

MOISTURE CONSUMPTION BY DOMINANT VEGETATION TYPES IN THE DRY ZONE OF SRI LANKA AND ITS INFLUENCE ON THE HYDROLOGIC CYCLE

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ABSTRACT

A study was carried out at Maradankadawala, in the catchment of Nachchaduwa tank, in the low country dry zone, to estimate the moisture consumption, seasonal recharging of the groundwater table and soil moisture storage under the dominant land use types, natural forest vegetation, scrub (abandoned chena) and chena. The data showed that moisture consumption or evapotranspiration of different land use types vary over a wide range during both maha and yala seasons. The natural forest and scrub consumed nearly 75% of rainfall during the maha season, while the soil moisture consumption under chena was only 40% of the maha rains. The soil moisture storage at the end of maha season was about 15% of the maha rainfall in lands under forest and scrub and about 30% in lands under chena. The soil moisture consumption under forest, scrub and chena (which was fallowed) were similar in yala season and exceeded the total yala rainfall. The seasonal contribution to the groundwater under forest and scrub was around 8% of the maha rainfall, while under chena it was nearly 12%. The contribution to groundwater from yala rainfall was not evident under any land use type studied. Surface runoff generations under forest and scrub were similar, and negligible. On the other hand runoff generated in chena lands was considerable.

KEY WORDS: Chena, Evapotranspiration, Land use, Moisture consumption, Soil water balance

INTRODUCTION

Soil moisture consumed by the vegetation through the process of evapotranspiration (ET) is an important component of the natural hydrologic cycle. Approximately 75% of the total rainfall on continental basis is returned to the atmosphere by evaporation and transpiration or evapotranspiration (Shish, 1985). Accurate estimates of ET are necessary for hydrologic studies, global atmospheric circulation models, irrigation and agricultural management. Accurate quantification of ET could also yield better estimates of surface water resources and groundwater recharge, very important information for planning water resources development projects

and programmes, especially in semi-arid and arid regions. Reliable average annual recharge rate of groundwater in an area is an essential information required to manage groundwater resources without causing adverse impacts on the environment.

Evapotranspiration from forests can be quite different from that of crop stands. Forest plants are taller and more clumped than agricultural crops; therefore, forest is aerodynamically rougher and have lower albedos than agricultural crops (Jarvis *et al.*, 1976; Mc.Naughton and Jarvis, 1983). This affects water vapour transport and available energy for evaporation. Forest canopies also exert higher surface resistance to vapour transfer than do agricultural crops (Jarvis, 1981). Furthermore, the large amount of standing biomass in a forest causes a substantial amount of net radiation to be consumed via canopy heat storage, further affecting evapotranspiration (Hicks *et al.*, 1975; Jarvis, 1976). Although many studies of evapotranspiration have been conducted over agricultural crops, only very few studies have been conducted under forest canopies (Jarvis *et al.*, 1976; Rauner, 1976; Mc.Naughton and Jarvis, 1983).

In the dry zone of Sri Lanka, none of the major or micro catchments is completely under natural vegetation. They are highly disturbed. Any micro- catchment consists of several land uses and is subjected to changes due to different uses and management practices such as slash and burn cultivation (chena), and human settlements. In the dry zone, any micro-catchment consists of primary and secondary forest, chena and scrub (abandoned chena). However, information on actual moisture consumption by any of these land use types, natural forest, secondary forest, scrub and chena is scarce. All vegetation types extract most of their water requirements from soil moisture storage.

In Sri Lanka, information on moisture consumption by the natural vegetation types is scarce. It is a common practice to estimate water loss by vegetation based on theoretical estimates of evapotranspiration. Therefore, *in situ* measurement of moisture consumption by natural vegetation types is an important parameter in catchment hydrological studies.

This study was carried out during the period from August 1991 to August 1993, with the objective of estimating moisture consumption by dominant land use types, seasonal recharge of groundwater table and soil moisture storage patterns under forest, scrub and chena. Based on such information it is possible to make more accurate estimates of available surface water resources for irrigation development.

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MATERIALS AND METHODS

Study area

This study was carried out at Maradankadawala (80° 5' N, 80° 34' E) in the Nachchaduwa catchment. The area lies in the agroecological region DL 1 (Agroecological Map of Sri Lanka, Land and Water Use Division, Peradeniya, 1976).

