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Soil Moisture Use and Growth of Young Hevea brasiliensis *as Determined from Lysimeter Studies*

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Young rubber plants subjected to differential soil moisture regimes and fertiliser levels in weighing lysimeters in the glasshouse, indicated that, the magnitude of difference in dry matter production due to differences in the availability of water was more than that obtained for the fertiliser types or levels of it. It was also evident from field lysimeters as well as glasshouse lysimeters that, Osmocote was superior to the other two fertilisers in terms of dry matter production and improvement of water use efficiency. It improved nitrogen and potassium uptake but not phosphorus and magnesium uptake.

A uniform annual distribution of rainfall is regarded as favourable for the growth of *Hevea* plants[1]. However, in Peninsular Malaysia, dry spells of between one and ten days are common in most months[2,3]. Prolonged drought periods also occur in regions with distinct dry seasons[4]. These lead to soil moisture stress of differential magnitude, affecting adversely the growth of young rubber[5,6,7]. It has recently become a common practice with the industry during drought periods to irrigate young rubber plants in the nurseries as well as field planted rubber in the initial establishment stages. However, irrigation is usually carried out without determining the most appropriate period and the actual amount of water needed for optimum growth of rubber.

This paper presents results from preliminary work on the water requirement of rubber, up to a period of two years from budding, as determined from lysimetric studies in the glasshouse and field. The information gathered was also used to test the usefulness of irrigating nurseries and field planted rubber during dry spells.

EXPERIMENTAL

Lysimetric Investigations in the Glasshouse

The growth of budded stumps of clone RRIM 600, from one-and-a-half months after cut back to thirteen months, was assessed under varying soil moisture conditions and fertility levels. The differential soil moisture regimes were maintained at 0.1-, 0.3- and 1-bar tensions. Three types of fertilisers, *viz.* a straight mixture, a natural rubber encapsulated fertiliser[8] and a commercially prepared slow-release fertiliser, (Osmocote; 18:19:13), at half optimum and optimum[9] applications, constituted the differential fertiliser levels.

The study was conducted in weighing lysimeters in the glasshouse. These were concrete containers of 30 cm internal diameter and 76 cm depth. Rengam series soil (Typic paleudult) was used as planting medium in all the containers. The moisture characteristics of this soil are given in *Table 1*[10].

The soil up to a depth of 30 cm was collected from a mature stand of rubber. It was sieved through 6 mm sieve and air-dried for fifteen days. A known quantity

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TABLE 1. SOIL MOISTURE CONTENT AS A PERCENTAGE OF DRY WEIGHT

Depth (cm)	Saturation (%)	Moisture content (%)			
		0.1-bar	0.3-bar	1-bar	15-bar
1 – 15	64.3	31.6	26.6	23.2	20.0
15 – 30	58.4	36.2	27.5	25.3	22.2
30 – 45	56.1	29.7	25.5	21.0	19.5
Mean	59.6	32.5	26.5	23.2	20.6

weight of this soil was used to fill each lysimeter to 2 cm from the brim. Random samples of the soil were also collected to determine the moisture content. The lysimeters were then brought to saturation point and allowed to drain for 48 h, after which, they were weighed at regular intervals till they approximately stabilised at a constant weight. This point was taken as the field capacity and gravimetric soil moisture determinations from each of the lysimeters revealed a mean moisture content of 34% of dry weight, which closely tallied with the laboratory determinations by Soong and Yap[10].

A single polybag budding of RRIM 600 at the first whorl stage and with the leaves hardened was transplanted in each lysimeter. Care was taken to select materials of uniform size and fresh weight. For every six plants removed for planting, one was used for initial dry matter determination. Successive fresh and dry matter determinations were done at three-monthly intervals, from the plants that were left over, to make adjustments for the weight of plants in the lysimeters.

The drying cycles in lysimeters at 0.3-bar and 1-bar were commenced only when the plants were established and the second whorl had just emerged. Lysimeters at 0.3-bar and 1-bar were allowed to dry until the moisture content reached 7% and 23% of dry weight, respectively. Weekly weights of all lysimeters were recorded. The difference in weight between weeks was used to compute the water requirement for the ensuing week. Fertiliser treatments were introduced at the same time as differential moisture regimes.

