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SURFACE RUN-OFF AND SOIL EROSION FROM ARABLE LANDS IN THE BOMBAY-DECCAN

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(With Plates XXXI and XXXII and eight text-figures)

Introduction

IT is universally recognized that, in the famine areas of the Bombay-Deccan, the most important single factor contributing to crop failures is the inadequacy of soil-moisture which is entirely dependent upon the monsoon rains, often precarious and uncertain in this tract. In an examination of the problem of these crop failures under the Bombay Dry Farming Research Scheme, investigation into the ultimate disposal of rain water naturally forms an important plank in the research programme of the Scheme. It is obvious that a considerable part of the rain water is lost by surface run-off but no definite information regarding the actual quantity of rain water lost in this manner, nor the circumstances under which such losses occur, is available. Rain water, while running over cultivated, fallow or grazing lands, removes part of the surface soil, causing what is known as sheet erosion which is sometimes difficult to recognize. Where such water gains bulk and momentum, e.g. at lower levels, it causes gully erosion which can generally be easily recognized on account of its conspicuous eroding effect. Investigations into the run-off of rain water thus necessarily include the determination of the extent of soil erosion of both the types mentioned above.

Evidence placed before the Royal Commission on Agriculture in India [1926] showed that the action of monsoon rains on the sloping hillsides of upland tracts in peninsular India, more especially in the southern districts of the Bombay province, produces soil erosion similar to that produced by fluvial action of rivers in Northern India. The Royal Commission, therefore, recommended that ' the exact extent of soil erosion in the Bombay Presidency should be investigated.'

In the programme of work under the Bombay Dry Farming Research Scheme at Sholapur, elaborate experiments have been included to determine the loss of rain water by run-off and also the extent of erosion by rainfall on

arable lands. Prior to these experiments at Sholapur, experiments of a preliminary nature were carried out under the Soil Physicist to the Government of Bombay at a small Dry Farming Station at Manjri near Poona from 1929 to 1933. The plot, however, on which these early experiments were carried out, had a slope that was much greater than the average slope of the majority of agricultural lands in the Bombay-Deccan. The experiments which are herein described were laid down on a piece of land with a natural slope which could be considered to be typical of the majority of agricultural lands in the Bombay-Deccan. No similar experiments to determine the extent of soil erosion from arable lands have been done before in India and the results presented here are the first of their kind, not only in the Bombay-Deccan, but also in the whole of India.

Sir Archibald Geikie has mentioned in his *Text-book of geology* the huge figure of 356·3 million tons of solid matter as being carried off the land by the Ganges during a single year. Sahasrabuddhe [1929] has given a figure of little less than 100 tons of solid matter estimated to be carried away by the Mula river near Poona on a day during the monsoon. With the exception of such limited references of a general nature, no data of any precise character are available with regard to the quantitative aspect of erosion of arable lands in India.

Some experiments on this subject have been reported by Gorrie [1938] from the Punjab, but these were carried out on forest soils and the plots chosen for experimental work were very small.

A very large number of experiments on rainfall run-off and soil erosion have been carried out at a large number of experimental stations in the U. S. A. and, of late, the subject of soil erosion has received considerable attention all over the world.

II. Review of previous literature

As an outcome of this work, a mass of data has now been collected and published. In this section, however, only such literature which bears directly on the experiments described in this paper is briefly reviewed. Two comprehensive publications on soil erosion and its control in different countries have been published by Eden [1933] and Jacks and Whyte [1938]. Recently, Gorrie [1939] has compiled a bibliography of Indian work dealing with the subject of soil erosion.

There is a consensus of opinion that all rainfalls do not produce run-off and erosion. Dickson [1929] noticed very heavy erosions with an average annual rainfall of only 21·68 inches. Lowdermilk [1931] found a correlation between run-off and intensity of rainfall. On the other hand, Conner, Dickson and Scoates [1930] failed to establish any direct relation between erosion and intensity of rainfall. They found, however, that run-off was influenced by the moisture content of the soil at the time of rainfall. Christiansen-Weniger [1934] is of the opinion that ' average precipitation is of little importance, the chief factors being maximal precipitation and the distribution of rainfall in the different seasons.' It seems, therefore, that the total rainfall of a tract is no criterion for judging the possibility of the occurrence and extent of erosion. It is the intensity of rainfall that is most responsible for causing run-off and erosion.