The rainfall in the area is seasonal and the annual average is about 1300 mm. Nearly two-third of the annual total rainfall occurs in the maha season (late September to mid January), a period of about 3 1/2 months. The maha rains commence in late September or early October with convectional high intensity thunderstorms. These rains are followed by North East monsoon rains in November and usually end in mid January. The yala rains which are convectional commence in the latter half of March and end in the early half of May. The atmospheric temperature in the area is high and uniform throughout the year and it lies within the range of 30 - 34°C. The average wind speed is 3.1 km/hr, but the wind speeds during summer months are high.

In the study area, well-drained Reddish Brown Earths (RBE) occur on undulating uplands of average slopes 4-8% and poorly drained Low Humic Gley (LHG) soils occur on level valleys. The upland soils have moderate infiltration rates. The water holding capacities are low to moderate. The physical properties of LHG soils in valleys are somewhat different from that of RBE soils. The infiltration rate of LHG is about one-fourth that of RBE soils and water holding capacity is slightly higher.

Site characteristics

Experimental plots were located on a slope of 3-4% in well-drained RBE. The soils at the site are moderately deep to deep. One set of plots was covered with a primary forest of 40-50 years old consisting of broad-leaved trees and root zone of about 3 m. The set of plots on scrub was covered with secondary vegetation of not more than 5 years old. This secondary vegetation consisted of young broad-leaved bushes and shrubs of about 1-1.5 m tall with a root zone less than 2 m. The site under chena was cultivated with cowpea of which the maximum root zone was about 60 cm from the surface. This plot was fallowed during yala season.

As all plots were located on mid-slopes, assumption was made that there was no net gain or loss from the soil profile due to sub surface lateral movement of soil water. Thus, soil water gains are only due to the infiltration of rainfall and irrigation (if any) and the soil water losses are due to deep percolation and evapotranspiration.

Estimation of evapotranspiration

Different techniques have been developed for estimation of ET. Most of them are based on the Law of Conservation of Matter. Each method has certain advantages as well as limitations. In this study, soil water balance method was used to estimate ET. This method equates water input on a specific soil volume during a specific time period to the change in soil moisture storage in that soil volume plus all forms of outflows from that specific soil volume. Water input is on a specific surface area, part of which enters the soil and part of it may flow out as surface runoff. Some portion of the water that enters the soil may be lost as lateral outflows during the same time period and another portion is lost as ET.

***In situ* water balance**

In situ water balance consists of rainfall plus irrigation less the outputs consisting of runoff, evapotranspiration, deep percolation losses and lateral seepage losses. Changes in the soil moisture content beyond a certain depth from the root zone is considered as deep percolation. By selecting a site at mid slope position on a simple sloping plain surface the net transfer of moisture through lateral movement can be considered negligible. Thus the water balance equation based on the Law of Conservation of Matter is as follows:

$$ET = RF + Irr. - RO \pm SM - DP$$

or

$$SM = (RF + Irr.) - (RO + DP + ET)$$

where ET = Evapotranspiration; RF = Rainfall; Irr. = Irrigation; RO = Runoff; SM = Change in soil moisture storage; DP = Deep percolation; and all variables are expressed in depth units. In this equation ET can be equated to the change in soil moisture storage, which is same as root zone moisture depletion rate, when other components are measured or estimated and accounted for. In the rainfed uplands the term Irr. = 0; RF can be measured; DP can be estimated by subtracting a fraction from the total moisture loss (ET+DP) which is dependent on the rate of ET during the period where there is no limitation of soil moisture but prior to start of deep percolation; and the changes in soil moisture storage can be monitored. The only quantity ET, which is not directly measurable can be calculated based on the water balance equation. Summation of soil water loss due to plant extraction over a period of a season and an year are important components of the hydrologic cycle.

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Rainfall measurement

Non-recording rain gauges were installed in an open space close to the experimental site to measure the daily rainfall. Rainfalls below 0.3 mm / day were not accounted for analysis for plots under forest canopy and scrub, because such low rainfalls do not reach the soil surface as throughfall or stemflow.

Runoff measurement

Three plots with overflow divided tank system were constructed to collect the runoff water for each land use type. The length and width of each plot under forest cover and scrub were 22.1 and 7.3 m respectively, while the length and width of the plots under chena were 22.1 and 1.5 m respectively. In order to include a reasonable canopy cover into the plot, a broader plot width was used for plots under forest and scrub. But the plot lengths which would have had an effect on runoff, were kept similar in all three land use types.

