

Water use by vegetation under different land uses in the mid country intermediate zone of Sri Lanka

Abstract

Deterioration of the water resources is a major land related problem faced by many nations in the world at present. The problem has been gradually developed in Sri Lanka over the last several decades and now it has reached to a critical level. It has been well documented that dry weather flows in our streams show a decreasing trend while peak flows following heavy rain storms show an increasing trend. Percentage of rainfall, which is subjected to runoff in major river basins, has increased by about 1 - 2 % annually over the recent past. These changes have been attributed to changes of land uses that have been taken place in the catchments. Change of land use will change the vegetation. Vegetation is responsible for many hydrologic processes of the land. Vegetation influences the soil properties and controls the infiltration capacity, which in turn determines the soil water status. The soil water status moderates the evapotranspiration rate and regulates water flow in the soil. At present many watershed management programs have been initiated in the country in order to reclaim the already deteriorated water resources. However, such programs are based on many assumptions, which have not been field-tested. Further, these programmes have been planned without proper understanding of their hydrological implications. The research discussed in this paper is an attempt to determine the water use by vegetation under some important land uses in the mid country intermediate zone of Sri Lanka. Water use data for most of the vegetation types in Sri Lanka are not available at present but essential for planning of watershed management programmes.

Water balance approach was used in determining the water use by vegetation under land uses namely natural forest, hedgerow cropping system (sloping agricultural land technique) mixed perennial cropping (Kandyan forest garden) and grassland in micro runoff plots over two year period. Rainfall, runoff and soil water storage were measured in the field. A drainage lysimeter with grass was used to determine the (reference crop evapotranspiration, ET₀) potential evapotranspiration of the area.

The data showed that the ET₀ (as determined by the lysimeter) varied between 3.8 to 6.4 mm/day over the year. The lowest ET values under all four land uses were experienced during dry months such as June, July and August while highest values were observed in January, February and April months where soil water levels and radiant energy remained comparatively high. The paper will make comparison of water use by different vegetation.

Key words: Land use systems, vegetation, evapotranspiration, soil water, rainfall.

Introduction

Documentary evidences suggest that the water resources of the country are at risk. Recent studies show that rainfall pattern is changing in some areas of the country (NARESA 1991, Maddumabandara and Kuruppuarachchi, 1989). Studies also have indicated increasing trends of runoff/rainfall ratios in our major rivers (Maddumabandara & Kuruppuarachchi 1989, NARESA, 1991) and decreasing trends of dry weather flow (Maddumabandara & Kuruppuarachchi 1989). Several factors including global or regional climatic change and land use changes in catchments have been attributed as causes to these problems.

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Risks of sedimentation of the reservoirs have been highlighted by recent research. The studies of Hydraulic Research, Wallingford (1995) showed that the Rantambe reservoir was silted up by 1.8% of its designed capacity by 1992, just in 3 years of its impoundment. The Polgolla barrage was silted by 44% of its capacity by 1993. The high rates of sedimentation of the reservoirs have threatened the life span of these reservoirs. Dharmasena (1992) reported that some minor tanks in the Anuradhapura district filled with sedimentation at a rate of about 2.4 % of their capacity during 1983-1993.

Degradation of watersheds is thought to be a cause to some of the problems such as increasing rainfall-runoff ratios, decreasing dry weather flows and high sedimentation rates. At present there are many projects and programmes which are aimed at improving the degraded lands through watershed management. Gamage (1995) reviewed the "state of art and status of watershed management in Sri Lanka". According to this review much attention of watershed management programs of the country at present has paid to soil conservation aspect. It can be seen that hydrologic implications of land management practices have not been given due consideration in many of these programmes. In the soil conservation programmes vegetative measures have been given priority. These measures include reforestation, afforestation, agroforestry & hedgerow or alley cropping (SALT) systems. Introduction of these land use systems may affect the hydrology of the catchments. The effects of different vegetation in catchments are much debated and are a controversial issue. The water use by vegetation is a major factor, which affects the hydrological behaviour of catchments. The water use data of many vegetation types are not available at present. This paper reports results of a research conducted to determine the water use of vegetation under some important land use systems in the mid country intermediate zone of Sri Lanka.

