J. Rubb. Res. Inst. Malaysia, 33(2), 70–82

*A Critical Study of the Hydrological Cycle in a Mature Stand of Rubber (*Hevea brasiliensis *Muell Arg.)*

G. HARIDAS AND T. SUBRAMANIAM

In fifteen-year-old LCB 1320 trees, rainfall interception varied between 18% – 24%. Level of fertiliser application and canopy conditions apparently influenced interception losses and, depending on the time of the year and rainfall intensity, interception was as high as 32%. Moisture storage in the soil also depended on the rainfall distribution. But this could not be related to rubber yields, perhaps, owing to loss in tapping days during rainy spells.

For most economic tree species, the hydrological cycle has been worked out, by and large, in forested catchments. In a mature stand of rubber, the need for such information is all the more important for a number of reasons. Stemflow interferes seriously with tapping operations and therefore, yield depressions are likely during wet months[1]. Rainfall interception by the canopy causes direct evaporation from the leaves and this amount of water is lost to the crop. Teoh[2] carried out stemflow and throughfall measurements for rubber and observed that, on an average, about 2% of the rainfall reached the ground as stemflow and about 83% as throughfall. Stemflow and throughfall differences between clones were also evident. Although there were no marked differences in rainfall interception between clones, it was generally apparent that interception increased when rainfall decreased. For example, in clone RRIM 605, the percentage interception for a rainfall of 3 cm was estimated to be 17%, whereas, it increased to 44% for a 1-cm rainfall. Increasing tree density increased rainfall interception and stemflow but reduced throughfall in some of the clones studied.

The proportion of water from rainfall reaching the ground as stemflow and throughfall, also called 'net rainfall' is of great importance to agricultural crops. This essentially is what percolates the soil and is stored in the soil for crop use. A large proportion of the water could be lost to the crop by way of surface runoff, especially in undulating and steep terrain. For rubber, which is a rainfed crop, this amount of water reaching the ground is of important consequence to its yield or productivity. Efforts are made in this paper to critically evaluate these aspects.

COMMUNICATION 760

EXPERIMENTAL

The experiment was laid out in an existing fertiliser trial consisting of fifteen-year-old trees of clone LCB 1320 and tapped on *Panel BO-2*. The initial stand per hectare in the field was 447 trees. At the time of commencement of the experiment the stand was about 325 trees per hectare. The soil in the experimental area was Rengam series (Typic paleudult), with texture increasing from sandy clay to clay with depth. Each plot, which formed a plot-sized catchment was 0.13 ha in dimension, and each one plot consisted of one fertiliser treatment; *viz.*, O level (nil fertiliser), Level 1(L_1) (682 g, 454 g, 341 g and 341 g respectively, of ammonium sulphate, Christmas Island rock phosphate, Muriate of Potash and Kieserite per tree, annually) and Level 2 (L_2) being twice L_1[3].

Stemflow

Stemflow is the amount of water from rainfall that is trapped by the canopy and reaches the ground by flowing down the trunk of the tree[4]. Five trees of uniform girth were randomly selected and metal collars fixed on the tree trunks. The metal collars were sealed to the tree trunks and rendered 'water tight' with latex. Collections were made through a polythene delivery hose after each storm *(Figure 1)*.

Throughfall

Throughfall is termed as the water from rainfall that falls directly onto the ground from the leaves, twigs and branches. This was measured by distributing plastic buckets in the inter-row and inter-tree space of selected trees. They were also periodically re-located to avoid biased catches[4].

Interception Losses

It is that portion of precipitation that is retained by canopy and that which is either absorbed by the leaves or retrieved by the atmosphere through evaporation[5].

Throughflow

The lateral and vertical flow of water through the soil is termed 'throughflow'. Two throughflow pits were dug per plot. They were of the same dimensions as the ones installed by Roose[6] in the Ivory Coast. Alluminium plates of 60 cm long, 36 cm wide and 2.5 mm thick with gutters welded on, were slowly thrust into slits cut into the upslope face of the pits. The lowermost plate was placed about 90 cm from the surface. Thin strips of timber were inserted into the cut slits below the plates to reinforce and prevent collapse of soil. The gutters had outlet tubes and throughflow was collected in bottles *(Figure 2)*. All the pits were covered with zinc roofing which were only removed when collections were made after each rainfall.

Surface Runoff

Surface runoff is the portion of rainfall that, after having reached the ground, does not percolate the soil but flows freely along the surface. This was collected in drums placed in pits at the downward end of each plot *(Figure 3)*. Measurement of the amount of water collected was made after each rainfall.

