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Soil Moisture Redistribution as affected by Throughfall and Stemflow in an Arid Zone Shrub Community

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Abstract

Changes in soil moisture under various densities of mulga (*Acacia aneura* F. Muell.) were followed from December 1971 to October 1973. Stemflow was instrumental in storing water at depth in the soil, being particularly noticeable with medium-sized (~75 mm) rainfall events; large (~160 mm) rainfall events tended to mask the effect.

Throughfall increased linearly with aggregate rainfall, and percentage throughfall decreased with increasing tree density. Of incoming precipitation, 94% was partitioned as throughfall under a tree density of 40 trees ha^{-1} compared with 86% at a density of 4000 trees ha^{-1}. No distinct soil moisture patterns due to throughfall were found.

Infiltration rates of water into the soil decreased with increasing distance from trees, being 46, 22 and 17 mm hr^{-1} after 10 min at distances 0·25, 0·5 and 2 m from a tree bole respectively, thus demonstrating that stemflow waters are absorbed at close proximity to the tree bole.

The results are discussed in terms of the ecological importance of stem flow and soil moisture patterning to the survival and growth of mulga and associated ground flora.

Introduction

Mulga (*Acacia aneura* F. Muell.) is an important fodder tree in arid Australia (Everist 1969) which has adapted to its harsh environment on an individual basis (Slatyer 1965) as well as on a community basis (Slatyer 1961; Goodspeed and Winkworth 1973). Branches of individual trees tend to be vertically orientated, which enables a high proportion of intercepted rainfall to be channelled to the ground as stemflow (Slatyer 1961). Stemflow from mulga in central Australia approximated 40% of the total rainfall over the tree canopy (Slatyer 1965) and in south-western Queensland constituted about 18% of rainfall received over a 15-month period (Pressland 1973). The root distribution of mulga is such that stemflow water can be readily absorbed (Pressland 1975). Mulga has the ability to withstand very high soil moisture deficits and possesses a high resistance to desiccation (Slatyer 1960), though not as high as that of brigalow (*Acacia harpophylla*) (Connor and Tunstall 1968).

Groving of mulga communities leads to a more efficient utilization of available water in central Australia than that from trees growing randomly (Goodspeed and Winkworth 1973). Groving is a feature of some mulga in Western Australia (Speck 1963), central Australia (Perry 1970) and far south-western Queensland (Dawson and Boyland 1974). However, it is not a feature of the more mesic eastern portion of the mulga zone in which this study was undertaken and where mulga attains 'its highest biomass and approaches open forest structural formation' (Nix and Austin 1973). The objective of this investigation was to detail the extent of redistribution of rain-water by mulga trees and to determine the importance of soil water patterns on tree growth and survival.

Materials and Methods

The experimental site was situated on the Charleville Experimental Reserve 5 km south of the town of Charleville (26° 25′ S., 146° 17′ E.). Eighteen 0·4 ha plots were marked out in a mulga open forest of about 4000 trees ha^{-1}. Nine of the plots were thinned on a grid pattern in September 1970 to give three replications of 40, 160 and 640 trees ha^{-1}, six plots were totally cleared and three plots were untouched. Trees selected for retention were not always equidistant as it was necessary to select them on the basis of vigour and size as well as position. As many mature trees as possible were included, but it was often necessary to retain immature trees because many of the larger trees were infested with bracket fungi (family Polyporaceae). All debris was retained on the plots. The densities of mulga used in the experiment were selected as: (1) approximating an open mulga woodland or density often left following clearing 'on a face' (40 trees ha^{-1}); (2) suggested by early observations (Everist 1948) to be the optimum (160 trees ha^{-1}); and (3) commonly found in mature stands (640 trees ha^{-1}) (Pressland 1975).

Throughfall under each timbered plot was recorded with six rain gauges placed at random positions 0·5 m above ground level. Three gauges were installed in each of the totally cleared plots to measure incoming precipitation. Two pluviometers at the site also recorded rainfall aggregate and duration. Regression analysis was used to show the relationship between throughfall and precipitation. Differences in percentage throughfall received under various densities were determined by the t-test applied to a population of mean differences (Little and Jackson Hills 1972).