The objectives of the research was to determine the evapotranspiration (ET) rates of vegetation under four land use systems namely: hedgerow system (alley cropping or SALT), grassland, mixed tree crops (Kandyan forest garden) and natural forest in the mid country intermediate zone of Sri Lanka.

Materials and Methods

The study was conducted in the mid country intermediate zone 3 (IM3) (Land and water use division, 1979) falling in the upper Mahaweli Catchment (UMC). The UMC and the IM3 zone are shown in fig. 1. Experimental sites having required land use systems were selected at different locations within the study area in Pallekele (hedgerow system), Kundasale (grassland), Digana (mixed tree crop system) and Hanguranketha (natural forest) (fig 1). ET was determined by water balance approach in micro plots constructed at the experimental sites. Following water balance relationship was used.

$$ET = RF - RO - \Delta S$$

Plot size was approximately 500 m². Plots were isolated using an earth dike of about 30 cm high and compacted very well. Each plot was more or less of uniform slope. The runoff water from each plot was directed to one out let from the plot for measurement. Rainfall was measured at each site in an open area closer to the site with a non-recording rain gauge. Soil water content down to decomposing bedrock in the soil was measured using a neutron moisture meter (neutron probe) and several aluminum access tubes installed in the field at random. Readings were taken at 30cm intervals starting 30cm from the surface at regular intervals of one week. Soil water content at 10cm depth was determined by gravimetric method. Probe was calibrated for soils at each site.

A meteorological station was set up at the Pallekele site. Equipment namely, maximum-minimum thermometer, wet-dry bulb thermometer, anemometer, sunshine recorder, and recording rain gauge were installed at this station. Data was collected daily. A

drainage type lysimeter was constructed and maintained at the meteorological station at Pallekele as described by FAO (1982) to determine the reference crop evapotranspiration (ET grass or ET₀) of the area. The Size of the lysimeter was 1.2m x 1.2m and 1.5m deep. *Bracharia brizantha* (grass) was grown in the lysimeter. Daily irrigation of 7mm was made in order to prevent any soil water shortage. Irrigation was suspended if the previous day rainfall was more than 10mm. Daily rainfall and drainage was measured. Soil water content at 30cm interval was measured at weekly intervals using the neutron moisture meter. Water balance was made for periods of about 30 days using the relationship $ET = RF + IR - D - \Delta S$ where IR is irrigation and D is drainage.

Soil profiles at each site was examined for depth and texture at different depths. Soil texture was determined by pipet method.

Data analysis

Reference crop ET (ET₀) was determined by the lysimeter data for each month and daily rates were estimated. ET₀ was also estimated by CROPWAT computer programme (FAO, 1992) using climatic data. These two data sets were compared and validity of the CROPWAT estimate of ET₀ was established. ET was determined on monthly basis for different vegetation using the water balance equation given above for period where water losses from the soil profile by percolation and lateral flow was not expected. These period were determined by looking at the soil water contents (SWC). Months where SWC rose above field capacity level were avoided. ET of vegetation during months where there was no water shortage was considered as potential ET. PET/ET₀ ratio for these months for different vegetation was estimated. The ratio was named "vegetation factor"(VF). This factor was used to estimate the PET of different vegetation in the other months.

Results and discussion

Vegetation

The hedgerow plot consisted of hedges formed by plant species namely, *Caliendra calithyrus*, *Gliricidia sepium*, *Cassia spectabills* and *Tithonia diversifolia* and spaced at approximately 6m interval. The crop namely *Solanum melangina* (eggplant) was grown during the period from October each year. The crop was maintained until end of January. The field was left fallow thereafter. The grassland consisted of *Panicum maximum*, a grass known as Guinea A. This was growing naturally, but mow by the people for feeding cattle. The grass had complete coverage of the ground. The mixed tree crop site consisted of vegetation described as "Kandyan forest garden" with canopy coverage of about 75%. The natural forest comprised of forest vegetation characteristic to the area and had canopy coverage of about 90%.

Soil characteristics.

