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MOISTURE BALANCE IN THE SHIMBA HILLS, KENYA

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a Hills are important as the source plies for the town of Mombasa There is now a programme to waters of Mzima Springs to pipeline. However, the com- s programme will not lessen the l water resources. The Coast area Kilindini estuary, where import- expansion is already under way, upon local water supplies. Hence anagement to provide maximum ter from the Shimba Hills will portant to the coastal area.

tion of the importance of the es of the Shimba Hills the proper anagement for the area has been considerable interest and concern. nment report prepared by the Survey, Coast Division, Public tment in 1949 [1], the need for tilization for catchment manage- en stressed, and specific recom- re given as to how this can be . It is pointed out that small he Shimba Hills still remain in but that the majority of the land sland. The comparison is then the relative effectiveness of these vegetation for water resource con- the Shimba Hills catchment.

attention is drawn to the sparse hat is the result of annual fires. with regard to the grasslands: he area is open country, covered ch in some places grows thickly, lly found in clumps about 6 in. nd 9 in. to 36 in. apart. Where ave been most frequent these ost sparse. Between the clumps ce is visible, either as bare soil, ve been recent, covered with fine carbonaceous material". It is further stated that: "The grass clumps have fine, interwoven roots extending some 12 in. to 24 in. below ground level, the average being 18 in. The roots spread out, so that even when the clumps are separated by 12 in. to 18 in., their roots are still interconnected beneath the surface and form a continuous mat below ground level, which helps to bind the surface soil together. As the clumps are thinned out more and more by fires, this mat will presumably thin out also, and its effect become less. Samples of the grass clumps were dug out and observed at several points over the area; the grass appeared to be of the same type throughout, and the above observations apply for the whole area. The main difference was in the spacing of the clumps of grass".

In view of this very limited amount of vegetation present on the grass area it is concluded that transpiration would be less than from an area of more dense vegetation. Also it is assumed that of the water entering the soil mass, a larger proportion would become available for recharge of the ground water aquifer supplying streamflow.

The present note reports some results of an additional survey of catchment conditions made in the Shimba Hills during the months of June and October, 1952. Because some of the results touch upon broad aspects of catchment management of general interest, they are presented here as a basis for further discussion.

In the present survey the writers were able to confirm the sparseness of the grass cover. During the growing season one's first impression is that the open areas are apparently well covered with grass. A closer inspection reveals that the grass clumps actually occupy less than 40 per cent of the ground surface. Between the

e provisions of the American Fulbright Act, the senior author was attached to the E.A. Forestry Research Organization for the year 1952, during which an extensive study was made conditions. A full report and recommendations on "Forest Management in East Africa in climate, water and soil resources" is published in the E.A. Agriculture and Forestry Research nual Report for 1952.

s completely destitute of any rovide protection against the the tropical sun. Surface 20° to 140° F. were observed

ant succession in any locality factor in catchment manage- ge patterns within the Shimba loped under a dense closed of which still exist. This is area of natural grassland. In so-called grassland has only m land once under intensive abandoned and burned over ctically only one grass species an *Andropogon* species that ned areas of depleted fertility orld. It does not form a true ly in isolated separate clumps. atable and nutritious for live- xcept when quite young and furnishes a very inadequate conservation. If left alone plant succession soon passes Under good forestry it could closed tropical forest similar mnants still remaining in the

ble to establish a ley of sod- ecies this would of course be ocedure in some localities. ere exists considerable mis- garding the use of grass for gement. The term grassland loosely in East Africa and l to vegetative types ranging e ground to elephant grass ecies of grasses on poor, dry allow rooted and have only a g period. Others, like Kikuyu erated moist soils develop a ystem and grow for most of lize all the soil moisture avail- Kikuyu grass near Nairobi easured 36 in. of water from of soil in the two dry periods). Except for a few favoured assland is difficult to maintain ries. As a rule, grazed grass- m is commonly used, is a factory vegetative cover for ement. One has only to look of square miles in East Africa orated through unsupervised nvinced of the difficulties of ment management.

