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Correct citation:

Jürgen Hagmann (1994) *"An Approach for the Calculation of the Biomass Production of Short Growing Periods in the Rangelands of Northern Kenya"*, E. Afr. agric. For. J.

E. Afr. agric. For. J. (1994) *59 (4)*, 317 - 326

AN APPROACH FOR THE CALCULATION OF THE BIOMASS PRODUCTION OF SHORT GROWING PERIODS IN THE RANGELANDS OF NORTHERN KENYA

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(Accepted for publication in February, 1994)

Biomass production is a major factor in the determination of the human carrying capacity of arid and semi-arid rangelands. It is rather problematic, however, to quantify and to predict primary production. A detailed estimation of production would enable better range management and thus protect overused degraded areas by utilising under- utilised areas in a more efficient and sustainable way. In view of the vast extent of degraded lands in Northern Kenya, such an approach seems to be worth trying.

Mainly, two different methods are used for estimating biomass production in Kenyan pasturelands. Herlocker and Dolan (1980) correlated primary production with annual and seasonal rainfall. Good results were obtained for some physiognomic classes of the vegetation. It is, however, only a rough estimation as vegetation is rather heterogenous. The other method, in which remote sensing techniques are applied, is based on the assumption that a certain plant community produces a certain annual amount of biomass. This characteristic production depends on the vegetational cover. Thus, the grazing potential can be determined (Dreiser *et al.*, 1989).

In this study, the soil-water balance of short growing periods was determined in the field and used to calculate biomass production. The main objective of the study was to develop an approach for determining biomass production of short growing periods on the basis of the soil-water balance. This requires the assessment of all factors influencing the water balance as well as the effects of the limited rainfall on the thornbush savannah vegetation (growing characteristics). Growth effective rainfall and the plant water consumption have to be quantified by applying water balance data.

MATERIALS AND METHODS

The Study Area

The study area is located in Northern Kenya (Isiolo-District), 22 km west of the district capital Isiolo, approximately 300 km north of Nairobi.

Morphologically, the area is still part of the downslopes of the Mount Kenya volcanic massive. The altitude ranges from 1100 to 1200 m a.s.l. The climate of the area is semi-arid with an average annual rainfall of 510 mm (Schultka and Schwartz, 1987), occurring in a bimodal distribution (March to May and November/December). A detailed analysis of the climatic situation has been worked out by Mäckel *et al.* (1991). Rainfall pattern during the study period is shown in Fig. 1.

The vegetation of the area is classified as a dwarf shrub bushland. Soils are mainly pellic Vertisols, vertic and calcic Cambisols, described by Hagmann (1988) and Mäckel and Schultka (1989).

Methodology for Assessing the Soil Moisture Regime

Measurement of Soil Moisture

The calcium carbide method (Steubing, 1965) was used for determining soil moisture percentage (by volume). According to Steubing (1965), test results are insignificantly different from results obtained by the standard gravimetric method.

