NOTES ON THE WATER HOUSEHOLD OF THE KAPOKTREE *CEIBA PENTANDRA* (L.) GAERTN. [1]

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SUMMARY

In connection with the results of investigations on the ecology of *Ceiba pentandra* (L.) Gaertn. (kapoktree) in South Eastern Asia, the author studied the water household of this tree. For a period of 18 months the trend of the saturation of the trunk and the branches was investigated and the transpiration of leaves and fruits was determined.

At all appearances the limiting factor for fruitsetting is the length of the period during which the tree stands in full leaves at the beginning of the dry monsoon. In that period there is a severe competition for the available water between the transpiring leaves and the numerous growing young fruitlets.

The total water consumption of a kapok plantation and its transpiration ratio could be roughly estimated; these values were compared with data on other plants, annual and perennial.

It seems that the kapoktree is using the available water quite economically; this is in accordance with the fact that cacao can be planted with great succes as a covercrop.

INTRODUCTION

From 1930–1939 the author studied the periodicity of the kapoktree and the influence of the distribution of rainfall on the fruiting of this crop (TOXOPEUS, 1935, 1936, 1939, 1950). Conditions appeared to be favourable for the cultivation of kapok in regions with a single pronounced dry season per year. The total annual amount of rain should be at least 1500 mm and during the four driest months there should occur at least 10 and at the utmost 25 rainy days and the total amount of rain in that period should not be less 150 mm and not exceed 300–350 mm.

This statement was arrived at after detailed studies of the rainfall in special kapok regions and after a study of the correlation between rainfall and production during a long series of years. Studies on the growth conditions of kapok in the southern part of Celebes, along the Mekong river in Cochin China and Cambodja and in Thailand fully confirmed the conclusions arrived at in Java.

As the available quantity of water is a limiting factor in many cases, a study has been made of the water household of the tree. Observations were made during a period of 18 months in 1936 and 1937.

The water contents of the trunk, the main branches, the newly formed twigs, the flowers and fruits was determined at regular intervals and the transpiration of leaves and fruits was studied.

The data gained have been worked out during the Japanese occupation. In many cases they are badly in need of confirmation; in fact, such work should be done for many years in succession before drawing conclusions.

As it was impossible to continue the work and it is very improbable that such studies ever will be repeated, the author has tried to give an interpretation of his results. Though the conclusions arrived at should be taken with much caution, the author's intimate acquaintance with *Ceiba pentandra* may be some guarantee that they are not too far from the truth.

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The kapoktree and its periodicity

The kapoktree consists of a main trunk which bears at regular intervals horizontal stories of, as a rule, three branches. Normally the lower whorls of branches are shed in an early stage of development and the first permanent story is formed at ca 4 m from the ground or still higher. However, there is a group of varieties, that do not shed their lower laterals; these are the so-called "lanang" types.

In the rainy season the kapoktree bears a profusion of leaves the abscission of which takes place in the beginning of the dry season; in Java [3]) as a rule during June. In the same period the flowerbuds develop in the leaf axils. Flowering starts towards the end of June or the beginning of July. Subsequently in July and August the fruits develop and attain their full size in the course of one month. They mature towards the end of September and during October. Harvesting takes place mainly in the months of October and November.

From the middle of July until after harvest, i.e. during the dry season, the trees are completely bare. Development of new leaves takes place during November and December, depending on the beginning of the rainy season. At first a rosette of leaves is formed at the end of the bare branches and only 1–2 months later new branches develop. Exclusively on this new wood flower buds develop next season.

The time of leaf shedding is mainly determined by the formation of new leaves some 6–7 months earlier. Thus, the leaves possess a fixed span of life and as the length of the rainy season is not at all constant, it may happen, that the tree still bears a full canopy of leaves during a varying number of weeks in the beginning of the dry season. It will appear from the discussion that the latter period may be of prime importance for the fruitsetting.

The periodicity in the kapok regions in Java has been recorded schematically in the following table.

