Net Rainfall and Interception Losses in a Burkea Africana-Ochna Pulchra Tree Savanna

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Abstract

The effects of vegetation on the amount of net rainfall and interception losses are analysed on experimental plots in Burkea savanna. The influence of the interception process in the hydrological cycle is briefly explained. The components of the process and the variables influencing them are then discussed. It is shown that rainfall duration play a primary role in the interception process. From the available data it is not possible to state that in general, higher intensity yields higher interception losses.

Introduction and Definitions

In natural vegetation the amount of precipitation reaching the ground surface is largely dependent on the nature and density of the plant cover. Vegetation intercepts part of the falling precipitation and temporarily stores it on surfaces from where the water is either evaporated back into the atmosphere or falls to the ground (Ward, 1975). The four main components in the interception process viz. throughfall, drip, stemflow and interception losses are fully explained by De Villiers (1977).

Only in the case of interception losses is water prevented from reaching the ground surface and so taking part in the terrestrial portion of the hydrological cycle. In this sense, therefore, interception loss may be regarded as a primary water loss (Ward, 1975).

Some authorities (Stewart, 1977) do not consider interception as a net loss in grasslands, because interception is largely compensated for by a corresponding reduction in loss of transpiration. In contrast, others (Leyton *et al.*, 1967) have indicated that the rate of evaporation of intercepted rainfall from forests is between 3 and 10 times higher than the transpiration rate. Interception loss is therefore only partly compensated for by the suppression of transpiration and net interception losses could very well be up to 90% of the precipitation intercepted (Leyton *et al.*, 1967).

Large parts of Africa are covered by savanna vegetation for which hardly any water relations data exists. An interception study was therefore generated in a *Burkea Africana-Ochna pulchra* tree savanna to quantify the components of the interception process. This was done as part of a larger water relations study.

Interpretation of Interception

Total interception is the sum of water stored on vegetation at the end of the storm and evaporation from plant surfaces during the storm. This relationship can be expressed in an equation of the form

$$I = S + RET \qquad (1)$$

where I is the interception in mm depth over the projected area of the canopy, S is water stored on the vegetation in mm depth over the projected area of the canopy, E is evaporation rate in mm depth per hour during the storm from the evaporation surface, R is the ratio of the evaporating surface to the projectional area and T is the duration of the storm in hours (Leonard, 1967). From equation (1) it is evident that the depth of interception changes as anyone of the other factors change, thus setting in motion a chain of interlocking reactions throughout any given drainage basin. S and R are functions of the amount of foliage and size of crowns.

From the above it follows that interception has a redistribution function involving the redistribution of precipitation on the soil surface and within the surface layers of the soil, resulting in localized areas of considerable excess and deficit (Eschner, 1967). The cumulative effect of such a pattern may in time result in different floristic and soil moisture patterns. A fixed pattern of increasing amounts of rainfall penetration through the canopy with increasing distance from the stems of individual trees, effecting the soil bulk density, has also been reported (Rogerson, 1967). In agricultural crop production the canopy could be so dense that rainfall penetration is decreased to the extent that fertilizer breakdown and assimilation is delayed or prevented and thus also plant development (De Villiers, 1978).

The stemflow component of the rainfall redistribution process has been determined in interception studies (De Villiers, 1976; 1977; Jackson, 1975) and it represents a concentrated application of water to the soil at a point where conditions are ideal for entry. A zone of increased soil moisture (up to one metre in diameter) results, thereby causing wetting considerably deeper than rainfall on open land (Eschner, 1967). It follows that this zone is of considerable importance to tree growth and the hydrology of forested areas.

Study Area and Method

The study was conducted near Naboomspruit in the Nylsvley Nature Reserve. The experimental plots were situated on a sandy plateau at 1 100 m, dropping gently towards the Nyl River floodplain (1 080 m) over most of its extent, although a fairly steep fall occurs along the northern margin. The sands overlie sandstones, conglomerates and grits of the Waterberg system.