COPYRIGHT © MALAYSIAN RUBBER BOARD

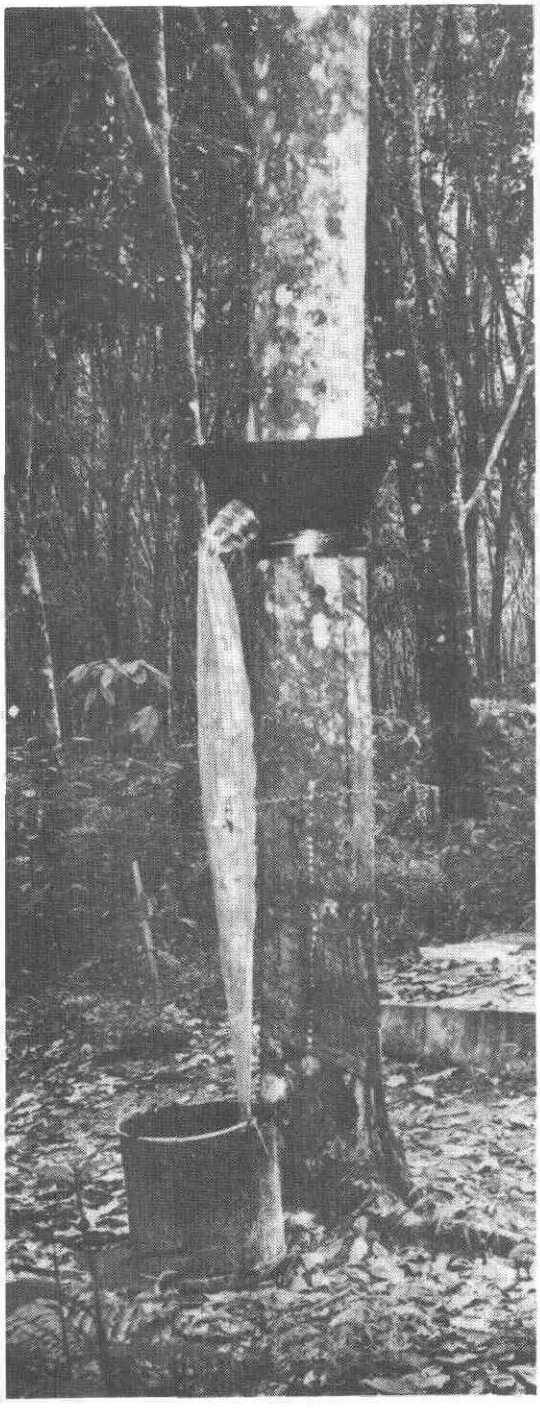

Figure 1. Apparatus for measuring stemflow.

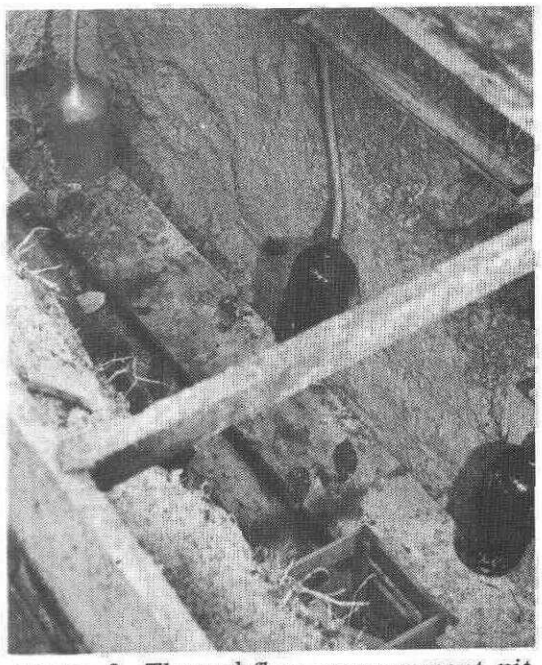

Figure 2. Throughflow measurement pit.

Figure 3. Surface runoff measured in drums placed in pits.

Rainfall

In the study of forest hydrology, inferences concerning gross and net rainfall are made. Gross rainfall refers to the total rainfall per storm precipitated over the forest canopy[4]. Attempts were not made to measure rainfall above the canopy in each of the plots. Rather, rain gauges were distributed (three in all) in open areas in the immediate vicinity of the field. A mean of the three readings was taken as gross rainfall for easy computation. Net rainfall refers to the water reaching the surface of the ground as stemflow and throughfall.

Water Balance Equation

A simple water balance equation was used to calculate moisture retention in the soil down to a depth of 90 cm during the course of eighteen months when the experiment was carried out. A cumulative of the amount of water stored in the soil for intervals of three months was construed as the water available for use by the stand of rubber during the period. The equation was:

$$Wu = P - R - Pr$$

where Wu = water available for use by trees
P = gross rainfall
R = surface runoff
Pr = percolation losses below 90 cm.

