# Rangeland Production and Annual Rainfall Relations in the Mediterranean Basin and in the African Sahelo-Sudanian Zone

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**Highlight: The study of the relationships between annual rainfall and range production in the Mediterranean Basin and the Sahelian Sudanian tropical zones of Africa shows a close correlation between average range production and average rainfall over large geographic areas. For a given amount of rain, net production is higher in the Mediterranean than in the Sahel. The regressions developed show that, on the average, each millimeter of rainfall produces 2 kg/ha of consumable dry matter, or 0.66 Scandinavian Feed Units (FU), in the Mediterranean, whereas in the Sahelian and Sudanian zones these figures drop to 1 kg/ha and 0.40 FU.**

Pasture production depends on various factors such as climate, nature of soil, botanical composition and vegetation structure, and type and intensity of management, e.g., grazing patterns and stocking rates, fire, and wildlife (including insects and rodents).

Since all these factors or group factors can limit yields, one should be able to integrate them all in a single mathematical model. Such a model would make it possible on the one hand to assess potential yield of grazing lands, and on the other to determine, through simulation, the effects on these yields of any modification in one or several factors. Some attempts towards this aim have already been made for the Sahel (Seifert and Kamrany 1974; Picardi 1975). Data are now being collected in order to build such models, and the programming of simulation models is being studied as well.

In order to form some idea of the importance of climatic factors on the production of natural pastures, an attempt was made to correlate this production with average annual rainfall in two large areas: the Mediterranean Basin and the Sahelian and Sudanian zones of Africa. The average annual rainfall was selected because of its apparent importance where forage production is concerned.

Many authors have attempted to relate pasture production to average rainfall, e.g., Walter (1954 and Walter and Volk (1954) in South Africa; Stewart (1960) in Libya; Condon (1968) in Australia; le Houérou (1964, 1969, 1973, 1975) in North Africa; Braun (1973) and Lamprey (1975) in East Africa; Cook and Sims (1975) in the United States; Breman (1973) in Mali; Seifert and Kamrany (1974) and Picardi (1975) in the Sahel.

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## Material and Methods

Forty-five pairs of data on average annual rainfall and pasture production were gathered from eight countries in the Mediterranean Basin. An equal number of pairs were gathered from eight countries in the Sahelian-Sudanian zone. For the Mediterranean area, the eight countries (with an average annual rainfall of 20 to 900 mm) included France, Italy, Greece, Syria, Libya, Tunisia, Algeria, and Morocco. Some few data from Egypt, Portugal, Iran, Turkey, Spain, and Israel, although perfectly fitting the overall figures, were not used, in order to keep the number of observations similar in both areas. For the Sahelian-Sudanian area, the countries (with an average annual rainfall of 100 to 1,500 mm) were: Mauritania, Senegal, Mali, Upper Volta, Ivory Coast, Chad, Niger, and Sudan.

The reason for the rather small number of pairs is that many data from low rainfall areas (100–400 mm) were discarded on the basis of geographic criteria in an effort to obtain as balanced as possible a curve over the rainfall spectrum considered. Rainfall data are usually those occurring during the years of measurements—otherwise average annual rainfall is plotted against average range production.

The geographic zones involved in the study are shown in Figure 1.

### Why Average Rainfall?

Average rainfall is obviously not the only factor of importance for range production. However, in the Mediterranean Basin, as in the Sahelian and Sudanian zones of Africa, average rainfall is correlated with a number of other climatic factors such as rain variability, number

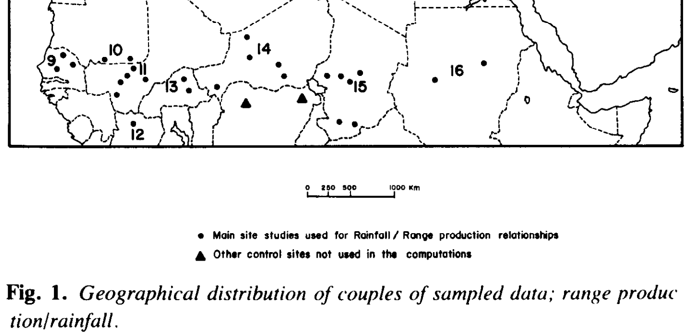
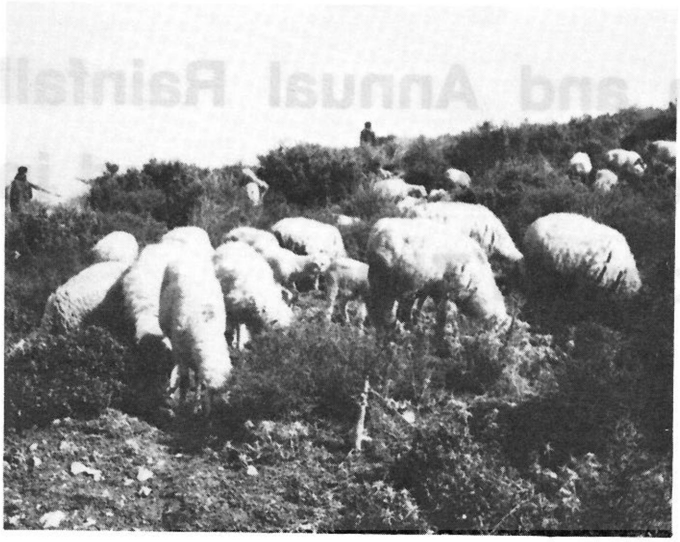



**Fig. 1.** *Geographical distribution of couples of sampled data; range production/rainfall.*



*Mediterranean Basin, Algeria, Aurès Mountains. Rainfall 400-600 mm. Shallow soil on limestones and marls, woody rangelands wth* Quercus ilex, Rosmarinus tournefortii, Ampelodesmos mauritanicum, Pistacia lentiscus.

of rainy days, length of dry and rainy seasons, and potential evapotranspiration.

