Rainfall Patterns in the Central Negev Desert*

L. SHANAN,** M. EVENARI*** and N. H. TADMOR***

THE Bible (Gen. 41:53, 54) credits Joseph with forecasting a climatic fluctuation of 'seven years of plenteousness' followed by 'seven years of dearth' and so indicated that already in biblical times the occurence of wet and dry periods had been noted in Egypt, Canaan and the Negev. This problem of rainfall variability in the Negev has since been discussed by many historians and scientists (Amiran, 1963; Huntington, 1911; Newmann, 1960; Reifenberg, 1955; Rosenan, 1963). The historian is primarily interested in its effect on the rise and fall of ancient civilisations, while the scientist is concerned with present and future agricultural development. The Negev desert in southern Israel may serve as a compact crucible for the study of rainfall variability both from historical and modern aspects.

THE STUDY AREA

The Negev desert covers about 1,000,000 hectares (Fig. 1) and is a link between the Sinai peninsula in the west and the deserts of Arabia in the east. The Negev highlands lie 60-80 km. from the Mediterranean coast and consist of a series of parallel anticlines with elevations ranging from 450 to 1000 m. above sea level and have an annual rainfall varying between 50 and 150 mm. (Climatological Normals, 1953). The general physiographic conditions and plant habitats (Tadmor and Hillel, 1956) prevailing in the area are summarised in Table I.

However, despite these very arid conditions, extensive remains of ancient agriculture and habitation are found all over the area (Evenari et al., 1961).

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** Consultant Water Engineer, Tel Aviv.
*** Department of Botany, The Hebrew University of Jerusalem.

The ancient town of Eboda ('Avdat, 'Abda) lies in the centre of the highlands and on the fringes are ancient Mampsis (Kurnub), Subeita (Shivta, Sbeita) and Nessana (Niṣanah, 'Auja el-Ḥafîr). Large scale terracing, flood water diversion and water harvesting projects were constructed by the ancient settlers, and the remains of their intensive agricultural projects cover 10,000-15,000 hectars (Evenari et al., 1961; Shanan et al., 1958, 1961). These ancient projects date back at least to the 9th and 8th centuries B. C., with the peak of development during the Nabatean-Roman-Byzantine era, 300 B. C. to about A. D. 600 (Evenari et al., 1961). All these ancient agricultural development, as well as part of the domestic and town water supplies of the inhabitants, were based on the exploitation of surface runoff from small and large watersheds, and have been termed 'runoff farming' (Evenari et al., 1961, 1963).

In 1958/59, two of these ancient runoff farming systems in the Negev highlands were reconstructed (Evenari et al., 1963, 1964), one at Shivta and the other at 'Avdat (Fig. 1). A research programme was initiated to study rainfall, runoff and surface hydrology of the area, the agricultural use of the runoff water, and plant ecology. This paper deals with rainfall and precipitation data collected to date. The records of five consecutive years were combined with other Negev rainfall data to determine average annual rainfall, monthly rainfall distribution, number of rainy days, and maximum rain intensities for the area. These estimates, together with dendrochronological data obtained previously by A. Fahn and collaborators (1963), were used to assess long-term variations in the rainfall of the Negev highlands.

Rainfall in the Negev highlands occurs only in the winter months, with 90% of the rain falling between early November and late March. Rainfall is generally associated with the passage of storm fronts connected with a depression centered in the Cyprus area. As the fronts move south and southwest towards Beersheba and into the highlands, they approach the high divide of the Miṣpeh Ramon ridge with elevations of 950-1000 m. above sea level. This orographic rise induces a relative increase in the amount of rain but most of the precipitation is usually expended by the time it has reached the high divide. Rainfall south of the Ramon ridge is extremely erratic and varies from 10 mm. to 50 mm. a year. Heavier rainfall south of the ridge may occur occasionally when a barometric depression lies far south of Cyprus and over the Sinai peninsula (Ashbel, 1951).

TABLE I. OUTLINE OF ECOLOGICAL CONDITIONS IN THE NEGEV HIGHLANDS

Habitat	Percent of the highlands area	Soils	Plant associattions	Water available for plant growth (depth in mm.)
Rocky slopes	80-90%	Shallow, gravelly, saline, 0-50 cm. depth	Artemisietum herbae—albae; and Zygophylletum dumosi	10-60
Loessial plains	10-15%	Deep loessial soils; salts leached to 30 cm. or more	Anabasidetum hausknechtii; and Haloxylonetum articulati	20-50
Wadi beds	3-5%	Deep loessial soils, or gravel and silt fill	Retama roetam assoc., with many annuals	Gravelly wadis, 60-100 Loessial wadis, 400-600

TABLE II. SUMMARY OF PRECIPITATION RECORDS FOR THE NEGEV HIGHLANDS AS COMPARED TO THOSE FOR BEERSHEBA

Station	Recording Period	Average rainfall P (mm.)	Max. annual M (mm.)	Min. annual m (mm.)	Quotient of variation a*	% Range of variation, VR*	% Relative variability Vr*	Coefficient variability Vc*
Revivim	1943-63	101	178	33	5.3	143	32	38
Beersheba	1943-63	180	293	42	7.0	133	26	33
Sedeh Bôqer	1951-63	76	137	23	6.0	150	39	45
Beersheba	1951-63	168	293	42	7.0	141	34	41
ʻAvdat	1960-65	95	159	28	5.7	137	56	60
Beersheba	1960-65	202	339	42	8.0	147	50	54
Mamshit	1942-48	135	191	58	3.3	96	28	37
Beersheba	1942-48	195	291	108	2.8	94	28	30
Beersheba	1920-65	195	339	42	8.0	152	30	35

* See text for explanation.