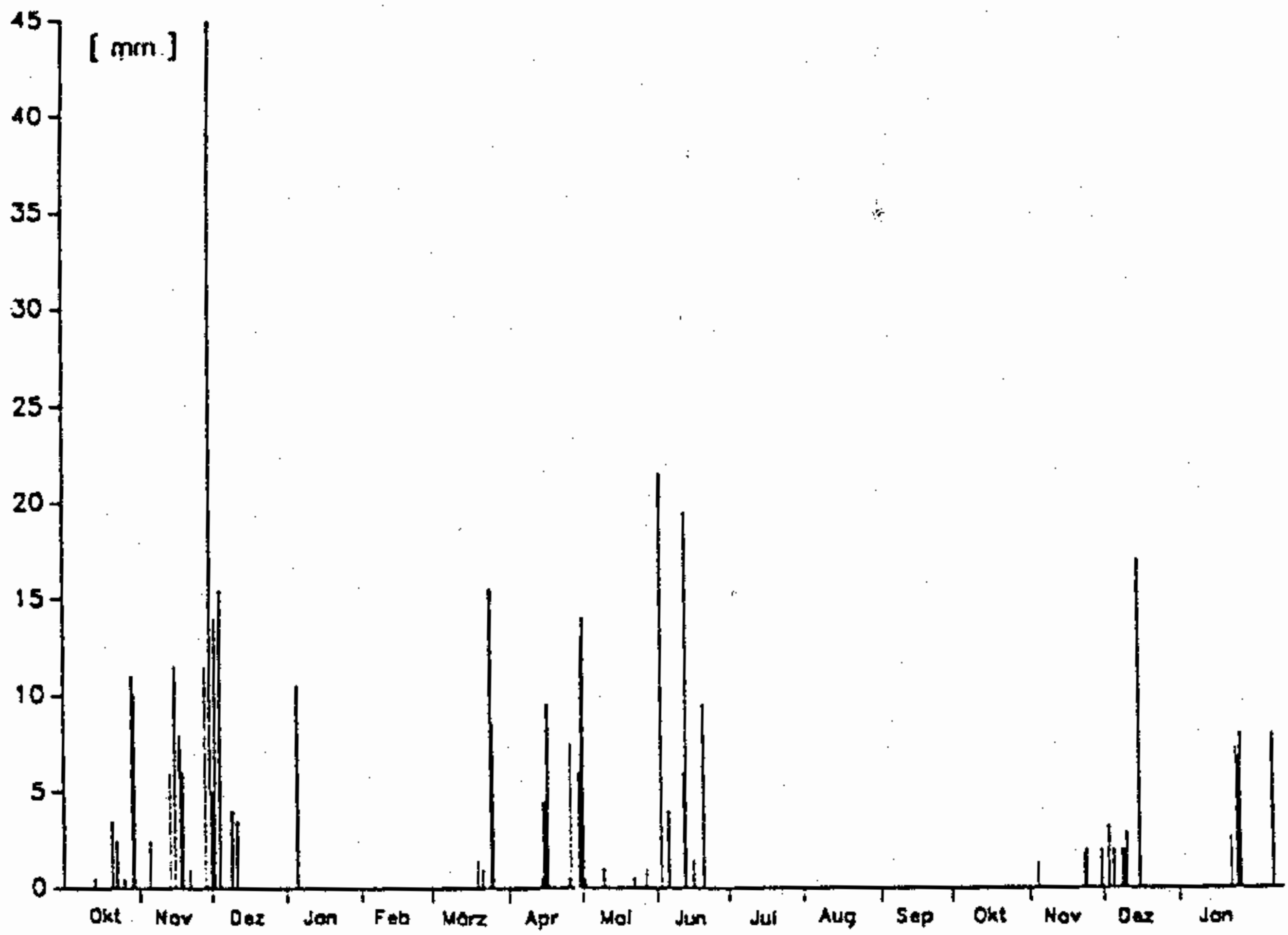

Fig. 1 - Daily rainfall (October 1986 - January 1988) Ngare Ndare Research Station

Test sites were close to raingauges to minimise the error in calculating the soil-water balance accurately. Sampling was carried out at three profiles, each time newly dug at a certain test site. Out of the profiles, several samples from defined depths were taken from profiles and for each depth, a composite sample was ptrepared, homogenised and measured.

Apart from soil moisture determinations, depths of the wetting front and of the dried up surface layer were recorded. Bulk density of the soil as obtained using 100-cc core samplers was determined.

This method was simple, cheap and easy to apply in remote areas with little infrastructure. Comparative measurements with gravimetric determination of the soil-water content showed an error of the calcium carbide method which was below the inhomogeneities of the soil moisture at the same site.

Determination of Plant Available Water and Effective Growing Periods

To calculate the plant available soil-water, it was necessary to determine the soil-water characteristics, like water content at saturation (field capacity) and the soil-water content at the wilting point.

