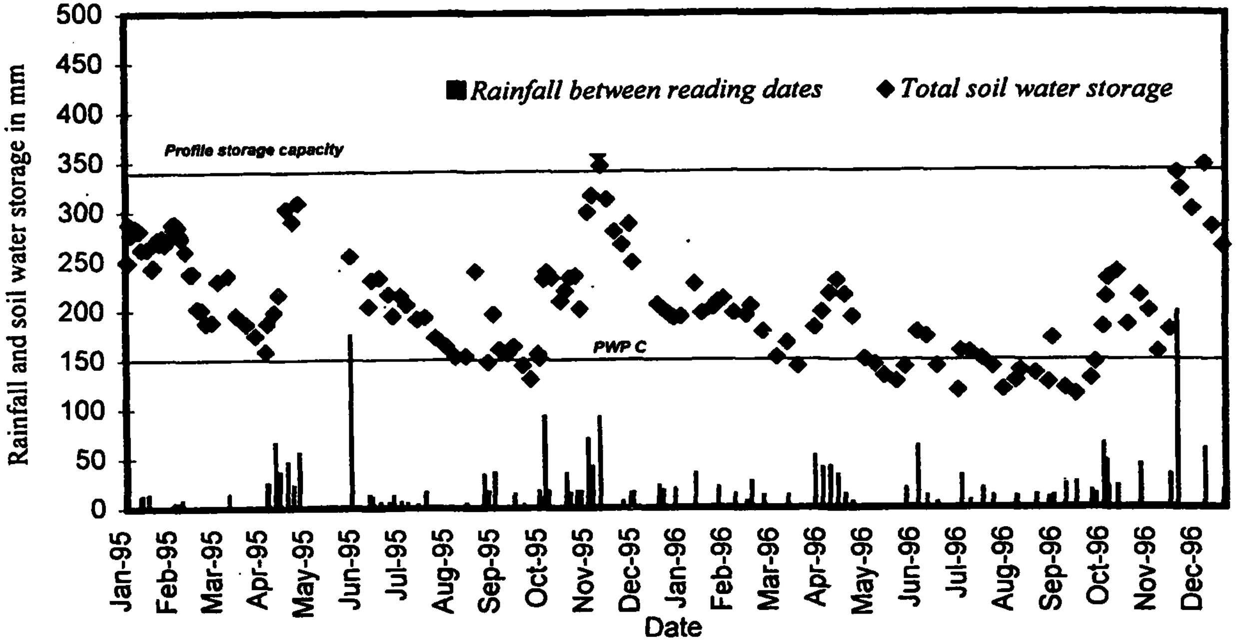

Figure 5. Change of soil water storage in 0–250 cm depth with time in 1995 and 1996 under an alley cropping system.

Table 2. **Deficit of soil water storage (in 250 cm) and rainfall in each month in 1995 and 1996.**

Month	1995		1996	
	Deficit[1] (mm)	Rainfall (mm)	Deficit[1] (mm)	Rainfall (mm)
January	91	41	146	77
February	66	24	131	66
March	152	14	162	13
April	182	298	158	185
May	32	153	148	3
June	85	50	198	96
July	146	27	197	71
August	177	57	197	38
September	193	58	204	78
October	185	215	210	166
November	106	211	155	276
December	53	69	19	77

[1] Deficit at the beginning of the month.

respectively, in 1995 and 1996. The highest deficit was shown in the months of September and October. There was also a higher SWD at the beginning of April. The highest deficit was almost as same as the available water capacity (AWC) of the profile, which was 199 mm. This indicates that during April, September and October, the soil profile was completely depleted of available