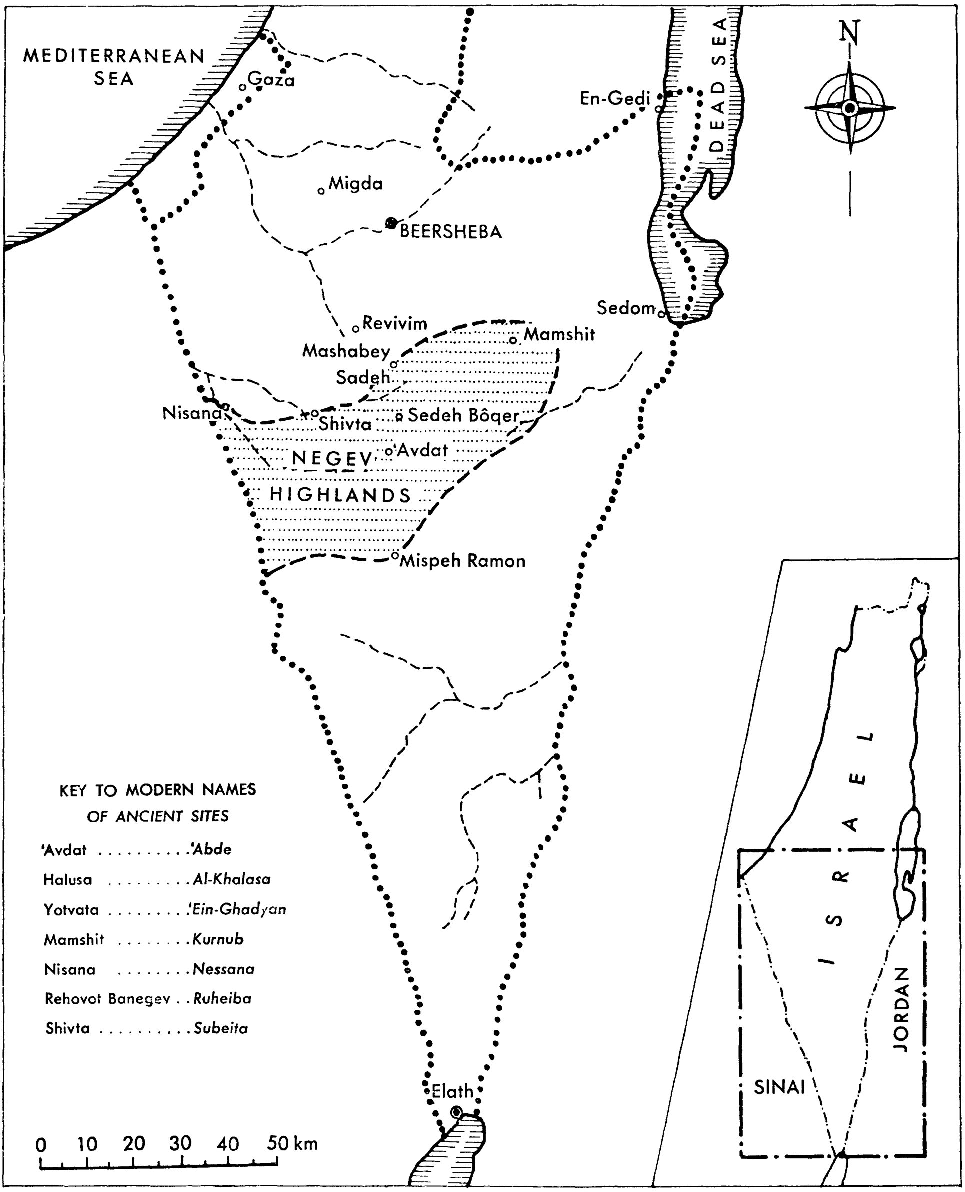

Fig. 1. Map of the Negev.

EXISTING RAINFALL RECORDS

Reliable records of the Israel Meteorological Service are available for the Central Negev highlands for 'Avdat (1960/61-1964/65), Sedeh Bôqer (1951/52-1964/65), Revivim (1942/43-1964/65), Mashabey Sadeh (1944/50-1964/65), and Mamshit (1942/43-1947/48) on the fringes of the area. All these records are short and also of a fragmentary nature. A reliable and relatively long-term record of 45 years (1920/21-1964/65), exists for Beersheba, situated about 50 km. distant from and about 300-400 m. lower than the highlands. Fragmentary records existing for Bir 'Asluj and Niṣanah were not included in this study. A summary of the pertinent records is given in Table II.

To the casual observer, the winter storms appear to be erratic and irregular over the whole northern Negev and the Negev highlands. However, a closer and detailed examination of the records shows a relationship between stations for any one storm period.

a) *Variability of the Annual Rainfall.* The following standard measures of annual rainfall variability (Katznelson, 1956a) were calculated for each station:

Quotient of variation, $Q = \frac{M}{m}$

% Range of variation, $VR = \frac{M - m}{P} \times 100$

% Relative variability, $V_r = \frac{1}{n} \Sigma_{d_i} \times \frac{100}{P}$

Coefficient of variation, $V_c = \frac{100}{P} \sqrt{\frac{1}{n} (\Sigma_{d_i})^2}$

where

M = max. annual rainfall for the period
m = min. annual rainfall for the period
P = average annual rainfall for the period
d_i = deviation (from the average)
n = number of years in the period.

Table 2 shows that the four variability indices of all stations are similar to those of Beersheba for all periods of observation, indicating that the rainfall at Beersheba can be regarded as a good indicator of the overall rainfall characteristic of the highlands.

Closer inspection of Table II shows that the percent range of variation, the percent relative variability and the coefficient of variation are generally slightly higher for the highlands than for Beersheba. Keeping this in mind, and considering the 45-year indices for Beersheba (Katznelson, 1956a), the following long-term average indices are suggested for the highlands:

Quotient of variation, 8.0;
% Range of variation, 155;
% Relative variability, 33;
Coefficient of variation, 37.

b) *Mean, Maximum and Minimum Annual Rainfall.* Fig. 2 compares the cumulative (mass) rainfall of four stations in the Negev highlands and that for Beersheba for corresponding periods. When individual years are compared, there is a consistent relationship between the rainfall at Beersheba and every station studied; this can be expressed as:

$$R_A = a + KR_B$$

where

R_B = rainfall at Beersheba;
R_A = rainfall at any station;
a and K = constants.

Values of K as calculated from annual data are:

Station	Period and No. of years of observation		K	r	SD
'Avdat	1960/65	(5)	0.49	0.969	19.2
Sedeh Bôqer	1951/65	(14)	0.48	0.938	16.2
Shivta	1960/66	(6)	0.46	0.974	14.2
Mashabey Sadeh	1949/65	(14)	0.52	0.981	9.8
Bir 'Asluj	1940/50	(9)	0.51	0.891	17.4
Revivim	1943/65	(21)	0.54	0.934	16.4

r = the coefficient of correlation between Beersheba rainfall and any station;
SD = the standard deviation of any station rainfall about the regression.

The values of a, on the other hand, for no station were significally different from zero; i.e. these regressions may be considered to pass through the origin of the axes.

The values of K indicate that the average annual rainfall is 20% higher at the western fringes of the Negev highlands than in the centre. This is in conformity with the general pattern of the decreasing rainfall reflecting the