The total amount of water used by the plants (*TW*) in each of the lysimeters over the period was calculated by the following equation:

$$TW = IW + WA - FW$$

where IW = Initial weight of lysimeters
WA = Water added
FW = Final weight of lysimeters on termination of the experiment.

Field Investigations

The concrete containers used as lysimeters were buried in the ground. The internal diameter and depth of these containers were 91 cm and 153 cm respectively. Nine units were embeded randomly in the field, maintaining the same spacing as field-planted RRIM 600 trees. The soils in this field were Rengam series soil (Typic paleudult). As the containers had to be sunk into the soil, the soil was dug out and laid in lots of 30 cm depth and filled back in the same order. While filling the soil and connecting the lysimeters to the collection pits, the normal techniques used in setting up lysimeters were followed[11,12]. The soil in all the lysimeters was allowed to settle for nine months. One-whorl buddings of RRIM 600 were transplanted in each of the lysimeters, at the same time as the commencement of field planting. They were allowed to grow for twenty-one months. Fertiliser treatments, which were the same as in the glasshouse experiment, were introduced when the second whorl of leaves were fully developed.

A simplified hydrologic equation was used to determine moisture use by the rubber plants in the lysimeters.

$$E = P - Q + Sm$$

where E = Evaporation (evaporation + transpiration)
P = Precipitation
Q = Run-off
Sm = Change in soil moisture storage in the soil column.

As run-off was prevented in this experiment, Sm, at any period, was obtained from:

$$Sm = P - Pr$$

where Pr = Percolate or leachate

However, the above equation was rewritten to work out the total amount of water used (TW) by the rubber plants in the following manner:

$$TW = Im + Sm\ (P - Pr) - Fm$$

where Im = Initial moisture content of the soil column which was at field capacity
Sm = Change in soil moisture storage in the soil column
Fm = Final moisture content of the soil column.

General Records and Observations

Monthly height measurements were recorded for both experiments. Total dry matter was obtained by destructive sampling on termination of the experiments. Composite sub-samples of roots, shoots and leaves were taken for chemical analysis to determine the percentage content of nitrogen, phosphorus, potassium and magnesium in the dry matter produced from the glasshouse experiment.

RESULTS AND DISCUSSION

Watering Regimes and Soil Moisture Use by Young Rubber

There were significant differences between watering regimes on the total amount of water used by one-year-old rubber plants in the glasshouse experiment *(Table 2)*. This trend was also reflected in the mean daily evapotranspiration rates. Depending on the availability of water, daily evapotranspiration varied from 6.9 mm per day at 0.1-bar, 3.5 mm per day at 0.3-bar and 2.1 mm per day at 1-bar *(Table 3)*

In the field lysimeters, mean daily evapotranspiration averaged over twenty-one months, worked out to be 4.4 mm per day *(Table 3)*. These mean values of actual evapotranspiration seem to fall within the range of mean daily potential evaporation values worked out by Niewolt[4], for the different water balance types, within Peninsular Malaysia.

It has been recorded elsewhere that calculated potential evaporation, obtained from Penman's combination equation[13], is almost equal to the values obtained from evaporation pans (USA type)[14]. Since actual evapotranspiration obtained for young rubber seems to be comparable to Niewolt's[4] calculated potential evaporation, it may be worthwhile to use evaporation pan readings to work out

TABLE 2. TOTAL WATER USED BY ONE-YEAR-OLD RUBBER PLANTS AND MEAN DAILY EVAPOTRANSPIRATION IN THE GLASSHOUSE

Moisture regime	Water used (litres)	Evapotranspiration (mm/day)
1-bar	53	2.1
0.3-bar	87	3.5
0.1-bar	172	6.9
	S.E. ± 0.14	S.E. ± 0.00055
	L.S.D. = 0.40	L.S.D. = 0.002
	Significant at 5% probability level	

TABLE 3. TOTAL WATER USED BY TWENTY-ONE-MONTH-OLD RUBBER AND MEAN DAILY EVAPOTRANSPIRATION IN THE FIELD

Mean of number of lysimeters	Water used (litres)	Evapotranspiration (mm/day)
4 (natural rubber coated)	1 881	4.4
4 (Osmocote)	1 891	4.5
1 (straight mixture)	1 809	4.3

irrigation requirement of young rubber under close planting system, in the nurseries. The validity of this hypothesis was tested on an *ad hoc* basis in the field.

