551.579 : 551.571.2 : 551.574.4

Water balance of *Prosopis spicigera* community

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ABSTRACT. An experiment on water balance of *Prosopis spicigera* community was conducted at the research farm of the Central Arid Zone Research Institute, Jodhpur. The experimental site is a typical habitat of the community with sandy to sandy loam soil. Chrono isopleths were drawn for the soil moisture observations taken during 1963 and 1964 and the water content in mm for every 50-cm layer from surface to 2-metre depth have been presented. Seasonal soil moisture changes occurring till the onset of monsoon, during monsoon and after monsoon have been discussed. Various water balance components such as evapotranspiration and run-off etc have been presented for different periods in the growing season of the vegetation. The evapo-transpiration of the community in the sandy soils of Rajasthan during the months other than the monsoon months is surprisingly low. *Prosopis spicigera* trees extract moisture not only from a very wide area but also take the same from the layers below the *kankar* zone usually at 1 to 2-metre depth below which their roots penetrate. The role of condensation of water in vapour phase for the arid zone communities has been indicated.

1. Introduction

An experiment on the water balance of *Prosopis spicigera* community was conducted at Jodhpur, located in the arid zone of northwest India. In this area, rainfall is by far the most important climatic factor affecting plant growth and studies of water balance of plant communities are consequently of great fundamental importance, since they would help in water conservation and better utilization of incident rainfall. Such studies will not only be useful in establishing relationships between amount, intensity, time of rainfall and the amount of water that entered the soil and the amount of water actually utilised by plants but will also help in establishing relationship between the water loss from soil with reference to the initial amount of water in the soil, atmospheric conditions and the characteristics of vegetation (Slatyer 1961). In order to develop general principles for assessing and interpreting climate in terms of its influence on the characteristics and responses of the vegetation, such studies assume that in each stable community in a given climatic and edaphic zone, there is an established pattern of water relationship not only in regard to individual species and their micro-environment, but also in regard to the total community which they comprise (Christian and Slatyer 1956). Such assumption may not be misleading because natural selection have produced plant types most fitting for survival under the trying conditions prevailing in the arid and semi-arid zones. However, Christian and Slatyer (1956) pointed out that the fact that a community has reached an apparent equilibrium with the environment may not necessarily mean that it makes efficient use of the water received by it or that a more efficient community cannot replace it.

In view of this concept a comprehensive experiment on the water balance of *Prosopis spicigera* (Syn. P. cineraria) community including soil moisture, micro-climatological, ecological and plant physiological observations was taken up specially for the evaluation of water balance and growth characteristics of this native community in relation to the arid environment and with a view to study the introduction of more productive species of herbage having low water requirements. In this paper, the moisture regime observations and the evaluation of water balance have only been presented and discussed. Papers on other topics are to follow.

2. Climatic conditions

Jodhpur region falls in arid zone with its Thornthwaite's moisture index −45. The climate is strongly seasonal and the year can be divided into 4 distinct seasons, *viz.*, winter (Dec to Feb), hot weather period (Mar to Jun), monsoon (Jul to Sep) and post-monsoon (Oct to Nov). The normal annual rainfall of Jodhpur is 366.0 mm of which 327·6 mm occurs in the monsoon season constituting 89 per cent of the total precipitation. The coldest month of the year is January with mean maximum and mean minimum temperatures of 25°C and 9°C respectively. On many occasions in winter, cold waves occur in the rear of moving western disturbances over the northwest India. Night temperature as low as −2·2°C has been on record in Jodhpur. Occurrence of frost is rare. Rise of temperature occurs from March and May is the hottest month of the year with average maximum temperature reaching 41 to 42°C. During the hot season, duststorms (*Andhi*) and dust raising winds (*Loo*) are frequent. The onset of the monsoon takes place

TABLE 1

Actual rainfall (mm) recorded at Central Research Farm, Jodhpur during 1963-64

Date 1963		Rainfall (mm) Daily	Rainfall (mm) Monthly total	Date 1964		Rainfall (mm) Daily	Rainfall (mm) Monthly total
Jan		Nil	Nil	Jan		Nil	Nil
Feb	16	1·3	1·3	Feb		Nil	Nil
Mar	30	1·8	5·9	Mar		Nil	Nil
	31	4·1		Apr		Nil	Nil
Apr		Nil	Nil	May	13	44·0	57·6
May	15	0·8	0·8		14	10·5	
Jun	29	5·6	5·6		20	2·3	
Jul	30	2·0	10·1		29	0·8	
	31	8·1		Jun	1	30·4	34·6
Aug	1	17·0	105·5		2	0·7	
	2	23·9			11	3·0	
	3	1·4			27	0·5	
	5	2·5		Jul	2	3·6	173·7
	13	17·8			3	6·0	
	27	6·3			7	3·6	
	29	19·8			8	82·6	
	30	16·8			25	22·0	
Sep	1	1·0	41·3		26	54·4	
	6	0·8			27	1·5	
	7	12·5		Aug	10	40·2	264·9
	8	0·3			11	25·4	
	10	18·3			12	0·9	
	13	8·4			14	0·1	
Oct	18	1·3	1·3		15	0·1	
Nov	15	6·6	6·9		16	8·6	
	25	0·3			17	1·6	
Dec		Nil	Nil		18	138·2	
					27	52·2	
					28	3·6	
				Sep	22	1·0	5·4
					28	4·4	
				Oct	14	1·6	1·6
				Nov		Nil	Nil
				Dec	9	2·7	2·7
Annual total			179·6	Annual total			540·5