Initiation of flower buds	Leaf shedding, development of flowers	Flowering, fruitsetting	Development of fruits	Harvest	New leaves	Formation of new branches	Assimilation, formation of reserves
May/June	June/July	July	August/ Sept.	Oct./Nov.	Dec.	Jan./ Febr.	March/ April

For our study we chose a ten year old tree of the "lanang" type on the estate Nieuw Gebangan (Weleri, Central Java, near the north coast). The production of this tree was about 4000 fruits in the last four years.

The tree was growing at 350 m above sea level and a rain gauge at a distance of 50 m indicated a yearly precipitation varying from 1800–3842 mm during the period 1924–1938.

The trunk of this tree and its main branches have been sketched schematically in fig. 1. The volume of the trunk was calculated at about 1.5 m^3

[3]) For convenience's sake the circumstances obtained in Java are given as an example when citing the date of periodicity.

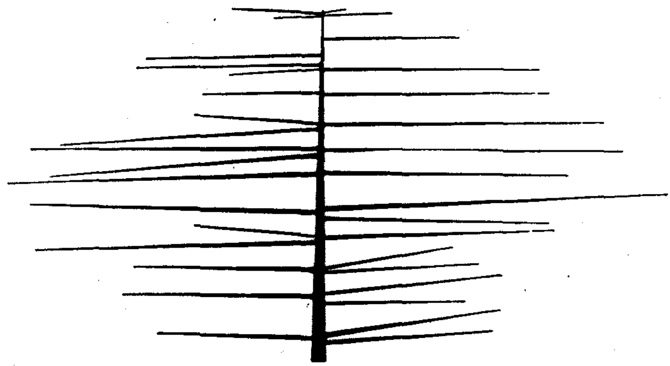

FIG. 1. EXPERIMENTAL TREE, ALL PRIMARY BRANCHES DESIGNED IN ONE PLANE.
1 cm = 3.50 m.

and that of the primary branches at 2.8 m^3. The total length of the leaf-bearing wood was estimated at 180 m.

WATER CONTENT OF VARIOUS PARTS OF THE TREE

For a determination of the water content of the trunk and the primary branches small cylindrical samples of 10 cm long were taken out by means of a corkborer each time at two diametrically opposed spots. These samples were cut into a central and a peripherical half.

For a study of the leaf-bearing wood at each date of sampling ten twigs were taken at random from a small stand of lanang trees of the same age and the same size as the one used for the study of the trunk. Twigs, leaves, flowers and fruits were weighed separately.

The general trend of the saturation of the trunk (fig. 2) shows a steady rise from the end of the wet monsoon to the middle of the dry period. During August and September the water content remains fairly constant followed by sharp decrease during October at the end of the dry monsoon.

The volume of the trunk is about 1.5 m^3, consequently the quantity of water present at the period of its highest saturation can be estimated at 70% or 1050 l. At its lowest contents it is about 60% or 900 l.

The saturation of the main branches is capricious to such an extent that no general trend can be observed. Their volume is about 2.8 m^3 so that the total quantity of water of both trunk and main branches might be estimated at 3000 l maximally and 2600 l minimally. The quantity of water that can be released therefore may amount to about 400 l at the end of 1937 and this quantity is of no significance at all when compared with the transpiration of the foliage.

Fig. 2 shows the water content of the branches developed during the wet season 1935/36; in addition the saturation of the branches developed in the next season is given from the moment they were full grown, when flowerbuds were visible in the leaf-axils. Each point is calculated from the total wet and dry weight of a sample of ten branches and may be considered as representative for all branches of that kind at that moment.

In the course of the year the values vary considerably, periodically rising to sharp peaks. Apparently these peaks are related with certain physiological