It is a summer rainfall region where more than 90% of

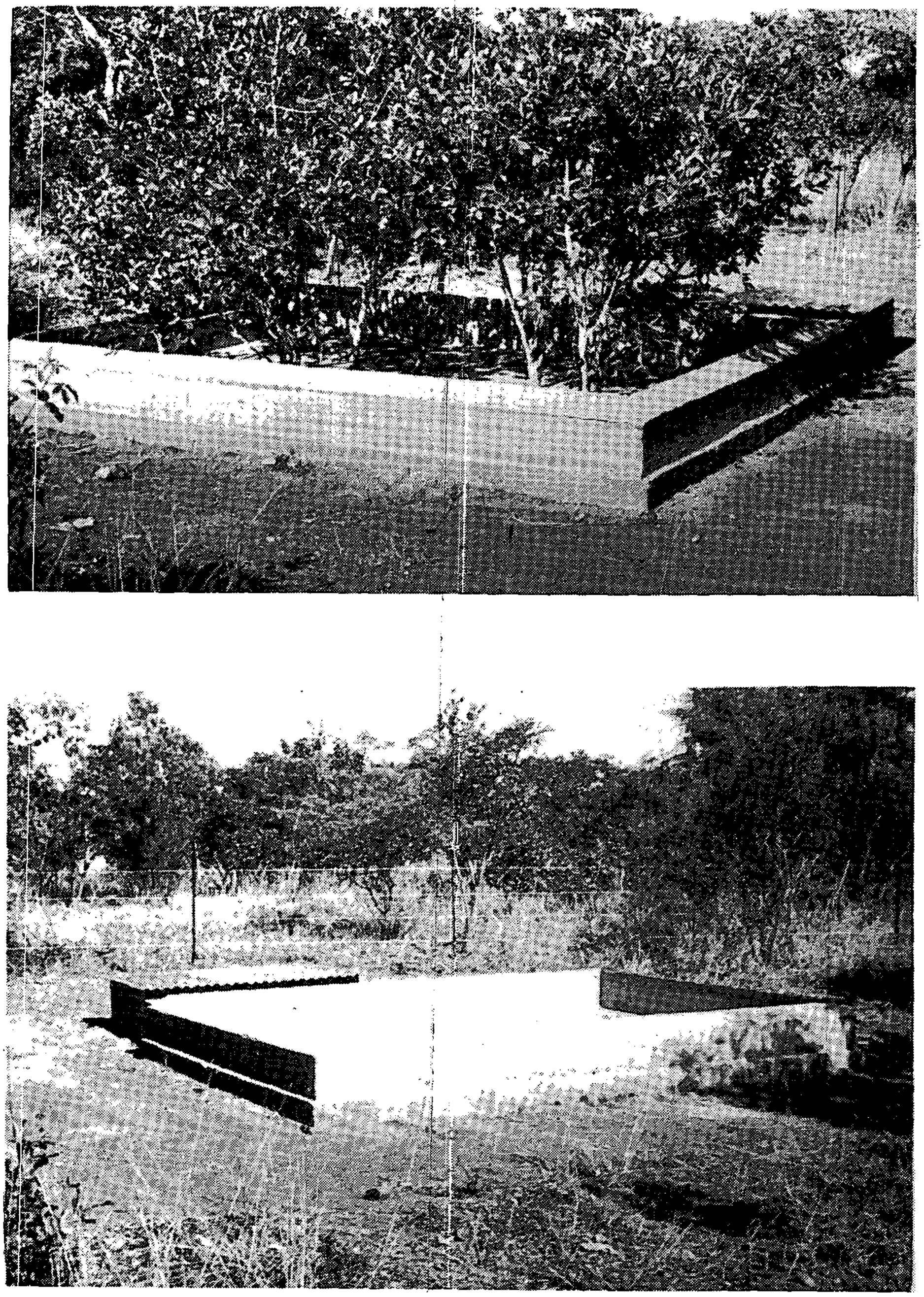

Figure 1
Ochna pulchra *experimental plot and control plot*

the rainfall is recorded during the period October to March. The mean annual rainfall of the region is 630 mm, the average number of rain days 62 and the mean annual temperature 18,3°C. Mean monthly maximum temperatures vary between 25,2°C in June and 34,8°C in January, whilst mean monthly minimums vary between −3,5°C in June and 11,6°C in January. The mean annual gross evaporation is more than 2 000 mm (U.S.A. class A pan) and the rainfall efficiency is, therefore, relatively low (Huntley and Morris, 1978; S.A. Weather Bureau, 1954).