Calculations were made for the Mediterranean Basin, using data from many climatic stations, each having over 50 years of records. A clear negative correlation between average rainfall ($\bar{R}$) and standard deviation of annual rainfall ($\sigma$) emerges.

The relation is:

$$\sigma = f(1/\bar{R});\ r=0.73;\ n=140;\ p<0.001$$

There is also a clear negative correlation between average rainfall and potential evapotranspiration (PET) (calculated according to Turc's method, and using 128 stations) =

$$\text{PET} = f(1/\bar{R});\ r=0.75;\ n=128;\ p<0.001$$

One could add that geographic variations in average rainfall are much larger (100 to 1,500 mm/year in both areas) than variations in potential evapotranspiration (1,000 to 1,500 mm/year in the Mediterranean area) there is, by and large, a zonal increase in potential evapotranspiration from north to south; and a reverse zonation in rainfall. The reverse is true for the Sahel, where rainfall increases from north to south, whereas PET decreases from north to south.

For the reasons given above, one may validly consider average rainfall as closely related to water availability for plant growth. Temperature is not usually a limiting factor for forage growth in the Mediterranean Basin, nor in the Sahel, at least not over long periods; and average rainfall seems to be by far the most important climatic factor affecting pasture production.

## Assessment of Pasture Production

The data on pasture production are expressed in amount of consumable forage produced annually. These are balanced figures averaging the various types of pastures encountered in a given zone with a given rainfall.

Data for range types located in depressions benefitting from runoff or water table have not been used, as such areas are not under the direct influence of rainfall. Neither have we used figures from rangelands improved through artificial fertilization, since, generally speaking, such practices are neither common nor economic. However, it has been experimentally shown that in high rainfall areas (R > 400 mm), fertilization may increase range production three to five times (France, Italy, Spain, Israel, Tunisia, ec. . . .).

One of the major difficulties was to make coherent the data collected in various ways and expressed in various units and systems. Available data were expressed in:

- Total above-ground phytomass (kg).
- Actually consumable forage in kilograms of dry matter or in kilograms of fresh matter per hectare per year.
- Feed units (FU) per hectare per year (one Scandinavian feed unit = 1 FU = 1 kg of barley = 1,650 kcal for adult ruminants consuming roughage).
- Feed units of oats (Russian system) per hectare per year.
- Starch equivalents.
- Carrying capacity in unit of tropical livestock at maintenance, weighing 250 kg (UBT/ha/year) for the tropical zone, or in head of sheep/ha/year or sheep unit/ha/year for the Mediterranean Basin.
- Stocking rates in head/ha/year.

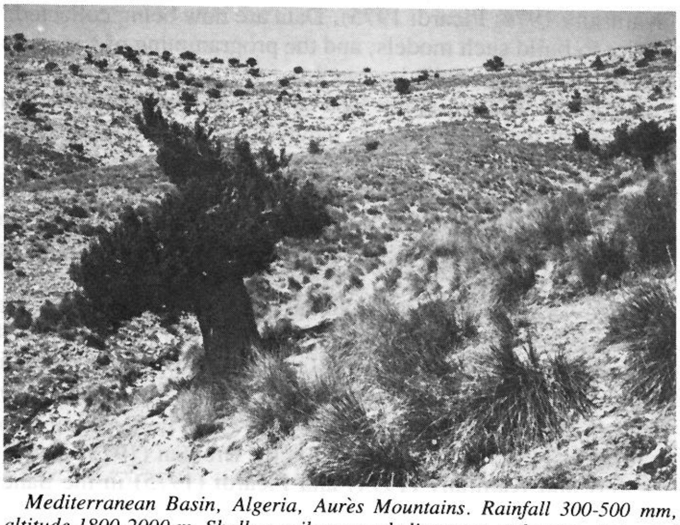
### *Conversion Factors*

Since our purpose was to obtain an approximative curve, several simplifications were admitted.

Conversion factors used are not the same for the Mediterranean Basin and the Sahelian and Sudanian zones of Africa. The main reasons are that livestock species and types are different in each case, and that Mediterranean natural pastures consist mainly of perennials, including many shrubs, whereas the Sahelian rangelands consist mainly of annual grasses and forbs.

*The Mediterranean Basin.* For the Mediterranean Basin, we have used the following conversion factors:

- One mature sheep (40 kg) = 0.2 cattle = 0.10 camel = 1.2 goats = 0.15 horse = 0.3 donkey = 300 FU/year = 495,000 kcal/year.
- One sheep unit = 1 ewe + 1 lamb up to 3 months old + 1/5 yearling ewe + 1/25 ram = 450 feed units per year = 1.5 head of sheep.
- One Scandinavian feed unit = 1.1 Russian feed units = 1,650 kcal (in the case of mature ruminants consuming roughage) = 0.70 starch equivalent = 1 kg of barley.
- One kilogram of dry matter (DM) = 0.33 feed unit = 550 kcal. (This figure is based upon numerous chemical analyses and some digestibility trials. According to these data, green grasses, legumes, and annual forbs are worth 0.4 to 0.6 FU per kg of DM whereas shrubs and dried up annuals or grasses are worth 0.2 to 0.4 FU per kg of DM. Since shrubs and dry stuff represent 65 to 75% of the annual diet, an average conversion rate of 0.33 FU per kg of DM seems to be reasonable order of magnitude. If anything, it may be slightly conservative.)



*Mediterranean Basin, Algeria, Aurès Mountains. Rainfall 300-500 mm, altitude 1800-2000 m. Shallow soils on marly limestone and marls. Degraded rangeland with* Juniperus thurifera, Ampelodesmos mauritanicum *and* Euphorbia luteola.