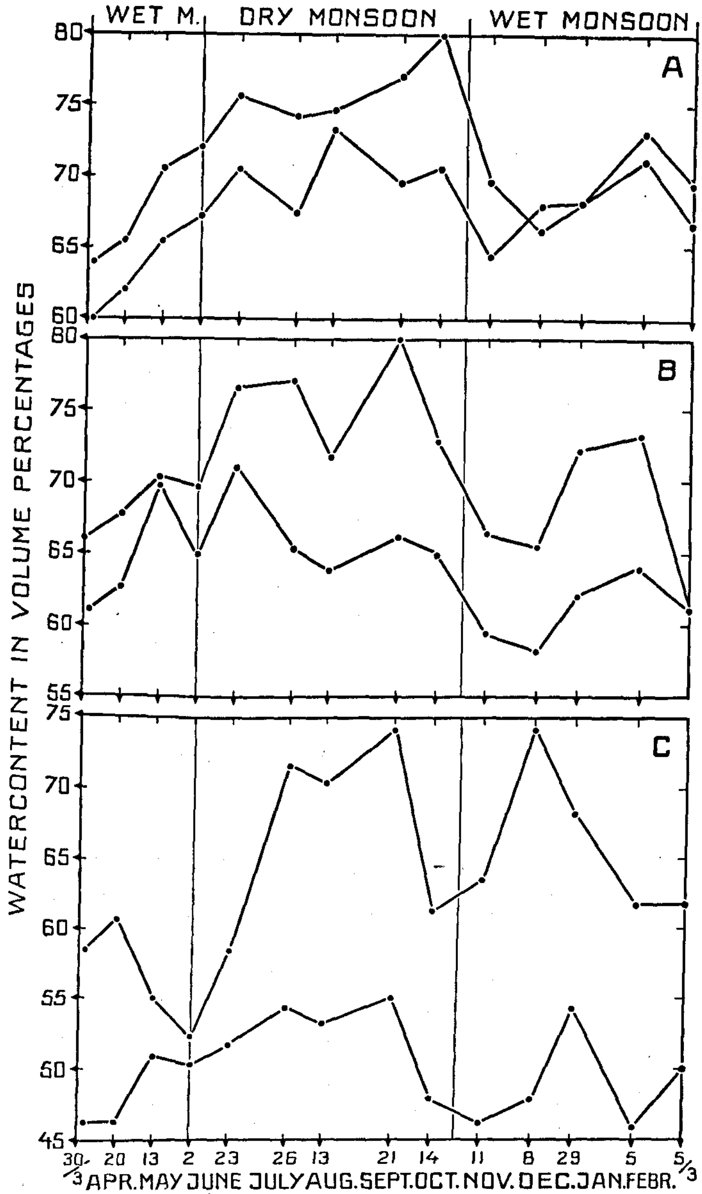

FIG. 2. TREND OF THE WATER CONTENT OF THE STEM: A at 1 m above the ground, B at height of 4 m and C at 7 m. The upper line represents the peripherical layer of 5 cm, the lower one the central layer. Each point is the mean of two opposite borings, in most cases the two values were only slightly different.

phenomena like leaf-shedding, flowering, leaf-formation and ripening of the fruits.

On an average the diameter of the full grown branches of the season 1935/36 is 1 cm; the volume of all of them (180 m) is calculated at the astonishing small volume of 13.5 dm^3. This makes it comprehensible that features like development of leaves, flowers or fruits may exert a strong influence of a temporary nature.