The vegetation cover consists of seasonal grassland and deciduous savanna with *Eragrostis pallens — Burkea africana* the main community. *Ochna pulchra* and *Grewia flavescens* are the dominant shrubs (Coetzee *et al.*, 1977).

The measurement of interception losses in a homogeneous canopy cover is usually done by placing rain gauges below the canopy and comparing the catch with gauges outside the canopy cover. Because of the large variation in throughfall and drip in a heterogeneous cover, like savanna, this method is not acceptable and a technique that was used in mixed bushveld (De Villiers, 1976) was therefore adapted and refined. It comprised surfacing the canopy projection on the ground with an impervious floor. The floor area of the plots was painted with a light green paint which reflected radiation and thus limited heating of the plot surfaces. The sloping floor ensured quick discharge into a calibrated concrete tank with a water level recorder fixed on it to record the net rainfall. To compensate for interception losses from the floor, control plots, identical to the experimental plots, were set up (Fig. 1). The low density canopies had only a slight shading effect which was considered irrelevant. This impervious floor technique has the advantage of sampling the whole canopy with the minimum observational bother.

Two of these paired plots were set up, respectively in a *Burkea africana* stand and an *Ochna pulchra* stand. The *Burkea africana* plot contained two stems with diameters of 210 mm and 244 mm, and the *Ochna pulchra* plot 14 stems with diameters varying between 26 mm and 47 mm.

Gross rainfall was measured with four standard rain gauges and a recording gauge fitted with weekly charts. The purpose of the recording gauge was to determine the volume, duration and intensity of the storms.

No problems were experienced in finding clearings in the vegetation next to the experimental plots which provided unobstructed sky views of 45° around the rain gauge orifices. The standard rain gauges were read after every storm.

Meteorological data, recorded at a first order weather station, approximately 400 m from the interception plots, were also used.

Stemflow was sampled in a third plot from two *Burkea africana* stems by means of spiral gutters leading into plastic containers (De Villiers, 1977).

Gross Rainfall (Pd), Net Rainfall (Gr), Interception Losses (I) and Stemflow (Sf)

Only storms with a depth varying between 2 mm and 25 mm and with a wind speed of less than 6 m/s were analysed. Storms of less than 2 mm did not fill the storage capacity and was thus disregarded.

The upper limit was fixed at 25 mm because larger storms were interrupted by rainless periods of more than 10 min, and was thus defined as separate storms. The wind speed threshold value was obtained from a model for the distribution of effective rainfall on slopes (Sharon *et al.*, 1976) and it ensured that no rain landed on the floor without penetrating the canopy.

The gross rainfall data obtained from the five rain gauges showed a high degree of uniformity, indicating that homogeneous rainfall occurred over the study area. An analysis of variance was carried out over the 34 showers selected for analysis and it indicated that the differences between the four standard gauges for a given storm were insignificant. For the purpose of this study the storm rainfall as recorded by the two control plots was subsequently accepted as the true rainfall input because plot evaporation losses are taken into account. Gross rainfall, net rainfall and interception losses per storm for both plots are shown in Table 1. From the table it is obvious that net rainfall and interception losses per storm show a small difference between the two plots with the mean net rainfall for the *Burkea* plot only slightly lower than the mean net rainfall for the *Ochna* plot. The mean interception loss in the *Burkea* plot is therefore slightly higher than in the *Ochna* plot. These unexpectedly small differences are probably owing to the different canopy structures.