by about the first of July. Temperatures during the monsoon season are moderate with minimum diurnal variation which is only 8 to 10°C compared to 14—16°C during other seasons. The range of maximum and minimum temperatures during the season is 25° to 35°C. During October, temperatures again increase slightly. The humidity of the air is low except for the period June to September. Under the hot arid climatic conditions, evaporation is very high. Standard USA open pan evaporimeter at Jodhpur indicates an average annual evaporation of 264 cm per month. Winter evaporation is low being 10—12 cm per month. The highest evaporation of 44 cm is recorded in May. Monsoon evaporation is of the order of 18—20 cm per month.

3. Soil types

The soil of the region varies from loamy sand to sandy clay loams in texture with calcareous *kankar* pan formation at depths varying from 50 to 200 cm. At the site where this experiment was conducted, the *kankar* pan is at the depth of 200 to 230 cm. This *kankar* pan, however, permits penetration of roots and water down the profile. The physical characters of the soil and description of the soil profile have been given by Abichandani *et al.* (1967).

4. Material and methods

The site of the experiment is located in the Central Research Farm of the Central Arid Zone Research Institute, Jodhpur. It is a typical habitat for the *Prosopis spicigera* community. The soil at the experimental site is sand upto 15-cm depth (clay content 6 per cent) and sand to loamy sand upto 200 cm (average clay content 8 per cent). Below this sheet of sand, there is a thick layer of *kankar* (with thickness more than ten metres at places). The *kankar* is an accumulation of calcium carbonate concretion material and the pebbles of crystallizic and palaeozoic rocks. The soil texture is quite uniform and unaggregated to a depth of 200 cm with a nearly constant bulk density of 1·5 g/cm³. The plot for determining the water balance in *Prosopis spicigera* community has an area of 1228 sq. m. Among the grasses the dominant species are —

(1) *Dactyloctenium sindicum,*
(2) *Eleusine compressa,*
(3) *Cenchrus catharticus,*
(4) *Cenchrus setigerus,*
(5) *Panicum antidotale,*
(6) *Aristida adscensionis and*
(7) *Cyperus rotundus.*

This area was fenced off. On one side, a run-off plot (area 68 sq. m) was constructed and in the middle of the area the requisite meteorological instruments were installed. In addition to standard thermometers, continuous records of rainfall, temperature, humidity and soil temperatures at 2 depths were obtained by self-recording instruments. Microclimatological observations, *viz.*, temperature and humidity profile over the community were taken by means of Assmann psychrometer.

The soil moisture contents were determined by gravimetric method on soil samples obtained by auger borings at three sites within the experimental plot. The gypsum block units developed by Bouyoucos and Mick (1940) were installed at depths of 5, 25, 50, 75, 100, 150 and 200 cm. The block readings were taken every two weeks. Block resistance *vs* moisture content calibrations were done by many field observations and calibration curves were drawn for various blocks. The block resistances were corrected for temperature following the procedure suggested by Slatyer and McilRoy (1961). The observations with the help of neutron moisture meter were also taken in the monsoon season of 1964 in addition to the above observations.

The graphical integration method suggested by Harrold and Dreibelbis (1951) was followed for determination of water content in different layers of soil profile for various decades (ten-day periods) in the years 1963 and 1964. The soil moisture percentage in different layers were plotted against the dates of observations and the chrono-isopleths were drawn. The mean water content of each 25-cm layer for each ten-day period was determined from these diagrams by graphical interpolation. The multiplication of mean percentage moisture content by weight, thickness of layer (in decimetre) and the density of soil (which was uniformly 1·5 g/cm³) gives the water storage of various layers in mm.

Whenever the water content of the soil decreased in a particular decade compared to previous decade it was considered as output and when the water content increased it was taken as input. Harrold and Dreibelbis (1951) called such output and input as evapo-transpiration and accretion condensation respectively. In this study also the sums of outputs for all periods after taking into account run-off is taken as the negative part of the water balance and the sums of inputs as positive part.

5. Results

The rainfall distribution over Jodhpur (recorded at Central Research Farm) for the years 1963 and 1964 are given in Table 1. The monthly totals for each month have also been indicated in the same table.