The soil profile depths were 165 cm at Kundasale (Grassland site) and Hanguranketha (natural forest site) and 250cm at Digana (mixed tree crop site) and Pallekele (hedgerow site). The sites consisted of coarse textured soils. The soil at Pallekele and Digana belonged to Reddish Brown latosolic soils. Grassland site at Kundasale consisted of Immature Brown Loam soil while the soil at Hanguranketha was Mountain regosols formed by colluvials.

Reference crop evapotranspiration (ET₀)

Two-year means of ET₀ as determined by the lysimeter and estimated by the CROPWAT programme are given in table 1. The mean daily observed ET₀ rates varied from 3.8 mm in December to 6.5 mm/day in March. The mean value for the year was 5.5 mm/day with a standard deviation of 0.78 mm/day. The estimated ET₀ values varied from 3.6 mm in

November and December months to 5.4 mm per day in March with annual mean value of 4.1mm with standard deviation of 0.49. However, CROPWAT estimates were about 25% lower than observed values. The CROPWAT program, which is based on the Penman-Monteith Equation (FAO, 1992), is supposed to give a better estimate of the ET.

It must be noted that the lysimeter determination of ET used the water balance approach. The rainfall that was used in the estimation procedure was incidental rainfall, but not the "net rainfall". The vegetation generally intercepts part of the rainfall. As a correction was not made to the interception loss, ET could have been over estimated in this method. It is argued that the transpiration is reduced by the rainfall interception and reduced transpiration is balanced by the interception. Burgy and Pomeroy (1958) and McMillon and Burgy (1960) have experimentally confirmed this view. But, they have not ruled out the possibility of having high water losses from the vegetation when rainfall is intercepted under certain environmental conditions.

Interception data for grassland are not available for local conditions. Gunawardena (1994) reported that the annual interception losses by Kandyan forest garden vegetation were 30% of the annual rainfall for the same area where this experiment was carried out. In the absence of interception data for grass this values was used to correct the rainfall for the "net rainfall" and used in the computation of ET₀ by the lysimeter. The results showed that the reduced considerably in rainy months but in dry months CROPWAT estimates remained about 30 % lower. This was only for months of May, June and July. The mean annual estimate of ET₀ by CROPWAT was 4.1 mm while that of lysimeter was 4.6 which is 10 % difference. The reason for higher observed values in dry months may be due to higher interception rates in these months. The results indicate that there is greater agreement between CROPWAT estimates and lysimeter determination of ET₀. It must be noted that the CROPWAT estimates do not include interception losses and will not estimate total evaporation from the canopy.

Potential ET and vegetation factor

ET of a vegetation at non-limiting soil water and other conditions were considered as potential ET. The potential ET of different selected months (with non-limiting conditions) and vegetation factors (VF) for different vegetation are given in the table 2. The vegetation factors were 0.9 for hedgerow system and 1.1 for land use systems namely grassland, mixed tree crop and natural forest (values rounded off to closest .05). This data indicate that the potential ET of grassland, mixed tree crop and natural forest vegetation is the same. PET for different vegetation in different months can be calculated using the relationship $PET = ET_0 \times VF$. The estimated data are given in table 3. The PET of natural forest, mixed tree crops and grassland seems to be similar. The PET of hedgerow system seems to be lower by about 375 mm per year than that of the other three vegetation types.

ET of vegetation under different land uses

The daily mean ET rates of different vegetation in different months are given in table 4. The data show that the rates are different for different vegetation in different months. The ET rates of hedgerow system varied from 2 mm/day to 4.4 mm/day during the year. The annual mean was 3.1 mm/day with standard deviation of 0.71 mm. The low values corresponded with the months namely, July, August and March. These are usually dry months and soil water contents remained low. The high values corresponded with the months namely January, April and October.

The daily ET of grassland varied from 1.9 mm/day in February to 4.4mm/day in January on average. The low rate in February was due to mowing of grass in that month. The mean annual daily rate of ET under grassland was 3.2 mm/day with standard deviation of

0.66mm. Unlike under the other vegetation ET rates under grassland did not vary greatly among different months.