Usually these characteristics are determined in the laboratory by means of a water content/water potential relationship whereby pF 4.2 is taken as the permanent wilting point. Well-adapted plant species of a dry savannah, however, bring up a higher suction energy. Therefore, they are able to reach more of the limited soil-water than cultivated plants (Walter, 1984). During the determination of field capacity in the laboratory, the soil is soaked for several days, allowing the clay minerals to swell fully. Rainfall patterns in field conditions, however, do not allow the soil *in situ* to soak fully. For soils with a high content of swelling clay, the short period in which the soil is soaked and saturated influences the swelling process, which is a major factor in soil-water storage (Heinonen, 1985). Hence, field capacity measured *in situ* tends to be lower than the field capacity determined in the laboratory. The field capacity measured in this study is defined in the sense of the functional field capacity concept described by Heinonen (1985). These considerations led to the determination of the soil-water characteristics in the field by using soil moisture measurements and observations of the plant phenology.

Field Capacity

Field capacity in general is defined as 'the amount of water which a soil can retain against gravity' (BGR 1982:148). This definition was applied to determine the field capacity in Ngare Ndare. It was observed that the field capacity was reached 24 hours after a heavy storm event - when no downward movement of water could be assessed any more,d ue to cloudy conditions after the rains, surface evaporation was low by then. At that point the soil moisture of the saturated soil layers below the surface was determined and taken as moisture content at field capacity. This procedure was repeated at different sites and after several rain periods. As the readings were consistent throughout the sites and the rain periods, it was possible to attribute a reliable field capacity to each soil type.

Wilting Point

Precise observations of the plant phenology were required to determine the wilting point. The reactions of the vegetation on rainfall were subdivided into three periods, namely greening and growing; enduring rolling of leaves or changing colour to greyish-green; and permanent wilting - leaves turning yellow, dropping and drying.

Effective growth was restricted to the first period. No growth was assessed during the second period, which could also be called 'non-permanent wilting' period. During this period, plants endured up to the next rainfall period with minimum transpiration. This phenomenon enabled the plants to continue growing immediately after the onset of a subsequent rainfall. When no rainfall occurred during the days that followed, the vegetation started wilting permanently and dropped its leaves (permanent wilting point, PWP). The time between the start of growing and (non-permanent) wilting of the plants was defined as the effective growing period.

In the following sections, the transition from the growing period to the enduring period will be the main focus. This transition is the non permanent wilting point (WP).

Parallel to the observation of the plant phenology, the course of the soil moisture was measured regularly during the different periods. By correlating wilting of plants with soil moisture (which was measured at the same time) the characteristic water content at the non permanent wilting point could be assessed for the different soils and plants.

It was assumed that all the plant available water of the moistened soil volume was used up even if vegetational cover varied. After determination of field capacity and wilting point, the water balance was applied to calculate the available water (AWC) of the wetted soil layer. Growth effective rainfall (GER) was then calculated by relating the available water to the rainfall of each rain period.

RESULTS AND DISCUSSION

Soil Moisture and Drying

For each soil type, soil moisture data were plotted to assess the process of drying and the daily rate of evapotranspiration (Fig. 2).

Drying Process

After a medium to heavy rainfall, the clayey soil surface is soaked with water. This condition can last some hours or even a whole day. Then, if highly evaporative conditions prevail, the uppermost layer will dry up quickly. As the soils contain swelling clay, this process leads to the formation of a crust which in the further drying process forms a polygone system with uplifted edges. Hence, it follows that about one to two days after a storm, an evaporation barrier is formed. This reduces subsequent soil evaporation considerably. This characteristic represents a counterforce to the generally high water conductivity of clay soils. The effect of this evaporation barrier results in the break of the capillary rise by the disconnected dry crust layer. The rapid drying is of great importance for the water balance in arid conditions (Heinonen, 1985). with further drying, the surface crust crumbles into very small particles. A loose and fluffy soil surface susceptible to wind erosion results. The loose soil surface results in very high initial infiltration rates during a subsequent storm event. The course of the soil moisture shows that the soilwater in the deeper layers decreases slowly (Fig. 2). It can therefore be deduced that, even while vegetation is in full growth, the soils are drying mainly from the surface downwards. Hereupon it can be assumed that plant roots tend to use the water near the surface first, thus minimizing water losses due to ineffective evaporation.