The amount of rainfall lost as run-off has been measured by a few workers. Mosier and Gustafson [1918] noticed a marked seasonal variation in percentage run-off. Over a period of three years, the run-off varied from 31 to 50 per cent of the annual rainfall. Gorrie [1938] recorded a run-off varying from 5 per cent, in the case of plots covered with grass and shrub, to 25 per cent from a bare soil. As regards the amount of silt lost per acre as a result of rainfall run-off, the results vary considerably. In Russia [Jacks and Whyte, 1938], the average soil losses varied from 20 tons per hectare per annum on gentle and moderate slopes to 50 tons on steep slopes. In Ceylon, Holland and Joachim [1933] found that, under current estate practices, the loss by erosion varied from 56 to 101 tons per acre during a period of six years. Gorrie [1938], in India, records nearly 8 tons per acre as the amount of soil lost from a bare plot during a single monsoon.

The effect of some sort of cover on soil has been recorded by several workers. Duley and Miller [1923] found that plots under annual crops suffered more than plots under sod. They also noticed that a wide-sown crop, like maize, allowed more run-off and erosion than a close-spaced one. Holland and Joachim [1923] found that soil erosion was greater in control plots than in plots having vegetation. In Africa very similar results were obtained by Thompson [1935] and Staples [1936]. Thompson found that 'annual hay crops were less detrimental. Among perennial planted grasses, Rhodes grass was not effective in preventing erosion and run-off.' Staples obtained the least percentage run-off with perennial grass and deciduous thickets, followed by Bulrush millet. Russian investigators, as quoted by Jacks and Whyte [1938], have come to a similar conclusion as regards the importance of grass in preventing run-off and erosion.

As regards the effect of cultivation, the data of Lowdermilk [1931], Holland [1930] and Duley and Miller [1923] show that cultivation increases the rate of erosion. Duley and Miller's results show that, while cultivation increased erosion, it reduced run-off. Deeper cultivation, however, was found to cause less erosion than shallow cultivation. The results obtained by Miller and Krusekopf [1932] fail to substantiate the common belief that deep ploughing is markedly better than shallow ploughing in reducing erosion losses. The results of Staples [1936], however, show that flat cultivation on a bare plot caused less run-off and erosion as compared with a bare uncultivated plot. Eden [1933] cites other workers who consider deep tillage to be effective in checking erosion, though, in conclusion, he observes that the effect of cultivation must be regarded as an open question.

Duley and Ackerman [1934] recorded a larger percentage run-off from short plots than from long ones. Their results on soil erosion were less consistent but they appear to indicate that, when the rainfall is light, short plots may undergo greater erosion, but that the reverse is true when the rainfall is heavy.

As regards the amount of nutrients removed in the process of soil erosion, Duley and Miller [1923] observe that the losses are in some cases greater than the annual crop requirements. The losses in general follow the trend of the actual losses of soil. Most of the nitrogen is removed from the soil as organic nitrogen, the loss of nitrates being very low. This view was later confirmed by Duley [1926] who found very little nitrates in run-off water. He found

that calcium formed the largest proportion of the total nutrients removed in the run-off water.

Miller and Krusekopf [1932] support the findings of Duley and Miller. Their mechanical analysis of the eroded material showed that the uncropped plots lost more sandy material than the others.

Just as soil type influences erosion, erosion changes the soil type. Bennett [1931] gives examples of new soil types having been formed by erosion. In many cases the present surface soil is the original 'B' horizon. This leads to the formation of what are known as truncated profiles. Elsewhere, e.g. in Russia and Africa [Jacks and Whyte, 1938] and in England [Robinson, 1936], similar cases have been recorded.