The *Burkea africana* is a single layered, flat crowned tree with small leaves whilst the *Ochna pulchra* shrub is a broad leaved coniform with a relatively large canopy water storage capacity. This is substantiated by Rutherford (1979), finding a much larger leaf area and biomass in *Ochna pulchra* than in the same size *Burkea africana*.

TABLE 1
GROSS RAINFALL (Pd), NET RAINFALL (Gr) AND INTERCEPTION LOSSES (I) IN mm IN TWO EXPERIMENTAL PLOTS

	Burkea plot			*Ochna* plot		
	Pd	**Gr**	**I**	**Pd**	**Gr**	**I**
1	10,7	9,0	1,7	11,3	10,1	1,2
2	11,6	9,2	2,4	12,4	11,0	1,4
3	8,6	6,8	1,8	9,1	7,9	1,2
4	5,4	4,4	1,0	5,8	4,6	1,2
5	8,1	7,0	1,1	9,0	7,7	1,3
6	2,9	1,0	1,9	3,4	1,4	2,0
7	13,9	12,2	1,7	15,0	13,4	1,6
8	13,9	12,4	1,5	14,4	13,0	1,4
9	13,3	11,6	1,7	13,6	11,6	2,0
10	2,7	1,0	1,7	2,9	1,6	1,3
11	7,8	6,0	1,8	8,0	6,8	1,2
12	11,8	9,8	2,0	12,4	10,6	1,8
13	8,8	7,2	1,6	9,1	7,8	1,3
14	11,7	9,8	1,9	12,2	10,6	1,6
15	2,7	1,3	1,4	3,0	1,7	1,3
16	7,8	6,2	1,6	8,3	6,7	1,6
17	7,1	6,0	1,1	7,9	6,9	1,0
18	6,3	4,8	1,5	6,7	5,3	1,4
19	2,8	1,2	1,6	2,8	1,4	1,4
20	6,3	5,0	1,3	6,7	5,4	1,3
21	2,6	1,2	1,4	3,0	1,6	1,4
22	10,8	9,0	1,8	11,3	9,7	1,6
23	3,4	2,0	1,4	3,5	1,8	1,7
24	13,8	10,6	3,2	14,6	12,3	2,3
25	8,5	6,7	1,8	8,9	7,4	1,5
26	10,8	8,8	2,0	11,2	9,4	1,8
27	3,4	2,2	1,2	3,6	2,6	1,0
28	21,1	18,6	2,5	22,0	20,0	2,0
29	18,4	15,3	3,1	19,7	17,0	2,7
30	13,8	11,2	2,6	14,6	12,5	2,1
31	8,5	6,7	1,8	9,4	7,4	2,0
32	16,1	13,6	2,5	17,2	14,7	2,5
33	5,4	2,7	2,7	6,0	4,6	1,4
34	7,0	5,5	1,5	7,8	6,6	1,2
T	307,8	246,0	61,8	326,8	273,1	53,7
A	9,1	7,2	1,8	9,6	8,0	1,6
%	100%	79,9%	20,1%	100%	83,6%	16,4%

Storm size was found to be one of the most important factors influencing the variation between storms in net rainfall for a specific plot. A linear regression analysis was calculated for each plot relating gross rainfall to net rainfall (Figs. 2 and 3) using the data from the 34 selected storms.

With correlation coefficients of 0,99 for both equations it is obvious that storm size accounts for most of the variation in net rainfall.