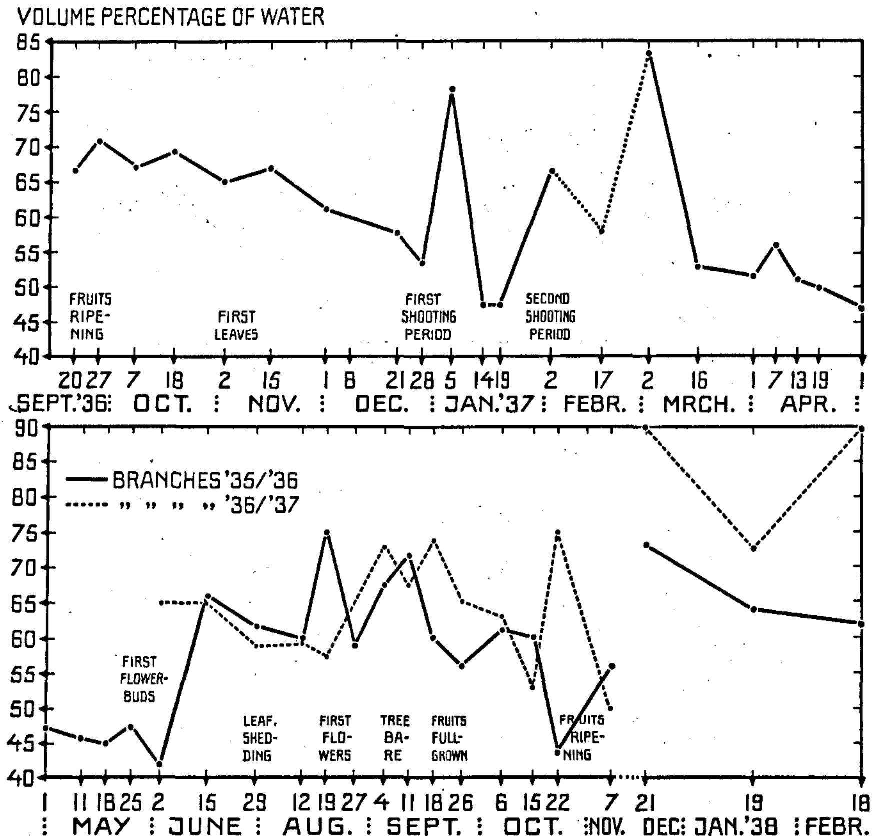

FIG. 3. TREND OF THE WATERCONTENT OF THE FRUITBEARING BRANCHES.

Although those parts of the branches that have developed during foregoing seasons yearly increase in diameter, they do not attain by far the diameter of the primary branches and they cannot have any significance as a store of water.

The development of some 30 000 leaves and 40 000 flowers takes 50 and 40 l of water respectively.

About 4–6 days after flowering 60% of the young fruitlets drop as a consequence of insufficient fertilization. Thus about 16 000 young fruits start growing; however, a fortnight after opening of the flowers there is a second period of fruitdropping. At that time the young fruits contain 4 g of water, their total content being 64 l.

Fruits that remain at the tree after the second drop all grow out into mature fruits. They attain their full size about 30 days after flowering, the quantity of water per fruit on an average rising from 45 to 90 g in the course of a fortnight. During the next period of 40 days the water content practically remains constant. Finally during the period of ripening the fruit wall loses 80 g of water within about 12 days.

THE TRANSPIRATION OF THE TREE

The method adopted for the determination of the transpiration of the *leaves* depends on the fact that the evaporation from cut leaves remains constant at the value just before cutting for a period of 3–6 minutes (PFLEIDERER, 1933, COSTER, 1937).

A leaf or a leafy shoot is weighed as quickly as possible after cutting, then brought back to its original site, after 2 or 3 minutes weighed again etc. Observations were made at different times of the day on leaves exposed to the sun and others hanging in the shade. Stomata being present only at the underside of the leaves, when calculating the rate of transpiration their area is only once taken into account.

The results of these experiments justify the following conclusions:

1. about 1–2 hours after sunrise the transpiration amounts to about 2500 mg per dm² per hour. Differences between leaves in the sun and in the shade do not occur as yet;
2. from 2 hours after sunrise onwards the transpiration of leaves exposed to full sunlight rises, with a clear sky at 12.00 attaining a level of 4000 mg/dm² per hour. Leaves in the shade do not evaporate appreciably more than in the morning;
3. slight cloudiness already causes the transpiration to decrease to the level of leaves in the shade;
4. after midday transpiration decreases, also when the sky is clear; apparently the stomata start closing at that time;
5. transpiration during the night could not be measured. It may be estimated at a value found for leaves about ten minutes after they have been cut off, when the stomata are closed. Because the relative moisture of the atmosphere during the night is much higher than that in daytime, the evaporation should actually be estimated as being even lower. On this basis it can be assessed at about 300–400 mg/dm² per hour.

From the available information the total leaf area of the experimental tree is estimated at about 250 m². If the sky remains cloudy during the whole day the transpiration can be estimated at $12 \times 2500 \times 25000 = 75 \times 10^7$ mg = 750 l, totalling about 870 l together with some nightly evaporation.