III. Factors affecting run-off of rain water and soil erosion

The environmental factors that influence the extent of run-off of rain water and of consequent soil erosion are :—

(1) Topography, (2) soil types and their geological origin, (3) vegetation cover and (4) the climatic factors, of which the temperature and the extent and distribution of rainfall are the most important.

The area under the Dry Farming Research Station, Sholapur, is very representative of an extensive tract of the Bombay-Deccan, which is liable to periodic famines and scarcity. This tract includes the three entire districts of Ahmednagar, Sholapur and Bijapur, and also the eastern portions of Nasik, Poona, Satara, Belgaum and Dharwar districts. It forms the area lying between E. longitude 74° and 76° and the parallels of latitude 16° and 21° N. L. and is about 26,000 square miles in extent. The Western Ghats or the Sahyadri range of mountains forms the western boundary of this tract. In fact, the Sahyadri range itself is a comparatively less eroded ridge of hard Deccan trap of volcanic origin. Numerous spurs from the Sahyadri range extend to the east and protrude at right angles to the main range into the tract forming the Bombay-Deccan. The general slope of this region is towards the east. The whole tract, therefore, consists of a plateau or a tableland with gentle undulations intersected by spurs from the Sahyadri range at right angles to the main range, thus forming a series of ridges and valleys across the plateau. The elevation of the Deccan Plateau ranges from about 2,000 ft. in the west to about 1,400 ft. at the eastern boundary of the Bombay province. The geological formation of the whole area forming the Bombay-Deccan from the river Godavari in the north to the river Krishna in the south is the well-known Deccan trap or basalt. To the south of the Krishna river in the Bijapur district, other formations of the transition series and of still older periods are met with. The whole tract which is gently undulating with alternate ridges and narrow valleys, consists of agricultural lands which have undergone varying degrees of erosion, leaving only a thin cover of soil in many places. Along the banks of the rivers, more extensive, level and deep lands are to be found. These topographical features which are the result of geological agencies, influence very greatly the run-off of rain water and the extent of soil erosion in different portions of the tract. A detailed contour map of any portion of the tract shows very distinctly the undulating character of the area. The map of Bijapur taluka (Fig. 1), which is given as an

illustration, shows that the area is traversed by a large number of *nallas* and their tributaries. All these *nallas* finally coalesce into larger streams such as the Don or the Krishna rivers and serve as surface drains for the storm-water received during heavy and intensive showers in the monsoon months. Accordingly, every year these rivers and streams carry away millions of tons of suspended soil or silt from the agricultural lands of the tract which mainly consists of the finer and more fertile fractions of soil. The area is characterized by the absence of any large tree growth except in the region of heavy rains just adjacent to the Western Ghats. Even annual vegetation is generally stunted and of very poor growth. The open, bare and uncovered nature of the tract facilitates losses of rain water and contributes to soil erosion on an extensive and widespread scale.