Watering Regimes and Dry Matter Production

Dry matter production was also significantly affected by increasing the moisture content of the soil from 1-bar to 0.1-bar, in the glasshouse experiment (*Table 4*). More available water led to higher usage of water, which, in turn, produced more dry matter. This tendency was reflected by the highly significant and positive correlation obtained between total water used and shoot, root and total dry matter produced (*Table 5*).

TABLE 4. TOTAL DRY MATTER WITH DIFFERENT FERTILISERS AND MOISTURE REGIMES

Moisture regime	Total dry matter (g/plant)			
	Natural rubber encapsulated	Osmocote	Straight mixture	Mean
1-bar	132.99	148.24	129.78	136.99
0.3-bar	183.05	216.35	185.58	194.99
0.1-bar	202.03	308.11	275.61	295.25
Mean	206.01	224.24	196.99	S.E. ± 8.51
	S.E. ± 8.51			L.S.D. = ± 24.39
	L.S.D. = 24.39			
	Significant at 5% probability level			

TABLE 5. REGRESSION EQUATION OF DRY MATTER PRODUCTION ON TOTAL WATER USED

Plant component	y = a + bx	r
Shoot	y = 67.6603 + 0.6796x	0.6537***
Root	y = 6.8273 + 0.6181x	0.8883***
Total	y = 74.4876 + 1.2978x	0.8522***
	Significant at 0.1% probability level	

Watering Regimes and Efficiency of Water Use

Although increasing the rate of water application may lead to increased dry matter production, it does not necessarily mean that it improves the efficiency of water use. This is evident in the glasshouse experiment where, significantly more units of water were used to produce one unit of dry matter as the watering rates were increased from 1-bar to 0.1-bar *(Table 6)*. Viets[15] considered maximising the efficiency of water use not always practical because it would entail the production of maximum possible dry matter, sometimes at the expense of using excessive water. Therefore, a more acceptable method would be to encourage more dry matter production by irrigation when needed, such that the efficiency of water use is kept within reasonable limits, which for most crops under normal conditions is betweeen 200 units and 500 units[16].

The fact that fewer units of water were used to produce one unit of dry matter with watering regimes at 1-bar and 0.3-bar than at 0.1-bar, could be usefully exploited under field conditions, especially during dry spells when water supply is limited. During such periods it would be preferable to sustain modest growth of rubber by partially eliminating soil moisture deficits, rather than try to obtain near maximum growth by irrigating to field capacity. However, the problem as to how much or how little water is to be applied and at what intensity of dryness, irrigation should commence has still to be worked on in a methodical manner.

TABLE 6. EFFICIENCY OF WATER USE IN THE GLASSHOUSE EXPERIMENT WITH DIFFERENT FERTILISERS AND MOISTURE REGIMES

Moisture regime	Water used (cc/g dry matter)			
	Natural rubber encapsulated	*Osmocote*	Straight mixture	Mean
1-bar	422	357	430	403
0.3-bar	495	413	471	460
0.1-bar	594	570	510	598
Mean	504 S.E. ± 19.77 L.S.D. = 56.93 Significant at 5% probability level	447	510	S.E. ± 19.77 L.S.D. = 56.93

In an *ad hoc* nursery experiment with five- to six-month-old RRIM 703 and PB 235, about 25% of the estimated soil moisture deficits (precipitation less evaporation) were replenished for over six months (effluent from block rubber factory was used as an alternate source of water). For RRIM 703, there was an increase in dry matter production by about 17% over control, and for PB 235 the difference was negligible *(Table 7)*.

In another field investigation with stumped buddings it was observed that 50% irrigation around the base of the plants (60 cm radius) during dry spells, brought about a 4 cm girth advantage over control in twelve months for RRIM 703 and nil response to irrigation in GT 1 and RRIM 612 *(Table 8)*. These results indicate a probable differential clonal response to irrigation.