Percolated water below 90 cm was considered a loss to rubber; because from earlier findings it was evident that there was little feeder root activity below this depth[7].

RESULTS AND DISCUSSION

Throughfall, Stemflow, Interception and Runoff

Values of mean percentage stemflow, throughfall and interception for fifteen-year-old LCB 1320 were 1.6%, 79% and 19% respectively for the period of eighteen months *(Table 1)*. These values seem to fall very closely with the mean values for stemflow, throughfall and interception obtained generally for rubber by Teoh[2]. However, differences in rainfall interception pattern were apparent between the three fertiliser treatments. Percentage rainfall intercepted in the canopy of treatment L_2 was higher than that of treatments L_1 and O level. In fact, interception was found to be consistently higher in the L_2 plot throughout the eighteen months when measurements were taken. This trend was also evident when interception losses were accounted for on a three-monthly basis *(Table 2)*. It could not be established whether this trend was on account of better canopy conditions in the L_2 plots as this was not studied. Nevertheless, Tan[3], working in the same field with clone GT 1, observed distinct differences in leaf litter collections between the three fertiliser levels during peak leaf-fall period in February – March 1973. About 1050 kg, 860 kg and 640 kg per hectare leaf litter were collected from L_2, L_1 and control plots respectively during this period. The leaf litter collected for the whole year worked out to be 2862 kg, 2601 kg and 2359 kg per hectare respectively, for the same treatments. Leaf N, P, K and Mg values for LCB 1320 in 1974 *(Table 3)* show the influence of fertiliser levels on the nutri-

TABLE 1. MEAN PERCENTAGE STEMFLOW, THROUGHFALL, TOTAL THROUGHFALL AND INTERCEPTION FOR FIFTEEN-YEAR-OLD LCB 1320 AT DIFFERENT FERTILISER LEVELS

Fertiliser level	Stemflow	Throughfall	Total throughfall	Interception	Surface runoff
O (nil fertiliser)	2	80	82	18	1.6
L_1	2	83	85	15	0.5
L_2	1	75	76	24	1.0
Mean	1.6	79.3	81.0	19.0	1.0

TABLE 2. PERCENTAGE INTERCEPTION OF RAIN BY THE CANOPY OF RUBBER UNDER THREE FERTILISER LEVELS

Period	Gross effective rainfall (mm)	Percentage interception		
		O	L_1	L_2
May – Jul., 1974	282	12	10	16
Aug. – Oct., 1974	409	20	17	26
Nov., 1974 – Jan., 1975	450	16	8	24
Feb. – Apr., 1975	561	22	16	24
May – Jul., 1975	416	14	18	21
Aug. – Oct., 1975	573	24	20	32

TABLE 3. NITROGEN, PHOSPHORUS, POTASSIUM AND MAGNESIUM LEVELS IN LEAVES IN 1974

Fertiliser level	N (%)	P (%)	K (%)	Mg (%)
O (nil fertiliser)	3.44	0.176	1.18	0.169
L_1	4.00	0.218	1.29	0.209
L_2	3.69	0.221	1.64	0.209

tional status of leaves. From these findings, it is strongly inferred that fertiliser levels play an integral part in canopy density and influence nutrient status of leaves, and thus, may have influenced rainfall interception through the canopy.

Although, on an average, between 18% – 24% of the gross rainfall is intercepted in the canopy of rubber, this phenomenon is very rarely considered while discussing rainfall patterns and yield of rubber. Hamilton and Rowe[8] defined interception loss as that portion of the precipitation retained by the aerial portion of the vegetation and is either absorbed by it or is returned to the atmosphere by evaporation. In some temperate forest species, such as Norway Spruce, losses of as much as 48% of the annual gross rainfall have been recorded, and these high values were obtained even after thinning down the tree density[9]. In this experiment, the trees were fifteen years

old with the stand at about 325 trees per hectare. Interception loss of as high as 32% was observed for a period of three months in the L_2 plots *(Table 2)*. With the present move towards higher planting density for rubber, it is likely that water yields in the field would be further reduced. This would seriously impede the storage of water in the soil and consequently availability of soil moisture during stress periods. The gross effect of this on growth and yield of rubber can be large. Teoh[10] found interception losses increasing with increasing planting density for clones RRIM 600 and RRIM 703.