Measurement of changes in soil moisture storage

To determine the changes in soil moisture storage at short intervals, a neutron probe was used. Two aluminium access tubes were installed in each plot on randomly selected places, up to a depth of 3 m. Soil moisture was measured at depths of 30, 60, 90, 120, 150, 180, 210, 240, 270 and 300 cm from the surface. A field calibration of neutron probe was done to facilitate soil moisture measurements. Gravimetric moisture measurements were made for the surface layers (0 -15 cm).

RESULTS AND DISCUSSION

Moisture consumption through evapotranspiration

The results indicate that under all three land use types studied, the evapotranspiration rates varied over a wide range during both maha and yala seasons (Fig. 1). The ET rates were low when soil moisture was limiting, but it rapidly increased with the increases in soil moisture. Higher rates of ET under forest cover and scrub were observed during early February to mid March. The soil moisture reserve left behind just after the maha rains, readily supplies water that is required by deep-rooted vegetation which is receiving a higher amount of solar radiation during this period. As a result, the soil moisture reserve depletes rapidly. On the other hand, under chena land high ET rates were observed in mid April to mid May, during which period new flush (after fallowing) emerges with the rains. Under very dry conditions (during July-August), when soil moisture levels were very low, plants extracted very low quantities of soil moisture, probably just enough to maintain the plants without allowing them to wilt permanently.

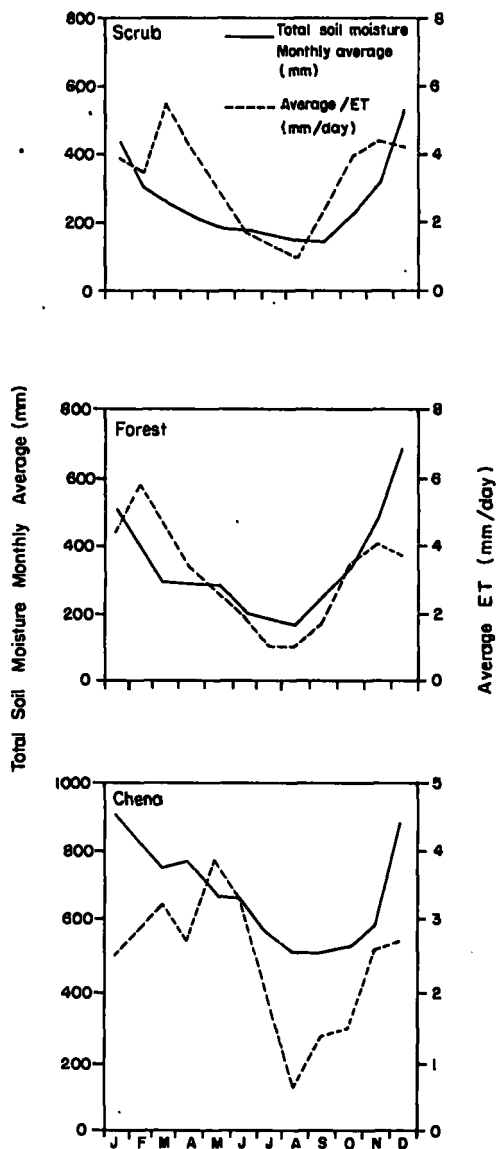


Fig. 1 : Variation of evapotranspiration (ET) with soil moisture under different land uses.

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Evapotranspiration by natural forest

The evapotranspiration by natural forest cover was in the range of 0.2 - 6.0 mm/day (Table 1), the lower values were when the soil moisture balance was very low, whereas when the soil was wet, rates of water extraction from the soil profile were high. The rate of soil moisture loss from the profile was high immediately after wetting of the surface layers. The average rate of evapotranspiration by the forest in maha season was about 3.5 mm/day and 2.8 mm/day in yala season (Table 1). The natural forest cover consumed 45 - 60% of the maha season's rainfall by the middle of January and nearly 77% by end of the season (Table 2). The variation in moisture consumption during the two maha seasons (91/92 and 92/93) was apparently related to the number of days with high soil moisture content; hence, it depended on the number of rainy days in the season (data not shown). In maha 91/92 which had less number of rainy days, moisture loss by mid January was 45% of the rainfall, compared to maha 92/93 which had more number of rainy days and the moisture loss was 60% by mid January, indicating a close relationship between moisture loss and soil wetness (data not shown). More water is lost as ET in seasons of well distributed rainfall, showing that under well distributed rains in the dry zone the availability of surface runoff for agriculture is very limited. The moisture consumption by forest during yala (March to late August) exceeded the yala rains by about 60% (Table 3), which has been met by the moisture stored in the soil.