The top 4-cm layer dries up to a rest water content of less than 10 % whereas the deeper layers never dry up below a water content of 20 %. As the surface layer is continous with the turbulent air, the drying up of the top layer is caused by the high saturation deficient of the air under these climatic conditions. The high amount of unavailable water (20 %) in the deeper layers reflects the high suction energy of the clayey soils.

Soil-Water Balance

Several soil moisture courses were plotted for each soil to establish the water balance for short rain periods (Fig. 2). The soil in site RG 3, the pellic Vertisol, is representative of the most widespread soil type in the experimental catchment. The rainfall distribution between the 18th and the 23rd of April (Fig. 2) is typical of the short rain periods in Ngare Ndare. It was cloudy and cool during these rain periods of about 3 to 6 days, and a storm occured almost every 3 to 6 days. Evaporation was low.

From 18th to 23rd April, total rainfall at site RG 3 was 24 mm. On 23rd, at the end of the rain period, the wetting front had reached a depth of 11 cm. The initial water content before the storms, contained in the layer up to 11 cm deep, amounted to 22 mm of unavailable water. After the rains, the wetted layer of 11 cm contained 42 mm of water, thus 20 mm had infiltrated. Total rainfall, however, was 24 mm. The difference (4 mm) between the infiltrated water and the rainfall, was lost due to interception and evaporation. The growth of the plants started about 3 to 4 days after the first rain.

After 12 days of effective growth, most of the plants reached the (non-permanent) wilting point. Some trees and bushes (*Acacia mellifera* and *Acacia horrida* in particular) grew for 2 to 3 days more. They were able to use water which had infiltrated into deeper cracks of the vertisol. With the method applied, this additional source of water could not be quantified, and was not relevant for biomass production, as it was only available to two species.

Measurements of the soil moisture content at that non-permanent wilting point after 12 growth days showed a remaining moisture of 24 mm in the previously wetted layer of 0- to 11- cm depth. This high remaining moisture was not readily available for plants because of the high suction energy with which the clayey vertisols can hold water. The