Effect of Fertilisation on Efficiency of Water Use

The type of fertiliser used greatly influenced the efficiency of water use by rubber plants in the glasshouse as well as in field lysimeters *(Tables 6* and *9)*. It was very evident from the glasshouse experiment that, Osmocote when compared to natural rubber encapsulated fertiliser

TABLE 7. TOTAL DRY MATTER PER PLANT IN CLONES RRIM 703 AND PB 235

Treatment	Total dry matter (g)	
	RRIM 703	PB 235
Non-irrigated	872.55	726.98
Irrigated	1 020.67	743.94

TABLE 8. MEAN GIRTH INCREMENT PER TREE DUE TO IRRIGATION

Clone	Treatment	Pre-treatment girth (cm)	Girth after 12 months (cm)	Increase in girth due to irrigation (cm)
GT 1	Non-irrigated	15.3	25.8	0.6
	Irrigated	16.8	26.7	
RRIM 612	Non-irrigated	14.4	23.6	Nil
	Irrigated	15.2	24.4	
RRIM 703	Non-irrigated	13.3	20.6	3.6
	Irrigated	16.1	27.0	

TABLE 9. EFFICIENCY OF WATER USE IN THE FIELD EXPERIMENT

Fertiliser	Efficiency of water use (cc of water/g dry matter)		
	Half optimum fertiliser level	Optimum fertiliser level	Mean
Natural rubber encapsulated	680	565	623
Osmocote	542	479	510
Straight mixture		538	

and straight mixture used significantly fewer units of water to produce one unit of dry matter. This trend was also readily seen in the field lysimeters. It is likely that there could be savings in irrigation inputs, if slow-release fertilisers were used, especially in rubber nurseries. Conversely, it is possible that slow-release fertilisers, such as, Osmocote, could be used effectively during dry spells when soil moisture status was usually below optimum levels. Osmocote fertilisers are resin-coated granules which do not allow quick entry of water into its inner core. Therefore, it is not dependent on large volumes of water in the soil at one time for its efficient release of nutrients. Instead, it has the capacity to absorb any available water surrounding it and regulate the flow of nutrients into the soil for longer periods. Hence, its ability to produce more dry matter than the other two fertilisers in the glasshouse experiment, even when soil moisture status was maintained at 1-bar and 0.3-bar *(Table 4)*. Although the natural rubber encapsulated fertiliser was meant to be a slow-release fertiliser, it did not function like one. This flaw could be associated with the thickness of its coating. The initial formulation of this fertiliser had only a single coating. Subsequently, Soong *et al.*[17] observed that fertiliser Mag X coated thrice was more efficient than the single coated form which was used in both the glasshouse and field lysimeters.

Increasing the dosage of fertilisers especially under stress conditions, is known to decrease the quantity of water required to produce dry matter[18]. In 1974 and 1975, when the lysimeters were in the field, severe soil moisture deficits were experienced and perhaps this explains why Osmocote and natural rubber encapsulated fertiliser at the optimum rates were superior to half the optimum rates in terms of efficiency of water use *(Table 9)*.

Watering Regimes and Extension Growth

Maintaining soil moisture status of the glasshouse lysimeters at 0.1-bar had an overall advantage in height of plant over the other two treatments. Yet, even in these lysimeters there were periods when little or no height increment occurred; *viz.*, in November 1974, March 1975 and August 1975 *(Figure 1)*. A similar ten-

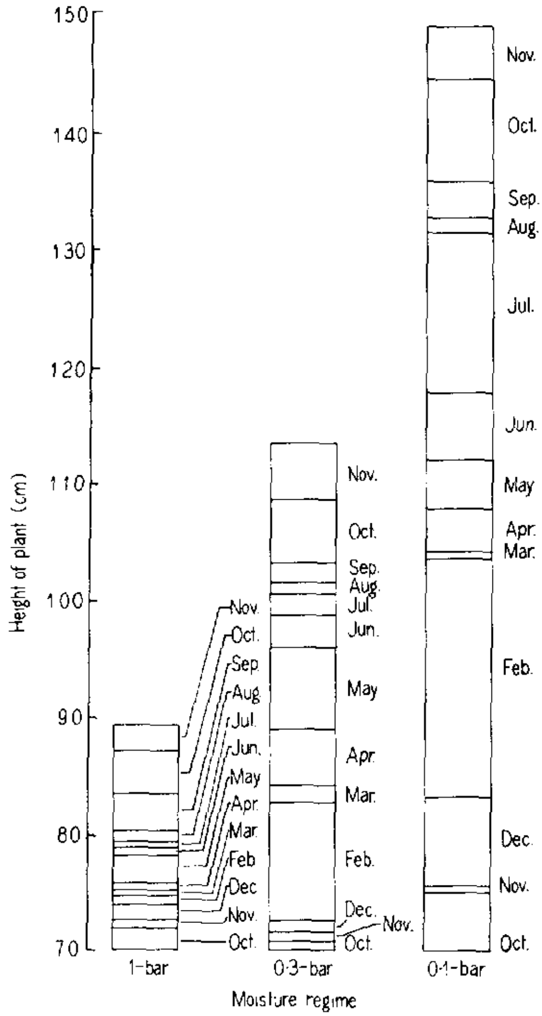

Figure 1. Height increment of rubber plants.