Evapotranspiration by scrub

The moisture consumption by scrub was very similar to that of forest cover (Table 1). The daily rates of soil moisture consumption under scrub ranged from 0.1 to 6.8 mm/day. The average rates of soil moisture loss by scrub was 3.6 mm/day during maha and 2.7 mm/day during yala. As in the case of natural forest, under scrub, the moisture consumption by the end of maha season was high (Table 2). Moisture consumption in the yala exceeded the yala rainfall by 42% (Table 3), which again was supplied by the stored soil moisture.

Evapotranspiration by chena

The rate of evapotranspiration by chena crops varied from 0.1 to 6.0 mm/day with an average of 2.1 mm/day during maha and 2.8 mm/day in yala fallow period (Table 1). The total moisture consumption by crops by mid January was about 40% of the maha rainfall and 42% by the end of maha season (Table 2). Thus, it indicates that the moisture consumption under chena/fallow exceeded yala rainfall by about 42% (Table 3), which was supplied by stored soil water.

Table 1. Seasonal and annual averages of evapotranspiration (ET) under different land uses

Land use	Season	ET (mm/day)		
		Seasonal average	Annual average	Range observed
Forest	Maha	3.5	3.2	0.2 - 6.0
	Yala	2.8		
Scrub	Maha	3.6	3.2	0.1 - 6.8
	Yala	2.7		
Chena/ Fallow	Maha	2.1	2.5	0.1 - 6.0
	Yala	2.8		

Table 2. Evapotranspiration under different land uses during maha season

Land use	Year	RF (mm)	ET			
			At mid Jan.		End of maha	
			Total (mm)	% RF	Total (mm)	% RF
Forest	91/92	997	446	45	NA	-
	92/93	797	478	60	615	77
Scrub	91/92	915	448	49	NA	-
	92/93	856	539	62	637	74
Chena	91/92	928	375	40	NA	-
	92/93	889	292	39	373	42

RF = Rainfall; ET = Evapotranspiration; NA = Not available

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Table 3. Evapotranspiration under different land uses during yala season

Land use	Year	RF (mm)	ET	
			Total (mm)	% RF
Forest	92	-	NA	-
	93	341	547	160
Scrub	92	295	NA	-
	93	367	523	142
Chena(Fallow)	92	322	NA	-
	93	383	546	142

RF = Rainfall; ET = Evapotranspiration; NA = Not available

The results show that the moisture consumption by all three land use types, forest, scrub and chena/fallow, were similar in yala season where moisture consumption exceeded the total rainfall of the season (Table 3).

The annual average evapotranspiration by forest and scrub was 3.2 mm/day and by chena/fallow it was 2.5 mm/day (Table 1). During the period 26.08.1992 - 26.08.1993, in a whole year the total moisture consumption by forest and scrub was very similar and nearly all the incident rainfall was used (Table 4) and therefore, these vegetation types have very similar hydrologic properties. The annual moisture consumption by chena/fallow was about 72% of the annual rainfall. Information derived clearly shows that annual moisture consumption by natural forest and scrub is more compared to that by chena/fallow. This may be attributed to shallow rooting of annual crops compared to forest and scrub.

Contribution to groundwater

The root zone of all three land uses studied was less than 3 m; therefore assumption was made that water moving beyond 3 m depth would not be available for extraction by plants. Furthermore, in all locations the groundwater table was 10 m below the surface. Therefore, the capillary rise towards the root zone from ground water table was considered negligible or zero. In this study, to estimate ground water recharge, the fraction of soil moisture that moves beyond monitored depth (3 m) was considered as the component responsible for recharging the groundwater.