The soil moisture content was followed from December 1971 to October 1973 by gravimetric soil sampling at 15 cm intervals to a depth of 135 cm. In each timbered plot three trees were selected at random on each sampling date, and soil samples taken 0·5, 2 and 4 metres from each of the selected tree boles. The cleared plots were sampled in a similar manner except that all nine sampling positions were selected at random. Soil samples were oven-dried at 105°C for 24 hours and the gravimetric moisture content determined and later subjected to analysis of variance. The mean moisture content at each 15 cm interval was converted to a volumetric basis after analysis by correcting for the bulk density of the soil at each depth.

The rate of infiltration of water into the soil 0·25, 0·5, 1 and 2 m from a mature tree was determined by using double ring 15 cm diameter infiltrometers. Three determinations were made at each distance from the selected mulga tree.

Results

Throughfall was found to be linearly related to incoming precipitation (Fig. 1). Although only the composite line is shown in Fig. 1, the individual relationships were:

$$t_{40} = 0{\cdot}93p + 0{\cdot}47\ (R^2 = 0{\cdot}99),$$

$$t_{160} = 0{\cdot}88p + 1{\cdot}71\ (R^2 = 0{\cdot}99),$$

$$t_{640} = 0{\cdot}83p + 2{\cdot}06\ (R^2 = 0{\cdot}99),$$

$$t_{4000} = 0{\cdot}85p + 0{\cdot}65\ (R^2 = 0{\cdot}99),$$

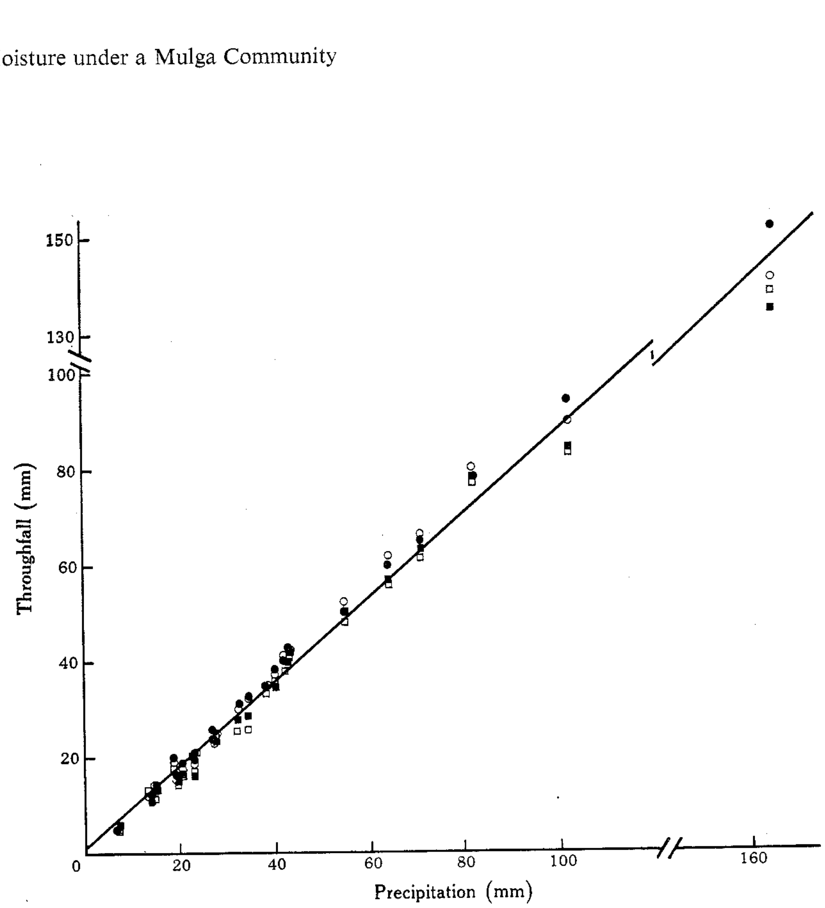

Fig. 1. Relationship between throughfall and precipitation under mulga forests of 40 (●), 160 (○), 640 (■) and 4000 (□) trees ha^{-1}.