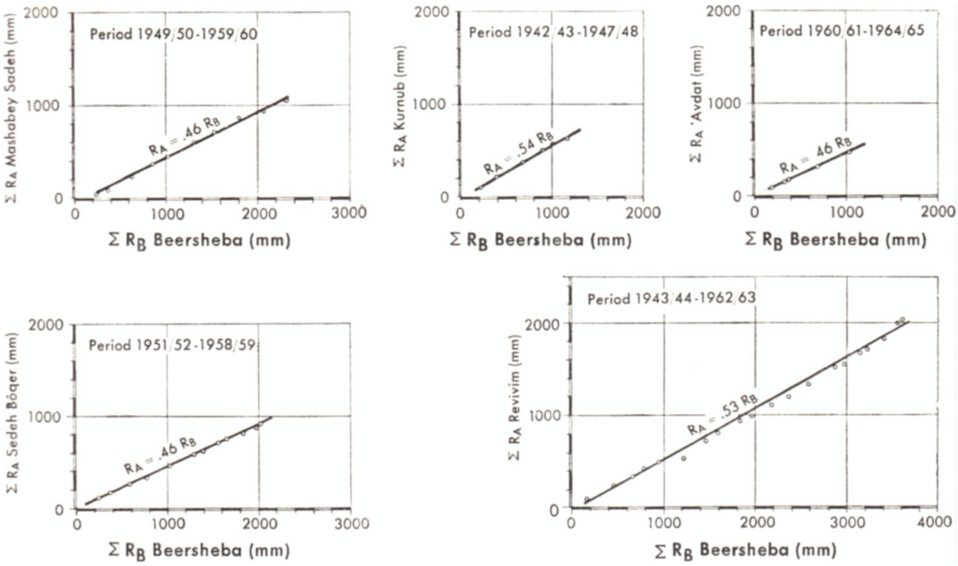

Fig. 2. Cumulative annual rainfall, comparison between Beersheba (ΣR_B) and stations in the Negev highlands (ΣR_A).

degree of continentality—the distance from the Mediterranean (Climatological Data, 1952). The centre of the Negev highlands is situated some 200-300 m. above the foothills, and the degree of continentality appears to have a greater effect than the orographic conditions, since the annual rainfall decreases in the centre of the area despite the rising elevation.

The value of K = 0.48 can be considered as representative of the Negev highlands, and the general relationship for the annual rainfall of the Negev highlands will be

$$R_A = 0.48\ R_B \qquad (1).$$

Based on the 45-year record of Beersheba, eq. 1 gives the following estimates:

Maximum predicted $R_A = 339 \times 0.48 = 162$;
Minimum predicted $R_A = 42 \times 0.48 = 20$;
Mean annual $R_A = 198 \times 0.48 = 94$.

This indicates that the extremes already recorded in the highlands at 'Avdat (159 mm. maximum and 28 mm. minimum, Table, II) are close to the expected deviation over a 45-year period.

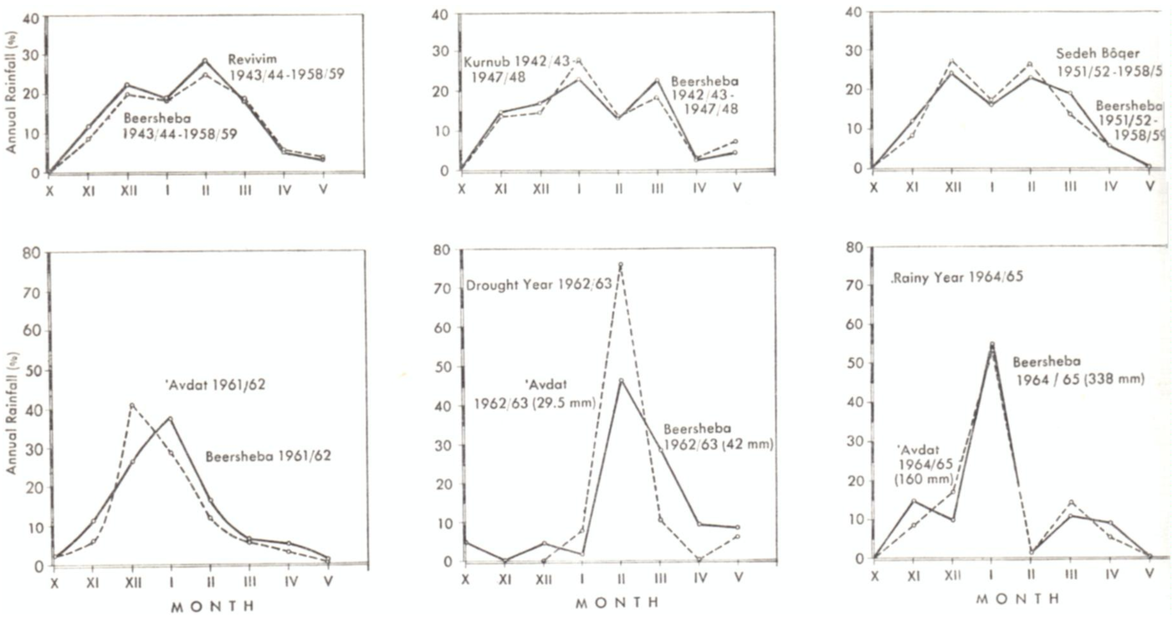

Fig. 3. Average monthly rainfall, comparison between Beersheba and stations in the Negev highlands.

c) *Monthly Rainfall.* The monthly rainfall distributions for Revivim, Mamshit, Sedeh Bôqer, and ʿAvdat were compared to those of Beersheba during the same observation periods (Fig. 3). The monthly rainfall distribution for all stations was very similar to that of Beersheba. This similarity is true even for the extreme drought year (28 mm.) and the extreme wet year (159 mm.) at ʿAvdat (Fig. 3).

The monthly distribution of rainfall as recorded in Beersheba may therefore be used to estimate rainfall distribution for the Negev highlands. Based on the 30-year (1921-1950) long-term average of Beersheba (Katznelson, 1956b) the monthly rainfall distribution and percent cumulative monthly rainfall for the Negev highlands is shown in Figs. 4a and b, respectively. Two-thirds of the annual rainfall falls in December, January and February, and over 90% can be expected from the beginning of November through the end of March. Furthermore, over 60% of the total annual rain can be expected to fall before the start of January. The cumulative seasonal rainfall (Fig. 4b) can be expressed as:

$$P = -7 + 107e^{-\left(\frac{230-n}{130}\right)^2}$$

where

P = cumulative % of rainfall;

n = number of days after the first day of September.

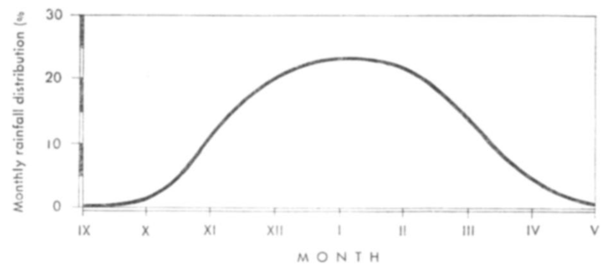

Fig. 4a.
Monthly rainfall distribution (in %) in the Negev highlands.

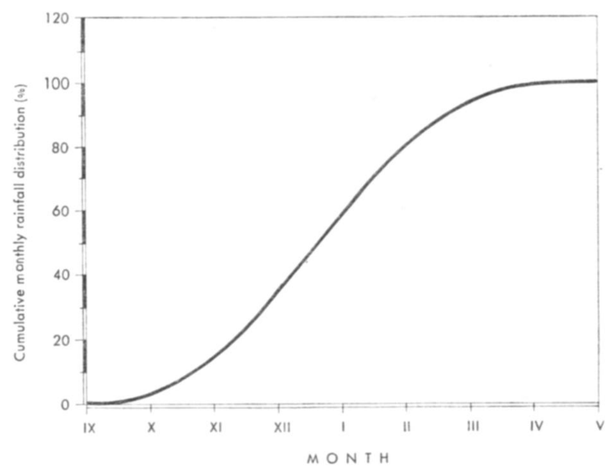

Fig. 4b.
Cumulative monthly rainfall distribution (in %) in the Negev highlands.

d) *Mean Number of Rainfall Days per Year.* Table III shows the total number of rainfall days per year for Mamshit, Sedeh Bôqer, 'Avdat and Beersheba for comparable periods, as well as the breakdown of the rainy days according to depth of rainfall per day.