The daily ET rate of mixed tree crop vegetation varied from 1.9mm/day in July to 6.2 mm/day in March. The annual mean was 2.9mm/day with standard deviation of 1.3mm. The data show that the daily ET in March, May, June July, August and September were about 30%-40% lower than that of other months.

In the case of natural forest vegetation ET rate varied from 1.1 mm/day in August to 5.2mm/day in April. In this land use also the low values were experienced in period of May to September. The mean annual ET rate was 3.6 mm/day with standard deviation of 1.2 mm.

Discussion

The data clearly indicated that the variation of ET over the year by all four vegetation followed a similar pattern. The highest rates were observed during the months of January, February and April. The lowest rates were shown generally during the period of July, August and September. The variation could be related to soil water content and rates of incident solar radiation. The highest rates were observed during the period when higher solar radiation coincided with higher soil water contents. Months of January, February and April satisfy this condition. The solar radiation rates in the area are at their highest during the period from January to April and then begins to decline (CARP, 1990). It is lowest during November and December months when the soil water content is at maximum. After December the soil water content begins to decline until end of March. In April it again rises to higher level. The soil water contents remain at a higher level in January and February compared to that in March. Because of this situation ET rate are higher in January, February and April but lower in March.

Comparison of PET data in table 3 with ET in table 4 show that the ET rates during dry months are far below the PET of the same months. This can be attributed to low water availability during this period. Fig. 2 shows that the soil water storage during these months decline to levels closer to permanent wilting point. The rainfall also remains comparatively low during this period. The data indicate that during these months the soil water controls the ET rates rather than the vegetation.

It can be seen that during dry period of June to September, the ET rates of all land uses were low and remained between 2 - 3 mm/day. However, during period of high soil water availability such as February - March and April, there were differences among ET rates of different land uses. Higher rates of 4 - 4.5 mm/day were observed for Natural forest and mixed tree crops (KFG) systems while lower rates of 3.1 mm/day was observed for hedgerow system and grassland. It must be noted that in April, natural forest, mixed tree crop system and hedgerow system showed similar daily ET rates. The low ET rates of grassland in this month could be due to mowing of the grass.

Data on water use by different vegetation are scanty for tropical climates. Available data mostly covers the seasonal agricultural crops. However, since recently the data seems to be generated. Munasinghe and Somasiri reported that in the dry zone the daily ET rate of forest vegetation varied from 0.2- 6.0mm/day. The lowest rates were observed during the dry months where soil water contents declined to very low levels. ET rates as low as 1.7 mm/day during long dry spells in deep profiles have been reported by Hodnet et al (1996) in Amazonian forest. They also reported low ET rate of 2.5 mm/day by pasture during a 50 day long dry period. The research was conducted in an area with similar tropical climate and ET data closely compares with that of present study.

The annual ET rates of the four vegetation varied from 1025mm to 1385mm. The highest was shown by the mixed tree crop system and the lowest by the hedgerow system. The annual ET rate of natural forest also was very closer to that of mixed tree crop

vegetation; it was 1320 mm. The annual ET rates of natural forest and the mixed tree crop system (Kandyan forest garden) seems to be very close. The data in table 5 show that the annual ET of all four vegetation was very close to the incident rainfall at respective sites. This indicates that the most of the rainfall have been used to meet the ET of the vegetation at each site. The table 4 shows the PET of the different vegetation of this climatic region. It varies from 1257 for hedgerow system to 1636 mm for other 3 vegetation types. The annual rainfall at the four sites varied from 1180 – 1385. The comparison of rainfall with PET data show that the PET of grassland, mixed tree crop system and natural forest was about 250 mm above the annual rainfall.

Conclusions

The CROPWAT estimates of ET₀ are in agreement with that of lysimeter estimates when interception losses of rainfall by the grass are not considered. Hence the programme can be used to determine the ET₀ in the study area.

The ET rates of hedgerow system varied from 2 mm/day in July to 4.4 mm/day in April during the year. The daily ET rate of mixed tree crop vegetation varied from 1.9mm/day in July to 6.2 mm/day in March. In the case of natural forest vegetation ET rate varied from 1.1 mm/day in August to 5.2mm/day in April. The variation of ET in grassland was 1.9 mm/day in February to 4.4 mm/day in January. The ET of grassland was affected by mowing of grass.