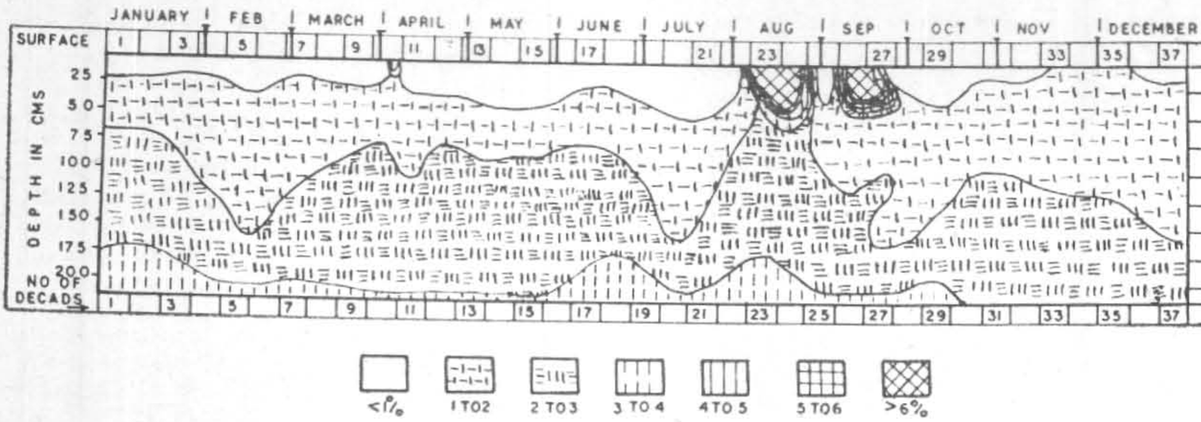

Fig. 1. Moisture regime in *Prosopis Spicigera* community 1963

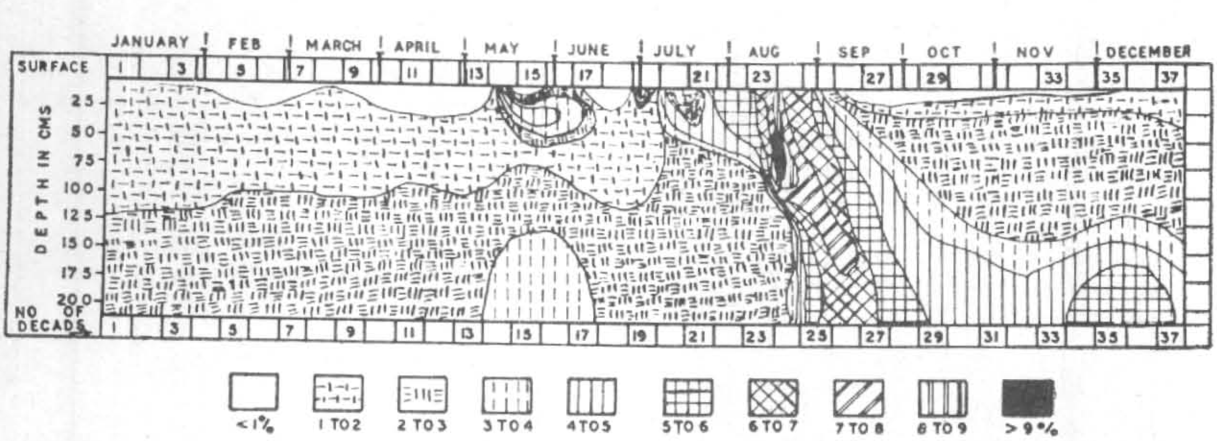

Fig. 2. Moisture regime in *Prosopis Spicigera* community 1964

It would be seen that there is a marked difference in the rainfall data during the two years under study, the rainfall during year 1963 being much below the normal and in 1964 above normal, the normal annual rainfall being 366 mm. The seasonal distribution of rainfall and its peculiarities have been described in the summary of moisture regime pattern for the years 1963 and 1964 given below.

6. Moisture regime pattern in the years 1963 and 1964

The chrono-isopleth maps of soil moisture in percentage by weight for the years 1963 and 1964 are presented in Figs. 1 and 2. The water content in mm for every 50-cm layer from surface to 200-cm depth calculated by the method described above is given for the years 1963 and 1964 in Tables 2 and 6 respectively. The regime pattern is described year-wise.

The year 1963 is divided into three periods, *viz.*, January to the onset of the monsoon, the monsoon period and from the withdrawal of monsoon to the end of the year. The first and third periods received very little rainfall and the bulk of the rainfall was received during the monsoon. The soil moisture pattern for these periods is given below—

(*a*) *Period from 1 January 1963 to the onset of the monsoon*—The initial water content of the soil layer from surface to 200-cm depth on 1 January was 66·5 mm. It decreased rapidly as little rain occurred during the season. The humidity of air was low. The temperature of the deeper layers of the soil was higher than that of surface layers. Upto 19 February the decrease in water content in the successive 50-cm layers down from surface were 1·7, 4·9, 7·2 and 4·9 mm. Thus a water loss of 19 mm was registered in the layer from surface to 200-cm layers in the first 50 days. Since the available moisture in the upper layers of the soil had already been depleted very much (a low moisture content of 8·6 mm in surface to 50-cm depth in the first decade) in the autumn of 1962, the losses from deeper layers especially in 100 to 150-cm layer were greater than those of upper layers.