It now becomes apparent that the number of rainfall days in the Negev highlands is about 40-50% of those in Beersheba with an average of about 45%. Furthermore, the breakdown of the rainfall is very similar in the highlands to that of Beersheba, with about 15% of the rainfall days yielding more than 10 mm.

Based on the 15-year averages of Beersheba (Katznelson, 1956b), the following expression for the Negev highlands was developed for the number of rainy days ≧ to a given daily rainfall:

$$N = 13.3 \times 1.1^{-P_D} \times P_D^{-0.78}$$

where

N = number of rainy days ≧ to a given daily rainfall;
P_D = given daily rainfall.

TABLE III. NUMBER OF RAINFALL DAYS IN BEERSHEBA AND THE NEGEV HIGHLANDS

Station	Recording period	Cumulative number of rainfall days for period, according to depth (mm./day): 0-2.9 mm.	3.0-10.0 mm.	>10.0 mm.	Total	% for period according to depth (mm./day): 0-2.9 mm.	3.0-10.0 mm.	>10.0 mm.	Average number of rainfall days/years	% days/year, Station/Beersheba
Mamshit	1941/2-1947/8	46	56	16	118	39	46	15	16.9	46
Beersheba	1941/2-1947/8	126	93	40	259	46	39	15	37.0	
Sedeh Bôqer	1951/2-1958/9	100	38	18	156	64	24	12	19.5	52
Beersheba	1951/2-1958/9	151	81	49	281	54	29	17	35.0	
'Avdat	1960/1-1964/5	41	33	13	87	47	38	15	17.4	42
Beersheba	1960/1-1964/5	116	58	34	208	56	28	16	41.0	

This relationship is shown in Fig. 5 and gives the following figures for Beersheba and the Negev highlands:

	Beersheba	Negev highlands
Average number of rainfall days/year (> 0.1 mm.)	35.1	15.8
Average number of rainfall days/year (> 1 mm.)	27.3	12.1
Average number of rainfall days/year (> 10 mm.)	5.9	2.7
Average number of rainfall days/year (> 25 mm.)	1.2	0.5
Average number of rainfall days/year (> 50 mm.)	0	0

These estimates suggest that there is an average of 16 rainy days per year in the Negev highlands, with 12 having rainfall greater than 1 mm., and three days greater than 10 mm. A rainfall of 25 mm./day is expected no more than once every two years and a rainfall of 50 mm./day is highly improbable (Fig. 5).

e) *Rainfall Intensities.* Fig. 6 shows the maximum rainfall intensities for 'Avdat, in the central highlands, during the wet year of 1963/64, and Fig. 7 shows the maximum intensities during 1964/65 for 'Avdat and for Migda, which lies about 20 km. north-west of Beersheba (Fig. 1).

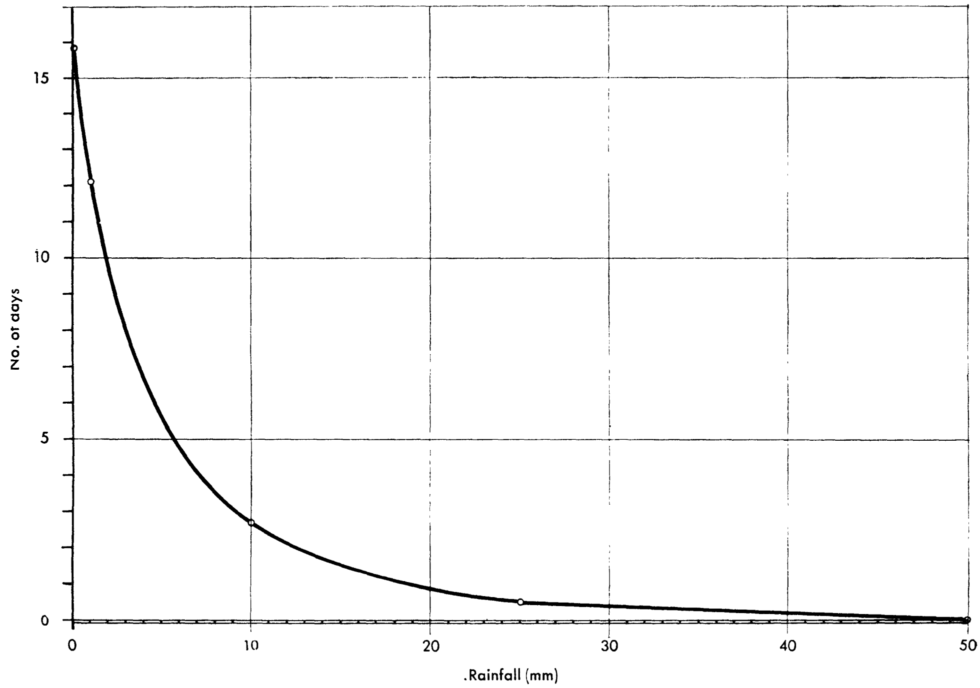

Fig. 5. Number of rainy days per year greater or equal to given rainfall in the Negev highlands.

These maximum intensity records may be expressed as:

$$I = K t^{-0.5}$$

where

I = rainfall intensity, in mm./hr.;
t = duration of rain, in minutes.

The maximum intensities recorded at 'Avdat during the 5-year period of 1960-65 have a similar slope (Fig. 6). This expression seems to be general, as the maximum intesity for the whole of Israel (Katznelson, 1955) takes the same form (Fig. 6). It may be concluded that the annual rainfall intensities of the Central Negev highlands are similar to those of the Beersheba area and that the general intensity curve for the Central Negev highlands is parallel to, but lower than the overall intensity curve for Israel (Fig. 6).