In the Shimba Hills it would certainly be impossible to maintain an improved ley sod without well-managed intensive grazing. Before intensive ley management can be considered as an alternative type of catchment management for these hills the nature and fertility of the local soils, local climatic seasons, and probably most important, the local water economy as expressed by the field moisture balance, must all be considered.

The soil mass is described in Government reports as being a deep porous sand through which water passes, "with great rapidity, possibly due to the large grain size". The only evidence given for this statement is that "although many steep slopes in the catchments have become so denuded of grass as to render erosion easy with ordinary soils, there has been practically no soil erosion in the hills".

In the present survey the sandy nature of the surface soil was confirmed but the entire soil profile did not meet this description. A sandy soil was encountered only to a depth of about five feet. Then an exceedingly impervious clay zone was encountered. Clay zones of this kind are not uncommonly found under relatively porous surface soil horizons. They are known to retard percolation of free ground water and hold it sufficiently close to the surface so that when other conditions are favourable to rapid evaporation from exposed soil the water comes back into the atmosphere instead of contributing to the ground water recharge of underlying aquifers.

Data collected in adjacent forest and grassland conditions, both typical of the catchment area, are set out in Figure 1. Soil cores 4 in. in diameter and 3 in. deep were collected by a sleeved sampling tool from the faces of a freshly dug deep pit in the grassland, and from shallow pits in the forest. After vacuum-wetting in the laboratory they were tested for percolation rates under a static head of 1 cm. of water. The rates of steady flow are good measures of the relative permeability of successive soil horizons, but they are not, of course, a measure of the actual rate of free flow of water through the whole soil profile. They show clearly, in Figure 1, the impervious nature of the clay zone.

Further evidence of the compact nature of the clay at the 5-ft. depth was obtained by using the core-sampler as a penetrometer. The sleeved cylinder was driven into the soil by an 8-pound sliding hammer, mounted on the was allowed to fall through a ance and the number of blows for netration of the cutting edge was ie very high resistance at 5 ft. is Table 1.

ɔMPACTNESS OF SOIL IN GRASSLAND

	o. of Penetrometer Blows per 3-in. Core
.	33
ı.	28
t.	20
't.	28
't.	25
't.	31
t.	92

range of the grass was observed ned to the soil above the clay ereas auger samples within the d the clay zone to be full of live ɔots of this type of tropical forest en in Kenya railway cuttings and res to penetrate to depths of over tall forest the clay layer is thus erforated by roots. The contrast conditions under forest and under blished sparse grassland can also n the behaviour of young trees. ations some four miles from the e showed that individual trees ılished with great difficulty because exposure and unfavourable soil ı the grassland, whereas saplings g freely on the edges of the forest ing on the pioneer growth of the ipheral scrub, whose roots penetrate the clay layer. Under similar soil conditions in the United States of America this effect is utilized in forestry practice by peripheral planting.