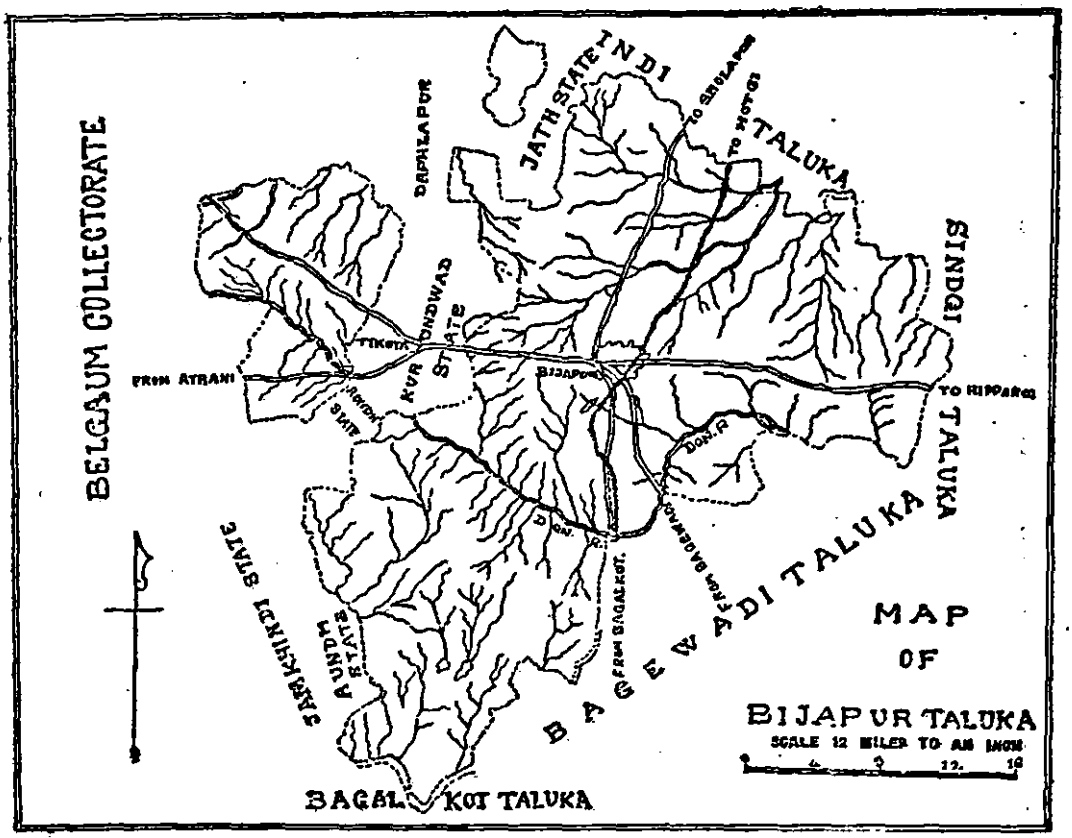


FIG. 1. Map of Bijapur taluka showing natural surface drains

IV. CLIMATIC FACTORS INFLUENCING RUN-OFF AND SOIL EROSION IN THE BOMBAY-DECCAN

(*A*) *Temperatures*

As the atmospheric temperatures of the tract at different periods of the year have an indirect influence on the extent of run-off and erosion, they are discussed here very briefly. In this extensive tract, the prevalent tempera-

tures throughout the year show considerable variance from north to south as well as from west to east. The extent of elevation above sea-level also has considerable influence on prevailing temperatures. If the records of temperatures at the four important district towns are examined (Table I), they clearly indicate the great range through which the seasonal temperatures of the tract fluctuate.

TABLE I*

Record of temperatures at important towns

	Nasik north-western area	Ahmednagar north-eastern area	Sholapur south-eastern area	Bijapur south eastern area
Highest monthly mean maximum (°F.)	100	103	106	104
Lowest monthly mean minimum (°F.)	48	51	56	55
Absolute maximum (°F.)	107	110	110	108
Absolute minimum (°F.)	42	44	48	46

* Figures given in Tables I and II are from the Statistical Atlas of the Bombay Presidency [1925].

The highest monthly mean maximum and the lowest monthly mean minimum temperatures show a difference of nearly 50°F. at all stations, while the absolute maximum and minimum show a difference of more than 50°F. during the year. The maximum temperature is reached either in April or May, while the minimum is experienced either in December or January. The air is very dry for six months of the year from November to April. During this period, the soils become extremely dry and loose and are easily blown away by the wind and carried off in suspension by water if a heavy shower of rain is received. More detailed data regarding temperatures and humidity from month to month at Sholapur are given later while discussing experimental work at this centre. The figures given above for the four recording centres illustrate how the maximum temperatures increase from north to south and also from west to east. The minimum temperature is lowest in the northern tract, as represented by Nasik, and gradually rises towards the south, i.e. Sholapur and Bijapur.

(*B*) *Rainfall*

The average monthly rainfall statistics for the same four centres show how the total rainfall, and more particularly its distribution from month to month, vary from west to east.