$Gr = 0{,}92\ Pd - 1{,}16$ *Burkea* plot
$Gr = 0{,}92\ Pd - 1{,}06$ *Ochna* plot

Interception losses are primarily determined by the storage capacity of the vegetation cover and by meteorological factors. A relationship was, therefore, sought between interception losses, gross rainfall, rainfall duration, temperature and wind speed. In the initial regression analysis equations were developed to predict interception losses from all possible linear combinations of the independent variables mentioned. From

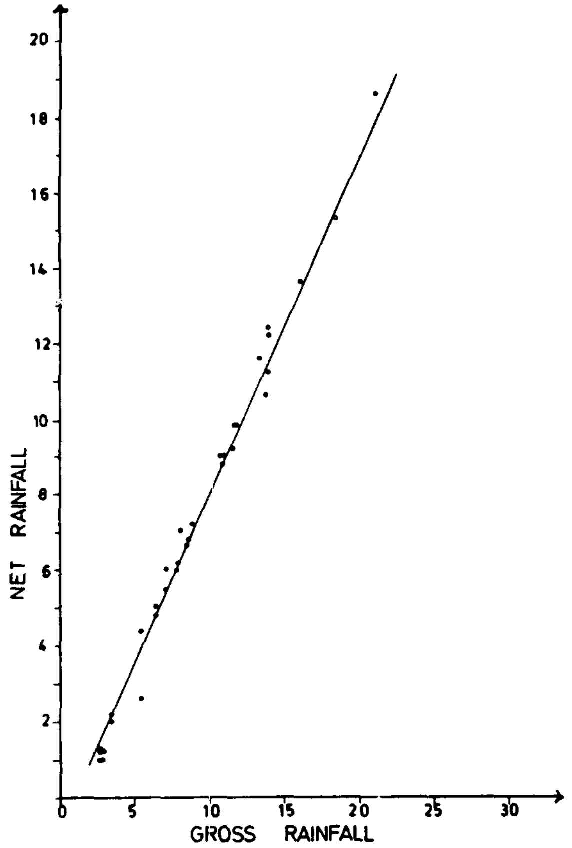

Figure 2
Gross rainfall and net rainfall in mm per storm, Burkea *plot*

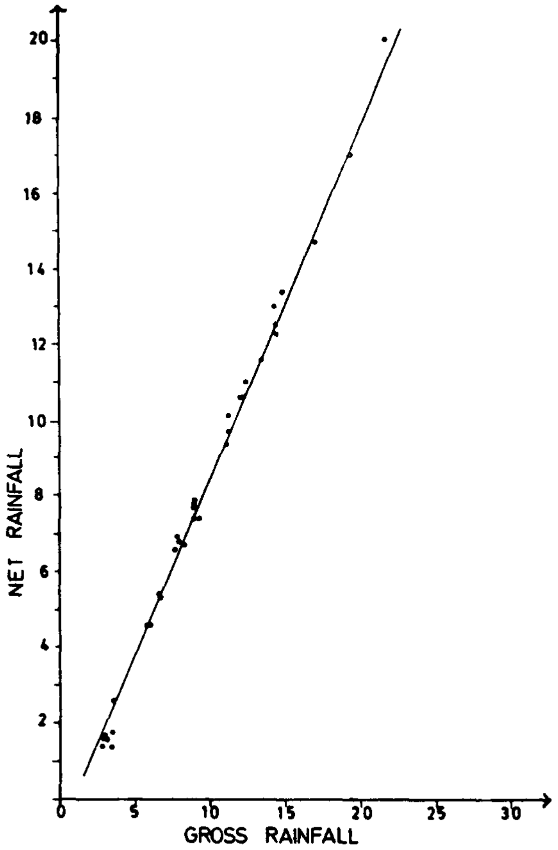

Figure 3
Gross rainfall and net rainfall in mm per storm. Ochna *plot*

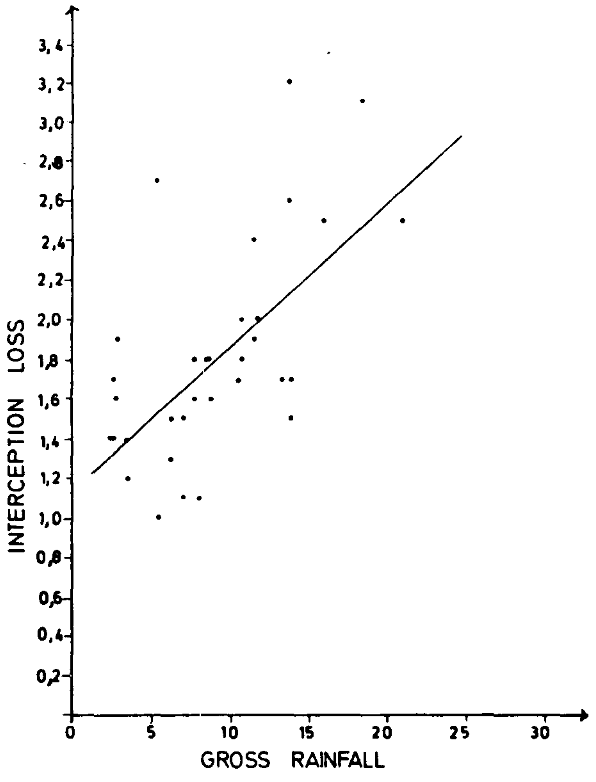

Figure 4
Gross rainfall and interception losses in mm per storm, Burkea *plot*

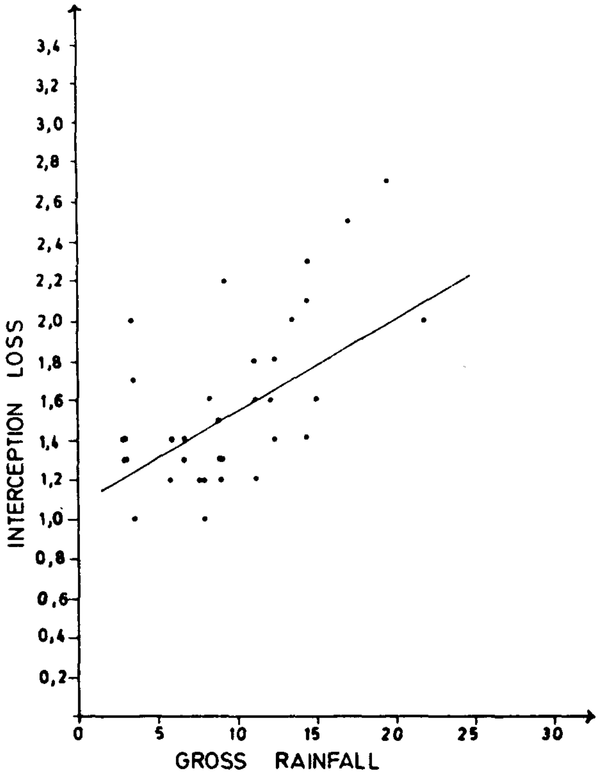

Figure 5
Gross rainfall and interception losses in mm per storm, Ochna *plot*

this it was apparent that the inclusion of more than two variables was only justified in the case of interception losses, gross rainfall and rainfall duration (T) which resulted in additional improvements.

The gains with temperature and wind speed were insufficient to justify the computations. The rainfall duration effect is explained by the large variation in this parameter which varied between less than 10 min and 155 min. Wind speed variation was largely excluded by the 6 m/s threshold value whilst temperature differences between storms did not exceed 5°C. Table 2 depicts the results of the analysis.

Rainfall amount was the only single variable correlated with interception losses. The regression equations were defined as

Ib = 0,07 Pd + 1,17 *Burkea* plot
Io = 0,05 Pd + 1,07 *Ochna* plot

with correlation coefficients of 0,39 and 0,40 respectively (Figs. 4 and 5).

Rainfall intensity was then considered with rainfall duration to determine its effects on interception losses. Storms with a relatively accurate relationship between interception losses, rainfall duration and rainfall intensity are depicted in Table 3. From the table it is apparent that interception losses increase with an increase in rainfall intensity.

The explanation by Jackson (1975) that higher rainfall intensity ensures a higher storage of rain in the canopy and thus a higher evaporation rate of intercepted water, also applies to some storms in this study. It is however not possible to state that in general higher intensity yields higher interception losses.