Table 4. Annual water balance under different land uses (26.08.1992 - 26.08.1993)

Land use	RF (mm)	SMB (mm)	RO (mm)	DP (mm)	ET	
					Total (mm)	% RF
Forest	1138	-101	10	67	1161	102
Scrub	1223	-9	0	72	1160	95
Chena/ Fallow	1270	26	232	95	917	72

RF = Rainfall; SMB = Soil moisture balance; RO = Runoff; DP = Deep percolation; ET = Evapotranspiration

The seasonal contribution to the groundwater under each land use type was different (Table 5). It was found to be about 7, 8 and 12% of the maha rains in scrub, forest and chena respectively. There was no contribution to groundwater from yala rains for the three types of land uses. This is due to the reason that moisture consumption in all three land uses was more than the rainfall received in yala and hence no moisture would be left in the soil profile to contribute to groundwater.

Table 5. Contribution of seasonal rainfall to groundwater under different land uses

Land use	Season	Year	RF (mm)	Contribution to groundwater	
				Total (mm)	% RF
Forest	Maha	91/92	997	81	8
		92/93	797	67	8
	Yala	92	335	NA	-
		93	341	0	0
Scrub	Maha	91/92	915	60	7
		92/93	856	72	8
	Yala	92	295	NA	-
		93	367	0	0
Chena/ Fallow	Maha	91/92	928	109	12
		92/93	889	95	11
	Yala	92	322	NA	-
		93	383	0	0

RF = Rainfall; NA = Not available

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Runoff

The total surface runoff under forest cover and scrub was very low in maha (< 1% of the rainfall); in yala there was no runoff under these land uses (Table 6). On the other hand, runoff from the lands under chena was 15 - 20% of the maha rainfall. In fallow land (which was cropped during maha), the contribution to runoff from yala rains was comparable to the maha runoff. Thus runoff generation was greater from chena than from other two land uses. It is a common assumption that forestation of catchments is necessary to improve water yield from catchments. However, in a region with a climate where annual potential evaporation is higher than annual rainfall, the catchment yield of forested catchments cannot be high. The observed high surface runoff from lands under chena can be attributed to surface sealing due to the impact of rain drops and reduction of infiltration rates due to compaction of soil by repeated cultivation. In contrast, forest and scrub with protected soil surface from the impact of rain drops maintain a higher infiltration rate resulting in reduced runoff generation. Further, the water infiltration may be enhanced under forest and scrub due to rapid moisture depletion through ET by the deep-rooted vegetation.

Table 6. Runoff generation under different land uses

Land use	Season	Year	RF (mm)	Runoff	
				Total (mm)	% RF
Forest	Maha	91/92	997	10	1
		92/93	797	10	1.2
	Yala	92	335	NA	-
		93	341	0	0
Scrub	Maha	91/92	915	2	0.2
		92/93	856	0	0
	Yala	92	295	NA	-
		93	367	0	0
Chena/ Fallow	Maha	91/92	928	181	20
		92/93	889	129	15
	Yala	92	322	NA	-
		93	383	102	27

RF = Rainfall; NA = Not available

Soil moisture

At the end of maha season the remaining moisture storage in lands under natural forest and scrub land was around 15%, whereas in lands under chena, it was around 30% of the total maha rainfall (Table 7). This shows that due to chena cultivation in maha season a more wetter soil profile is left at the end of maha season compared to that of forest cover and scrub. However, this soil moisture was more concentrated within the depth of 120 - 240 cm from the surface (Fig. 2). Whatever soil moisture reserve that was left behind by maha rains, was depleted in the yala season.

Table 7. Soil moisture balance under different land uses during maha season

Land use	Year	RF (mm)	Soil moisture balance			
			At mid Jan.		End of maha	
			Total (mm)	% RF	Total (mm)	% RF
Forest	91/92	997	460	46	NA	-
	92/93	797	241	30	105	13
Scrub	91/92	915	405	44	NA	-
	92/93	856	244	28	148	17
Chena	91/92	928	263	28	NA	-
	92/93	889	314	35	291	32

RF = Rainfall; NA = Not available

CONCLUSIONS

Evapotranspiration under different land uses was found to vary within a wide range during both maha and yala seasons. The rate was low when soil moisture was limiting, but increased with the build-up of soil moisture levels. The natural forest and scrub consumed nearly three fourth of the maha rainfall by the end of the season itself, and the total annual consumption was almost the same as the annual antecedent rainfall. Thus both, natural forest and scrub showed similar behaviour with respect to moisture consumption. The moisture consumption under chena land during maha was less compared to the other two land uses. But during yala fallow period the moisture consumption was similar to the other two land uses.