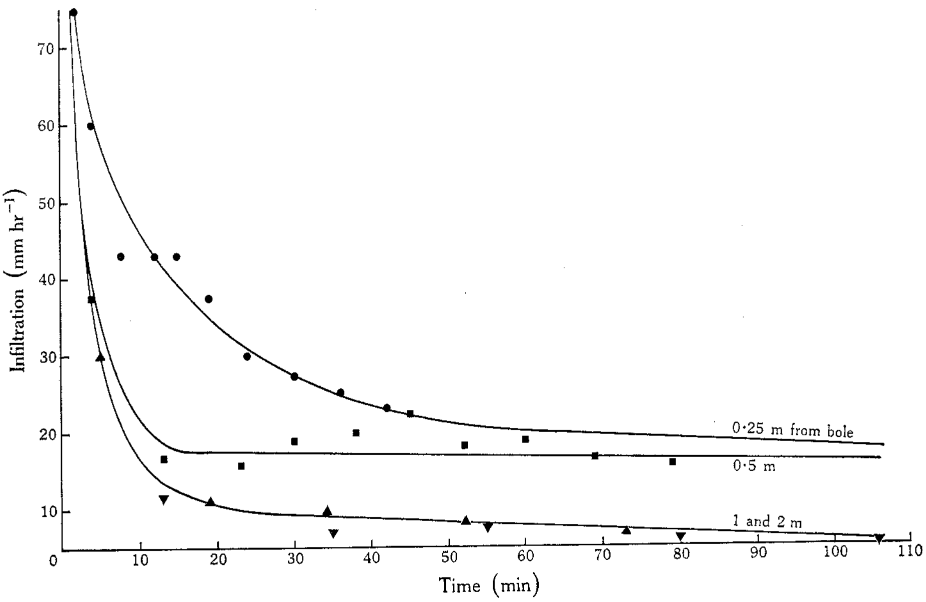

Fig. 2. Change in infiltration rate with time at distances of 0·25 m (●), 0·5 m (■), 1 m (▲) and 2 m (▼) from a mulga tree bole. (One infiltration curve is shown for the data taken at 1 and 2 m from the tree.)

where t_{40}, t_{160}, t_{640} and t_{4000} are the throughfall (mm) under plots of tree density 40, 160, 640 and 4000 trees ha^{-1} respectively; p is the incoming precipitation (mm); and R^2 is the coefficient of determination.

Table 1. Potential soil water increase due to stemflow

Precipitation (mm)	Tree circumf'ce (cm)	Stemflow (calculated)[A] 1 (litres)	Stemflow 2 (mm)	Stemflow 3 (mm)	Increase over actual precipitation (mm)	Increase over actual precipitation (%)
5	20	2·5	0·7	7·1	2·1	42
	40	5·0	0·5	5·0	0	0
	60	9·0	0·5	8·4	3·4	68
10	20	10·0	2·9	29·4	19·4	194
	40	17·5	1·7	17·7	7·7	77
	60	29·5	1·5	27·2	17·2	172
20	20	14·5	4·2	42·1	22·1	110
	40	30·0	2·9	30·4	10·4	52
	60	56·0	2·9	51·3	31·3	156
40	20	23·0	6·5	65·8	25·8	65
	40	49·5	4·8	50·1	10·1	25
	60	94·0	4·8	86·5	46·5	116

[A] 1, calculated from regressions detailed in Pressland (1973); 2, calculated on tree canopy area basis; 3, calculated on area of infiltration basis. See text for full explanation.

Throughfall expressed as a percentage of incoming precipitation decreased with increasing density. Percentage throughfalls under the 40, 160, 640 and 4000 trees ha^{-1} treatments were 94% (SD* 5), 93% (SD 5), 88% (SD 6), and 86% (SD 6) respectively.