Water yield of a catchment is an important aspect of watershed management programs. The water yield basically depends on the ET, which is a function of the vegetation of the catchment. Land use determines the type of vegetation. The data presented showed that in this climatic region soil water content controlled the ET during most months of the year. There were very low levels of soil water storage during this period. During dry months the monthly ET of all the four vegetation were less than the monthly PET. However, when there were no soil water deficit ET takes place at potential level. The different vegetation had different rates of evapotranspiration when there was no shortage of soil water. However, when there was soil water deficit all the vegetation showed the lowest ET rates. The rainfall determined the soil water content and hence it is the rainfall, which controlled ET in the area.

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Table 1: Observed and estimated daily ET₀ (means of two years) values for different months of the year.

Month	ET ₀ observed mm/day	ET ₀ estimated mm/day
January	5.8	4.2
February	5.4	4.4
March	6.5	5.4
April	6.1	4.3
May	6.0	4.1
June	5.9	3.7
July	5.4	3.7
August	4.8	4.1
September	4.5	3.9
October	6.0	4.0
November	5.7	3.6
December	4.0	3.6
Annual mean	5.5	4.1

Table 2:- Potential evapotranspiration (PET) of different vegetation, ET₀ (CROPWAT estimate) and vegetation factor (VF) for selected months.

Land use	Variable	Month				Average
		Jan	Feb	Apr	Oct	
	ET ₀	4.2	4.7	5.4	4.0	4.58
Hedgerow	PET	3.6	4.0	4.4	3.8	3.95
	Vegetation factor	0.86	0.85	0.81	0.95	0.87
Grassland	PET	4.4	-	-	4.6	4.5
	Vegetation factor	1.04	-	-	1.15	1.09
Mixedcrop	PET	4.9	-	5.5	4.8	5.07
	Vegetation factor	1.16	-	1.02	1.2	1.12
	PET	4.9	4.9	5.9	3.9	4.9
Natural forest	Vegetation factor	1.16	1.04	1.09	0.98	1.07

Vegetation factor = PET Vegetation / ET₀

Table 3: Potential ET of vegetation under different land uses in different months of the year.

Month	Hedgerow	Grassland, Mixed tree crop & Natural forest
January	3.8	4.6
February	4.2	5.2
March	4.9	5.9
April	3.9	4.7
May	3.7	4.5
June	3.3	4.1
July	3.3	4.1
August	3.7	4.5
September	3.5	4.0
October	3.6	4.4
November	3.2	3.9
December	3.2	3.9
Annual mean	3.7	4.5
Annual Total	1257	1636