By the end of February when the winter was at its end, there was an increase in the moisture content. This increase was more significant in the deeper layers (100 to 150 cm). After this first increase of water storage in soil the second half of March and the whole of April did not show great changes except for decreasing moisture in the surface layers. The end of May and the beginning of June brought out again a small increase in the moisture-content in 150 to 200-cm layer. By the end of June, however, the moisture-content began to decrease in all layers which continued upto the onset of monsoon on 29 July. The monsoon this year was late by about a month.

The water balance for this period as a whole (1st to 21st decade) for various layers is given in Table 3.

Thus taking the period as a whole there is a net water loss at all layers with maximum loss in 50 to 100-cm layer. The moisture gain by condensation is maximum in the layer 100 to 150 cm. Though there is net evaporation loss of 8·9 mm, as there was 13·5 mm rain in the period occurring in small intensities and getting evaporated in the top 25-cm layer, the net evaporation loss for the period is 22·4 mm.

(*b*) *Southwest monsoon period* (*30 July to 27 September*)—The southwest monsoon rainfall (July to September) during 1963 was 157 mm which was 140 mm below normal. The deficiency from normal values for the months of July, August and September were 98, 26 and 16 mm respectively.

It would be seen from Table 2 that the water content upto 2-m depth just prior to the onset of the monsoon (*i.e.*, on 21st decade) was 57·6 mm and the same just after monsoon (*i.e.*, on 27th decade) was 57·8 mm. This shows that whatever rain occurred during the period were all lost. The monsoon rainfall during the year affected the moisture regime of the soil only upto 100-cm depth. Increase of moisture in the layer 50 to 100 cm was noticed only for the initial spells and not for those that occurred by the end of August or September. Under these circumstances, water loss by deep drainage beyond 2-m depth is considered improbable.

The run-off component as measured in the run-off tank constituted only 0·4 per cent of the monsoon rainfall. This extremely low rate of run-off in the experimental plot can be attributed to comparatively lower intensity of rainfall during the year, very gentle slope of the plot, grass cover and the presence of large number of burrows of desert gerbils. The sandy nature of the soil is also responsible for the low value of run-off.

The various components of the water balance, soil moisture change and distribution of rainfall are presented decade-wise in Table 4.

It is seen from Table 4 that 157 mm rain that occurred during the monsoon was practically spent during the period of 60 days (30 July to 27 September). The evapo-transpiration in mm ranged from 1·05 to 4·83 mm per day in successive ten-day periods.

(*c*) *Period from 28 September to end of 1963*—Very little fluctuations in soil moisture took place during the period. October had a rainfall of 1·3 mm while November had rainfall of 6·9 mm. The

TABLE 2

Water content (mm) in *prosopis spicigera* experimental site upto 2 metres in 1963

Decade No.	Date of beginning (1963)	Surface to 50 m	50 to 100 cm	100 to 150 cm	150 to 200 cm	Surface to 200 cm
1	1 Jan	8·6	16·1	18·8	23·0	66·5
2	11 Jan	8·6	14·1	18·7	22·1	63·5
3	21 Jan	8·6	11·3	17·3	20·7	57·9
4	31 Jan	7·4	11·3	13·3	18·5	50·5
5	10 Feb	6·9	11·2	11·6	18·1	47·8
6	20 Feb	8·3	11·2	15·8	18·7	54·0
7	2 Mar	8·3	11·3	16·6	18·7	54·9
8	12 Mar	7·6	12·5	18·8	18·7	57·6
9	22 Mar	8·1	14·8	18·7	18·7	60·3
10	1 Apr	7·4	11·8	18·1	18·7	56·0
11	11 Apr	7·3	14·2	18·8	18·7	59·0
12	21 Apr	5·6	13·7	18·8	18·7	56·8
13	1 May	4·9	12·4	18·8	18·7	54·8
14	11 May	4·9	13·0	18·7	18·7	55·3
15	21 May	5·2	14·1	18·7	18·7	56·7
16	31 May	7·2	14·5	18·7	20·8	61·2
17	10 Jun	7·3	13·3	18·7	23·0	62·3
18	20 Jun	5·2	11·3	17·8	21·1	55·4
19	30 Jun	4·4	11·3	11·3	18·2	45·2
20	10 Jul	4·0	11·3	12·1	18·3	45·7
21	20 Jul	6·5	12·8	17·8	20·5	57·6
22	30 Jul	31·1	17·9	18·7	22·9	90·6
23	9 Aug	41·4	19·2	18·0	21·7	100·3
24	19 Aug	20·3	16·4	18·7	19·7	75·1
25	29 Aug	23·5	11·3	17·0	18·7	70·5
26	8 Sep	43·6	11·3	16·8	17·7	89·4
27	18 Sep	13·5	11·3	15·5	17·5	57·8
28	28 Sep	8·3	11·3	11·5	19·2	50·3
29	8 Oct	8·7	11·3	13·9	18·8	52·7
30	18 Oct	9·2	11·7	18·7	18·7	58·3
31	28 Oct	9·2	11·1	18·6	18·7	57·6
32	7 Nov	10·4	11·3	17·2	18·7	57·6
33	17 Nov	11·3	11·3	16·2	18·7	57·5
34	27 Nov	11·3	11·3	17·1	18·7	58·4
35	7 Dec	10·1	11·3	17·4	18·7	57·5
36	17 Dec	8·8	11·3	11·3	18·2	49·6
37	27 Dec	9·5	11·3	11·3	17·3	49·4