The equation $I = 60\,t^{-0.5}$ (Fig. 6) for the year 1964/65 probably has a 3-5-year period of return. For a 24-hour rainfall it gives a value of I = 1.35 mm/hour, i.e., about 31 mm./day—a figure that is in good agreement with the previous estimate arrived at independently that a rainfall greater than 25 mm. but less than 50 mm. is expected about once every two years. The period of return

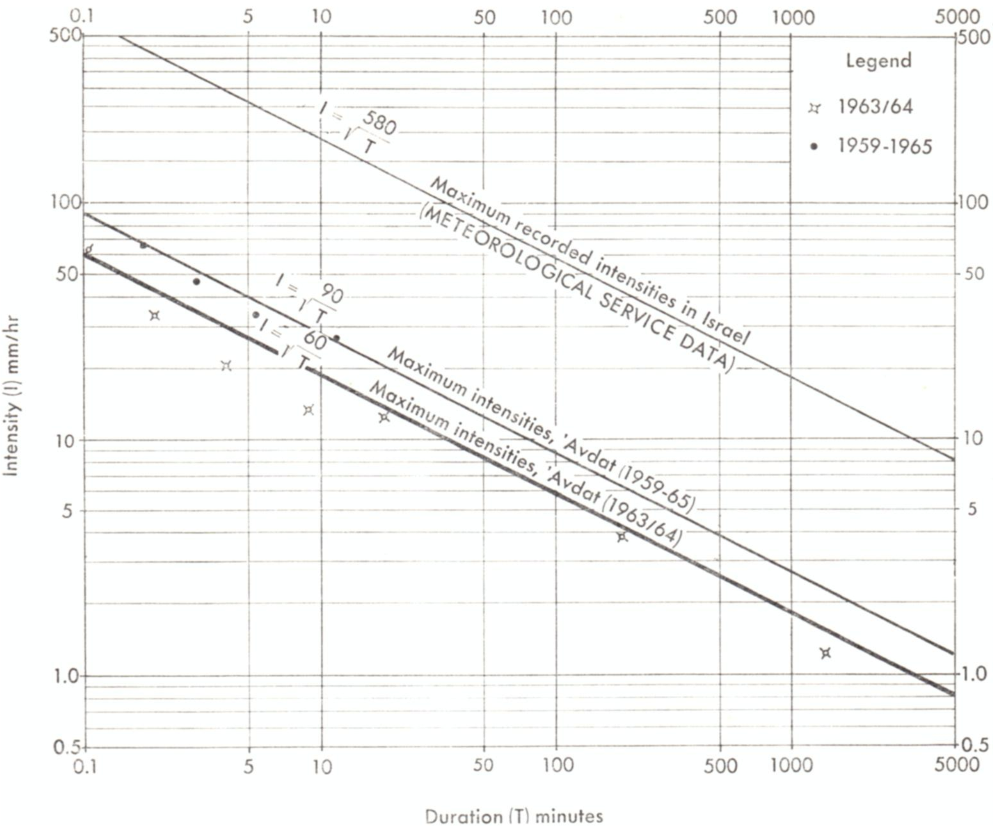

Fig. 6. Maximum rainfall intensities in 'Avdat (1963/4 and 1959-65).

of the equation $I = 90\ t^{-0.5}$ (Fig. 6) cannot be estimated but is probably in the vicinity of the 10-20-year frequency.

All these records show that with very few exceptions (Katznelson, 1959) the maximum intensities of the rainfall in the Negev highlands are much lower than in the rest of Israel. In fact, the storms of the Negev have relatively low intensities. This confirms the opinion held by Katznelson (1959) that contrary to general belief, it is not a high rainfall intensity that causes the sudden flash floods in the desert.

COMPARISON BETWEEN ANNUAL RAINFALLS IN JERUSALEM AND BEERSHEBA

Fig. 8 shows the four-year moving average annual rainfall of Jerusalem (Rosenan, 1955) and Beersheba for the period 1920-1950. It is clear that there is no relationship between the records. Extremely wet periods in Jerusalem

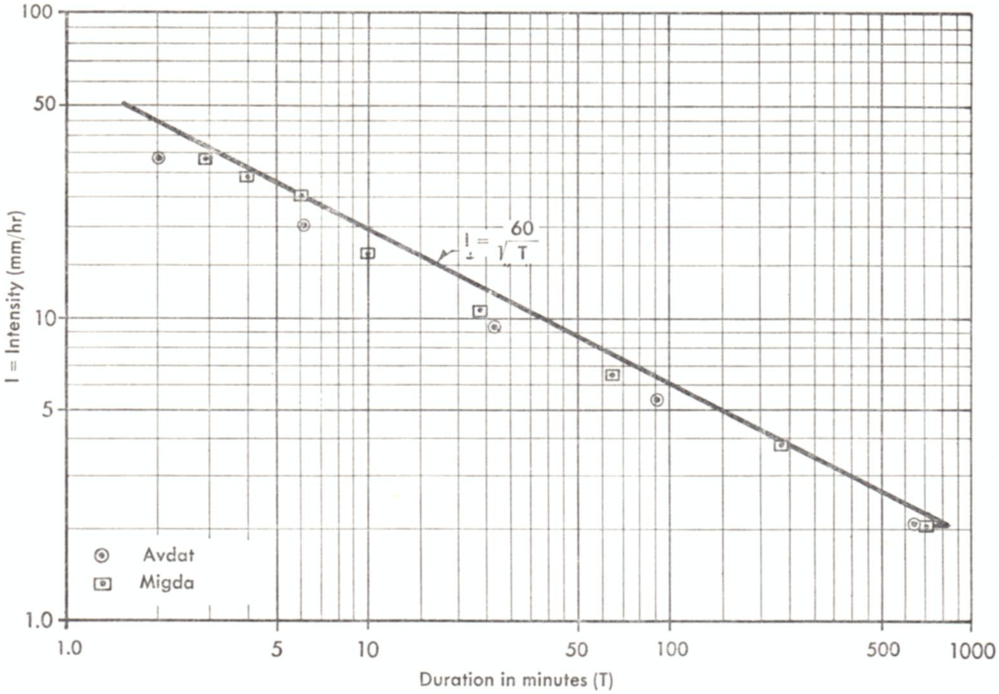

Fig. 7. Maximum rainfall intensities at 'Avdat and Migda (1964/5).

(1937-1942) may be dry or relatively dry in Beersheba and vice versa (1930-36). A similar reversal in climatic variations in other desert regions was found by Callender (1961) and also by Dubief (1963), who showed an inverse relationship between rainfall in the littoral and in dry inland areas in North Africa.

LONG-TERM ANNUAL MEANS AND CYCLES

In 1959-1962 Fahn et al. (1963) investigated the annual growth rings of *Zygophyllum dumosum* shrubs and *Pistacia atlantica* trees growing in the Negev highlands. They concluded that *Zygophyllum* shrubs are especially suitable for dendrochronological studies for the following reasons: "1) the annual ring is produced in the rainy season, i.e., from the end of December till end of April; 2) it (i.e., *Zygophyllum dumosum*) has distinct annual rings; 3) the rings show distinct fluctuations in width; 4) it (i.e., *Zygophyllum dumosum*) grows on hills and slopes and therefore its water source is influenced by precipitation only; 5) it is very common in the Negev; and 6) seventy percent of the specimens examined exhibited similar growth ring curves" (Fahn et al., 1963, p. 298). They concluded that the *Zygophyllum dumosum* shrubs indicated a 100-