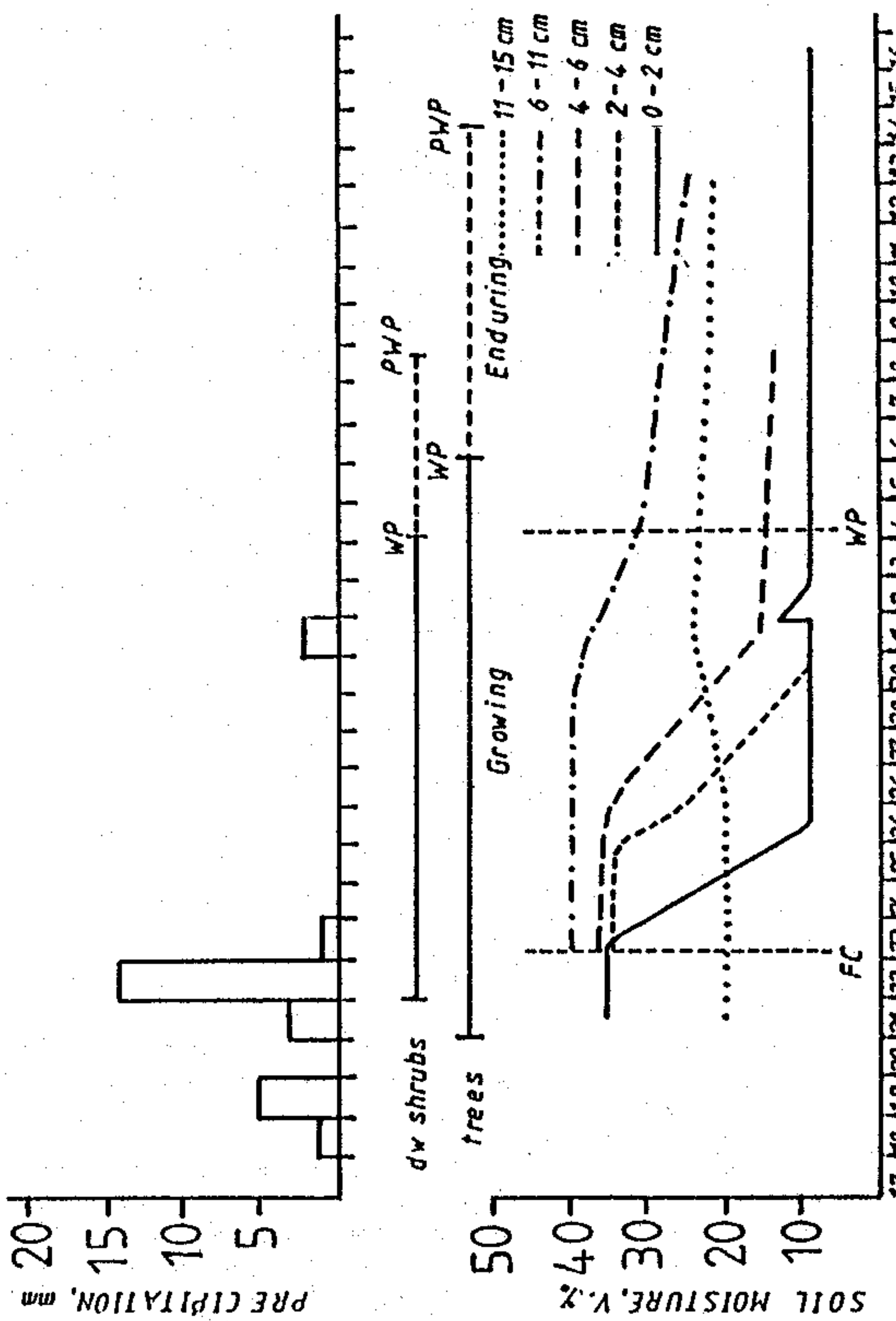

Fig. 2 - Rainfall, course of soil moisture and related growing periods at Vertisol site (RG 3), Rain Period 2

difference between the moisture content at field capacity after the end of the rains (42 mm) and the moisture content at the wilting point (24 mm), was 18 mm, which was used up in evapotranspiration and was thus growth effective. The remaining 2 mm (20 mm had infiltrated) was fixed in the clays with a high suction energy and was not easily available to plants. It was 'lost' as evapotranspirated during the succeeding enduring phase of the vegetation until the final wilting point was reached.

The average evapotranspiration rate during this growing period on the Vertisol was 1.5 mm/day (18 mm in 12 growth days). This low rate was due to the highly adapted species growing under these climatic conditions and to the effective evaporation barrier of the vertic soils. Related to the amount of rainfall of this rain period, the effectively evapotranspired 18 mm of water, defined as the growth effective rainfall, represented 75 % of the total rainfall. The light shower of May 1 (2 mm) did not show any effect on the vegetational growth. This water evaporated immediately on the heated soil surface and was ineffective for the vegetation.

Observation of Plant Phenology

Results of the observation of the plant phenology during the study period are shown in Fig. 3. Besides the assessment of the duration of the growing periods a main objective was to find out effects of the various storms on different plant species. Figure 3 shows that most of the species react homogeneously to a storm event. The growing periods of trees and bushes are often longer than those of dwarf shrubs and grasses. *Acacia tortilis* especially was able to keep the leaves - sometimes even up to latein the dry season. Rainfall (Fig. 3) was measured at the Ngare Ndare Research Station. Due to the spatial variability in rainfall, small differences in duration of growing periods were recorded at different sites. Along drainages, plants grew for a few more days and the trees with roots reaching the groundwater kept the leaves for some weeks after the trees in the surrounding areas had lost theirs. The observations shown in Fig. 3 refer to sites outside these drainages. Herbs and grasses had the shortest growing periods. This was true for *Tribulus terrestris* (an indicator for overgrazing) in particular. One day after a storm, this species covered big areas densely and died a few days later when the water of the uppermost layer had evapotranspired. Because of the drought in May 1987, vegetational growth stopped completely.