During a sunny day it is more difficult to assess the transpiration, because the percentage of leaf area exposed to the sun is not known. The assumption cannot be far wrong that from 9.00 till 16.00 half of the leaf area is shaded. On an average the transpiration during those 7 hours would be about 3500 mg/dm²/hour; before and after that part of the day ca 2500 mg/dm²/hour. For the whole day transpiration would amount to 920 l; when evaporation during the night is added it might be estimated at about 1040 l.

During a shower and during a period of varying length afterwards there will be no transpiration at all. The average length of this period in the months December, January, February, March and April is about 2 hours a day, consequently the dayly evaporation in the wet monsoon can be roughly estimated at about $5/6 \times 900$ mm = 750 mm.

For the determination of the transpiration of the *fruits* a cluster was cut off and the time measured in which the fruits transpired 100 mg of water. The results of these experiments indicate that green full grown fruits transpire bout 300–400 mg per dm² per hour. The loss of water of such a fruit may be estimated at 12 mg per minute, during at least 7 hours a day (9.00–16.00);

before and after that period it will be appreciably less and when taking this as about half as large, the total loss during daytime is about 6.8 g.

During development the transpiration is less. From flowering until the fruit has reached its full size, about 30 days elapse. Assuming that the loss of water on an average is half of that of the full grown fruit, 100 g of water is transpired during that period. After reaching full size 40 more days elapse until yellowing, in which time $40 \times 6.8 = 270$ g may be supposed to evaporate.

Until yellowing a fruit requires for transpiration $100 + 270 = 370$ g, apart from the evaporation during the night that might be some 50 g.

A full grown fruit starting to yellow was found to transpire 14 mg per minute or 7.1 g a day. If this loss remains of the same order during the 12 days of ripening the loss of weight of 80 g could easily be explained. However, it is most probable that the rate of transpiration falls off quickly during this period. Part of the water lost from the fruit may be transported back to the tree causing the rise of water content of the branches in that period (see fig. 3).

Discussion

The need for water and precipitation

The size of the experimental tree calls for a space of 12×12 m, so calculations of precipitation should comprise an area of 144 m^2.

During the wet monsoon the tree bears its full canopy of leaves and the transpiration is bound to vary according to the percentage of sunshine and to the duration of the rains. It is estimated at about 750 l per day corresponding with 5 mm of rain.

From 1924 till 1938 the average dayly precipitation during the wet monsoon varied from 9 to 20 mm. As the canopy is not dense and the shape of the leaves and their surface is such that the water runs off quickly, interception cannot be but very low. So nearly all of this water reaches the soil and it is apparent that this quantity is sufficient to cover the needs of the tree and its undergrowth.

A more critical period is the dry monsoon. In kapok regions the dry period starts at some time during the course of May or June and the rains come again in October or November. When the rains cease early, as a rule, the dry period is severe and of long duration.

As there is no causal relation between the ceasing of the rains and leaf-shedding it happens that the tree stands in full leaves during a sunny period of varying length in the beginning of the dry monsoon, transpiring at the rate of at least 6 mm of rain per day and draining the soil to a considerable extent.

For this reason it is highly probable that the length of this period is decisive for the fruit setting.

After leaf shedding begins, the transpiration of the canopy rapidly decreases and when the tree is bare it needs water only for the development and the transpiration of flowers and fruits. However, this quantity is relatively small as may appear from the following survey:

water contents of	40 000	flowers	40 l
„ „ „	12 000	fruitlets second drop	48 l
transpiration of	12 000	„ „ „ „	36 l
water contents of	4 000	full-grown fruits	360 l
transpiration of	4 000	fruits	1780 l
		Total	2264 l

or the equivalent to 16 mm of rain.

The transpiration of the trunk and the branches has to be added. Their surface can be set at about 40 m², so when the bark transpires at the same rate as the leaves, the dayly evaporation would amount to the equivalent of 1 mm of rain. However, from the structure of the bark it is apparent that the transpiration cannot be but a small fraction of this value. So the total loss of water from flowers, fruits and bark may not exceed 30 mm of rain in the period of 80 days elapsing from flowering until ripening of the fruits. As stated in the introduction there should fall no less than 150 mm of rain during the four driest months, so during the period of 80 days just mentioned, the minimum rainfall may be estimated at 100 mm.

