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Hydrology of Small Forested Catchments in the Arid Region of Rajasthan

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Abstract : Hydrology of small catchments dominated by *Acacia tortilis* and *Colophospermum mopane* forested catchments was studied during the 1993 and 1994 monsoon seasons. Nearly 86.5% of throughfall was received from plots covered with *A. tortilis* compared with 79.9% in *C. mopane* plots. Canopy interception averaged 21.4% for *C. mopane* forest stand and 13.1% for the *A. tortilis* forest stand. Interception was positively related with canopy cover and negatively related with throughfall. Stemflow was influenced by tree species characteristics. Plot size had no effect on canopy interception, throughfall and stemflow. Surface runoff in plots with *A. tortilis* cover was nearly 53% higher compared with *C. mopane* stand. Among plots higher surface runoff was received from 10 m x 10 m plots.

Key words : Canopy interception, hydrology, plantation stand, runoff, stemflow, throughfall.

The hydrology of a forested catchment is influenced by tree species, architecture of the trees, storm size and intensity, as well as catchment size (Madgwick and Ovington, 1959; Geiger, 1965; Carlisle *et al.*, 1967). After a dry period, approximately 1-3 mm of precipitation is required to wet the canopy prior to the transfer of water to forest floor (Geiger, 1965). After the canopy has become saturated, rain water falls either as throughfall or stemflow or both (Eaton *et al.*, 1973). The overland flow is influenced by throughfall, vegetation and length of water run (Bren and Turner, 1979). This has great importance for watershed area, but has been little studied in the Indian arid region. The present study, therefore, deals with this aspect in an area of *Acacia tortilis* and *Colophospermum mopane* plantations in arid Rajasthan.

Study Area

The study was carried out at the research farm of Central Arid Zone Research Institute (CAZRI), Jodhpur (26°0'N and 73°1'E). The two plantation sites (*Acacia tortilis* and *Colophospermum mopane*) are situated within a distance of 1 km. The average monthly rainfall ranges from 0.4 mm in December to 133.3 mm in July with an average annual rainfall of 379.1 mm. Over 90% of rains are received between July and September during the southwest monsoon. The mean annual maximum and minimum temperatures are 44.8°C and 18.7°C, respectively. The average annual wind speed is 8.9 km h^{-1} and relative humidity 49%.

Materials and Methods

In each plantation stand three plots of 40m x 10m, 20m x 10m and 10m x 10m were demarcated for this study. To control the inflow and outflow all the plots were embanked upto a height of 30 cm. All trees in the plots were counted, their circumference at breast height (cbh) were measured, and the basal cover was calculated. Tree canopy was measured by laying transect lines in several directions in each plot. Tree density, tree height, crown diameter, basal cover and percent canopy are given in Table 1.

Rainfall intensity and amount were measured using a Stevention automatic raingauge that was installed away from the influence of tree canopy. For detailed observations four trees in each plot were selected. Throughfall and stemflow were measured by placing eight graduated plastic containers beneath the canopy of trees, extending 10cm from the tree trunk to the periphery of the canopy, as suggested by Pathak *et al.* (1983). Measurements were taken during all the rainfall events in the monsoon season of 1993 and 1994. Samples for stemflow were collected in clean polyethylene containers directly from the tube

Table 1. Plot characteristics in plantation stands at CAZRI research farm (1993-94)