The permanent wilting point had been reached so that leaves turned yellow and dropped. At the end of May when further storms occurred, growth had to start completely anew. Trees showed a quick recovery whereas grasses (except *Tribulus*) took longer to turn green again. The occurrence of the observed species in the study area was often restricted to a single soil type. Therefore, the determination of the influence on the duration of the growing periods was limited to the existing soil types. However, differences are assumed to be insignificant because of the high similarities in the clay content of the soils.

Calculation of Growth Effective Rainfall and Plant Water Consumption

The growth effective rainfall was calculated for 13 storms and rain periods at four different sites by means of the water balance of the moistened soil volume (Table I). After each rain period, the mean depth of the wetting front was assessed to calculate the water content at field capacity. Measurements of soil moisture at the end of the growing period showed that the wetting front had occasionally moved downwards about one centimetre. This observation was taken into account in the calculation of the water content at wilting point. Seepage, on the other hand, never occurred. During all rain periods, the wetting front formed a well defined limit which never exceeded a depth of 10 to 20 cm within the surface (Table I).

Characteristics of the rooting systems (Figs 4 and 5), salt distribution in the soil profile, infiltration characteristics and the typical rainfall distribution and evaporation characteristics indicate that wetting of these soils hardly exceeds a depth of 30 cm (Hagmann, 1988; Mäckel *et al.* 1991). Consequently,

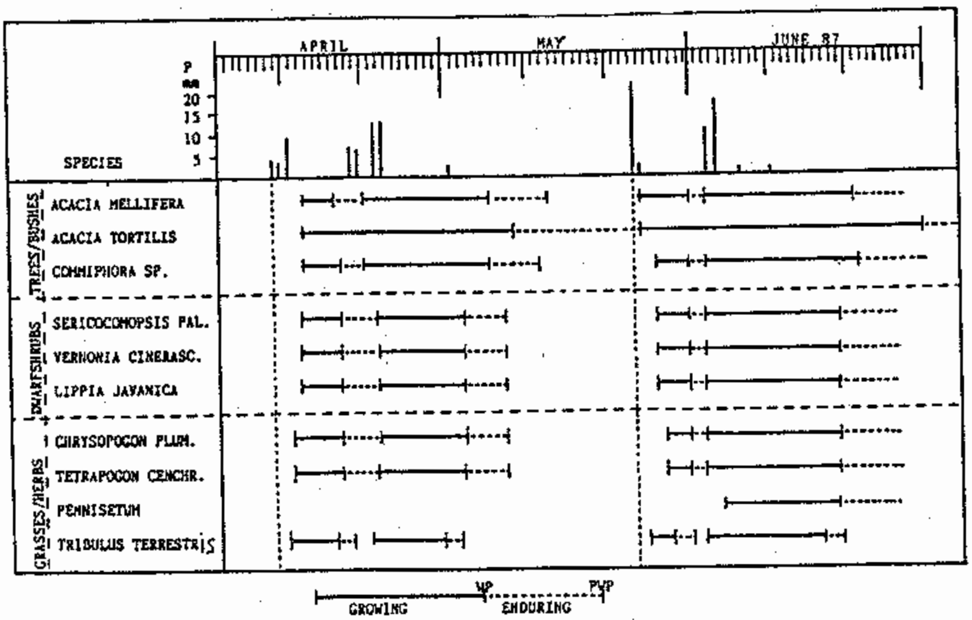

Fig. 3 - Effects of rainfall amounts on growing periods of different species

plant water supply in general is limited to the upper soil horizon. Therefore, short growing periods charaterize this area. Sufficient rains occurring regularly at intervals of about 10 to 15 days would be required for long, continuous growing periods.