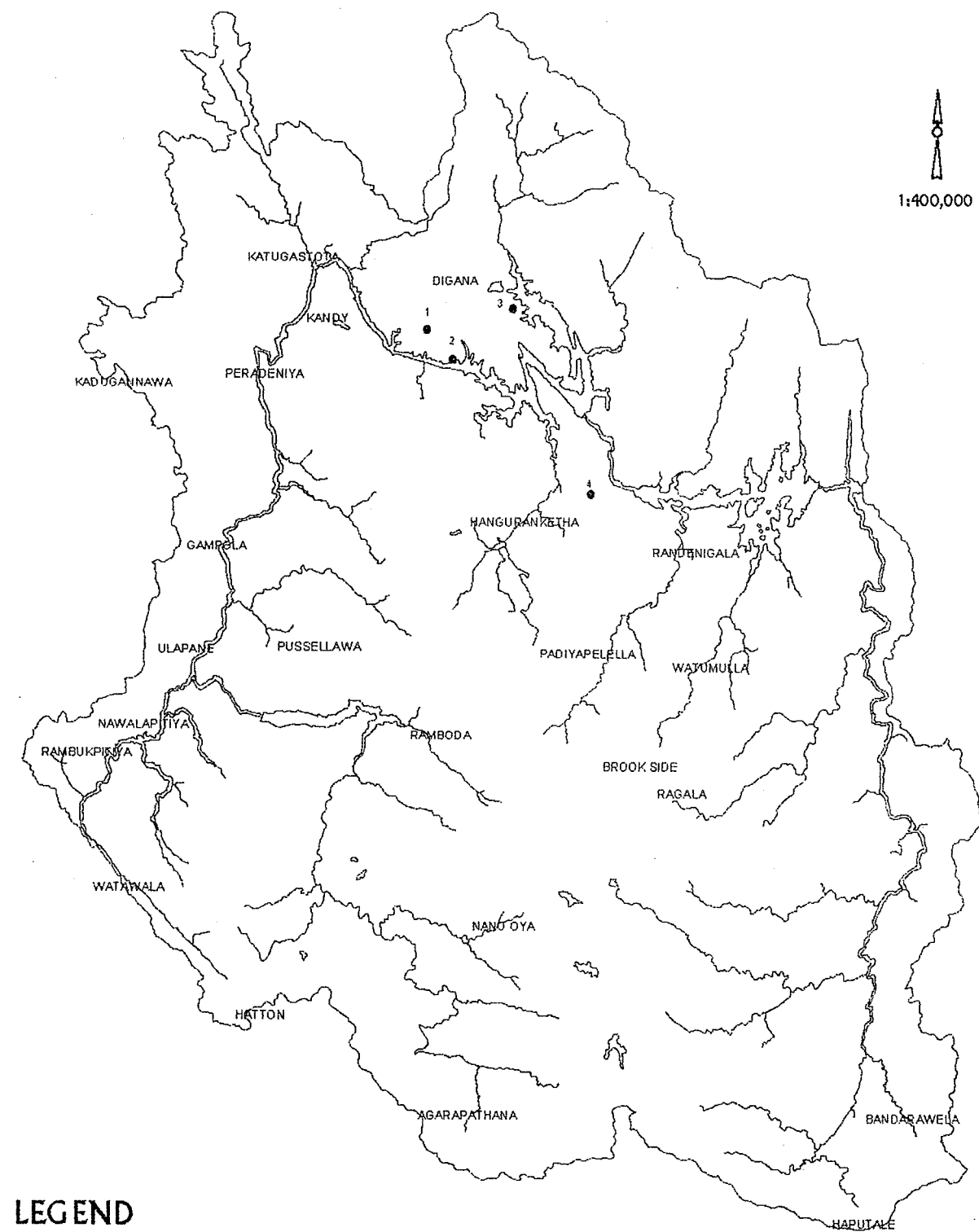
Table 4: - Mean daily (mm/day) and annual ET (mm) of vegetation under different land uses in different months of the year and annual rainfall at the sites

Month	Daily ET			
	Hedgerow	Grassland	Mixed tree crop	Natural forest
January	3.6	4.4	4.9	4.9
February	4.0	1.9	6.2	4.9
March	2.0	4.3	3.3	4.2
April	4.4	2.4	5.5	5.2
May	3.0	3.5	2.4	3.4
June	2.4	3.3	3.9	3.9
July	2.0	3.3	1.9	1.7
August	2.6	2.9	2.5	1.1
September	3.2	3.1	2.5	3.9
October	3.5	2.9	4.8	3.9
November	3.2*	3.3	4.5 *	2.6
December	3.2*	3.4	4.0 *	4.0 *
Annual mean	3.1	3.2	3.9	3.6
Annual total (mm)	1025	1185	1395	1320
Annual rainfall (mm)	1180	1342	1265	1385

* Estimated

Note: 1. Hedgerow pruning: 13th January, 18th June, 3rd October and 29th November in 1995 and 25th January, 25th April, 16th November in 1996

2. Grass not mowed in 1995. Mowed 15th February, 29th March, 5th June, and 16th October in 1996.



LEGEND

- Experimental Sites
- Upper Mahaweli Catchment boundary
- Main Streams/Reservoirs

Fig .1. Study area and experimental sites

Fig.2:- Change of soil water storage in soil profiles in response to rainfall in different months of 1995 & 1996 under different land use systems