• Rate of forage consumption is assumed to be 50% of annual production (estimation and measures vary from 40 to 60%).

• It is usually admitted that average forage consumption is 25% of total above-ground standing phytomass, or 50% of total annual production.

• Percentage of dry matter in fresh plants varies from 20 to 70%, according to species and season. The figures used here depend on range type and season measurement.

*The Sahelian and Sudanian zones of Africa.* For the Sahelian and Sudanian zones of Africa, we have used the following conversion factors:

• One tropical livestock unit (TLU) = 1.5 cattle = 10 sheep = 12 goats = 2 donkeys = 1 horse = 0.8 camel.

• One TLU corresponds to 1.5 head of average cattle counted. One TLU equals 0.54 livestock standard unit (LSU), as defined in East Africa (Brown 1971) and weighing 1,000 pounds (454 kg).

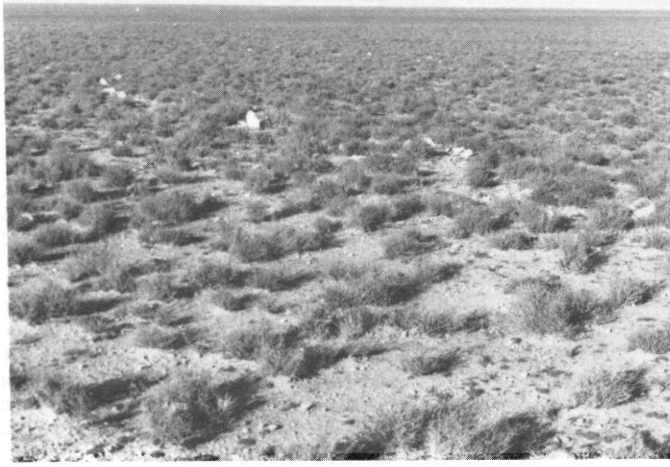
• The average feed value is reckoned to be 0.40 feed unit per kilogram of consumable dry matter, i.e., 0.60 during the rainy season and 0.25 during the dry season.

• Actually consumable forage of grasses and forbs is 70% of the above-ground biomass during the rainy season; this amount decreases to 30% during the dry season. The rainy season is considered as lasting an average of 3 months, and the dry season 9 months. Thus the consumable forage is 17.5% in the rainy season and 22.5% during the dry season, i.e., a total use rate of 40% above-ground phytomass on a year-round basis. These figures, agreed upon by most of the specialists for the area concerned, may be slightly conservative.

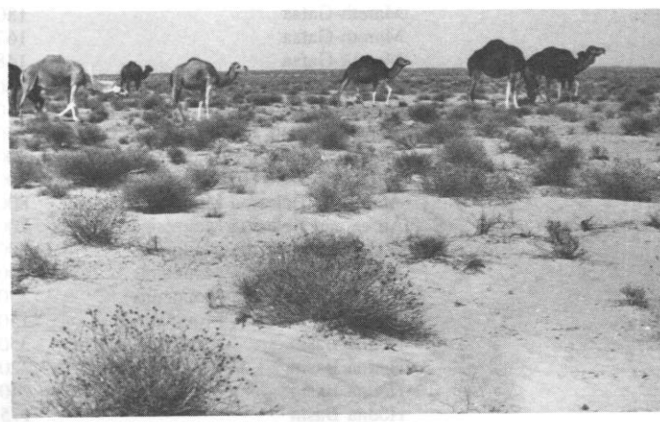
• The TLU is a conventional stock unit of a mature zebu weighing 250 kg (Boudet and Rivière 1968), where maintenance needs are 6.25 kg of DM or 2.8 FU and 156 g of digestible protein per day. The annual maintenance dietary needs of a TLU are thus 1,000 FU or 2,300 kg of DM and 57 kg of digestible protein (in round figures). A weight gain of 100 kg/year (300 g/day) or a production of 1,000 kg of milk would require 350 extra FU/year (0.95 FU/day) and 28 kg of digestible protein (75 g/day).

• Production from shrubs and trees has not been counted, since very little data is available; however, it is estimated to be qualitatively important during the dry season as a source of protein and vitamins. Thus the figures given in Table 2 are definitely conservative.

*Mediterranean Basin, Morocco Mid Atlas Mountains steppes North of Jebel Ayachi, west of Midelt (alt. 1600 m). Fairly shallow soil on quaternary limecrust. White sage steppe:* Artemisia herba alba, Artemisia mesatlantica.



*Mediterranean Basin, Eastern Morocco west of Berguent. Rainfall 200 mm. Silty soil on limecrust. Steppe of* Artemisia herba alba *and* Anabasis aphylla.



*Mediterranean Basin, Southern Tunisia, near Medenine. Rainfall 150 mm. Steppe of* Rhantherium suaveolens *and* Artemisia Campestris.

## Data Representativeness

In a given region, a given amount of rainfall is plotted against a single production figure. The latter is the average value of the various types of pastures balanced against their acreage whenever possible. Each production figure thus, refers to a geographic area of rangeland, including several range types of various values and may therefore be considered as representative of the geographic zone under consideration.

## Results

Table 1 gives the countries and areas where the studies were made, with corresponding production and rainfall data as well as references to the studies for the Mediterranean Basin. Table 2 gives the same information for the Sahelian and Sudanian zones of Africa. Yields are given only in feed units (Scandinavian) per hectare per year, but all calculations were made in four different unit measurements: feed unit (Scandinavian); consumable matter; total dry matter; and carrying capacity (sheep/ha/year, for the Mediterranean Basin and TLU/ha/year for the Sahelian and Sudanian zones of Africa). Four different kinds of units were calculated because readers may be more familiar with one system than another.