TABLE 3

Moisture changes in mm from 1 January to 29 July 1963
(calculated on decade basis)

Surface to 50 cm	50 to 100 cm	100 to 150 cm	150 to 200 cm	Surface to 200 cm
+ 6·8	+ 9·6	+14·4	+ 7·2	+35·4
— 8·9	—12·9	—15·4	— 9·7	—44·3
— 2·1	— 3·3	— 1·0	— 2·5	— 8·9

TABLE 4

Soil moisture changes and water balance for 1963 monsoon season

Decade No.	Middle date	Soil moisture change (in mm)					Rainfall (mm)	Run-off (mm)	Evapo-transpiration (mm)
		Surface to 50 cm	50 to 100 cm	100 to 150 cm	150 to 200 cm	Surface to 200 cm			
21	25 Jul	+ 2·5	+ 1·5	+ 5·7	+ 2·2	+11·9	Nil	—	—
22	4 Aug	+24·6	+ 5·1	+ 0·9	+ 2·4	+33·0	52·4	0·2	19·2
23	14 Aug	+10·3	+ 1·3	— 0·7	— 1·2	+ 9·7	20·3	0·1	10·5
24	24 Aug	—21·1	— 2·8	+ 0·7	— 2·0	—25·2	Nil	—	25·2
25	3 Sep	+ 3·2	— 5·1	— 1·7	— 1·0	— 4·6	43·9	0·2	48·3
26	13 Sep	+20·1	0	— 0·2	— 1·0	+18·9	40·3	0·2	21·2
27	23 Sep	—30·1	0	— 1·3	— 0·2	—31·6	Nil	—	31·6
Total							156·9	0·7	156·0

soil moisture content in the top layer (*viz.*, surface to 50 cm) increased gradually from 8·3 to 11·3 mm by the end of the post-monsoon season but decreased again to 8·8 mm by the third week of December. The layer 50 to 100 cm had water content 11 to 12 mm while 100 to 150 cm layer had only 11·5 mm to start with but gradually increased to 18·7 mm by 18 October. Sudden fall of the moisture content in 100—150 cm layer was registered by the second fortnight of December. The lowest layer of 150—200 cm had 17·3 to 19·2 mm moisture during the period with minor fluctuations.

The water balance for this period (27th to 37th decade) as a whole is presented in Table 5.

The changes registered during the period were of much smaller magnitude than those found in the earlier dry period of January to mid-July. The highest change in case of outputs and inputs occur in respect of 100 to 150 cm layer followed by the layer from surface to 50 cm. Though the net evaporation was only 8·4 mm, as there was 8·2 mm rain in the period not indicated in the moisture changes, the net evapo-transpiration was 16·6 mm.

TABLE 5

Moisture changes in mm from 28 Sep to 31 Dec 1963
(calculated on decade basis)

Surface to 50 cm	50 to 100 cm	100 to 150 cm	150 to 200 cm	Surface to 200 cm
+ 3·7	+ 0·6	+ 8·4	+ 1·7	+ 8·9
— 7·7	— 0·6	—12·6	— 1·9	—17·3
— 4·0	0	— 4·2	— 0·2	— 8·4

During the year 1964 good pre-monsoon rainfall occurred from 13 May and monsoon showers extended upto 28 September. Hence moisture regime pattern has been discussed below separately for three distinct periods, *viz.*, 1 January to 9 May (Decade Nos. 1 to 13), 10 May to 6 October (Decade Nos. 14 to 28) and the rest of the year. The moisture pattern for the year has been presented pictorially in Fig. 2 and decade-wise water content in mm in Table 6.