There seems to be some controversy among forest hydrologists concerning the validity of considering intercepted rainfall as a total loss to the water yields in the catchment or field. This stems from the argument that evaporation from wet foliage should be compensated by a corresponding reduction in transpiration[11]. Many others have observed that evaporation rates of intercepted water are many times higher than transpiration rates from the foliage or the absorption rates of intercepted water by the leaves[12, 13]. Although systematic studies on this aspect were not done in this experiment, it was evident that at no time during the eighteen months did rainfall interception exceed potential evaporation from an open pan *(Figure 4)*, thus suggesting that the evaporative capacity of the atmosphere was high enough, even during the wet months, for the vaporisation and diffusion of the entrapped water in the canopy into the atmosphere. It seems probable therefore, that intercepted water in the canopy of rubber is a loss to the crop. It is imperative that more work along these lines be done to define clearly the relationship between rainfall and interception losses. For example, the effect of diurnal and noctural rainfall and the preponderance of one or the other in a particular month and its influence on rainfall interception are not known. However, monthly rainfall interception seemed to follow closely the monthly rainfall distribution patterns; the higher the gross monthly rainfall, the higher the interception losses *(Figure 4)*. In fact, there was a positive and significant correlation between gross rainfall and interception losses in the L_2 plot *(Table 4)*.

When the absolute amount of rain water retained in the canopy from individual rainstorms over 24 h was considered, it

TABLE 4. REGRESSION EQUATION OF GROSS RAINFALL ON RAINFALL INTERCEPTION, THROUGHFALL AND STEMFLOW IN L_2 PLOTS

x (gross rainfall)		r
Rainfall interception	$y = 3.22664 + 0.18814\,x$	0.85688***
Throughfall	$y = -3.70322 + 0.80467\,x$	0.98931***
Stemflow	$y = 0.48113 + 0.00682\,x$	0.62255***
Net rainfall	$y = -3.2210 + 0.81150\,x$	0.99025***