As there is hardly any interception and only a small runoff from the well terraced plantation, it is highly probable that from a minimum of 100 mm precipitation 30 mm can be taken up by the roots.

In accordance with our supposition that the precipitation during this period does not act as a limiting factor is the fact, that the young fruits, when surviving the second fruitdrop at 14–16 days after opening of the flowers, all attain maturity. The mature fruits mainly originate from flowers fecundated during the first two weeks of flowering. These facts strongly focus the attention on the beginning of the dry monsoon, when the tree may either still bear its full canopy of leaves as one extreme of may be entirely bare from the start of the said period.

When there are many leaves on the tree during the period of second fruit drop there exists a strong competition for the available water between the transpiring leaves and the young developing fruits. It may well be that the rate at which the three can take up the water from the soil lags behind the need, resulting in a drying out of a great part of the young fruits as a consequence of the priority of the transpiration of the leaves. The dropping fruits, indeed are smaller and drier than those of the same age remaining on the tree. In this way one can understand the available water to be decisive for the number of mature fruits.

When the rains cease early, the tree, as a rule, will bear many leaves in the beginning of the dry monsoon and as a consequence production will be low. Generally such a dry monsoon will be very dry and of long duration and this relation between early breaking of the rains and the severity of the dry period explains the fact, that a strong positive correlation has been found between the production and the rainfall during the four driest months of the year as was already stated in the introduction.

This study reveals that this correlation is probably of a secondary nature only and that the rainfall in the first part of the dry monsoon combined with the transpiration of the leaves in that period is essential.

Transpiration ratio

In literature the quantity of water which has to pass through a plant for the production of 1 kg of dry matter is often referred to. Available data in our case only allow for the making of a very rough estimate on this subject.

The transpiration of the tree, bearing its full canopy of leaves from January until May inclusive, can be estimated at 750 l per day.

In December, the total surface of the leaves is very small and in June all leaves drop in the course of a fortnight. Hence the transpiration during both periods will not amount to more than 300 l per day on an average. In July, August and September, the quantity of water lost may be estimated at 3000 l and in the months of harvesting, October and November, transpiration is negligable.

The total annual transpiration derived from these data amounts to 151×750 l $+ 61 \times 300$ l $+ 3000$ l $= 134\,550$ l. The dry matter produced in that period can be estimated at:

4000 fruits of 25 g	100 kg
flowers, fruits of 1st and 2nd fruit drop	20 kg
leaves and leaf-bearing branches	30 kg
girth increment of the tree and its branches	100 kg
Total	250 kg [4])

Hence for the formation of 1 kg of dry matter the kapoktree takes up 538 l of water. Every day in the beginning of the dry monsoon that the tree stands in full leaves takes about 900 l water extra and diminishes the number of fruits; thus raising the ratio about 5 points.

For comparison the ratio's of a series of annual plants and forest trees are given (see Houk, 1951). The figures of the annual plants are weighted values in pounds of water per pound of total dry matter. Most figures of forest trees are from Höhnel, who made his investigations for the Austrian Forest service during 1878–1880 with 5–6 years old seedlings, growing in large pots. Transpiration ratios were computed on the basis of total dry-leaf matter. Thus, compared with the data of the annual crops and of kapok his figures are too high. The ratio of kapok amounts to 897 when not considering the gain in dry weight from the stem.

Annual plants	
Sorghum, Minnesota amber	274
Corn, N.W. Dent (Zea mais)	274
Sudan grass	380
Wheat, Kubanka	491
Potato, Irish Cobbler	499
Cotton, Triumph	568
Oats, Swedish Select.	634
Alfalfa, Grimm	851
Franserium tenuifolium	1131

4) Newgrowth of roots could not be estimated, so this figure is somewhat too low and as a consequence the ratio is too high.