Periods of Ground Water Recharge

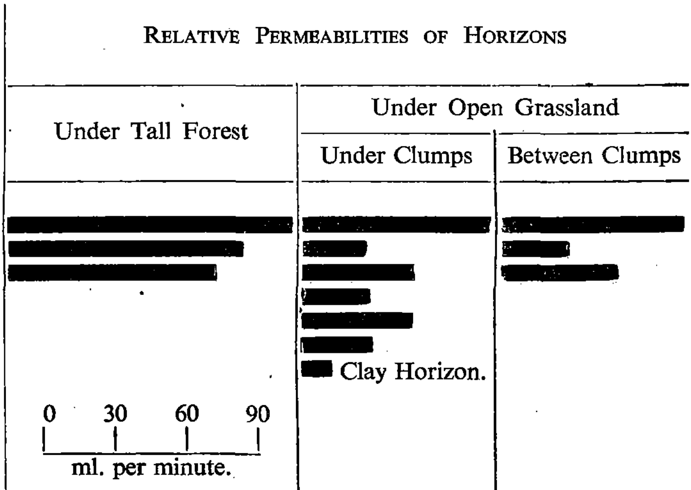
It is a well-known hydrologic fact that ground water recharge takes place principally when there is no field moisture saturation deficit, that is when all the capillary moisture requirements have been satisfied. These periods of the year are not frequent even in regions of considerable rainfall. When these periods do occur, for example after an accumulation of 4 to 6 in. of rain falling within a period of a few days, the amount of ground water recharge depends solely on soil conditions favouring rapid downward percolation. Consequently a major objective of catchment management is to create and maintain local soil conditions that favour rapid infiltration and percolation of free water through the entire soil profile. In the Shimba Hills the natural forest creates more favourable conditions for percolation of free water through the entire soil mass than does the present *Andropogon* grass cover.

Evaporation from Soil

Several distinctive soil conditions contribute towards increasing the amount of moisture evaporation from the grass area within the Shimba Hills. The bare areas of exposed sandy soil between the grass clumps absorb the sun's rays and conduct the heat deep into the soil profile. In mid-November of 1952 temperatures of over 80° F. were recorded at a depth of

FIGURE 1

L TEXTURE ven Dry Soil)		
Clay	Silt	Sand
10	21	69
18	13	69
20	13	67
26	11	63
28	15	57
44	19	41
46	22	34



resentative grass cover. These soil temperatures did not hroughout the day and night. Table 2.

from the data given in Table 2 e temperature gradient under sult in the vaporization of porous sandy horizon of the nt towards the cooler surface either loss as evaporation, or, e circumstances, to condensa- rface where it would become ation the following day.

est trees the soil is insulated both by the foliage and by r mulch. The result is that duced to a minimum, and soil by evaporation are not a sig- n the field moisture balance. ent grass cover outside the on from the soil is of para- ce and accounts for much of e losses that take place. Free nd held above the clay horizon periods is subject to vaporiza- andy soil that becomes heated the tropical sun. Soil moisture hrough evaporation, long after ovements have ceased.

area of 2 square feet, and , were filled with sections of om grass clumps, bare soil and forest litter respectively. riplicate, were exposed *in situ*, unk to bring the samples into soil surface. The pans were minutes before sunset, and rise (a procedure complicated by the presence of elephant and buffalo in the forest edge). A newly calibrated thermohygrograph was operated among the grass clumps and recorded 100 per cent R.H. and 70° F. for 12 hours on the three successive nights of this test (24th, 25th and 26th November, 1952). The grass was covered by beads of moisture but the gains in weight were very small, amounting to less than 1 millimetre of surface water in all samples. Heavy condensation of water occurred on the underside of the pans in the open grassland and under dishes inverted over bare soil. This was two or three times the weight of the dew, but no satisfactory quantitative methods of measurement could be improvised from the apparatus available on the spot. No such condensation occurred in the forest samples.

The capacity of the soil for water above the clay layer has been calculated from tension-table measurements made on the profile sets of soil cores. At 20 cm. of water tension, which reproduces the approximate conditions at the end of a wet spell in which rain sufficient to fill the soil has fallen, the grassland holds 20.7 in. and the forest 20.4 in., in the first 5 ft. of soil. At the time of sampling, the forest soil held 12.8 in. and the grassland 13.1 in., within this depth. Evaporation and transpiration from the sparse grassland and the heavy forest had thus caused equal losses from above the clay layer.