TABLE 6

Water content (mm) in *prosopis spicigera* experimental site upto 2 metres in 1964

Decade	Date of beginning	Surface to 50 cm	50 to 100 cm	100 to 150 cm	150 to 200 cm	Surface to 200 cm
1	1 Jan	10·0	11·3	15·8	18·7	55·8
2	11 Jan	10·1	11·3	16·1	18·7	56·2
3	21 Jan	10·4	11·3	16·1	18·7	56·5
4	31 Jan	9·9	11·3	16·7	18·7	56·6
5	10 Feb	8·5	11·3	18·5	18·7	57·0
6	20 Feb	8·0	11·5	18·7	18·7	56·9
7	1 Mar	9·0	11·3	18·7	18·7	57·7
8	11 Mar	10·6	11·3	18·7	18·7	59·3
9	21 Mar	9·4	11·3	18·4	18·7	57·8
10	31 Mar	7·9	11·8	18·7	18·7	57·1
11	10 Apr	7·9	12·9	18·7	18·7	58·2
12	20 Apr	7·9	11·9	18·7	18·7	57·2
13	30 Apr	7·9	11·6	18·7	18·7	56·9
14	10 May	16·5	14·3	19·1	24·2	74·1
15	20 May	22·1	15·3	21·0	26·3	84·7
16	30 May	24·4	14·9	21·2	26·3	86·8
17	9 Jun	15·7	12·1	18·7	23·5	70·0
18	19 Jun	9·0	11·3	17·3	18·7	56·3
19	29 Jun	13·3	11·5	18·3	18·7	61·8
20	9 Jul	24·4	17·7	18·7	18·7	79·5
21	19 Jul	27·6	15·2	18·7	18·7	80·2
22	29 Jul	38·4	20·5	18·7	18·7	96·3
23	8 Aug	45·3	27·1	18·7	18·7	109·8
24	18 Aug	50·5	61·7	22·3	20·3	154·8
25	28 Aug	44·7	52·4	50·5	42·4	190·0
26	7 Sep	27·1	43·6	47·3	50·5	168·5
27	17 Sep	16·6	33·6	34·5	45·5	130·2
28	27 Sep	13·7	25·1	32·4	39·1	110·3
29	7 Oct	13·3	19·7	28·7	34·1	95·8
30	17 Oct	13·3	18·7	25·2	33·7	90·9
31	27 Oct	13·9	18·7	22·2	33·0	87·8
32	6 Nov	14·2	18·7	20·8	31·5	85·2
33	16 Nov	14·3	18·7	21·1	32·5	86·6
34	26 Nov	14·6	18·7	22·0	36·1	91·4
35	6 Dec	15·0	18·7	24·8	39·3	97·8
36	16 Dec	15·4	18·7	24·9	39·5	98·5
37	26 Dec	14·3	18·7	21·8	33·8	88·6

(*a*) *Period from 1 January to 9 May 1964* — During the period there was no rain and very little fluctuations occurred in the total water content upto 200-cm depth which was 55·8 mm to start with. It slowly increased to 59·3 mm by the middle of March and decreased thereafter. The water content by the 1st week of May was 56·9 mm. The surface layer upto 50 cm contained 10 mm in the beginning which decreased to 7·9 mm by the end. The next layer of 50—100 cm contained 11 to 12 mm of water except during middle of April when the water content increased to 12·9 mm. Water content in 100—150 cm layer was 15·8 mm to start with, increased to 18·7 mm by end of February and maintained the same till the end. The bottom most layer contained 18·7 mm throughout.

The water balance of this period is presented in Table 7.

There is very little water loss and gain during the period compared to the corresponding period of the previous year. This may be partly due to the fact that the water content was low and partly due to the gypsum block technique which was mainly used during the period for soil moisture observations and which did not record the minor fluctuations in moisture content as clearly as the gravimetric method. However, realising this, routine fortnightly gravimetric observations were taken from June onwards. Supplementary moisture observations by neutron scattering technique were also taken during the monsoon period since a Nuclear Chicago Neutron moisture meter became available for this work in 1964. The soil moisture contents as determined by the neutron scattering technique have also been plotted in the chrono-isopleth maps and are taken into account while drawing chrono-isopleths (Figs. 1 and 2).

(*b*) *Period from 10 May to 6 October* (*14th to 28th decade*) — The premonsoon rainfall during May and June of 1964 were 57·6 and 34·6 mm against the normals of 9·7 and 30·7 mm respectively. The onset of the southwest monsoon took place on 2 July which is nearly the normal date for Jodhpur region. The rainfall surpluses during the months of July and August were 65·5 and 133·6 mm respectively while the deficiency in September was 52·0 mm. 536 mm of rain occurred during the period out of 540 mm of rain for the whole year. By summing up all additions of soil moisture decadewise in all the layers, we get only addition of 211 mm in the layer from surface to 200 cm layer if the data of individual layers are summed up and 178 mm if the layer is taken as a whole. Thus considerable part of the water was lost in surface run-off and deep drainage into *kankar* layers. The surface run-off pattern actually measured in the specially constructed run-off tank in the experimental plot on various occasions along with the intensity of the showers are given in Table 8.

The total run-off loss for the whole period was 125·9 mm which constitutes 23 per cent of the rainfall recorded. In the experimental plot which is a sandy level land with plenty of natural vegetation and very little slope, the run-off is normally very low but it sharply increases after 6 mm of daily rainfall. The run-off component is particularly high during 1964 due to the very high intensity of the rainfall on 8 July and 18 August.