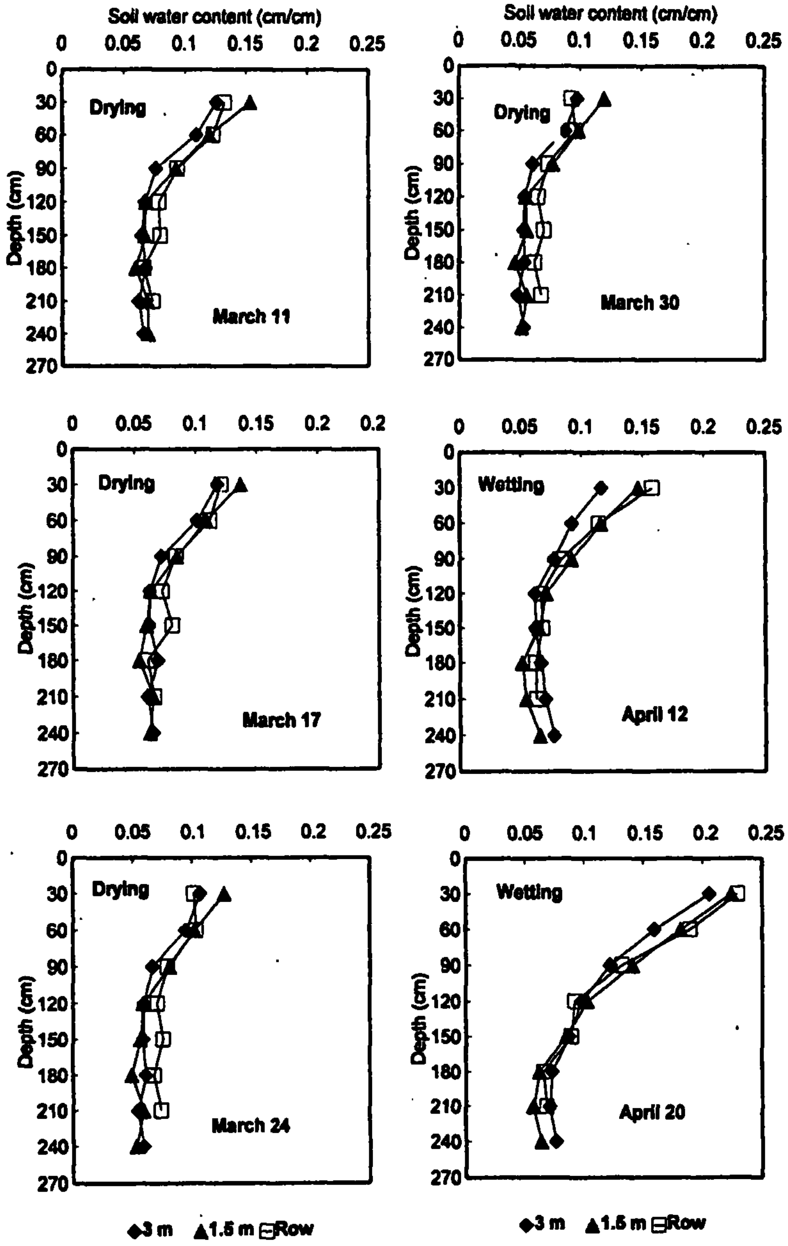

Figure 6. Change of soil water content in different depths at various distances from the hedgerow at Pallekelle in a dry and wet cycle in 1995.

water. As there was no soil water the vegetation would have survived by the low rainfall received during these months. The monthly rainfall exceeded the deficit shown at the start of April, November and December in both years. In all the other months the deficit exceeded the monthly rainfall. The excess of rainfall over deficit was highest in November. In this month, rainfall was 104 and 120 mm (98 and 77%) more than the deficit in 1995 and 1996, respectively. In November of both years the soil profile up to 180 cm reached the saturation level (Figure 2). Therefore, November is important from hydrological point of view as it is the only month which has some potential to contribute to the catchment yield form the rainfall. In all the other months almost all the rainfall is used to fill the soil water deficit and meet the evapotranspiration of the vegetation.

Effect of hedgerow on soil water content

The SWC at different distances from the hedgerow in various depths were examined during a dry and wet cycle. The dry period extended for 26 days beginning from 10th March, 1995 after a rainstorm. A period with continuous rainfall followed the dry period. This rainy period extended for 18 days beginning from 5th April 1995. Total rainfall of 196 mm was received during this period. The behavior of SWC during these dry and wet periods at different depths on the hedgerow and 1.5 and 3 m away from the row are illustrated in Figure 6. At the beginning of the dry period, the SWC at all depths among different distances were similar. The average total water storage at different positions were 215, 210 and 192 mm, respectively, at the hedgerow and 1.5 and 3 m away from the row. After 20 days of continuous dry period, this storage was depleted to 176, 168 and 152 mm, respectively, for the same positions. This indicates that the water extraction at different positions were more or less the same amounting to 39, 42 and 40 mm, respectively, at the three positions. Chirwa *et al.* (1994) reported similar results in an alley cropping system where the hedgerows were formed by *Leucaena leucocephala* and *Mangania congesta.* Chirwa *et al.* (1994) also reported that the hedgerows depleted same amount of water as depleted by the maize crop. During dry conditions there was higher moisture content under maize rows than under hedgerows. Figure 6 shows that at the end of the rainy period, there was no significant difference in the SWC at different positions. The results indicate that the hedgerows did not extract more water from the soil than the amount extracted by crop.

CONCLUSIONS

Results of this study showed that the soil water content (SWC) in different depths behaved differently in response to the rainfall during the two years. The SWC in soil layers above 30 cm (including 30cm) was highly responsive to daily rainfall and, below 30 cm (excluding 30 cm) was responsive to the seasonal rainfall rather than to the daily rainfall. In these layers, SWC increased to peak levels following rainfall in October and November and gradually decreased until end of March. After rains in April, SWC increased to a second peak and thereafter continued to decrease until October until rains started in November. Following rainfall in October–November the SWC in soil layer above 120 cm increased to FC level or above. During most of the months the soil water storage remained below the storage capacity of the soil and showed a soil water deficit (SWD). The SWD was highest at the end of September. By this time the profile had depleted almost all of the available water which was about 200 mm. The subsequent rainfall filled this deficit and the storage came to peak level in November. The rainfall in November in both years was excessively higher than the SWD at the beginning of the month. As stated above in this months most of the soil layers had reached the saturation level. These results indicate that only November rain fall had the potential to contribute to the catchment yield of the area due to availability of excess water over the water holding capacity. In the remaining months, the rainfall was below or same as the SWD. The rainfall of October, November and December months of the study period closely compares with average monthly rainfall in the area. Therefore, this observation should hold true in general for the area. The results indicate that the soil water conditions under this climatic–soil–vegetation combination do not favour for significant contribution from rainfall to catchment yield except in the month of November.

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