Significant at 0.1% level of probability

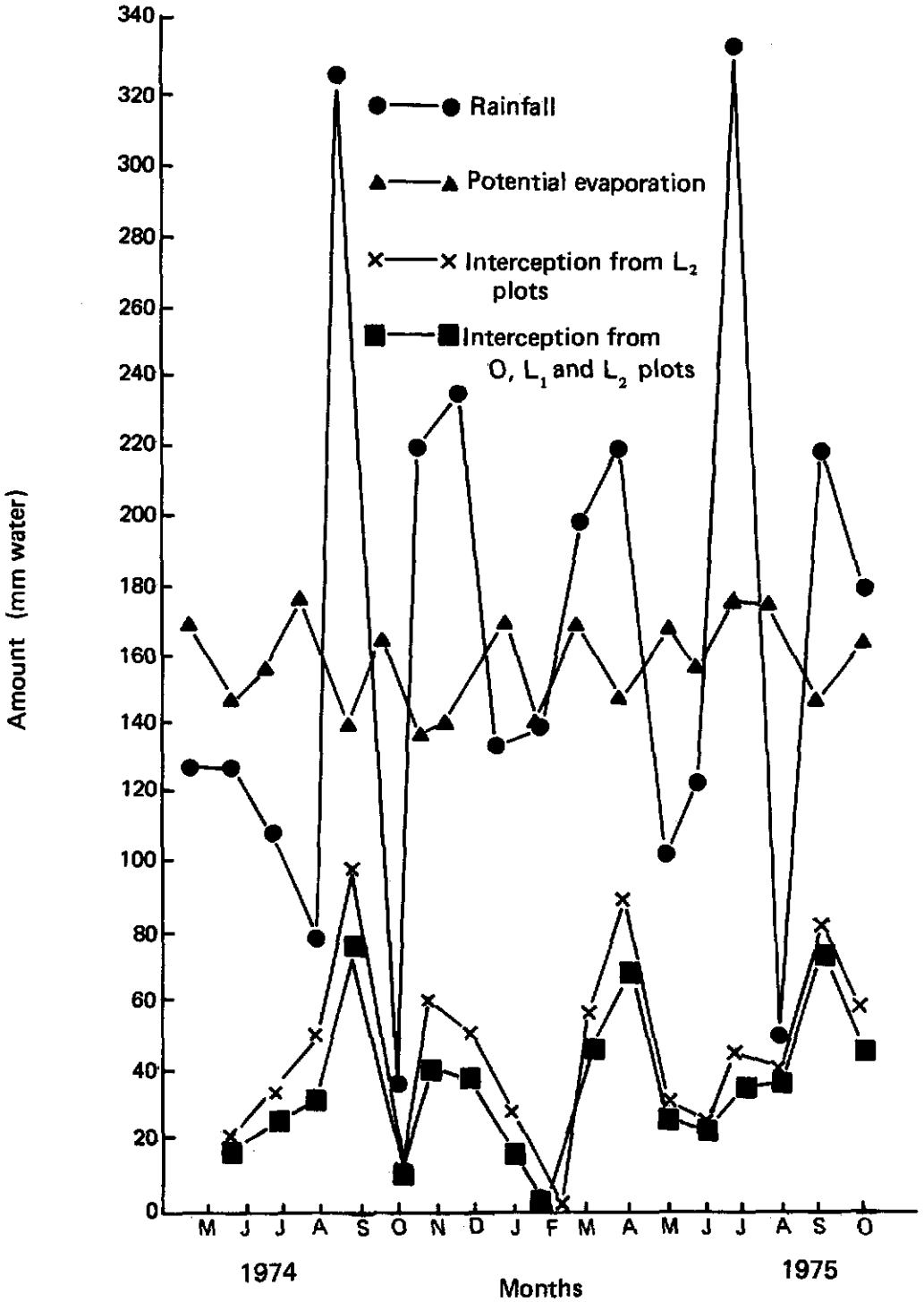

Figure 4. Gross rainfall, potential evaporation and interception.

generally increased with increasing gross rainfall *(Table 5* and *Figure 5)*. However, when these values were presented as percentage rain water retained, it did not vary very much according to rainfall *(Figure 5)*, and this is further evidenced by the lower standard deviation (S.D.) and coefficient of variation (C.V.) obtained *(Table 5)*. Teoh[2] observed decreasing interception percentage with increased rainfall for the five clones he worked with. Canopy conditions are never static through the year and between years. Thus, it is imperative that such studies are carried out for longer periods before conclusions are drawn. An understanding of the branching habits of clone, the manner in which the leaves are arranged on the twigs and the angle of this attachment, along with the age of the trees would help us understand rainfall interception more completely. Intensity of individual rainstorms and their length would also affect this phenomenon. Thus, for the same storm distributed over a short period, interception could be less than when the storm is spread over a longer period. Sufficient information on these aspects are not available from this experiment.

Intensity of individual storms (taken as gross rainfall) had a overwhelming influence on the amount of water reaching the ground as stemflow and throughfall. In effect, gross rainfall correlated highly and significantly with each of these parameters *(Table 4)*.

The rain water reaching the ground as net rainfall (stemflow + throughfall) is not all available for use by the rubber trees. Depending on the terrain and permeability of the soil much of it is lost as overland flow or surface runoff. This occurs when net rainfall is in excess of infiltration capacity of the soil. It could occur for short periods during or immediately after a storm. Subsurface stormflow moves laterally through the soil towards a stream channel. In the present experiment, subsurface stormflow was not accounted for. Rather, throughflow, and non-storm base flow were measured in throughfall pits. Under the circumstances leachate or percolated water beyond 90 cm of the soil column could not be related to individual storms, as, there was always a time lag between the actual incidence of rain and the time when the water finally flowed through the soil column. However, correlation between net rainfall and surface runoff was positive and significant at 0.1% level of probability in the L_2 plots ($r = 0.61315$***), and when pooled values for the three fertilisers regimes were considered (r = 57262***). Depending on the intensity of rainfall, between 0.5% – 1.6% of the

TABLE 5. GROSS RAINFALL OVER 24 H AND RECIPROCAL INTERCEPTION LOSSES

Rainfall (mm)	Interception (mm)	Percentage
20	3.63	18.15
30	5.53	18.43
40	7.27	18.17
50	11.07	22.14
60	11.27	18.78
70	13.23	18.90
80	11.63	14.54
90	16.26	18.07
100	18.70	18.70
110	21.36	21.48
S.D.	6.1	2.1
C.V. (%)	49.9	10.7