Effect of Dew and Mist

Because the sea breeze coming from the nearby Indian Ocean is practically saturated with moisture, dew occurs throughout the year in the Shimba Hills. However, the amount of dew varies for different seasons. The cooler

ABLE 2—AIR AND SOIL TEMPERATURE UNDER LIGHT GRASS COVER

Shimba Hills—Beginning noon 26-11-52, *ending* 9 *a.m.* 27-11-52

(Temperatures in Degrees Fahrenheit)

	12 noon	3 p.m.	7 p.m.	12 Mdt.	6 a.m.	9 a.m.
at 3 feet	87·0	80·0	73·0	69·5	70·0	83·5
at Ground Surface ..	99·0	82·5	74·0	69·5	71·5	85·0
at 1 in.	106·0	94·0	80·0	73·0	72·5	87·0
„ 6 in.	83·0	88·0	89·0	83·0	80·0	82·0
„ 12 in.	82·0	83·5	85·5	84·0	82·0	82·0
„ 18 in.	81·0	82·0	84·0	82·0	81·0	81·0
„ 24 in.	81·0	81·5	83·5	82·0	81·0	81·0
„ 36 in.	80·0	80·5	82·0	81·5	80·0	80·0
„ 48 in.	80·0	80·0	81·5	81·0	79·0	79·0

accompanying the Southern
: only produce a heavier dew but
accompanied by heavy mist and
t collects on all plant parts with
ıes in contact. Likewise the dew
: on all the leaves and stems that
'ast enough to become cooler than
d night air. Consequently the
ıter collected in a specific location
the sum total of surface area of
ıt. In the dense forest there are
s of vegetation in addition to
nes that climb through all the
e forest of the Shimba Hills the
ove the ground consists of dense
rubs 3 to 5 ft. high. Next there
med by the branches of low trees
range from 3 to 5 in. in diameter.
; an understorey of sub-dominant
there is the closed upper canopy
trees which may be from 100 to
: the ground surface. Considering
of leaf and stem surface on which
v can collect it is apparent that
face in the grassland is but a very
n of that exposed in the forest.
ıificance of such condensation as
the grassland is less since all such
ıppears soon after it is exposed
n the other hand, the dense forest
: to drip moisture well past mid-
:ause the fog and mist tend to
e forest for several hours longer
›pen.

:izing the above processes it can
during the period of the North-
n the total heat absorbed during
s to keep the night temperatures
ıere is less dew formation. During
onths from April through August
st Monsoon is accompanied by
:hat drench the forest canopies in
ıeavy dew formation. The result
continuous fog drip in the forest
tributes a very important amount
o the water economy of the forest
and soil samples taken in the
Kwale during June, 1952, showed
ıse of about one-tenth of an inch
ıe upper 6 in. of mineral soil, and
rease within the litter and debris
ing the mineral soil. More detailed
s would be required to estimate
ount of moisture that is added to
nomy of the forest in this manner,
of dew and fog drip is not uncommon. For example, in a somewhat similar coastal forest in Oregon it was found by measuring the fog drip caught in rain gauges that 11.25 in. of extra water was accounted for in this manner during a period of 142 foggy days [2]. That this type of moisture can be important in the Shimba Hills can be deduced from the fact that the natural high forest remnants contain large trees of the same species that are normally found only in areas known to receive from 80 to 120 in. or more of rainfall. The rainfall records taken near the District Commissioner's station at Kwale in a standard 5-in. gauge show an average annual rainfall of only 41 in. Since this is considerably less than the amount considered as necessary for a high tropical rain forest one can only conclude that the tree growth must be supported in part by other types of recharge of moisture than is measured as rainfall in standard types of rain gauge.

The fact that fog drip and dew do not appear to occur in large amounts at any one time when expressed on an area depth basis, has led many observers to conclude that these processes cannot be of any real significance in the total water economy of an area. A more thorough consideration of all water cycle factors does not justify such a conclusion. For example, during the hours when fog drip and heavy dews are present, evaporation and transpiration of field moisture are reduced to a minimum. The net result is to conserve such field moisture as is already present in the soil. Consequently since the soil dries out more slowly the water cycle will be operating under condition of a higher sum total water economy. There will be less field moisture saturation deficit and consequently less rain will be required before ground water recharge can take place. In other words the circulating water capital in the water economy of the forest is always greater than that of open grassland. This fact alone is of paramount importance in appraising the water economy of different land-use programmes for tropical countries.