The growth effective rainfall (GER) varied from 67 to 82 % of the total rainfall while total rainfall varied from 17 to 42.5 mm. The lowest value for GER (67 %) was achieved after the heaviest storm (42.5 mm) which resulted in wetting of the first 18 cm. The low GER of this storm was due to moistening of deeper soil layers which were dry (far below the wilting point) and which had to be saturated to a water content above wilting point first before moisture became plant-available and growth-effective. Hence, the amount of growth ineffective soil-water rose with the depth of the wetting front. After the rainstorm of May 25, the GER was higher than it had been during preceeding events. In this case the short duration of the rain period (2 days) and residual moisture from previous storms in the wetted zone resulted in the high GER value.

If heavy rains occur, losses due to runoff might reduce the percentage of the GER. During the study period, the high infiltration rates of the soils and the absence of very heavy rainstorms in the catchment area resulted in minimum runoff losses, the highest being 2.4% of the rainfall.

The GER related to the duration of the growing periods at the observed sites allowed the calculation of the mean rate of evapotranspiration per growing day. As already stated, these rates were extremely low and ranged from 1.5 to 1.7 mm/day (Table I). Related to the potential evaporation, Eo (pan evaporation measured on the Ngare Ndare Research Station), these low rates of evapotranspiration are equal to about 0.25 x Eo. Compared to cultivated plants, which consume up to 1.2 x Eo (Jäetzold, 1979), the difference is enormous.

TABLE I - SOIL-WATER BALANCE, GROWTH EFFECTIVE RAINFALL AND DAILY EVAPOTRANSPIRATION RATES OF 13 GROWING PERIODS IN NGARE NDARE

P (mm)	Days of P	Wetting Depth (cm)	Water Content 1 day after P(mm)	Water Content at WP (mm)	GER AW (mm)	GER % P	Growth Period days	Mean ET/day (mm)
Site RG 1 (vertic Cambisol)								
19	5	9	28	14.5	13.5	71	8	1.7
42.5	6	18	60	31.5	28.5	67	17	1.7
17	1	8	26	13	13	76	8	1.6
26	2	12	39	21	18	69	12	1.5
Site RG 3 (pellic Vertisol)								
24	6	11	42	24	18	75	12	1.5
17	1	7	26	12	14	82	8	1.7
26.5	2	10	38	19.5	18.5	70	12	1.5
Site RG 4 (calcic Cambisol)								
24	6	12	42	23	19	79	12	1.6
20.5	1	8	28	12	16	78	9	1.7
19	2	8	28	13	15	79	10	1.5
Site RG 5 (pellic Vertisol)								
32	6	13	50	27	23	72	15	1.5
17.5	1	8	30	16	14	80	8	1.7
21	2	10	38	21.5	16.5	79	11	1.5
Mean =	75 %							

Key:

P = Total rainfall of rain period Water content 1 day after P = water cont. at field capacity in wetted layer
Water cont. at WP = water content at wilting point in wetted layer GER = Growth Effective Rainfall
AW = Available Water (Diff. between field capacity and wilting point) ET/Day = Evapotranspiration/day

Field Capacities (% Vol.) for the Different Soil Types
Pellic Vertisol: 0 - 5 cm: 36 % 5 - 30 cm: 40 % Calcic Cambisol: 0 - 30 cm: 35 %
Vertic Cambisol: 0 - 5 cm: 30 % 5 - 20 cm: 35 %

The low transpiration is typical for the adapted vegetation of the dry savannah. Hence, potential evaporation (Eo) has far less influence on the actual evapotranspiration of the dry savannah than it has on the evapotranspiration of cultivated plants. According to Jäetzold (1979) rainfall amounts of less than 3 mm in the cultivated areas of East Africa are considered to be ineffective. This assumption can be confirmed for the dry savannah area of Ngare Ndare for rains which occur beyond a rain period. Light rainfalls occurring during rain periods, however, are able to infiltrate into the soil surface and thus are effective. This growth effectivity is a result of the low evaporation and the moist soil surface.

Calculation of the Duration of Growing Periods

Applying the concept of growth effective rainfall and the measured rates of daily water consumption, it was possible to calculate the duration of the growing periods subsequent to rainstorms/rain periods having more than 3 mm of rainfall.