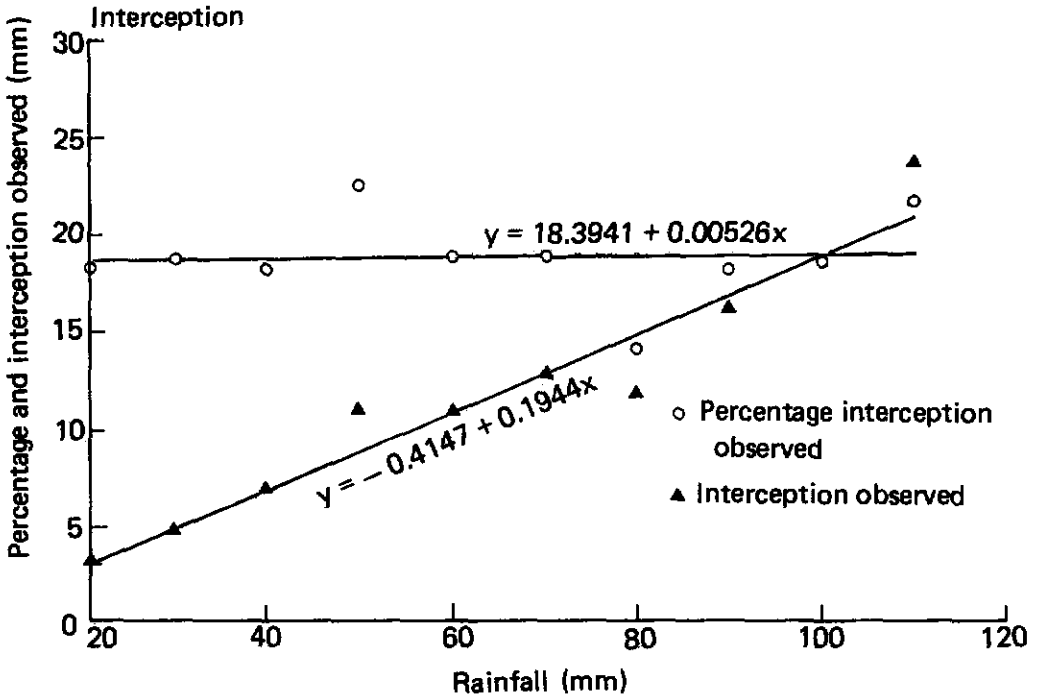

Figure 5. Gross rainfall over 24 h and reciprocal interception losses.

gross rainfall was lost as surface runoff in this experiment. On a rough estimate this was almost equivalent to the water that flowed down the trunk of rubber trees as stemflow after each rain *(Table 1)*. It is likely that in this experiment the tappers' path which was more compact than inter-row space caused unimpeded flow of water from stemflow over the ground in defined stream channels. Under the circumstances surface runoff under rubber would occur only during and immediately after a storm and this would also perhaps, explain the positive and significant correlations between net rainfall and surface runoff. Net rainfall also correlated positively and significantly with moisture storage in soil ($r = 0.99998$***).

SOIL MOISTURE STORAGE AND YIELD OF RUBBER

The availability of water in soil for the normal growth function of the rubber tree and its productivity is dependent on rainfall. There are times when severe dry spells occur in parts of the country and there are indications that yield depressions occur during such periods[14]. The importance of water relations in the tree system need not be over-emphasised, especially in view of the fact that 60%–70% of latex consists of water. Irrigating rubber trees during dry spells may not be a practical solution. However, it is still important to know how much water is used by the trees or the water requirement of the rubber tree, particularly with

reference to the feasibility of growing this tree crop economically in a particular area.

In this experiment the total amount of water retained in the soil upto a depth of 90 cm over the period of eighteen months was considered as the total amount of water available for use by the crop during this period. Reworking this on a three-monthly basis, there was a wide variability in soil moisture storage *(Table 6)*. Between May and July, 1974 available water was rather low and this was also reflected in the rubber yields obtained. As moisture storage increased, in the months between August – October, 1974 and November, 1974 – January, 1975, yields too increased *(Table 6)*. However, between February – April 1975, yields dropped suddenly, although available water storage had increased. In fact, 422 mm water to 90 cm depth *(Table 6)* is very close to the 419 mm per metre depth available water worked out by Soong[15] for Rengam series soil. This abnormal trend needs further explanation. Firstly, this period coincided with the wintering months, and probably could be one reason for the drop in yield. Secondly, the high rainfall during this period, particularly during March and April, could have resulted in loss in tapping days. The validity of the second reason was indirectly tested by introducing quadratic regression equations to number of rainy days *versus* yield and, rainfall intensity in millimetres of rain per rainy day *versus* yield. The relationships were carvilinear on both occasions *(Figures 6* and *7)*. Yields decreased with increasing number of rainy days. As for rainfall intensity, it was evident that yields increased upto the time when there was a precipitation of between 10 mm and 11 mm per rainy day for a particular quarter, after which, a declining trend set in February–April, 1975, had 15.6 mm rain per rainy day and this would have interfered with tapping. Thus, it is evident from results obtained that although moisture storage may be optimum in the soil it may not be congenial to the extraction of high yields on account of loss in tapping days due to continuous and persistently high precipitation[1]. Correlation between moisture storage in soil and

TABLE 6. SOIL MOISTURE STORAGE AND YIELD OF RUBBER FROM A MATURE STAND OF LCB 1320

Period	Gross rainfall (mm)	Rainfall intensity (mm rain/rainy day)	Mean yield (g/tree/tapping)	Moisture storage upto 90 cm	Available water (stored) (mm/day)
May – Jul., 1974	282	6.1	31.41	151	1.64
Aug. – Oct., 1974	409	10.5	66.71	257	2.79
Nov., 1974 – Jan., 1975	450	9.4	75.10	320	3.48
Feb. – Apr., 1975	561	15.6	41.95	422	4.74
May – Jul., 1975	416	7.6	57.64	278	3.02
Aug. – Oct., 1975	573	9.6	53.29	496	5.39