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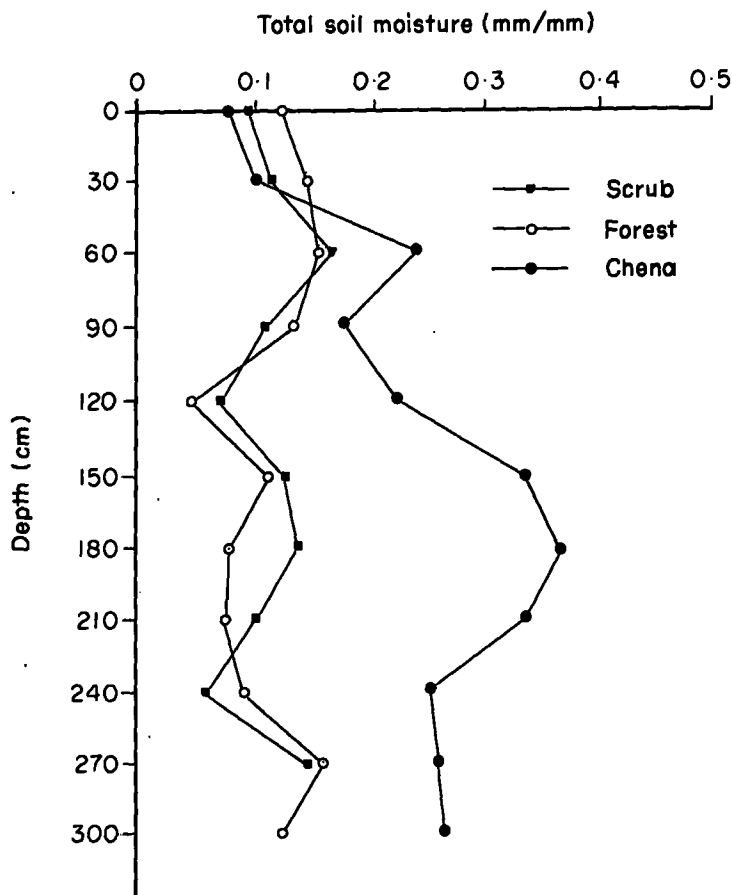


Fig. 2. Soil moisture profile under different land uses at the end of maha season.

The contribution to groundwater under forest and scrub was less compared to that under chena.

On moderately sloping lands, forest and scrub yielded very little surface runoff even during the maha season. Chena generated considerable surface runoff.

By the end of maha season the soil profile under chena cultivated land held more total soil moisture compared to the profiles under the other two land uses, though it was more concentrated within deeper layers. But this moisture reserve would be

used by the existing vegetation during yala fallow period. Hence, the moisture conservation during yala fallow period may help to enhance the groundwater contribution during subsequent maha. Studies are therefore needed to develop suitable moisture conservation methods applicable to fallow lands during yala season. Such studies should be carried out on a micro-catchment basis, so that more realistic ceilings for groundwater utilization could be made.

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REFERENCES

- Hicks, B.B., P.Hyson and C.J.Moore. 1975. A study of eddy fluxes over a forest. *J. Appl. meteo.* 14:58-66.
- Jarvis, P.G. 1981. Stomatal conductance, gaseous exchange and transpiration. *In* *Plants and their Atmospheric Environment*. pp. 175-204. Blackwell Scientific Publ., Oxford, UK.
- Jarvis, P.G., G.B.James and J.J.Landsberg. 1976. Coniferous forest vegetation and atmosphere. Vol. 2. pp. 171-204. Academic Press, London, UK.
- Mc.Naughton, K.G. and P.G. Jarvis. 1983. Predicting effects of vegetation changes on transpiration and evaporation. *In* *Water Deficits and Plant Growth*. Vol. 7. Ed. T.Kozlowski. pp. 1-47. Academic Press, N.Y., USA.
- Rauner, J.L. 1976. Deciduous forest. *In* *Vegetation and Atmosphere*. pp. 241-264, Monteith Academic Press, London, UK.
- Shish, S.F. 1985. Evapotranspiration, yield, water table and basinwide application in Florida. *In* *Proceedings of the National Conference on Advances in Evapotranspiration*, Dec. 16-17. 1985, pp 291-299. Chicago, USA.