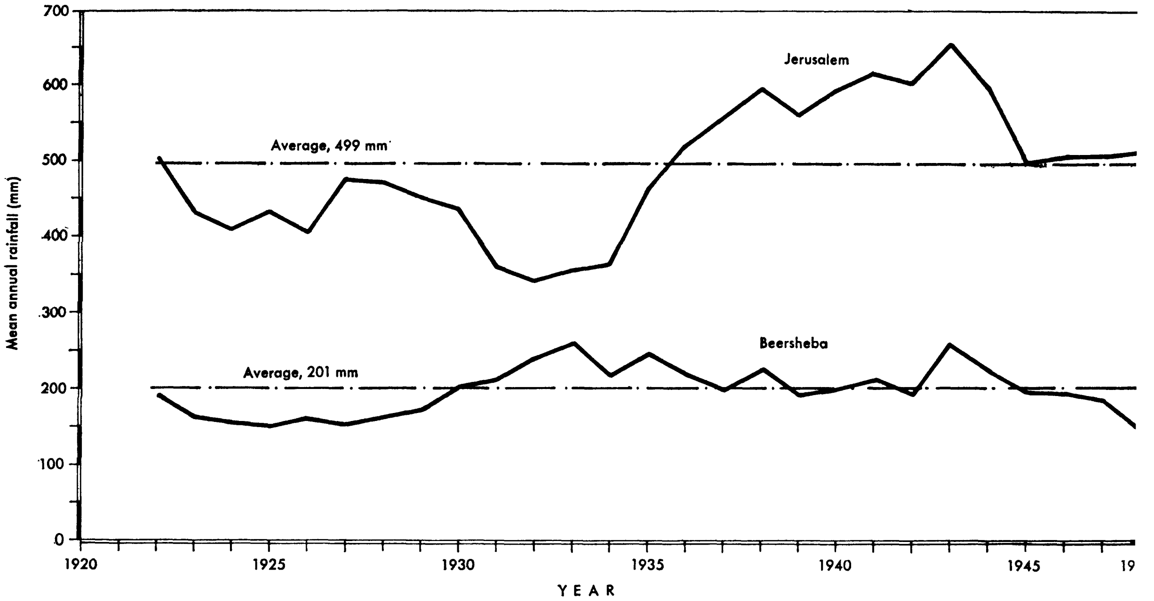

Fig. 8. Mean annual rainfall for Beersheba and Jerusalem (4 year moving average for the period 1920-1948).

year cycle from a minimum growth around 1790 to another minimum around 1890, and suggested that a similar cycle preceded this one and that these major cycles possibly include two or three minor ones. However, no relationship was found between the *Zygophyllum* growth curves and the 120-year rainfall record of Jerusalem (Rosenan, 1955). This is now understandable, since it was shown above that the Jerusalem records do not necessarily represent trends of the Negev rainfall. Accordingly, Fahn and his collaborators kindly placed at our disposal all their measurements so as to enable us to compare *Zygophyllum dumosum* growth to the rainfall of the Negev.

The cycles described above by Fahn were particularly obvious and well defined in his shrub No. 9 (1963). This shrub also has the longest record (1700-1960), and Fahn et al. suggest that it shows particular sensitivity since it reflects all the principal fluctuations represented by the other specimens. The growth curve of plant No. 9 was therefore compared to the measured rainfall in Beersheba during 1920 to 1965 (Figs. 9 and 10). The wet period of Beersheba (1931-1954) was reflected in the greater than average growth of the plant with a lag period of 3-4 years. Likewise, the dry periods (1922-1931 and 1955-1965) were represented by less than average growth, a similar 3-4-year

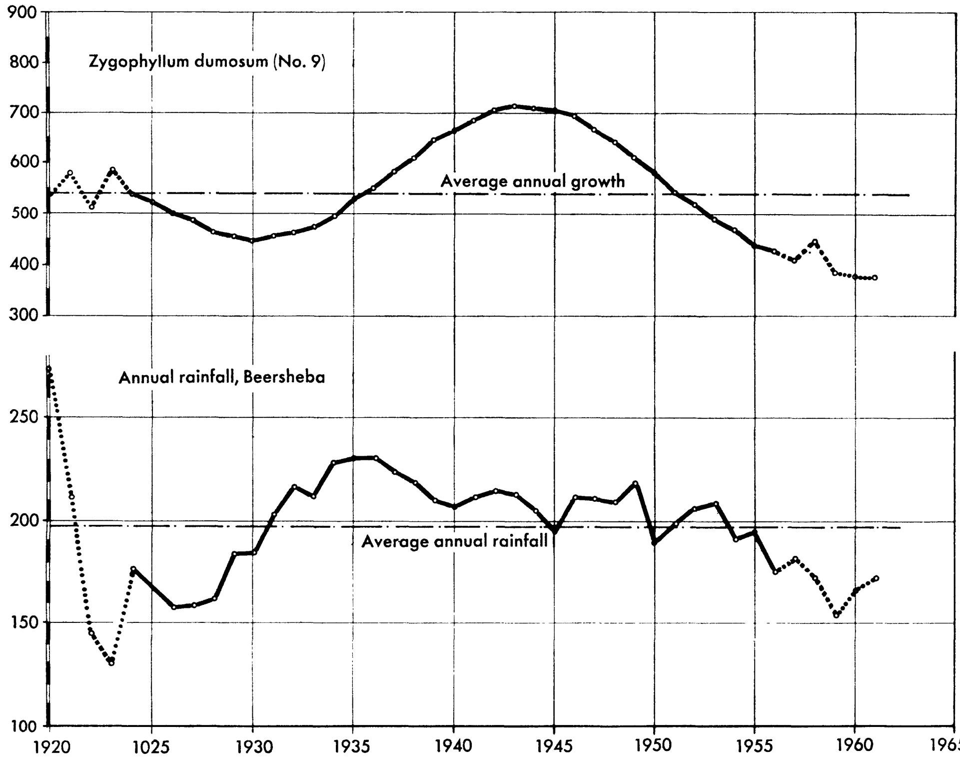

Fig. 9. Annual growth of Zygophyllum (No. 9) and annual rainfall at Beersheba (eight-year moving averages).

lag being evident. This lag may be due to residual soil moisture after rainy years and/or an ability of *Zygopyhllum* to store reserves during wet winters for subsequent use in drought stress periods. On the other hand, it may take a perennial plant several years to resume normal growth after a prolonged drought period. These points merit future study.

Statistical analysis of the data showed a good correlation between rainfall and a 3-4-year deferred growth only for the 1920-1939 period of increasing rainfall. No correlation was found for the 1940-1960 period of decreasing rainfall, except for a brief interval (1952-1958). In view of this, the graphical analysis presented below was carried out and further statistical treatment can only be done after additional plant growth and rainfall data have been collected.