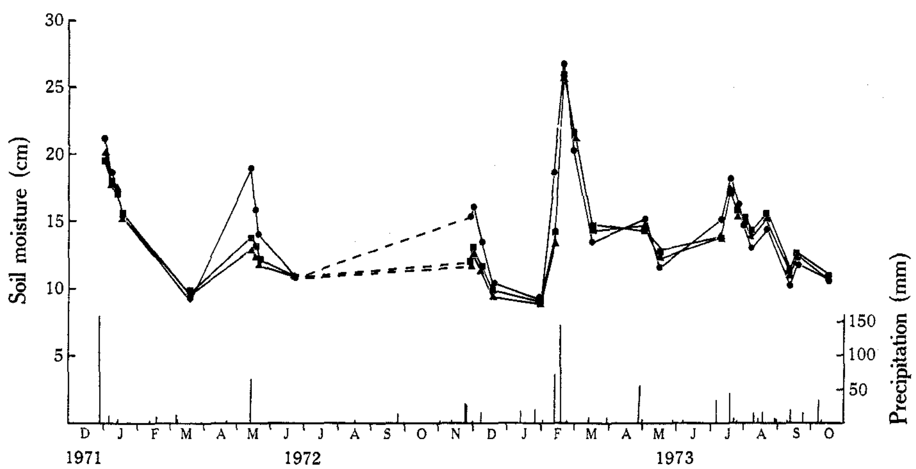

Fig. 3. Precipitation and soil moisture in the 135 cm soil profile at 0·5 (●), 2 (▲) and 4 (■) m from mulga tree boles during the period December 1971 to October 1973.

The percentage throughfall varied significantly between all tree densities except between the 40 and 160 tree ha^{-1} treatments.

* SD, standard deviation of the data.

The infiltration data show that stemflow could totally infiltrate the ground in close proximity to the tree. Fig. 2 shows that after infiltration had been proceeding for 5 min, the rates of infiltration at distances of 0·25, 0·5 and 1 or 2 metres from the tree bole were 57, 46 and 34 mm hr^{-1} respectively; after 10 and 20 min the respective rates were 46, 22 and 17 mm hr^{-1}, and 30, 16 and 11 mm hr^{-1}; and after 60 min they were 20, 17 and 8 mm hr^{-1}.

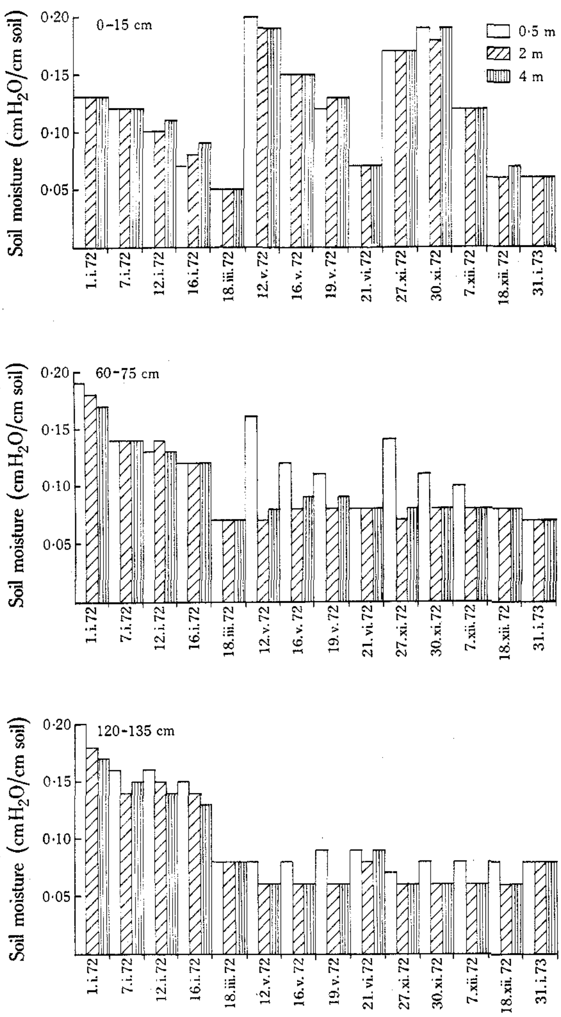

Fig. 4. Soil moisture in the intervals 0–15, 60–75, and 120–135 cm down the soil profile at distances of 0·5, 2, and 4 m from tree boles at selected sampling dates.