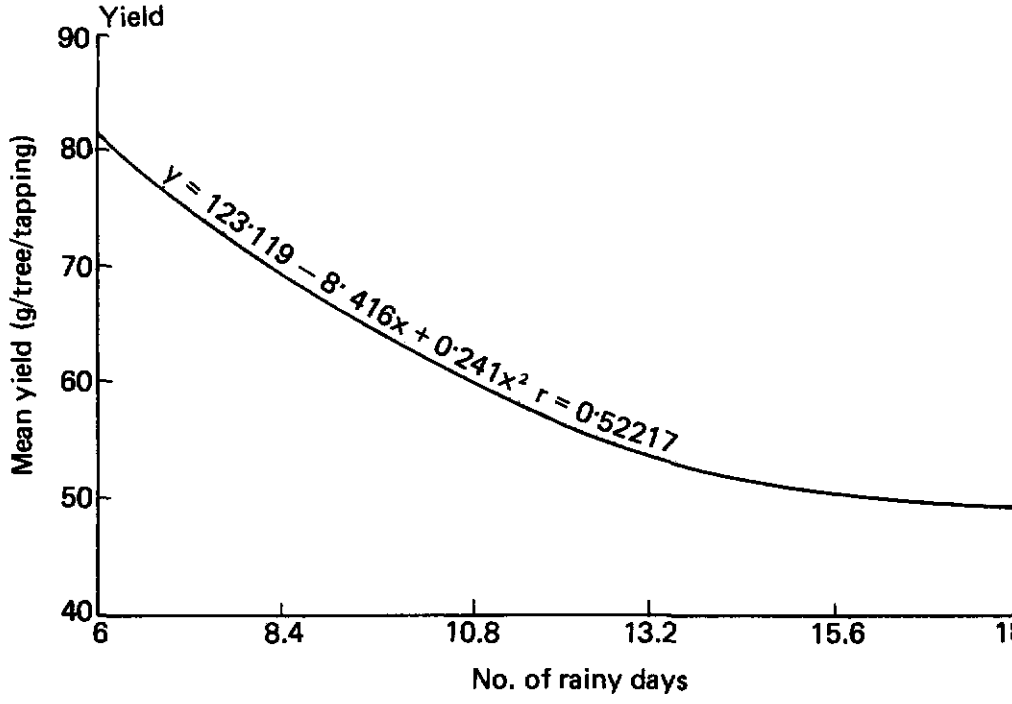

Figure 6. Yield versus *number of rainy days.*

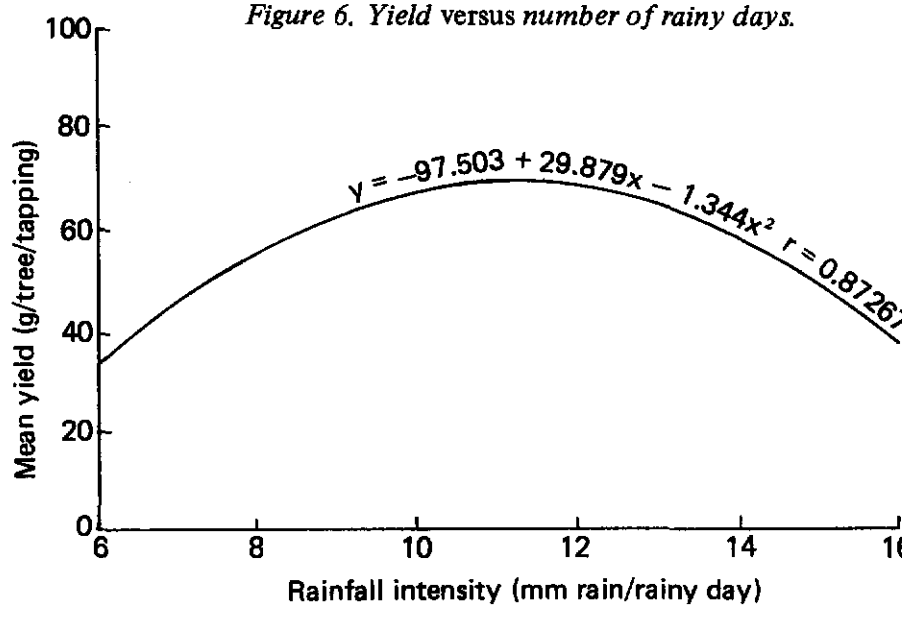

Figure 7. Yield against rainfall intensity.

yields was non-significant. Perhaps, this type of relationships is possible if rainrall does not interfere with tapping. It is felt that the use of rain-guards could overcome this problem and efforts are being made to study this in detail.