The relationship between cumulative growth and mass rainfall (Fig. 10) can be represented by the equation:

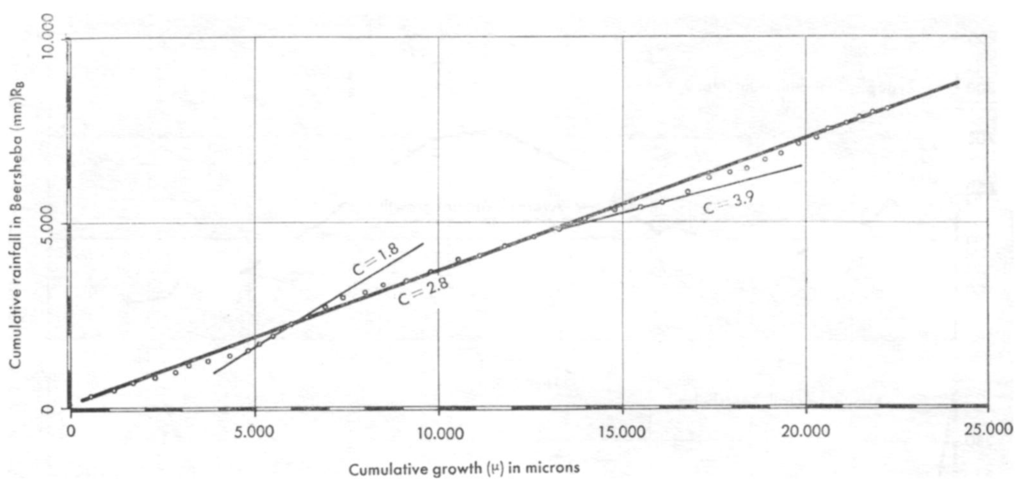

Fig. 10. Relationship between cumulative growth of Zygophyllum dumosum (No. 9) and cumulative rainfall in Beershbea ($\mu = CR_B$).

$$y = CR_B \text{ . . . . } \quad (2).$$

where

y = average annual growth, in microns;

R_B = average annual rainfall at Beersheba, in mm.;

C = constant.

The average value of C for the 45 years is 2.8, which is related to the average rainfall of about 198 mm. for the whole period. Fig. 10 shows that C varies from a low value of 1.8 to a high of 3.9. Taking into account the 3-4-year lag period, the value of C = 1.8 is related to the five-year low average rainfall of 170 mm. (1926-31), and the high value of C = 3.9 to the 4-5-year high average rainfall of 240 mm. (1941-46).

These three values of C (1.8, 2.8, 3.9) were plotted against the respective average rainfall (170, 198, and 240 mm.) in Fig. 11a and the following equation obtained:

$$C = 0.027\ R_B - 2.7 \quad (3).$$

Substituting this in eq. 2 we get

$$y = 0.027\ R_B^2 - 2.7\ R_B \quad (4).$$

Substituting eq. 4 in eq. 1 gives an estimated *Zygophyllum* growth in the Negev highlands of

$$y = 0.13\ R_A^2 - 5.9 R_A \quad (5).$$

Fig. 11a.

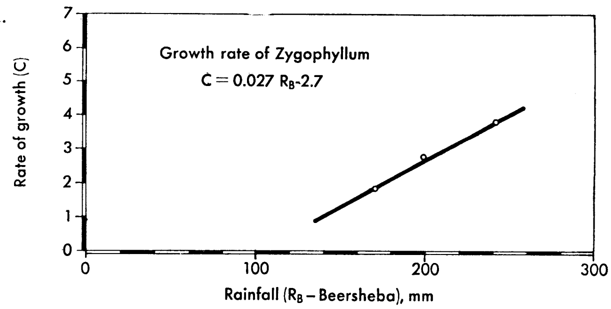

Fig. 11a-b. The relationship between the annual growth of Zygophyllum dumosum and the mean annual rainfall in the Negev highlands. (R_A).

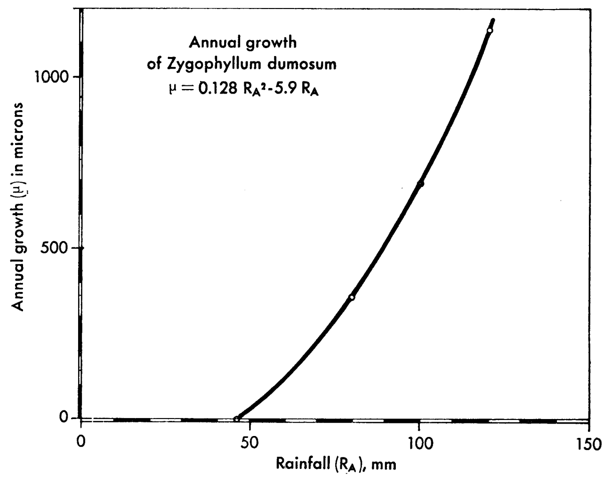

Fig. 11b.

This equation expresses the average annual growth of *Zygophyllum dumosum,* in microns, as a function of the average annual rainfall in the Negev highlands (Fig. 11b). Fig. 11b indicates that in the Negev highlands, *Zygophyllum* growth ceases when the average annual rainfall is less than 46 mm. This confirms field observations that without additional runoff water this plant grows only above the 50 mm. isohyet.

As a check on the derived values of C and eq. 4 and 5, the 20-year moving average rainfall of Beersheba was recalculated from the measured growth curves of two of the *Zygophyllum* plants (Nos. 9 and 13). The calculated average rainfalls (Fig. 12) are never more than $\pm$ 5% from the observed rainfall means. The calculated values show below average rainfall (relative to this period) during 1930-35 and 1945-50, and above average between 1935-45. This conforms to the observed wet and dry periods, and indicates that the *Zygophyllum* shrubs studied give reliable estimates of the average annual rainfall of Beersheba, and thus also for the Negev highlands.

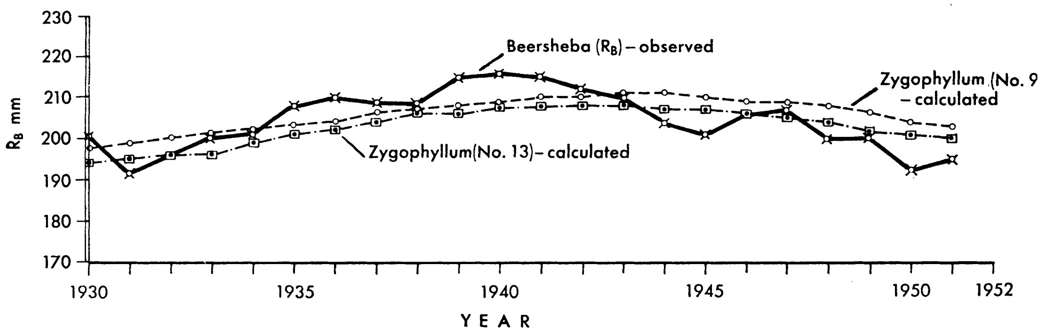

Fig. 12. Observed and calculated values of average annual rainfall in Beershbea (20 year moving average).

Fahn et al. (1963) studied the 3, 10, 20 and 21-year running averages of *Zygophyllum* growth and found that the best growth/rainfall correlations were obtained by taking moving 21-year averages, with the eleventh (middle) year being given a weight of 10, and the total divided by 30. Based on their 21-year moving average growth curve for plant No. 9, and using our eq. 4 and 5, the 250-year rainfall records for Beersheba and the Negev highlands were derived (Fig. 13).