An empirical equation for the determination of the length of growing periods was developed by using the correlation between rainfall, evaporation (class A pan) and the calculated water consumption of the dwarf shrub bushland vegetation

$$\text{Growing period (days)} = \frac{0.75 \times P \text{ (mm)}}{0.25 \times Eo \text{ (mm/day)}}$$

P: precipitation of a rainfall or continuous rain periods of some days

Eo: pan evaporation (was measured by a class A pan)

If no measured data for Eo exist, daily evapotranspiration rates of approximately 2 mm (Table I) can also be used in this equation (calculated data for Eo according to Woodhead (1968) proved to be too low). This empirical formula can only provide an estimate. It should not be used in areas with well distributed rainfall which results in long continuous growing periods.

For areas outside the study area, further investigations have to be carried out to confirm the applicability of this equation. In particular, in areas with soils with low infiltration capacities and in those with higher rainfall, processes might be sifferent. High runoff losses or long uninterrupted growing periods with abundant available water, might produce lower rates of GER due to ineffective evaporation losses. The fact that these experiments were carried out in a dwarf shrub bushland restricts the results to these conditions. Further studies should be conducted to extend the applicability of this approach to other plant associations.

Impact on Biomass Production

Knowledge of daily production rates during the growing periods is necessary for the calculation of the biomass production. Braun (1973) determined a daily production rate in the Serengeti grassland of 5 to 80 kg/ha/day, depending on the kind of grass, the rainfall distribution and the soil fertility. A growing period of 10 days, caused by a 25-mm rainfall, produced 50 kg/ha. A 700-mm rainfall with a continuous growing period of 150 days produced 12000 kg/ha (Braun, 1973). This example shows that the course of production is an exponential function of the duration of the growing period.

Since no specific data for the Ngare Ndare dwarf shrub bushland was available, Braun's (1975) data were used for the calculation. In Ngare Ndare, growth is often interrupted by dry periods even in the rainy season. When permanent wilting takes place after such an interruption, growth has to start anew with the subsequent storm. On average, duration of the growing periods in Ngare Ndare was hardly longer than 10 to 15 days (Fig. 3). Assuming that the daily production during these short growing periods was similar to Braun's results (e.g. about 5 to 7 kg/ha/day) production in Ngare Ndare in the rainy season from April to June 1987 can be calculated, knowing the number of the effective growing days. The average number of growing days during the study period amounted to 43 days (compare with Fig. 3). If the production had been 5 to 7 kg /ha /day, the biomass production for the whole rainy season should have been 215 to 301 kg/ha. This value is relatively low but it seems to be realistic, considering the weak rainy season with a rainfall of only 120 mm. However, as there are two rainy seasons, this low seasonal production cannot be relied upon to make any conclusions about the total annual production. Continous rainfall during a rainy season and dry season down-pours have a high impact on the production increase. For example, Braun (1973) estimated the production rate of a rainy season with a well distributed rainfall of 350 mm and 100 growing days at about 35 kg/ha/day. Therefore, the approach discussed should not be transferred to long growing periods before further investigations are done.

SUMMARY

Investigations on the soil plant water relationship were carried out in the semiarid thornbush savannah of Ngare Ndare, Isiolo District, Northern Kenya, to develop an approach for the determination of the biomass production on the basis of the soil-water balance. In order to determine the growth-effective rainfall, the soil-water balance of the short rain periods was correlated with the subsequent growing periods. During the study period, the growth effective rainfall of the different rain periods amounted to an average of 75 % of the total rainfall. Due to the highly adapted natural plants of this dwarf shrub bushland, the daily water consumption of the vegetation was below 2 mm/day. High growth effectivity of the rainfall and low water consumption led to long growing periods even after light rainfalls. Based on these observations, a formula for the calculation of the duration of the growing periods based on daily rainfall and evaporation data was developed. Knowing the number of

growing days, the biomass production of the study period was calculated using daily production rates as a function of the length of growing periods.

ACKNOWLEDGEMENTS

The field work for this study was financially supported by GTZ.

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