Table 1. Rainfall (mm) and rangeland production (FU/ha/year) figures for the Mediterranean Basin.

| Country | Area | Rainfall | Rangeland production | Author |
|---|---|---|---|---|
| 1. France | Montpellier | 900 | 900 | Long et al. 1967 |
| 2. Italy | Sardinia | 600 | 700 | Le Houérou 1968 |
| 3. Greece | Salonica | 500 | 200 | Liaccos & Mouloupoulos 1967 |
| 4. Syria | Wadi el Azib | 150 | 90 | Van der Veen 1967 |
| 5. Libya | Tripolitania | 500 | 430 | Le Houérou 1965 |
| | Sirte | 170 | 150 | Le Houérou 1965 |
| | Cyrenaica | 275 | 193 | Le Houérou 1965 |
| | Cyrenaica | 250 | 112 | Le Houérou 1965 |
| | Cyrenaica | 200 | 100 | Le Houérou 1965 |
| | Cyrenaica | 150 | 78 | Le Houérou 1965 |
| | Cyrenaica | 100 | 42 | Le Houérou 1965 |
| | Cyrenaica | 70 | 24 | Le Houérou 1965 |
| 6. Tunisia | South Medenine | 94 | 52 | Novikoff et al. 1975a |
| | Central and South | 400 | 363 | Le Houérou 1969a,b |
| | Central and South | 300 | 155 | Le Houérou 1969a,b |
| | Central and South | 200 | 110 | Le Houérou 1969a,b |
| | Central and South | 100 | 53 | Le Houérou 1969a,b |
| | Central and South | 50 | 25 | Le Houérou 1969a,b |
| | Central and South | 20 | 10 | Le Houérou 1969a,b |
| | Southern Gabes | 315 | 245 | Floret 1971; Floret et al. 1974 |
| | Mareth-Gafsa | 282 | 220 | Floret 1971; Floret et al. 1974 |
| | Mareth-Gafsa | 210 | 330 | Floret 1971; Floret et al. 1974 |
| | Mareth-Gafsa | 180 | 210 | Floret 1971; Floret et al. 1974 |
| | Mareth-Gafsa | 167 | 76 | Floret 1971; Floret et al. 1974 |
| | Mareth-Gafsa | 148 | 50 | Floret 1971; Floret et al. 1974 |
| 7. Algeria | Steppe Tadmit | 240 | 180 | Le Houérou 1968 |
| | Steppe Chellala Djelfa | 350 | 94 | Rodin et al. 1970 |
| | Steppe Chellala Djelfa | 250 | 102 | Rodin et al. 1970 |
| | Steppe Chellala Djelfa | 300 | 126 | Rodin et al. 1970 |
| | Steppe Chellala Djelfa | 300 | 144 | Rodin et al. 1970 |
| | Aures and Belezma Mountains | 800 | 467 | Van Swinderen 1973 |
| | Aures and Belezma Mountains | 700 | 300 | Van Swinderen 1973 |
| | Aures and Belezma Mountains | 500 | 240 | Van Swinderen 1973 |
| | Aures and Belezma Mountains | 350 | 165 | Van Swinderen 1973 |
| | Aures and Belezma Mountains | 250 | 126 | Van Swinderen 1973 |
| | Aures and Belezma Mountains | 150 | 50 | Van Swinderen 1973 |
| | Hodna Basin | 350 | 175 | Le Houérou 1971b |
| | Hodna Basin | 220 | 164 | Le Houérou 1971b |
| | Hodna Basin | 240 | 143 | Le Houérou 1971b |
| | Hodna Basin | 175 | 110 | Le Houérou 1971b |
| 8. Morocco | Atlas Mountains | 700 | 350 | Le Houérou 1971b |
| | Atlas Mountains | 500 | 250 | Le Houérou 1971b |
| | E. Steppes and Moulouya Valley | 300 | 157 | Loiseau & Sebillotte 1972 |
| | E. Steppes and Moulouya Valley | 300 | 65 | Loiseau & Sebillotte 1972 |
| | E. Steppes and Moulouya Valley | 200 | 49 | Loiseau & Sebillotte 1972 |

The first relationship sought is whether, within the limits of our study areas, range production may be considered as a linear function of average annual rainfall; equations are given in Table 3 (equations 1) for both areas with a correlation coefficient of 0.83 and a degree of freedom of 44. In both cases the linear regressions are highly significant ($p<0.001$).

These equations also confirm, at least for the Mediterranean Basin, (le Houérou 1964, 1969b; Evenari et al. 1971), the well-known fact that below an average annual rainfall of 50 mm, forage production may be considered as nil ($y = O = X = 48$ mm).

The extrapolation of the equations (1) for the Sahelian and Sudanian data is not fully satisfactory, since, when rainfall = 0, production is 16.9 FU. However, this value is very low and one may consider that our regressions go almost through the origin (no rainfall, no range production).

Although this relation seems reasonably satisfactory, it would mean that pasture yields would increase indefinitely as rainfall increases; however, this is not true since, as rainfall increases, other limiting factors such as soil infertility, water logging, temperature, lack of sunshine, etc. arise. For this reason we tried to find a curvilinear relationship between range production and rainfall. A second degree equation of the form

$$y = a+b_1x + b_2x^2$$

was first computed. Its correlation coefficient of 0.84, for the same degree of freedom, shows little improvement in respect to the above-mentioned linear regression.

Finally, an equation of the form

$$y = ax^b$$

(growth curve) was computed, having the values mentioned in Table 3 (equations 2). These equations have a correlation coefficient of 0.90 (for the Mediterranean Basin) and 0.89 (for the Sahelian and Sudanian zones), and a degree of freedom equal to 44, which is remarkably good. In other words, the logarithm of average annual range yields is a linear function of the logarithm of average annual rainfall.