Feature	Plantation stand					
	Acacia tortilis			*Colophospermum mopane*		
	40x10m	20x10m	10x10m	40x10m	20x10m	10x10m
Density (ind./100 m^2)	4.9	4.9	4.9	18.0	18.0	18.0
Av. height (m $tree^{-1}$)	7.1±0.32 (14.9)	6.5±0.43 (18.4)	6.4±0.19 (5.7)	3.0±0.38 (12.8)	2.9±0.12 (18.9)	2.7±0.15 (15.7)
Av. crown dia (m $tree^{-1}$)	8.1±1.74 (30.3)	6.6±1.0 (32.2)	7.1±0.97 (23.7)	3.1±0.06 (13.0)	3.1±0.13 (19.3)	3.2±0.18 (17.2)
Av. basal cover (m^2 $tree^{-1}$)	2.8±0.31 (37.7)	2.9±0.3 (28.7)	2.1±0.45 (42.5)	0.1±0.01 (38.1)	0.22±0.27 (67.4)	0.31±0.03 (15.9)
Total basal cover (m^2/100 m^2)	13.4±5.0 (37.8)	14.4±1.6 (28.9)	10.3±2.2 (42.6)	1.8±0.4 (38.1)	3.9±0.85 (67.5)	5.5±0.51 (16.0)
Canopy (%)	96	90	88	73	72	76

C.V. is given in the parenthesis.

of each observation tree. Surface runoff (overland flow) from each plot was collected in a GI metal container of 56 cm dia and 82 cm depth, installed underground in the centre of the lower side of the embankment. The surface runoff was measured by using an automatic stage level recorder installed with runoff collecting device. Stemflow was calculated using the formula of Killingbeck and Wali (1978) as suggested by Pathak *et al.* (1983).

$$S = [(D_1 + D_2/2) + (B_1 + B_2/2)]/2 \times V_c/A$$

where,

D_1 = total density (stem per plot)

D_2 = tree density of non-collared tree (stem per plot)

B_1 = total tree basal cover (cm^2 per plot)

B_2 = basal cover of non-collard trees (cm^2 per plot)

V_c = volume of stemflow collected (cm^3 per plot)

A = area of plot (cm^2)

S = stem flow (cm)

Throughfall was worked out using the following equation :

$$T_f = [A_1 x P_1) + (A_2 x P_2)]/A$$

where,

T_f = throughfall (mm)

A_1 = area without overhead canopy (m^2)

A_2 = area under canopy (m^2)

P_1 = precipitation in pen area (mm)

P_2 = precipitation under canopy (mm)

A = area of plot (m^2)

Stemflow plus throughfall represented the net rainfall. Canopy interception was calculated by subtracting the net rainfall from the gross rainfall. Water retained in soil profile was worked out by subtracting surface runoff from gross precipitation. Evaporation loss during rainfall period was not accounted for in this study.

Results and Discussion

The year 1993 was a deficit rainfall year with annual rainfall of 267mm, whereas 1994 was an exceptionally wet year with 504 mm rainfall. The average gross rainfall during the study period (1993-1994) was 385.5mm (Table 2). The rainfall distribution was erratic with intensity ranging from less than 10 mm h^{-1} to 60 mm h^{-1}. Among the two plantation sites, average stand throughfall (percentage of incident gross rainfall) was higher (86.5%) at the site covered with *C. mopane* (site 2) as compared with 79.9% at site covered with *A. tortilis* (site 1). Among the plots within same forest cover variation in stand throughfall was not significant. Similar results were reported for Sitka spruce plantation (Ford and Deans, 1979), tropical rain forest in peninsular Malaysia

Table 2. Hydrology of two plantation forest stands at CAZRI research farm (1993-94)

Feature	Plantation stand							
	Acacia tortilis				*Colophospermum mopane*			
	40x10m	20x10m	10x10m	Av.	40x10m	20x10m	10x10m	Av.
Canopy interception (mm)*	76.7 (19.9)	84.0 (21.8)	86.7 (22.5)	82.5 21.4)	56.3 (14.6)	43.2 (11.2)	52.0 (13.5)	50.5 (13.1)
Stemflow (mm)*	2.7 (0.71)	2.6 (0.68)	3.2 (0.83)	2.9 (0.74)	5.7 (1.48)	5.8 (1.51)	5.7 (1.49)	6.4 (1.67)
Throughfall (mm)*	306.1 (79.4)	299.2 (77.6)	295.6 (76.7)	300.3 (77.9)	331.5 (86.0)	340.4 (88.3)	331.5 (86.0)	333.5 (86.5)
Surface runoff (mm)**	47.3 (13.6)	48.0 (15.9)	51.4 (17.2)	47.3 (15.6)	39.1 (11.6)	37.7 (10.9)	39.1 (11.6)	34.7 (10.2)
Water retained in soil profile (mm)**	266.8 (86.4)	253.8 (84.1)	253.8 (84.1)	255.9 (84.4)	298.1 (88.4)	308.5 (89.1)	298.1 (88.4)	305.2 (89.8)

Rainfall received 385.5 mm

* Values in parenthesis are percentage of gross rainfall.