The various components of the water balance, *viz.*, moisture changes for soil layers and the distribution of rainfall have been presented in Table 9. Since the rainfall has occurred on many days in the period and the effect of components of the

TABLE 7

Moisture changes in mm from 1 January to 9 May 1964

(calculated on decade basis)

Surface to 50 cm	50 to 100 cm	100 to 150 cm	150 to 200 cm	Surface to 200 cm
+ 3·0	+ 1·8	+ 3·2	Nil	+ 4·7
— 5·1	— 1·5	— 0·3		— 3·6
— 2·1	+ 0·3	+ 2·9		+ 1·1

TABLE 8

Surface run-off in a few showers in the monsoon of 1964

Date	Amount of rainfall (mm)	Run-off measured (mm)	Percentage of run-off to rainfall
13 May	44·0	6·0	13·6
14 May	10·5	1·3	12·4
1 Jun	30·4	3·8	12·5
8 Jul	82·6	30·0	36·3
25 Jul	22·0	3·0	13·6
26 Jul	54·4	9·8	18·0
27 Jul	1·5	Nil	0
10 Aug	40·2	5·4	13·4
11 Aug	25·4	3·6	14·1
18 Aug	138·2	60·6	43·8
27 Aug	52·2	2·4	4·6

TABLE 9

Soil moisture changes (mm) and water balance during May to October 1964

Decade No	Period	Surface to 50 cm	50 to 100 cm	100 to 150 cm	150 to 200 cm	Surface to 200 cm	Rainfall	Run-off	Deep drainage and evapo-transpiration
14 and 15	10 May to 29 May	+14·2	+ 3·7	+ 2·3	+ 7·6	+27·8	56·8	7·3	21·7
16 and 17	30 May to 18 Jun	— 6·4	— 3·2	— 2·3	— 2·8	—14·7	34·9	3·8	45·8
18 and 19	19 Jun to 8 Jul	— 2·4	— 0·6	— 0·4	— 4·8	— 8·2	10·1	0	18·2
20 and 21	9 Jul to 28 Jul	+14·3	+ 3·7	+ 0·4	*0	+18·4	86·2	30·0	37·8
22 and 23	29 Jul to 17 Aug	+17·7	+11·9	0	0	+29·6	144·4	21·8	93·0
24 and 25	18 Aug to 6 Sep	— 0·6	+25·3	+31·8	+23·7	+80·2	198·4	63·0	55·0
26 and 27	7 Sep to 26 Sep	—28·1	—18·8	— 16·0	+ 3·1	— 59·8	1·0	0	60·8
28	27 Sep to 6 Oct	— 2·9	— 8·5	— 2·1	— 6·4	— 19·9	4·4	0	24·3
Total							536·2	125·9	356·8

TABLE 10

Moisture changes in mm from 7 October to 31 December 1964

(calculated on decade basis)

Surface to 50 cm	50 to 100 cm	100 to 150 cm	150 to 200 cm	Surface to 200 cm
+ 2·1	0	+ 4·1	+ 8·0	+13·3
— 1·5	— 6·4	—14·7	—13·3	—35·0
+ 0·6	— 6·4	—10·6	— 5·3	—21·7

water balance overlapped for successive decades. the water balance was worked out on two decade basis (*viz.*, 20 days basis) except for the last decade.

It is observed from Table 9 that out of 536·2 mm of rain that occurred during the period, 125·9 mm of water was lost as run-off and 356·8 mm as evapotranspiration-cum-deep drainage into *kankar* layers. Assuming that the losses occurring in the layers below 1 metre contribute to deep drainage, the same is estimated to be about 35 mm. Thus the bulk of the rainfall, *viz.*, 322 mm was utilised in evapotranspiration during the year. The average moisture loss per day for successive 20-day periods from 10 May are 1·09, 2·29, 0·91, 1·89, 4·65, 2·76 and 3·04 mm respectively and 2·43 mm in the last decade.

(c) *Period from 7 October to end of 1964 (29th to 37th decade)*—A rainfall of 1·6 mm in October and 2·7 mm in December, occurred during this period. The water content was 95·8 mm to start with but began to decrease gradually. There was also considerable increase from end of November to middle of December, the highest value being 98·5 mm. However the water content again dropped to 88·6 mm by the end of December. The water balance for the period (29th to 37th decade) as a whole for various layers is given in Table 10. The losses as well as gains are maximum in deeper layers below one metre.

7. Discussion

The results of the soil moisture observations of 2 years, *viz.*, 1963 and 1964 with the annual rainfall of 179 mm and 541 mm respectively have been presented in the preceding section. Since normal annual rainfall for Jodhpur is 366 mm, they constitute 49 and 148 per cent of the normal respectively. In case of deficient year there was a net evapotranspiration loss of 22·4 mm from 1 January to 29 July, 156·0 mm during 30 July to 27 September and 16·6 mm during 28 September to the end of the year. Thus total annual evapotranspiration worked out to be 195·0 mm and run-off loss to 0·7 mm. Since the rainfall of that year was only 178·6 mm, a negative balance 17·1 mm for the year was obtained (*viz.*, from 66·5 to 49·4 mm).