TABLE II

Average monthly rainfall in inches

Month	Nasik north-western area	Ahmednagar north-eastern area	Sholapur south eastern area	Bijapur south eastern area
January	0·10	0·17	0·15	0·09
February	0·04	0·13	0·07	0·06
March	0·03	0·10	0·20	0·22
April	0·18	0·23	0·46	0·80
May	0·92	0·92	1·05	0·31
June	5·57	4·57	4·67	3·37
July	8·67	3·61	4·20	2·51
August	5·09	2·77	4·54	2·88
September	5·93	6·84	7·71	6·33
October	2·81	2·78	3·02	3·88
November	0·46	0·83	1·05	1·52
December	0·18	0·55	0·46	0·31
Annual total	29·98	23·50	27·55	23·28
Average number of rainy days*	48·6	36·1	41·3	36·1

* According to the practice adopted by the Meteorological Department, only such days as receive 10 cents or more of rainfall during the 24 hours are counted as 'rainy days'. The same procedure is followed in calculating the data dealt with throughout in this article.

The rainfall at Nasik is typical of the south-west monsoon, which is restricted to a period of five months from June to October. This rainfall is generally evenly distributed during the four months of June to September and is usually received spread over a large number of rainy days. The maximum rainfall is received in July. Under such conditions, the effects of surface run-off and soil erosion are limited. The rainfall at each of the other three stations is similar in character and represents the type of monsoon generally experienced in the eastern parts of the Bombay-Deccan. The rainfall received during the first three months (i.e. June-August) amounts to about 50–55 per cent of the total precipitation, while the remaining rainfall occurs from September onwards. The number of rainy days is limited, especially during the latter part of the season. The rainfall in this tract largely consists of

intermittent heavy showers of great intensity. It should be remembered that the figures given in Table II are averages. The actual figures obtained in any one year may deviate very considerably from them. Such variation can be seen from the rainfall figures for five years at Sholapur which are given later.

Two other important factors which influence the climate of the tract are the average wind velocity and the atmospheric humidity. The nature of both these factors in the eastern tract differs considerably from their nature in the western tract of the Bombay-Deccan. These factors tend to make the climate in the eastern tract dry and desiccating even during the monsoon months, and, in this area, facilitate the quick drying of the surface soil after it has become loose and pulverized by such agricultural operations as harrowing and weeding. Therefore, the heavy downpours of rain, common in September and October, cause serious losses of such dry, loose and pulverized soil by erosion.

V. Experiments on rainfall run-off and soil erosion at the Sholapur Dry Farming Research Station

To begin with, experiments were laid down with a view to finding out as accurately as possible the amount of rain water lost by surface run-off and to enable an approximate estimate to be made of the total amount of soil carried off annually by erosion on a representative soil of the tract under the different methods of cultivation and cropping common in the south-eastern part of the Bombay province. The slope of the land chosen for this experimental work was as far as possible selected so as to be representative of the average slope to be found on the majority of the cultivated fields in the tract. The experiments were laid out on the same plan as was followed by Duley and Miller [1923] in their classical experiments at Missouri in the U. S. A., but due to differences in local environment, the plot dimensions chosen and the slope used were somewhat different from those adopted by these workers.

VI. Soil type and its physical and chemical characters

The soil of the experimental plots can be described as medium deep soil the depth varying from 9 in. to 18 in. This soil is derived from decomposition of the Deccan trap and is of a residual type, a portion of the 'A' horizon having been lost by previous erosion. Such decomposed trap is found immediately below the comparatively thin layer of surface soil. The colour of the soil is dark brown and it shows a compact constitution with the texture of heavy clay. The mechanical composition of the soil as determined by the International Soda Method is given below.

These data indicate that the soil contains a very high percentage of clay and can therefore be classified as belonging to the heavy clay type. Study of some of the physico-chemical constants indicates that this soil has a high moisture equivalent of 43·6, a high wilting coefficient of 20·10, sticky point of 57·7, with a shrinkage value of 62·7. The total exchangeable bases have been found to be 38·4 m.e. of which exchangeable lime is 30·0 m.e. It has a wide C : N ratio of 17 : 1 and the pH value of 8·14. The chemical composition of the soil, determined from the results of analysis by digestion with hydrochloric acid, is given in Table IV.