CONCLUSIONS

From the above discussions it is evident that a considerable amount of water from rainfall is intercepted by the canopy of rubber trees and is probably a loss to the crop. On an average, 18%–24% of rainfall was intercepted by the canopy of LCB 1320 and, depending on the period and intensity of rainfall, as much as 32% rainfall was intercepted. It seems likely that the level of fertiliser application and canopy conditions may also indirectly influence rainfall interception. However, this needs further verification. There was a positive and significant correlation between gross rainfall and interception losses; the higher the gross monthly rainfall the higher the interception losses. When individual gross rainfall over 24 h was observed, interception generally increased with rainfall. However, when this was presented as percentage interception of rain it did not vary very much according to rainfall. All other parameters, such as, throughfall and stemflow correlated positively and significantly at 0.1% level of probability with gross rainfall. Highly significant correlations were also observed between net rainfall and surface runoff and moisture storage in the soil. Higher moisture storage in soil did not however, mean higher yields. This discrepancy in the trend of yield is attributed to loss in tapping days during a rainy spell. Higher number of rainy days during a period decreased yields and rainfall intensity beyond 10 – 11 mm rain per rainy day was not congenial to high yields.

ACKNOWLEDGEMENT

The author wishes to express his thanks to the Rubber Research Institute of Malaysia for permission to write this paper. Special acknowledgements are also owing to Drs E. Pushparajah and Soong Ngin Kwi (now with Multi Purpose Holdings) for their interest and encouragement while setting up the experiment. Thanks are also accorded to Encik Wong See Kiong for supervising the work.

Rubber Research Institute of Malaysia
Kuala Lumpur *July 1984*

REFERENCES

1. PENMAN, H.L. (1963) Vegetation and Hydrology. *Commonw. Bur. Soil Sci. (Gt Br.) Tech. Commun. 53.*

2. TEOH, T.S. (1971) Where Does All the Rainfall Go? *Plrs' Bull. Rubb. Res. Inst. Malaya No. 115.* 215.

3. TAN KEH HUAT (1975) *Hevea* Leaf Litter Fall and Chemical Changes During Litter Decomposition. *Proc. Third Asean Soil Conf. 1975*, 147.

4. HELVEY, J.D. AND PATRIC, J.H. (1965) Canopy and Litter Interception by Hardwoods of Eastern United States. *Wat. Resour. Res.*, 1, 193.

5. HORTON, R.H. (1919) Rainfall Interception. *Mon. Weath. Rev.*, 47, 603.

6. ROOSE, E.J. (1967) Un Dispositif de Measure Du Lessivage Oblique Daus Les Sols en Plase. Adiopodoume, Cote d'lvoire, ORSTOM.

7. SOONG NGIN KWI (1970) A Study of Root Distribution of *Hevea brasiliensis* in Relation to Its Nutrition and Growth on Some Typical Malayan Soils. Thesis Submitted for the Degree of Master of Agricultural Science, University of Malaya. *Rubb. Res. Inst. Malaya Res. Archs. Docum. No. 69*, 1971.

8. HAMILTON, E.L. AND ROWE, P.B. (1949) *Rainfall Interception by Chaparral in California*, p. 43. California: Forestry and Range Experiment Station., in co-operation with California Division of Forestry.

9. LEYTON, L., REYNOLDS, R.C. AND THOMPSON, F.B. (1965) Rainfall Interception in Forest and Moorland. Forest Technology.

Proc. Sci. Found. Adv. Sci. Semin., State University, Pennsylvania, 1965, 163.

10. TEOH, T.S. (1974) Throughfall, Stemflow and Interception Studies on *Hevea* Stands in Peninsular Malaysia. *IBP – Synth. Meet. – Kuala Lumpur.*

11. BURGY, R.H. AND POMEROY, C.R. (1958) Interception Losses in Grassy Vegetation. *Am. Geophys. Union Trans.*, 39, 1095,

12. SYKES, M. (1960) Some Observations on the Effects of Foliage Wetting on Water Relations of Scots Pinc. Unpublished Thesis, Forestry Department, Oxford University.

13. WELLS, K.F. (1963) Some Aspects of the Role of the Forest Canopy in the Fate of Rainfall. Unpublished Thesis, Forestry Department, Oxford University.

14. RUBBER RESEARCH INSTITUTE OF MALAYSIA (1981) *Rep. Rubb. Res. Inst. Malaysia 1980*, 315.

15. SOONG NGIN KWI AND YAP WENG CHUN (1973) A Study on the Moisture Characteristics of Soils under Rubber in Peninsular Malaysia. *Malaysian Soc. of Soil Sci. Conf. on Fert. and Chemy of Trop. Soils Kuala Lumpur 1973.*