Forest trees	
Fir, *Abies pectinata*	96
Scotch pine, *Pinus sylvestris*	110
Oak, *Quercus pedunculata*	454
Field elm, *Ulmus campestris*	738
Black, alder, *Alnus glutinosa*	840
White birch, *Betula alba*	849
Linden, *Tilia grandifolia*	1038
Larch, *Larix europaea*	1165
Service berry, *Sorbus torminalis*	1748

Coster, who made a very important study of the transpiration of trees and shrubs in Java computes a transpiration ratio varying between 1000 and 1450 for *Tectona grandis* (teak) in the dry climate of central Java ; for the shade tree *Albizzia falcata* he finds 950 in the very wet climate of western Java and for *Crotalaria anagyroides*, a shrubby green manure he finds according to the stand of this crop a ratio varying from 600 to 1150 in the same region.

These data are directly comparable to the value of 538 found for kapok and from them one should judge the kapoktree to be more drought resistant than teak. In fact *Tectona* flourishes in much drier regions than kapok. One should be cautious in using the transpiration ratio as a measure for drought-resistance at least in trees that stand bare for a certain period.

Water consumption

At a planting distance of 12 × 12 m the transpiration of a kapoktree in a plantation can be calculated at about 930 mm per annum. According to data given by Houk (1951) the annual water consumption of a clean cultivated Citrus plantation in the San Fernando Valley, California is 575 mm, rising to 875 mm when a covercrop is used. Grapes transpire about 1000 mm in the same region and date palms 1800 mm, being about 86 % of the mean annual evaporation of a water surface.

Horton computed yearly transpiration from transpiration ratio's. For a stand of 30-year trees of Douglas fir he calculated 130 mm, for white pine 146 mm, red spruce 375 mm and for beech 415 mm. The annual transpiration of forests in temperate regions varies from 125–375 mm, but may be as much as 875 mm for dense stands of large trees on the best sites.

Coster (1937) estimated the water consumption of a stand of *Hevea brasiliensis* at Bogor to be about 1200 mm annually; of a wood of teak (*Tectona grandis*) in the central part of Java at 1100–1200 mm and of a 7-year old closed vegetation of *Albizzia falcata* at Bogor at 2300 mm.

Hevea and *Tectona* seem to use somewhat more water than Kapok. Though both trees flourish at the same site as the experimental kapoktrees, *Tectona* feels more at home in drier regions.

In the kapok areas in South Eastern Asia the peculiar situation is met with, that in regions where the precipitation during the dry monsoon is the limiting factor for fruiting, the rainwater falling during the wet monsoon is not consumed by the tree by far. On an average the trees even do not use half this precipitation in typical kapok regions. This might be responsible for the fact that cacao can be grown so succesfully under the kapoktrees.

Cultural measures to reduce water losses

Apparently the transpiration of the leaves during the first month of the dry monsoon is decisive for the number of maturing fruits. A common procedure in kapok-estates in the cutting down of the undergrowth ("babatan") in the very beginning of the dry period, followed by a light digging over ("patjulan").

The principal point to consider here is the transpiration of "lamtoro" (*Leucaena glauca*), a small leguminous tree, that is much used under kapok as a green manure.

According to Coster (1937) a vigorous, closed vegetation of this plant will evaporate all the available water in the soil up to an annual maximum of 3000–4000 mm. The stand of lamtoro in a kapok plantation is very wide, in fact it is growing more or less in hedges at 3–4 meter apart. Still this crop will transpire a quantity of water that might be of some influence in this critical month, when not cut down.

The harmfull effects observed with an undergrowth of lalang (*Imperata cylindrica*) in unkept gardens, are probably due also to the withdrawal of water. This becomes clearly visible in regions where shifting cultivation is generally practised (Celebes). In these regions the kapok trees are planted in hedges around the fields. If the soil is cultivated for one or two years, the trees will thrive; however, during fallow, when lalang and other grasses take possession of the field, they deteriorate very quickly, leaving only starving trunks after a few years. If the field is subsequently reexploited, the grasses are destroyed and the trees make new branches at a remarkably quick rate, producing a crop within a year.

A profuse lalang vegetation as is often met in unkept kapok plantations transpires at least 1000 mm annually, hence preventing the uptake of water needed by the tree.

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