Observations during rainfall events of various sizes and intensities indicated that all stemflow infiltrates the soil within 50 cm of large trees (circumference >40 cm, 30 cm above ground level) and 30 cm of small trees (circumference <20 cm). Table 1 shows the potential soil water increase due to stemflow on the basis of area of infiltration, compared with that on a basis of canopy area, based on regressions published previously (Pressland 1973). For example, 10 mm of rain falling over a tree of 20 cm in circumference measured 30 cm above ground level yields 10 litres of stemflow water. Calculated on a canopy area basis, this is equivalent to only 2·9 mm, but calculated on an area of infiltration basis it is equivalent to 29·4 mm, an increase of 19·4 mm (194%) over the actual precipitation. Similarly, it can be shown that 20 mm of rain over a tree of circumference 60 cm can in effect deposit 51·3 mm of rainfall at the base of the tree, an increase of 31·3 mm or 156% over the actual rainfall.

In other words, the water available to replenish the soil water within 50 cm of the bole of large trees and within 30 cm of small trees can be almost 200% higher than the recorded precipitation (Table 1).

The bulked soil moisture from all timbered plots at three distances from the tree bole (Fig. 3) and the detailed profile data (Fig. 4) reflect the infiltration and stemflow data. The soil moisture data from the May and November 1972 rains (~75 mm each) clearly show the stemflow effect, and even the rain in December 1971, February, April and July 1973 show the effect to a limited degree.

Differences in soil moisture at the three distances increased with soil depth and it. However, at the sampling on 21 June 1972 there was no difierence in soil moisture. at different distances from trees decreased with increasing time from rainfall. The soil moisture in the 60–75 cm horizon (Fig. 4) on 12, 16, and 19 May 1972 following the May 1972 rain was significantly higher close to the tree bole than 2 or 4 m from it. However, at the sampling on 21 June 1972 there was no difference in soil moisture. On the other hand, at a depth of 120–135 cm on 21 June, the soil moisture 2 m from the tree was lower than that at the other two sampling positions.

The stemflow effect tended to be masked by the large rainfall events of December 1971 and February 1973 (~160 mm) and also when antecedent soil moisture was high, as for example in August and September 1973. It can be seen that although the differences in soil moisture at the three sampling distances were minimal in the upper soil profiles following the rain in December 1971, at 120–135 cm they were readily noticeable (Fig. 4).

Discussion

The relationship between throughfall and precipitation in this study was similar to that found in an earlier study (Pressland 1973), though the percentage throughfall recorded here was higher than that recorded earlier, probably because of a change the method of measurement. (In the earlier study, gauges were distributed at fixed positions under 28 individual tree canopies.) One point should be clarified. The percentage throughfall is not the same as the slope in the regression between throughfall and precipitation, because the regression does not pass through the origin. If it did, the values would correspond. The differences are more obvious for the 160 and 640 trees ha^{-1} data as the constant terms are larger. The results support the conclusion of Orr (1972) and Pressland (1973) that correction factors based on tree or canopy density should be included in throughfall measurements.

A significant quantity of precipitation, ranging from 6% to 14% for the 40 and 4000 trees ha^{-1} plots respectively, is redistributed either as stemflow or interception, the latter generally being lost to the atmosphere by evaporation (Slatyer 1965). The quantity of water reaching the base of the tree as stemflow depends primarily on the amount of rainfall and the tree size (Pressland 1973) though Slatyer (1965) claimed that the percentage stemflow from mulga decreases with increasing rainfall intensity.

Specht (1957) also noted that stemflow effects on soil moisture close to the stem of two nanophyllous shrubs growing in heath country in South Australia were masked following high aggregate rainfall.