Figures 2 and 3 show all the pairs of data as well as the linear and curvilinear regressions.

Now we can compare the curves calculated for the Mediterranean Basin and for the Sahelian and Sudanian zones. Are they identical? Is the relationship between rangeland production and rainfall the same in both areas?

**Table 2. Rainfall (mm) and rangeland production (FU/ha/year) figures for the Sahelian Sudanian zones.**

| Country | Area | Rainfall | Rangeland production | Author |
|---|---|---|---|---|
| 1. Senegal | Doli | 550 | 226 | Valenza & Diallo 1970 |
| | Nord | 300 | 139 | Valenza & Diallo 1972 |
| | Ferlo/south | 800 | 179 | Diallo 1968 |
| | Ferlo/east | 600 | 261 | Fotius & Valenza |
| | Dahra-Djoloff | 520 | 259 | Raynal 1964 |
| 2. Mauritania | Hodh | 420 | 288 | Boudet & Duverger 1961 |
| | Kaedi | 391 | 142 | Mosnier 1961 |
| 3. Mali | Niono | 550 | 280 | Boudet 1970 |
| | Mopti | 550 | 255 | Boudet 1972 |
| | Yanfolila | 1,400 | 528 | Boudet & Ellenberger 1971 |
| | Transect Bamako-Nara | 350 | 144 | Breman et al. 1975 |
| | Transect Bamako-Nara | 500 | 320 | Breman et al. 1975 |
| | Transect Bamako-Nara | 650 | 368 | Breman et al. 1975 |
| | Transect Bamako-Nara | 800 | 440 | Breman et al. 1975 |
| | Transect Bamako-Nara | 950 | 464 | Breman et al. 1975 |
| | Transect Bamako-Nara | 1,000 | 560 | Breman et al. 1975 |
| | Transect Bamako-Nara | 1,300 | 720 | Breman et al. 1975 |
| | Transect Bamako-Nara | 700 | 400 | Breman et al. 1975 |
| | Transect Bamako-Nara | 868 | 448 | Breman et al. 1975 |
| | Transect Bamako-Nara | 1,127 | 784 | Breman et al. 1975 |
| 4. Ivory Coast | Bodokro | 1,200 | 360 | Audru 1974 |
| | Toumodi | 1.400 | 443 | Boudet 1963 |
| 5. Upper Volta | Leo | 850 | 440 | Toutain 1974 |
| | Markoye/Dori | 400 | 203 | Gaston & Botte 1971 |
| | Tin Arkachem | 462 | 144 | Gaston & Botte 1971 |
| 6. Niger | Nord Gouré | 210 | 116 | Dalbroux 1972 |
| | Nord Sanam | 330 | 1,221 | Peyre de Fabregues 1963 |
| | Nord Gouré | 400 | 167 | Peyre de Fabregues 1963 |
| | Zinder | 300 | 120 | Peyre de Fabregues 1963 |
| | Sud Tamesna | 244 | 124 | Peyre de Fabregues 1963 |
| | Dallol Maouri | 750 | 268 | Boudet 1969 |
| | "Zone de Modernisation pastorale" | 200 | 64 | Peyre de Fabregues & Rippstein 1972 |
| | "Zone de Modernisation pastoral" | 345 | 109 | Peyre de Fabreques & Rippstein 1972 |
| | "Zone de Modernisation pastorale" | 460 | 186 | Peyre de Fabreques & Rippstein 1972 |
| | "Zone d'Utilisation" | 350 | 160 | Peyre de Fabreques & Rippstein 1972 |
| 7. Tchad | Wadi Rimé | 325 | 98 | Gillet 1961b |
| | Piste Betail | 400 | 213 | Peyre de Fabregues 1975 |
| | Zakouma | 575 | 288 | Gillet 1969 |
| | Kanem | 340 | 121 | Gaston 1965 |
| | Kanem | 550 | 222 | Gillet 1961 |
| | Zone Sahelienne | 615 | 240 | Gillet 1967 |
| | Logone/Chari | 1,200 | 238 | Audru 1966 |
| 8. Sudan | Southern Darfur | 700 | 245 | Hunting 1974 |
| | Northern Kordofan | 185 | 72 | Shepherd 1968 |

**Table 3. Linear and curvilinear regression equations of y variables and annual precipitation (mm) for the Mediterranean Basin and the Sahelian and Sudanian zones.**

| | Mediterranean Basin | | | Sahelian and Sudanian zones | |
|---|---|---|---|---|---|
| | y variable[1,2] | Equations | | y variable[1,2] | Equations |
| | | $y = a + bx$ | | | |
| (1) | FU | $y = -34.57 + 0.72x$ | (1) | FU | $y = 16.88 + 0.41x$ |
| (1a) | CDM | $y = -103.72 + 2.17x$ | (1a) | CDM | $y = 42.17 + 1.03x$ |
| (1b) | TDM | $y = -414.89 + 8.68x$ | (1b) | TDM | $y = 105.42 + 2.58x$ |
| (1c) | sheep | $y = -1,158 + 0.002x$ | (1c) | YBT | $y = 0.0169 + 0.0004x$ |
| | | $r = 0.83$; $n = 45$ | | | $r = 0.83$; $n = 45$ |
| | | $y = ax^b$ | | | |
| (2) | FU | $y = 0.32x^{1.09}$ | (2) | FU | $y = 0.422x^{1.001}$ |
| (2a) | CDM | $y = 0.972x^{1.09}$ | (2a) | CDM | $y = 1.057x^{1.001}$ |
| (2b) | TDM | $y = 3.890x^{1.09}$ | (2b) | TDM | $y = 2.643x^{1.001}$ |
| (2c) | sheep | $y = 0.001x^{1.09}$ | (2c) | YBT | $y = 0.0004x^{1.001}$ |
| | | $r = 0.90$; $n = 45$ | | | $r = 0.89$; $n = 45$ |

[1] Units per hectare per year.
[2] FU = Scandinavian feed unit; CDM = consumable dry matter; TDM = total dry matter; YBT = tropical livestock unit.