For the year 1964, in view of very low water content in soil, there was no net evaporation loss upto 9 May but there was a gain of 1·1 mm. The rainy period of 10 May to 6 October had a net evapotranspiration-cum-deep drainage loss of 356·8 mm and surface run-off loss of 125·9 mm and a net loss of 26·0 mm during the rest of the year amounting to 508·7 mm. But since there was a rainfall of 540 5 mm and 1·1 mm of condensation there was a favourable balance of 32·5 mm (56·1 to 88·6 mm). The minimum water content recorded was 0·1 per cent by weight and was recorded at 5-cm depth on many occasions. The maximum water content recorded was 9·8 per cent by weight and was recorded at the depth of 75 cm on 19 August after heavy shower of 138·2 mm on 18 August 1964. Light rains moisten only surface layers and get evaporated whereas heavy showers percolate into deep layers. For instance in the years under study the rainfall that occurred in the seasons other than the southwest monsoon, evaporated from the surface layer of the soil. The real contribution in the inputs during this season is by the condensation water in vapour phase which is being described below separately. If the soil moisture observations are taken at closer intervals of time than at present, the actual occurrence of condensation can be determined more accurately. If the rainfall occurs in heavy downpours, as it happened in the case of 1964 (*viz.*, 82·6 mm on 8 July and 138·2 mm on 18 August) much of the water is lost as run-off. Daubenmire (1948) stated that the rain falling on a coarse-textured soil penetrates immediately so that ordinarily almost none is lost as run-off. But this is true only in the case of deficient years with rainfall occurring in spells of low intensities but not so for showers of higher intensities.

The data showed that the evapo-transpiration in the sandy soils of Rajasthan in months other than the monsoon months is surprisingly low. In fact the rainless season is marked by alternate occurrence of condensation and low evaporation. This is mainly achieved by the fact that the moisture that is in the deeper layers remained intact throughout the year by the dry upper layers of the soil protecting them as a blanket. Similar results have been found by Mighahid *et al.* (1953) in the Egyptian soil. He stated that the main source of water supply to the desert perennials is the water retained in the deeper soil layers, the so called permanent wet layer into which the absorbing roots extend. In the area under their study, this layer commenced from a depth of about 50 cm and water in that layer is prevented from evaporation by the dry upper soil. As early as 1907 King pointed out the importance of dry soil on the surface in breaking capillary connection with the immediate surface and advocated the so-called dust mulch for conserving water by reducing evaporation. The estimated water output of a *Prosopis spicigera* tree by determining transpiration by the Torsion balance method was 153·8 kg per day during winter; 112·3 kg per day during summer and 106·1 kg per day during monsoon. Assuming that the six trees in the site take moisture from the experimental area upto 200 cm depth, these losses would correspond to 0·75 mm per day, 0·55 mm per day and 0·52 mm per day respectively. Since so much moisture loss does not occur during a day in any of the seasons except the monsoon, it appears that *Prosopis spicigera* trees extract moisture not only from wider areas but also take the same from the *kankar* zone at 2 to 2·3 m depth through which the roots of the tree penetrate. Further it is felt that the transpiration requirement during dry months may be less than what is determined by Torsion balance method.

As regards grasses, ephemerals lasted from first shower to September/October in 1963 and 1964, the annuals remained green upto 1st fortnight of October in 1963 and upto January 1965 in case of the year 1964. During 1964 perennials remained green upto May 1965 while during 1963, they became dry by the end of 1963. These indicate again that the moisture status in soil is the main critical criteria in determining their growing seasons.

8. Condensation of water in vapour phase

As explained in previous sections, the condensation of water in vapour phase forms the main contribution in the input of the desert soils. The theory of this idea is explained by Lebedeff (1928) as follows.

The atmosphere in soil above its hygroscopic coefficient is normally saturated. Soil atmosphere is therefore generally saturated except surface layers which become exceedingly dry. Movement of water vapour is along a vapour pressure gradient. Hence it is affected by the relative temperature and vapour pressures of various horizons in soils as well as between soil and air and the occurrence of water table at considerably lower depths. Under deficient moisture conditions the film movement is exceedingly low and water vapour movement becomes important.

Soil temperatures will, therefore, play an important role in this type of movement. The thermal conductivity of soils is proportional to its water content and so the amount of heat that penetrates through wet soil on the bare plot must be approximately two times more than the amount of heat which penetrates through soil with natural vegetation. This was found to be true in our experiment. During winter, the radiation type thermal regime (*viz.*, the deep layer being warmer than the surface one) is noticed over Jodhpur while in the hot weather period, it has the typical regime of insolation (when the warmest place in the soil profile is the surface of the soil). The detailed examination of soil moisture and thermal regime is being done in a separate paper. Similar results of condensation especially in the hot weather period have been obtained by Mighahid (1961), Abichandani *et al.* (1964) and Krishnan *et al.* (1966).

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