TABLE 2
GROSS RAINFALL, INTERCEPTION LOSSES AND STORM DURATION RELATIONSHIPS

Experimental plot	Observations	Model	Correlation Coefficient
Burkea	34	Ib = 1,20 + 0,01 Pd + 0,01 T	0,45
Ochna	34	Io = 1,10 + 0,01 Pd + 0,01 T	0,45

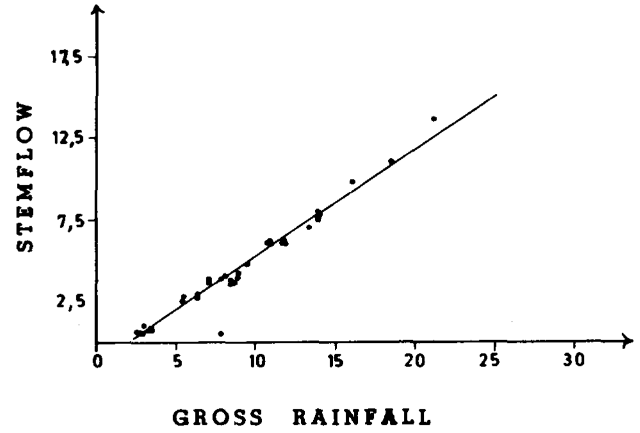

Figure 6
Gross rainfall in mm and stemflow in ℓ per storm

Stemflow quantity is mainly determined by the structure of the canopy. Studies by Leonard (1961) and Rutter (1963) indicate that the variation in stemflow quantities between stems of different bark textures are relatively small, but the mechanism of the process differs. In the case of smooth barks it is a flow process down the stem, whilst a drip process results with rough barks. A fixed relationship between stemflow quantity and stem diameter was found by Wicht (1941) which facilitates the calculation of total stemflow of an experimental plot.

In this study the selected *Burkea* stems were seen as a representative sample of a specific diameter class in a savanna cover. Stemflow between the sample trees did not differ significantly and average values were therefore used. Stemflow in litres was plotted against gross rainfall and a linear regression was calculated and defined as

Sf = 0,68 Pd − 1,58

with a correlation coefficient of 0,95 (Fig. 6). The total stemflow for the 34 showers was 126 ℓ per stem giving an average of 3,7 ℓ per stem per shower.

TABLE 3
INTERCEPTION LOSSES AND RAINFALL DURATION IN RELATION TO CERTAIN RAINFALL INTENSITY CATEGORIES

Intensity 0—4 mm/h				Intensity 4,5—6,5 mm/h				Intensity 7—15 mm/h			
No	Io	T	Ib	No	Io	T	Ib	No	Io	T	Ib
1	1,4	90	1,6	1	2,3	100	2,6	1	2,5	100	3,1
2	1,8	105	2,0	2	1,6	90	1,9	2	2,7	120	3,2
3	1,4	95	1,7	3	1,8	95	2,0	3	2,0	80	2,5
4	1,7	100	1,9	4	2,1	100	2,8	T	7,2	300	8,8
5	1,6	100	1,8	T	7,8	385	9,3	A	2,4	100	2,9
6	1,2	80	1,5	A	1,9	96	2,3				
7	1,3	90	1,7								
T	10,4	660	12,2								
A	1,4	94	1,7								

Io = Interception losses *Ochna pulchra*
Ib = Interception losses *Burkea africana*
T = Rainfall duration

Conclusion

Net rainfall is in fact less than the measured gross rainfall and interception loss is therefore a factor which necessitates consideration in any water balance study. The integration of the components throughfall, drip and stemflow as net rainfall yields reliable results and interception studies in shrub vegetation and agricultural crops could be approached in the same way. Independent stemflow measurements are, however, necessary to determine the contribution of this component to total net rainfall. The rainfall parameters, duration and intensity, influence the interception process and should thus be considered in modelling. The variation in interception losses and net rainfall between different plant types in a savanna cover is apparently relatively small. The possibility of comparing and integrating the data of different studies thus exists, which could yield models with a more practical use in hydrology and ecology.

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