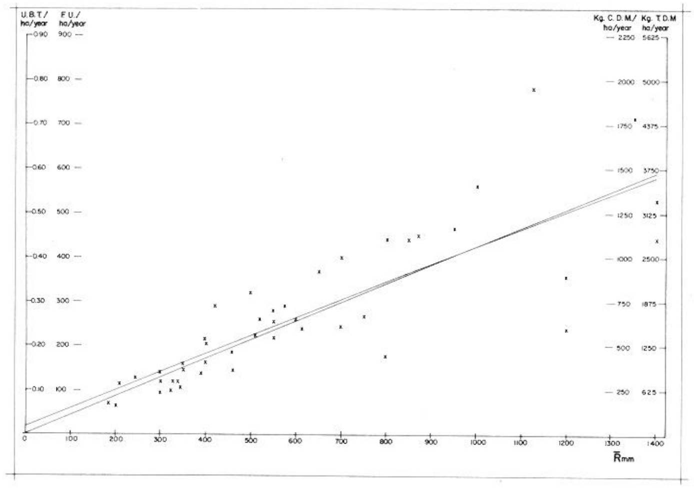



**Fig. 2.** *Sheep per hectare per year, Scandinavian forage units per hectare per year, consumable dry matter per hectare per year (kg), and total dry matter per hectare per year (kg) as related to annual precipitation (mm) in the Mediterranean Basin. Both linear and curvilinear relationships are shown.*

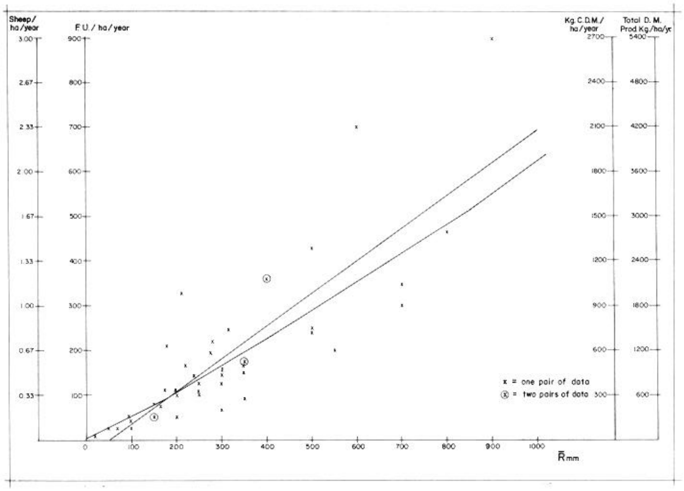



**Fig. 3.** *Tropical livestock units per hectare per year, Scandinavian feed unit per hectare per year, consumable dry matter per hectare per year (kg), and total dry matter per hectare per year (kg) as related to annual precipitation (mm) in the Sahelian and Sudanian zones. Both linear and curvilinear relationships are shown.*

To elucidate these questions, a covariance analysis was made comparing the data from the two areas as calculated in the linear regressions (comparison of the equations 1). This covariance analysis for the regressions expressed in FU/ha/year clearly shows that slopes and origins are significantly different:

comparison of slopes: $F_1^{86} = 13.70$ ($p<0.005$).

comparison of elevations: $F_1^{87} = 7.65$ ($0.005 < p < 0.010$).

Of course the same applies when the data are expressed in other units. Accordingly, no common regression can be calculated and no generalization can be made to cover both areas.

However, if a covariance analysis is made as between the exponential equations (equations 2) expressed in FU/ha/year, the conclusions are different:

comparison of slopes: $F_1^{86} = 0.57$ (n.s.).

comparison of elevations: $F_1^{87} = 10.62$ ($p<0.005$).

The comparison of the equations (2) is justified by the fact that in the regressions, the correlation coefficients and the part of the total variance due to the regression are greater than in linear regressions, so that the phenomena are better described and the curves are closer to the experimental figures.

The conclusion to be drawn from this analysis is that the relationship between range production and rainfall is similar in both cases, but that the level of production in the Sahel and Sudan is lower than in the Mediterranean Basin. In other words, rangeland production increases in the same proportion in both areas when rainfall increases; however, for a given rainfall, production is always lower in the Sahel than in the Mediterranean Basin. However, for the portion of the curves lying between the 300- and 400-mm marks, the application of the $t$ test gives the figure of 1.97, which is not significant at the $p=0.95$ level. In other words, for the lower part of the curves the difference between the Mediterranean Basin and the Sahel is not significant.

## Discussion

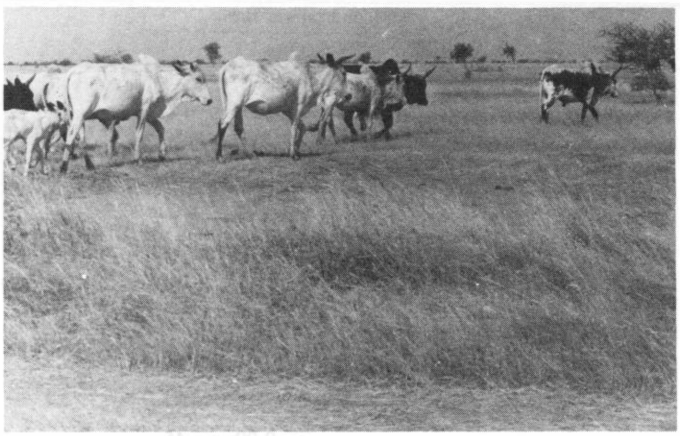
Dependence of range production upon rainfall is widely recognized. The subject was recently reviewed for the United States by Cook and Sims (1975), who show that variability in range production is closely related to variability in rainfall but that variability in the former is generally greater than in the latter, a fact that has been observed also in the Mediterranean Basin.