TABLE III

Mechanical analysis of soil of experimental plots

Expressed on per cent dry matter

	Surface layer 0—9 in.	Sub-surface layer 9—18 in.
Stones per cent on original soil	5·28	6·87
Loss by solution	1·64	2·67
Coarse sand	0·71	2·34
Fine sand	11·67	9·18
Silt	26·86	26·33
Clay	58·49	58·60
Difference	0·63	0·98

TABLE IV

Chemical analysis of soil of experimental plots

Expressed on per cent dry matter

	Surface layer 0—9 in.	Sub-surface layer 9—18 in.
Loss on ignition	7·73	8·58
Sand and silica	65·65	64·42
Iron oxide (Fe_2O_3)	10·99	10·48
Aluminium and titanium oxides ($Al_2O_3 + Ti_2O_3$)	11·48	11·29
Lime (CaO)	1·48	2·32
Magnesia (MgO)	0·35	0·79
Potash (K_2O)	0·44	0·48
Phosphoric acid (P_2O_5)	0·06	0·05
Nitrogen (N)	0·039	0·040

These figures show that the loss on ignition is high and is largely due to the combined moisture held by the colloids resulting from the high percentage of clay. The amount of sand and silica is comparatively high. The proportions of iron oxide and aluminium oxide are nearly equal. Phosphoric acid and nitrogen are both low, but other important plant-food ingredients, such as lime and potash, are adequate from the point of view of dry crop cultivation. The experiments described hereafter were conducted on this type of soil which can be taken as a typical representative soil to be found throughout the tract.