dency was also observed in lysimeters maintained at 0.3-bar and 1-bar moisture levels, during the same months. Perhaps it is possible that during its early growth stages, *Hevea* plant follows a rhythmic growth pattern whereby rapid shoot elongation periods are separated by rest periods or stagnant periods. Halle and Martin[19] measured shoot and root elongation of *Hevea* seedlings for 110 days. During this period, they encountered four successive flushes of shoot elongation separated by rest periods. It was also evident during this period that the main root grew at a constant rate, whereas, shoot elongation ranged between zero during inter-flush periods and values two to three times larger than root growth rate during flushing. It follows, therefore, that if shoot growth rates were to exceed root growth rates for long periods, it becomes necessary for a temporary arrest of shoot growth to maintain a balanced growth. If it were so, then, even under conditions of optimum soil moisture status this phenomenon should occur. The fact that root/shoot ratios were lowest in the wettest glasshouse lysimeters, and significantly lower than lysimeters at 1-bar *(Table 10)*, shows that the advantage in root growth rates due to favourable soil moisture conditions were not reciprocated by an equally high increase in shoot growth rates. Perhaps, the periodic arrest in shoot growth could be held responsible for this phenomenon. In cocoa, a disturbed interval water balance was suggested as the possible reason for this arrest in shoot growth[20]. During rapid elongation of shoots as well as leaves, the transpiring leaf surface is likely to increase much faster than the capacity of the roots to absorb water or, may be, the transport capacity of xylem vessels in elongating shoots. Thus, a water deficit is possibly felt in the shoot, particularly in the sub-apical meristem and in the expanding immature leaves bringing about an arrest in shoot growth.

Under the circumstances moisture status of the soil is not the only limiting factor to growth but enough of it during the shoot elongation process seems important. Therefore, it can be inferred from the glasshouse experiment that, the overall advantage in height increment of rubber plants in lysimeters at optimum soil moisture status; *i.e.* at 0.1-bar, was on account of adequate soil moisture being present during the shoot flush stages. However, as little is known about

TABLE 10. ROOT/SHOOT RATIOS WITH DIFFERENT FERTILISERS AND WATERING REGIMES

Watering regime	Root/shoot ratio			
	Natural rubber encapsulated	Osmocote	Straight mixture	Mean
1-bar	2.39	3.24	2.53	2.72
0.3-bar	2.28	2.41	1.94	2.21
0.1-bar	1.86	1.96	1.36	1.73
Mean	2.18	2.54	1.94	–

S.E. ± 0.199
L.S.D. for watering regimes = 0.55
Significant at 5% probability level

the flushing habits of rubber and its relation to the availability of soil water, and, as flushing is rarely uniform in the field, it is difficult to programme irrigation based on flushing. Rather, it would be more useful not to allow severe moisture deficits to develop so that there is sufficient moisture in the soil should flushing and shoot elongation occur.

Watering Regimes and Uptake of Nutrients

Increasing the availability of water enhanced the uptake of nutrients. At both 0.1-bar and 0.3-bar tensions uptake of nitrogen, phosphorus, potassium and magnesium was significantly higher than at 1-bar tension in the glasshouse investigation *(Table 11)*.

Attempts were also made to establish a relationship between uptake of N, P and K nutrients and dry matter production for the different watering regimes. Significant and positive correlations were found between the two variables at 1-bar and 0.3-bar watering regimes. As the watering rate was increased to 0.1-bar, P and K uptake were non-significantly correlated to dry matter production *(Table 12)*.

This kind of regression gives the impression that maintaining soil at the optimum soil moisture regime restricts nutrient uptake. But this is unlikely especially in view of the fact that the highest dry matter production was obtained with optimum soil moisture conditions. However, further field investigations are needed to evaluate nutrient uptake in rubber under differential soil moisture levels.