In comparing the present relation (equation 2) with those found by other authors, one should point out that Condon (1968) studied an area of 350,000 km² in western New South Wales, where detailed statistics of livestock numbers over 46 counties averaging 7,700 km² were available; his curve is a parabola fitting two different equations:

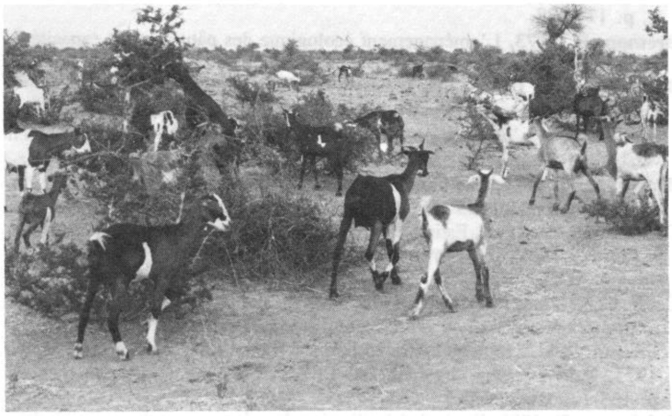
$$y = 0.5\,x^2 + 0.38x \text{ from 0 to 250 mm}$$
$$y = 0.2\,x^2 + 2.7x + 15.5 \text{ from 250 to 460 mm}$$

where y is grazing capacity in sheep per 100 acres (40.5 ha) and x is average rainfall per annum (inches). His figures are very close to those that we found in the Sahelian and Sudanian zones of Africa for areas with over 250 mm of rainfall, but about 40–50% lower than ours below the 250-mm isohyet; they are much lower than those that we found in the Mediterranean Basin.

Walter and Volk (1954) have given production for the "veldt" of South Africa of 8 kg DM/ha/mm of rainfall, a figure about 3 to 4 times higher than that for the Mediterranean range-



*Sahel zone, Northern Mali near Nampala. Rainfall 400 mm. Fairly good pasture with* Balanites aegyptiaca, Acacia senegal Shoenfeldia gracilis *and* Aristida mutabilis.



*Sahel zone, near Sokolo, Mali. Degraded rangeland heavily browsed by goats* Bauhinia rufescens, Piliostigma reticulata, Grewia tenax.

lands (le Houérou 1969b). Walter (1954) ex Boudet 1976, finds the equation:

$$y\ (DM) = 10x - 250$$

which corresponds to yields 3 to 5 times higher than we have observed.

Leith, ex Dyson-Hudson (1975), found an average of 20 kg DM/mm of rainfall in arid areas, which is about 6 to 10 times higher than our figures. Novikoff et al. (1975b) found in southern Tunisia on sandy soils an average of 2 kg DM/ha/year per mm of rain in the interval 15–182 mm/year over three consecutive years (1973, 74, and 75). These values are in good agreement with the figures we have observed in the Mediterranean Basin.

Since none of the foregoing authors have given their methods of calculations, the correlation coefficients, or the level of significance of the regressions they found, the accuracy of their findings cannot be assessed.

In the curve of carrying capacity estimates in relation to rainfall given for the Sahel by Seifert and Kamrany (1974) and Picardi (1975), the values are slightly below ours. For instance, under long-term sustained range yield conditions:

| | | |
|---|---|---|
| 30 ha per Animal Unit (450 kg) | or 16.50 ha per TLU under | 250 mm |
| 15 ha per Animal Unit | or 8.25 ha per TLU under | 500 mm |
| 7.5 ha per Animal Unit | or 4.15 ha per TLU under | 1,000 mm |

The authors reckon that the dietary needs of one Animal Unit are ideal, i.e., 2,500 FU/year, which corresponds to 1,375 FU/TLU/year. For the same amount of rainfall and with a weight gain of 100 kg/year (300 g/day) (1,350 FU/TLU/year), our curve (equations 2) gives the following figures:

| | |
|---|---|
| 250 mm | 12.72 ha/year/TLU |
| 500 mm | 6.35 " " " |
| 1,000 mm | 3.17 " " " |

The figures given by the above-mentined authors are thus comparable to ours, but 23% lower, which is extremely good, keeping in mind that Seifert and Kamrany's and Picardi's curves, are based upon *estimates*, whereas ours are based on *measurements*.

For the Sahel and Mali, Breman (1973) and Breman et al. (1975) give total primary production and palatable production figures that differ very little in value. This in itself is surprising, since most specialists on the Sahelian rangelands consider that only 30 to 40% of the total primary production can be consumed during the dry season, and 60 to 80% during the rainy season. If we apply to Breman's figures the same consumption rate that we used (40% of total primary production), we will find that his figures are very close to our own. Nevertheless, the relationships shown are mathematically unusual. Two straight line equations were calculated: (1) for rainfall between 100 and 400 mm and (2) for rainfall above 400 mm.

No identifications are given of the correlation coefficient or of the level of significance of these regressions; moreover, the two regressions are linked by an undetermined "S" shaped curve so as to give an impression of continuity to the phenomenon.

Another somewhat surprising fact is that if one were to extrapolate the first equation below the given limit of validity of 100 mm, one would find that when rainfall reaches zero, production appears to remain on the order of 720 kg/ha/year.