These long-term estimates indicate that the following average annual rainfall conditions have existed in the Central Negev highlands during 1710-1960:

Maximum 21-year mean annual rainfall = 100 mm.
Minimum 21-year mean annual rainfall = 72 mm.
Average 21-year mean annual rainfall = 86 mm.

The derived curve (Fig. 13) also indicates that there have been a series of fluctuations in rainfall in the Negev. Three wet periods (1710-1750, 1805-1855, 1910-1960) were interspersed by two dry periods (1750-1805 and 1855-1910). The derived 250-year rainfall curve is in clear conformity with the following observations for the Negev:

a) The extreme drought years of 1875-1880 (Huntington, 1911) in the Beersheba area, as well as the relatively wet years of 1905-1910.

b) The increasing annual rainfall during 1920-1945.

c) The decreasing annual rainfall during 1945-1965.

The early decades of the curve also confirm the estimates made by Neumann (1960) that the rainfall during 1780-1790 was at low levels in the region and that this period was followed by a temporary rise in the early 19th century.

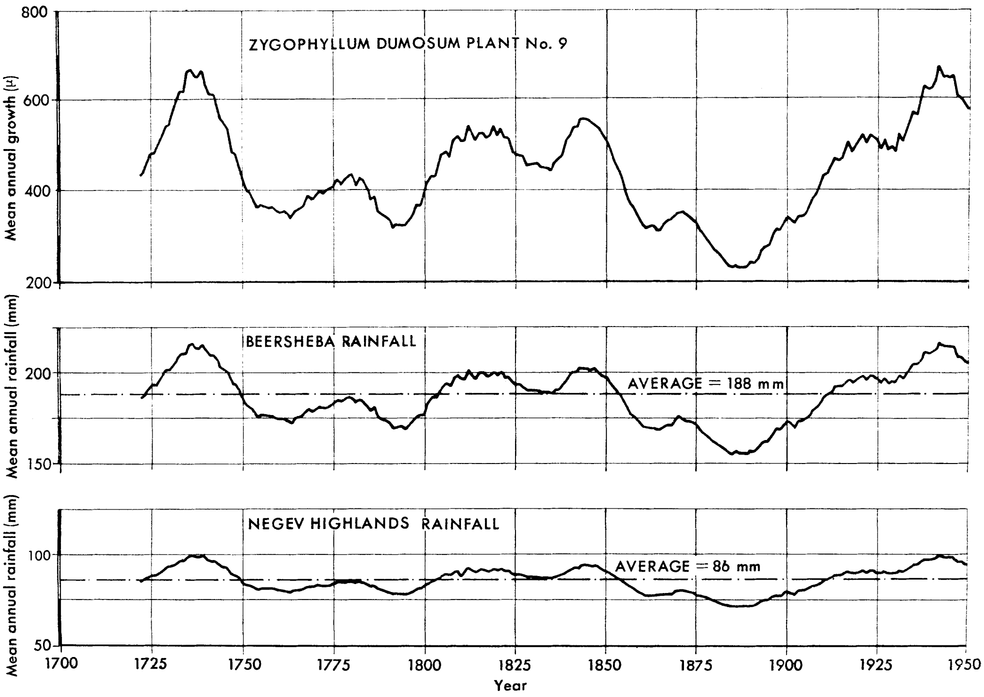

Fig. 13. Annual growth of Zygophyllum dumosum plant No. 9 and mean annual rainfall of Beersheba and the Negev highlands (21 year moving weighted means for the period 1720-1950).

CONCLUSIONS

It was shown above that the existing 45-year rainfall records of Beersheba could be used to estimate the mean number of rainy days per year, monthly rainfall distribution and average annual rainfall for the Central Negev highlands, where existing records are fragmentary and brief. Reevaluation of the dendrochronological studies of Fahn et al. (1963) of *Zygophyllum dumosum* shrubs in the Negev indicated that the average annual growth of this plant was related to the average annual rainfall of Beersheba. Using data on the annual growth curves of these shrubs, the 250-year rainfall records of Beersheba and the Central Negev highlands were then derived. The annual Negev highland rainfall was calculated to have fluctuated around a mean of 86 mm. with a cyclic variation of 28 mm. every 50 years, i. e., 50 years of above average rainfall followed by 50 years of below average rainfall.

These fluctuations and trends, as shown in the 250-year record, show a parallelism with the following world-wide climatic trends:

a) The 1850-1960 period is directly related to the secular temperature change. The periods 1850-1880 and 1945-1960, with decreasing rainfall in the Negev, corresponded to a period of decreasing world temperatures, while the period of increasing rainfall (1880-1945) occurred during the time of rising world temperatures (Murray, 1963).

b) The consistent rise in the rainfall of the Negev during 1850-1945 occurred during the general rise of world mean sea levels (Fairbridge, 1963).

c) The 250-year record shows cycles of about 90-100 years comparable to the 92-year sunspot cycle based on the 30-year moving averages (Naqvi, 1958). The tendency for an increase in sunspots during 1805-1855 and 1895-1950 is consistently related to the periods with more than average rainfall, whereas a decrease in sunspots (1855-1895) conforms to the period with less than average rainfall.

d) The curves follow the general patterns of climatic change as summarised by Krause (1958), who contends that something 'happened' about the end of the last century to affect not only the temperature regime but also the rainfall regime. He further contends that such changes have been most apparent along the shifting boundaries of climatic zones. A similar opinion has been expressed by Naqvi (1958), who found a comparable 37 mm. periodic variation in the rainfall of the arid zone of Karachi.

The 250-year record shows that rainfall in the Negev highlands was about 10% lower in 1900 than in 1930. This, however, is contrary to Butzer's (1961) estimate, which was influenced by the rainfall records of Jerusalem; we showed above that there is no basis for presuming that a relationship exists between the rainfall of Jerusalem and that of the Negev highlands.

With these remarks in mind, it is suggested that the above results warrant additional intensive dendrochronological studies of *Zygophyllum* and other desert shrubs to substantiate the trends indicated above. This is especially so in order to verify the latter part of the rainfall curve which seems to indicate that the Negev desert is now entering a period of decreasing rainfall which should last to the end of the century. Furthermore, an understanding of these climatic fluctuations in the sensitive area of the arid Negev may help to understand the global influences affecting them and thus provide an index of primary causes.

The rainfall estimates derived above have since been used to calculate runoff frequencies and volume, and water harvesting potentials for present-day agricultural development of the Negev desert and similar areas. These data will be presented in a separate paper. The above estimates also allow an efficiency analysis of ancient runoff-farming projects in this area. It may be stated that the results suggest that the relatively small periodic variation of 28 mm. in the mean annual rainfall indicates that the rise and fall of past agricultural civilisation in the Negev desert was due to socio-political factors rather than to climatic changes.

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