The rate of infiltration of water both in close proximity to the tree and further away are in agreement with previous studies in central Australia (Slatyer 1961) but the actual rates recorded in the present study are lower than those from central Australia.

The throughfall patterning displayed by a mulga community in central Australia (Slatyer 1965) was not reflected consistently by the soil moisture data in this study, nor in an earlier throughfall study in south-western Queensland (Pressland 1973). Immediately following rain, soil moisture 0·5 m from the tree bole was usually higher than 2 or 4 m away, but there was no consistent difference in the soil moisture at positions 2 and 4 m from the tree bole. It is noteworthy that there was no marked increase in moisture from 2 to 4 m as would be expected from the throughfall pattern detailed by Slatyer (1965). Voigt (1960) suggested that throughfall patterns may not be reflected in the soil moisture data for three reasons: localized concentrations of stemflow; branch drip, both from branch stubs and from the periphery of the crown canopy; and direct penetration of rain through random openings in the crown. Stem and leaf drip was considered to be the reason that the percentage stemflow from mulga decreased with precipitation in excess of 10 mm at a nearby site (Pressland 1973), although this was not associated with a corresponding increase in recorded throughfall. Pressland (1973) points out that 'as stem drip tends to occur at particular places (e.g. the intersection of two branches) it is reasonable to expect that this phenomenon would not be recorded in the throughfall gauges'.

The ecological significance of stemflow water has been the cause of some debate, but its importance to the xerophytic mulga has not been seriously questioned. Slatyer (1965) claimed that because stemflow is stored much lower in the soil profile and because of shading by the tree canopy, more water is available for transpiration as less is lost through evaporation.

Another aspect worthy of investigation is that stemflow may be a factor ensuring flower and seed set as well as normal leaf and wood development. In his study of mulga, Preece (1971) found that flowering was greater and seeding more successful following additional watering, or good rains. Preece further pointed out that although flowering can occur at any season, the principal flowering periods are in spring and late summer with only the latter period resulting in mature seed. He concludes by saying 'a wet winter is required after a critical flowering to give good seed'. Rainfall statistics* for Charleville show that although the frequency of rainfall events of less than 25 mm aggregate decreases during the months April, May and June compared with the preceding three months, the percentage of events less than 25 mm increases from 85% to 92%. The soil moisture data (Fig. 4) and calculated stemflow (Table 1) show that stemflow is more effective in storing water at depth from low aggregate rainfalls than from high aggregate falls. This water would improve the chances of flowering leading to mature seed set as detailed by Preece (1971).

Further, the data of Slatyer (1961) show that following an extended dry period, mulga phyllodes regain turgidity within 2–4 days of rain, although evaporation from

* Computer print-out supplied by R. A. Perry, Rangelands Research Unit, Division of Land Resources Management, Perth, W. A. Program developed by Keig and McAlpine (1969).

the surface soil is also highest during this period. Thus stemflow waters from low aggregate rainfalls may be instrumental in allowing mulga to regain turgidity and resume active transpiration earlier than in the absence of stemflow. In addition, elongation and phyllode production of mulga were shown to occur from falls of rain of less than 25 mm in central Australia (Winkworth 1973). This was probably a direct result of stemflow as even in winter the effects of such rain in the absence of stemflow would be minimized by high rates of evaporation.

Until stemflow is collected and removed as a source of soil water for an extended period its actual advantage to mulga is open to speculation. Nevertheless, the circumstantial evidence strongly indicates that stemflow is of ecological significance to individual mulga trees.

It may be argued that while stemflow could be beneficial to the tree, it may be to the disadvantage of associated ground flora. Apart from the very obvous wash area bare of both surface litter and grass or forbs within 50 cm of the tree, there is no visual effect—detrimental or otherwise—on the associated flora. There is a tendency for the ground flora to be more vigorous in open areas within closed mulga woodlands, but this is more likely to be due to less competition for water between the ground storey and the trees. Suitable soil surface microhabitats (Silcock 1973) are probably more important to ground flora development than any possible effect of stemflow.

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