The curve we have presented here is also subject to criticism in spite of there being a good correlation coefficient. In fact, the number of pairs is not always the same for each rainfall value; for instance, much more data are available for rangelands below the 400 mm isohyet, than for above. This fact may decrease the precision of our calculations for areas having relatively high rainfall. Moreover, we must remember that the complete relationship between average rainfall and range production includes two curves: an exponential regression (studied here), followed by an asymptotic regression characterizing high rainfall areas. As a matter of fact, graziers know that above 1,200 to 1,500 mm, the increase of production on rangelands is almost negligible; but we still lack scientific evidence for this.

For the exponential part of the phenomenon, the correlation we found can be considered excellent. This is probably because management practices are more or less homogeneous (no rotation pattern, general overgrazing). It is also due to the fact that soil conditions have been equalized by using global figures over large areas that represent various land systems and integrate their various components. Nevertheless it is obvious that under given rainfall conditions, yields may vary as much as 1 to 5 (exceptionally 1 to 10) according to soil conditions and range types. On the other hand, different management practices under similar climatic and soil conditions may induce variations in yields of the same order of magnitude (usually 1 to 5; exceptionally 1 to 10), as pointed out by many athors all over the world.

## Conclusions

Roughly speaking, one may say that each millimeter of rainfall in the Mediterranean Basin produced 4 kg of above-ground phytomass, or 2 kg of consumable dry matter, or 0.66 feed units; in the Sahelian and Sudanian zones of Africa, these figures drop to 2.5 kg, 1 kg, and 0.40 feed units, respectively. One can also still consider as more or less valid the old empiric statement that, in the Sahel, in the interval 100–1,500 mm, one needs as many hectares per head of cattle as there are months in the dry season. (Dry season here is taken to mean a period having less than 50 mm of rainfall/month.)

From comparison of equations (2) we can deduce that rainfall efficiency is different in the two areas under examination, the difference in net production (feed units per hectare) being on the order of 50% in favour of the Mediterranean Basin.

These differences between the two regions may be due to several factors:

- Shrub and tree production in the Sahel has not been taken into account.
- Rainfall distribution is different in the two regions, and the dry season is much longer in the Sahel. Rains occur during the

cool season in the Mediterranean climate, when plant water requirements are lower, whereas in the Sahel they occur in summertime, when water demand is high.

- Potential evapotranspiration for a given amount of rainfall is about 50% higher in the Sahel.
- Soils seem to be poorer in the Sahel, especially as regards their nitrogen and phosphorous content.
- Soils seem to be poorer in the Sahel, especially as regards their nitrogen and phosphorus content.
- Vegetation is entirely different in the two regions. Mediterranean rangelands are based on perennials that react to any substantial rain and can make use of deep, moist layers in the soil; whereas Sahelian ranges are based mainly upon annuals with very short life cycles and shallow root systems.

To be able to draw general equations valid for large ecological zones having an homogenous climate, we need much more data, especially for the high rainfall areas in both the Mediterranean and the Sudan. From practical experience, we suspect that production does not increase indefinitely with rainfall; but we cannot give evidence for it because we lack sufficient data from higher rainfall zones.

Finally, one should note that forage shrubs and trees were not counted in range production in the Sahel, nor was production from depressions benefitting from runoff; one, therefore, might expect our figures to be on the low side. Some correction to the above, however, is brought about, by the fact that most of the figures used were collected in the field during the late 50's and 60's while rainfall (and therefore range production) was above long-term averages. On the other hand, Sahelian rangelands were heavily degraded during the 1969–73 drought, and their present production is likely to be lower than in the 60's. For these reasons, the figures given in this paper are likely to be very close to long-term averages.

It is hoped that the definition of the complete relationship between rangeland production and average annual rainfall will help in the evaluation of forage resources and in the modeling of livestock production systems.

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## THESIS: NORTH DAKOTA STATE UNIVERSITY

**Growth, Production, and Browse Utilization Characteristics of Serviceberry (*Amelanchier alnifolia* Nutt.) in the Badlands of Southwestern North Dakota,** by Dean Elder Williams. MS, Botany. 1976.

Growth, production, and browse utilization characteristics of serviceberry (*Amelanchier alnifolia* Nutt.) were studied in the badlands of southwestern North Dakota during 1971, 1972, and 1973. The objectives of this study were to provide the information required to make predictive statements on the above characteristics as wll as for age and form classes on a site basis. Analysis of both shrub canopy cover and herbaceous understory, as well as soil cores, was carried out from each site. Results from the soil cores were highly variable and inconclusive.

All shrubs studied were assigned Dasmann age and form classes. More than two-thirds of the shrubs were in young or mature age classes and in form classes that showed little or no hedging, indicating that serviceberry had not been subjected to harmful browsing pressure.

Mean average twig length and average total annual growth appear to be closely related to age class and, to a lesser extent, form class. Growth decreased from 1971 through 1973. Growth of serviceberry is 87% completed by June 13, after which the growth curve levels off somewhat. The combined weight yields, from all sites were 172.4 lb/acre, 65.7 lb/acre, and 48.5 lb/acre, for 1971, 1972, and 1973, respectively. As in growth, there is a definite relationship between age and form classes and the total yield. Again there is evidence of a decrease in production from 1971–1973. Average composition of total yield for the three years is 82% for the leaves and 18% for the twigs.

Utilization of current growth of serviceberry was 11% and 15% for the winters of 1971–72, and 1972–73, respectively. Browsing pressure is apparently increasing but not to a level that may be judged to be harmful. Highest utilization recorded at any site was 31%. Percent utilization was directly related to the degree of hedging. Serviceberry was generally dominant in the shrub overstory, while the understory composition was varied. Vegetation reproduction of serviceberry is accomplished mainly through root sprouting. Both growth and production appear to be on the decline; this is observed to be due mainly to a rust infection and a combination of environmental influences and increased browsing pressure.