** Values in parenthesis are percentage of net rainfall (through fall + stem-flow).

(Manokaran, 1979) and forest cover in Kumaun (Pathak *et al.*, 1983). The throughfall directly beneath the canopy was lower by 2.5 to 5.6% compared to stand throughfall in different plots at two sites.

Average canopy interception in *A. tortilis* plantation stand was 21.4% (82.5mm) whereas in *C. mopane* plantation stand it was 13.1% (50.5mm). Interception was positively related with canopy cover in *C. mopane* (r = 0.896., P 0.05) and *A. tortilis* (r = 0.986, P 0.05). However, it was negatively related with throughfall for *A. tortilis* (r = -0.946, P 0.01) and *C. mopane* (r = -0.902, P 0.01) covers. These values are comparable with 3 to 48% for different types of forest cover (Kiltredge, 1948), 39% for a pine forest in New Zealand (Will, 1955), 16% for tropical forest in Ghana (Nye, 1961), 39% for Swedish spurce forest and 19% for Swedish beech forest (Nihlgard, 1970), 15 to 40% for Sitka spurce forest (Ford and Deans, 1979), and 25% for North Dakota gallery forest (Killingbeck and Wali, 1978). Variation in interception among the plots of same plantation stand was not significant. This may possibly be due to similar canopy cover among the plots of same tree species.

Stemflow volume in relation to the gross rainfall was insignificant. Rainfall less than 3mm did not produce stemflow. However, stemflow occured when a continuous rain exceeded 1.8 mm. In both the plantation stands stemflow was 2% of the gross rainfall. Similar results have been reported for Ghana forest (Nye, 1961), pine and aspen forest in New Brunswick (Mahendrappa, 1974), North Dakota gallery forest (Killingbeck and Wali, 1978), and for tropical rainforest of Malaysia (Manokaran, 1979). Stemflow was 0.74% for *A. tortilis* stand and 1.67% for *C. mopane* stand. This shows that species characteristics influenced the stemflow volume. For instance the smoother bark of *C. mopane* transported stemflow better as compared with rought bark of *A. tortilis*. Within the same plantation stand, variation in stemflow among plots was insiginificant. This was possibly due to the reason that in all the three plots, tree bark structure and also basal cover per unit area were similar.

The average surface runoff in *A. tortilis* plantation stand was 53% higher than in *C. mopane* stand. The hydrologic response of a forested catchment to rain is also dominated by plant species charactristics (Delfs, 1967). *C. moparte* is a under-canopy tree with lower branches exhibiting drouping habit and grow in linear groves or bands. The infiltration capacity of the soil within the groves is typically higher than that in the intergrove area. It is only in major prolonged rains that surface runoff occurs from the groves. A similar effect was reported for several types of vegetation banding over large areas of western Australia (Mabbutt and Fanning, 1987). Among the plots, within the same species cover, surface runoff was higher in 10 m x 10 m plot, followed by that in 20 m x 10 m plot. Lower runoff in bigger plot of 40 m x 10 m may be associated with high transmission loss of water in soil profile. Large transmission losses in bigger catchments have also been reported in southern Spain (Butcher and Thornes, 1978) and Australia (Cordery *et al.*, 1983; Stewart and Boughton, 1983).

Higher ground surface interception and lower surface runoff values in this investigation indicated that the studied forested catchments were highly infiltrating. Bren (1980) also observed meagre surface runoff of 0.005% of rainfall from steep, forested, infiltrating slopes in Australia.

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