Thus in comparing the water economy of the forest and grass vegetation in the Shimba Hills all the processes of the field moisture balance must come under close review. For example, although there is more canopy interception in the forest, this is offset by a much greater recharge of moisture from the condensation of mist and dew, and at the same time there is a total saving of field moisture drawn upon by the trees. Total transpiration is doubtless orest, but evaporation of soil ost insignificant. In the grass- ation of field moisture becomes ant form of water loss, due to e local soils and the associated ratures. During the occasional ble to ground water recharge free water through the deeper vill be more rapid under the us and minus values that must er in the solution of the com- noisture balance between two present a complex problem. of all the components of the tinuously throughout the year ogical approach to the solution ily the most practical one. For two adjacent covers, the olumetric) study of the soil es within their respective root continuous recording of soil on conditions under both, an adequate measure of their the water cycle. The duration itable for recharge of aquifers ranges, and the summation of these periods, is itself a com- nay decide an issue of catch- ent policy. No measurements rch of field moisture have ever the Shimba Hills although btaining water measurements tly improved during the past

easurements have been made ills for many years for the pur- ng minimum dependable water easurements are taken mainly s spot readings and are not construct a continuous hydro- nflow. They can be used to oximate base flow hydrograph ghly indicating the seasonal tion and depletion of ground no watershed boundaries have in the field it is quite impos- actual unit yields for different example cubic feet per second of catchment. There are two ing factors, one is that water- are indistinct for many of the ne northern half of the Shimba the water level topography. t in geological formations of streams may have a common quifer. However, there is one that merits intensive study in terms of independent catchments. This is the drainage area of the Mwachemwana River in the south-eastern portion of the plateau. Here the natural topography is such as to provide fairly definite watershed boundaries. Streamflow within this drainage basin represents the outflow from definite catchment areas and can be used to compute unit yields. No satisfactory rainfall measurements are available for the Mwachemwana River basin. However, streamflow records show that this river has a well-sustained base flow. For experimental purposes the basin can be divided into a number of independent catchments each with a permanent streamflow. The fact that much of the Mwachemwana River basin is in dense forest and bush detracts from conclusions reached in early reports that forests were unfavourable to high yields of water in the Shimba Hills. On the other hand it is most probable that if unit yields were determined for the Mwachemwana River drainage basin, they would compare very favourably with unit yields from important water-producing catchments outside of the Shimba Hills. It is unfortunate that no suitable data are available for estimating the water balance for the Mwachemwana basin as it is one of the few really desirable basins for hydrologic studies on the whole coastal area of East Africa [3].

Accurate streamflow records on which to compute the continuous unit yields of water when combined with rainfall data taken on independent catchment areas are valuable aids in interpreting land-use hydrology. However, such records as are available for the Shimba Hills are quite inadequate for this purpose. Some of the stream gauging stations already installed could be used for future catchment studies if the records were taken by means of suitable continuous water-level recorders.

Until the substantiating water yield data have been collected the writers can only express an opinion based on observations of the field moisture balance in the Shimba Hills. These observations point to the logical conclusion that under the natural forest which once occupied the Shimba Hills the water economy then favoured maximum sustained water yield. Such changes in vegetation as have taken place have resulted in changes in the field moisture balance leading to a reduction in the total circulating water capital and in the total water yield. It is considered that the re-establishment of the dense forest in this natural coastal mist belt will be the greatest insurance possible for

maximum yield of water from
[ills.

hrubs should, however, be cleared
gins of the streams as a matter
tchment area management. Such
th roots reaching the water tables
treams, has been shown by catch-
ıdies in other countries to cause
of water yield. Thus by planting
orest trees on the high ground,
ıe water table, while removing
thirsty scrub from the margins

of the streams, condition for maximum water yield could be achieved for those hills.

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