Fertiliser Types and Uptake of Nutrients

In terms of total uptake of N, P, K and Mg by rubber plants in the glasshouse experiment, Osmocote was by far the most efficient *(Table 13)*. Perhaps, a more regulated release of plant nutrients from the fertiliser capsule, as explained earlier, led to their more efficient uptake by the plants, producing significantly more dry matter *(Table 4)*.

There was severe scorching and subsequent shedding of leaves when natural rubber encapsulated fertiliser and the straight mixture were used, especially at the higher rate of application. It is possible that with these two fertilisers there was sudden surge in the release and uptake of nutrients whenever water was applied to the lysimeters. Residual N in the soil on terminating the experiment further confirms this reasoning *(Table 14)*. When the lysimeters were maintained at optimum soil moisture (0.1-bar), the soil in lysimeters with Osmocote had significantly more residual nitrogen. At 0.3-bar the trend was reversed, residual N with Osmocote remained the same.

TABLE 11. MEAN TOTAL NITROGEN, PHOSPHORUS, POTASSIUM AND MAGNESIUM UPTAKE PER PLANT

Nutrient	Mean total nutrient uptake (g/plant)			S.E. (±)	L.S.D.
	1-bar	0.3-bar	0.1-bar		
N	2.1397	3.6122	5.2722	0.1447	0.41
P	0.0938	0.1522	0.2605	0.41	0.013
K	1.0433	1.7241	2.8802	0.0865	0.25
Mg	0.1607	0.1836	0.2649	0.0149	0.04

Significant at 5% probability level

TABLE 12. REGRESSION BETWEEN NUTRIENT UPTAKE AND DRY MATTER PRODUCTION

Nutrient	Regression equations 1-bar	0.3-bar	0.1-bar
N	y = 43.5272 + 43.6810x r = 0.7425***	y = 66.8543 r = 0.7821***	y = 111.0324 + 34.9411x r = 0.7850***
P	y = 61.0530 + 808.7966x r = 0.7036***	y = 49.9976 + 952.5299x r = 0.8387***	y = 220.2616 + 287.8612x r = 0.2048 N.S.
K	y = 50.7379 + 82.6697x r = 0.6876**	y = 48.4801 + 84.9793x r = 0.8702	y = 200.4755 + 32.9057x r = 0.4592 N.S.

Significant at 0.1% probability level

TABLE 13. MEAN TOTAL UPTAKE OF NITROGEN, PHOSPHORUS, POTASSIUM AND MAGNESIUM

Nutrient	Mean total uptake of nutrients (g)			S.E.(±)	L.S.D.
	Natural rubber encapsulated	Osmocote	Straight mixture		
N	3.6413	4.0063	3.3764	0.1447	0.41
P	0.1730	0.1699	0.1637	N.S.	–
K	1.6956	2.1874	1.7656	0.0865	0.25
Mg	0.1432	0.2022	0.2637	0.0149	0.04

Significant at 5% probability level

TABLE 14. RESIDUAL NITROGEN IN THE SOIL

Moisture regime	Residual N (%)		
	Natural rubber encapsulated	Osmocote	Straight mixture
0.3-bar	0.1737	0.1640	0.1703
0.1-bar	0.1547	0.1640	0.1573
	S.E. ± 0.00235 L.S.D. = 0.007 Significant at 5% probability level		

CONCLUSION

Soil moisture use by young rubber, both in the glasshouse and field lysimeters depended on the availability of water. Actual mean daily evapotranspiration followed closely the mean daily potential evaporation. It has been shown elsewhere that calculated evaporation values agree well with readings from evaporation pans. Therefore, it is suggested that for calculating soil moisture deficits and irrigation requirement of closely planted rubber plants in the nurseries, evaporation pan readings be used.

Efficiency of water use for young *Hevea* plants was better at 1-bar and 0.3-bar than at 0.1-bar moisture regimes. This shows that young rubber plants are capable of accumulating dry matter at moisture levels in the soil below the upper limits of available water. There were also indications that enough soil moisture during shoot flush and the elongation phase was very important. Thus, it might be possible to thwart the effects of drought spells on the growth of young *Hevea* plants by applying restricted quantities of water during critical times.

The use of slow-release fertilisers in nurseries may be suggested. It seems to promote uptake of plant nutrients and growth of *Hevea*, even under suboptimal soil moisture conditions.

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