VII. Plan and equipment of the experimental plots

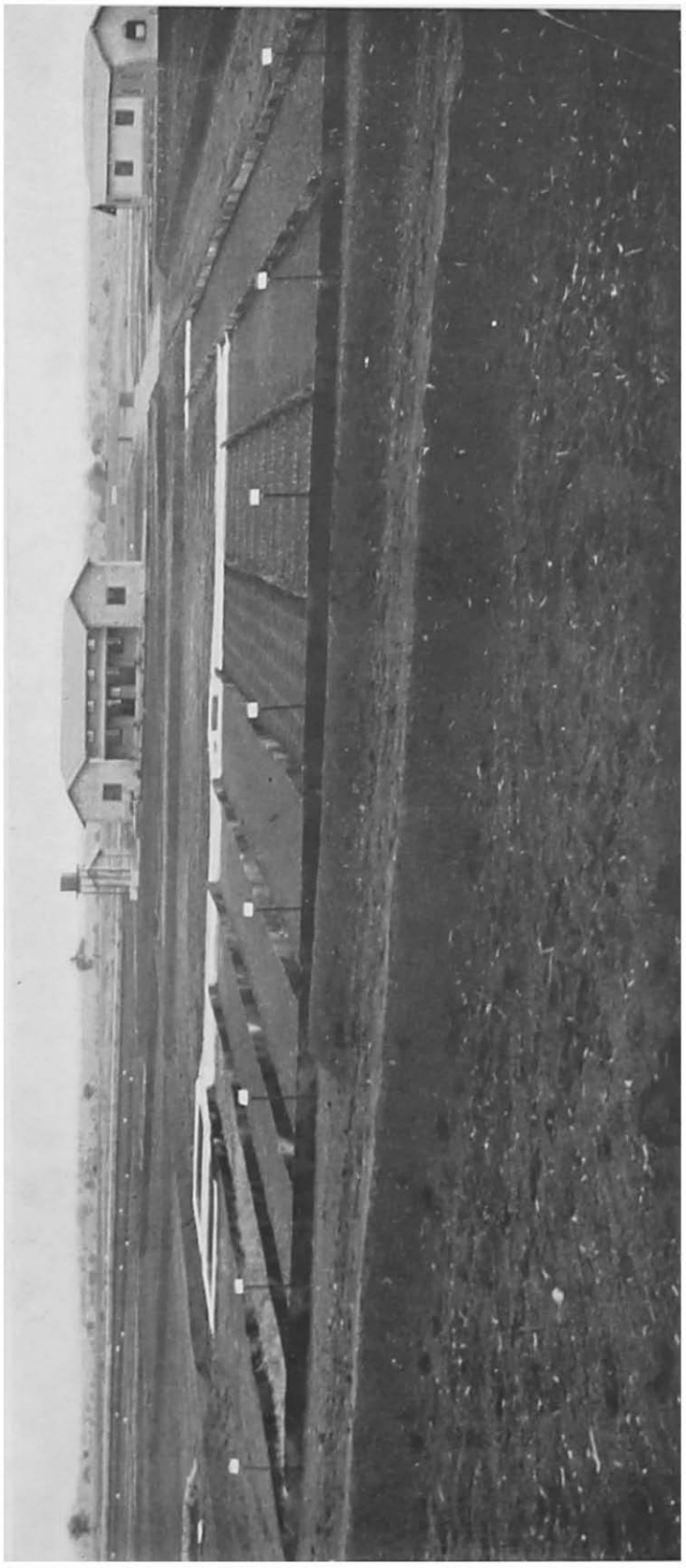
The area of the experimental plots was surveyed and the levels were determined at a distance of every 5 ft. The major slope was found to be in the north-westerly direction and the lay-out of the experimental plots therefore was fixed in the same direction. Eight unit plots were laid out. The size of each unit plot was fixed at ½ *guntha* or 1/80th of an acre for seven plots, the shape being a long narrow rectangle having its breadth and length in the proportion of 1 : 8. In the case of the eighth plot, the length was 16 times the breadth and the size of this plot was one *guntha* or double that the others. The average slope of all plots was 1·18 per cent (fall of 1 in 84). As the length of each of the seven plots was 66 ft., the total vertical fall in each plot was 0·78 ft. In the eighth plot, the length was 132 ft. and the total vertical fall from top to bottom was 1·56 ft. Each plot was surrounded on three sides by galvanized iron sheets 18 in. wide, half of which were buried in the ground and fixed by means of stout iron stakes at a distance of 4 ft. apart. The fourth and lower side of each plot was open and was level with the top of the side wall of a series of masonry tanks constructed at the lower end of each plot to catch the run-off of rain water and silt. Each tank had a flat bottom. Seven of these masonry tanks had dimensions of 8 ft. × 3·3 ft. × 3 ft., while the eighth one was 8 ft. × 5 ft. × 4 ft. An outlet pipe was provided in each tank which could be opened or closed as required. The ground-plan of the eight experimental plots and the tanks is shown in Fig. 2. All the outlet pipes opened into a drain whence the water from the tanks could be allowed to escape through an underlaid china pipe of 4 in. diameter to outside the experimental area. Plates XXXI and XXXII illustrate the general arrangement of the experimental plots and the tanks.

VIII. Treatment of the experimental plots

The undernoted eight treatments were given respectively to the eight plots mentioned above.

Plot 1 : *Retention of natural vegetation or sod* (*Treatment 1*)

This plot was kept unstirred and in its original condition, i. e. covered with the usual annual flora which was rather sparse at the commencement of the experiment. This vegetation was allowed to grow and develop naturally during the monsoon and to dry up during the hot weather months. During the five years' experimental period, the whole plot became completely covered with vegetation. In the hot weather, much of this vegetation dried up, but generally sprouted again during the monsoon. The most common species of plants present were : *Cynodon dactylon, Ischaemum pilosum, Euphorbia*



A general view of plots for run-off and soil erosion experiments at Sholapur

Some of the run-off plots with tanks

hyperecifolia, Justicia quinqueangularis, Tridax procumbenx, Tephrosia purpurea, Indigofera linifolia, Merremia emarginata, Panicum isachne, Panicum ramosum, Iseilema anthophoriodes, Cocculus villosus, Euphorbia dracunculoides, etc.

Plot No.	Treatment	Plot No.	Treatment
1	Weeds preserved	5	'Scooped'
2	Weeds removed	6	*Kharif* crop of *bajri* and *tur*
3	Harrowed only	7	Ploughed and harrowed
4	*Rabi* crop of *jowar*	8	Ploughed and harrowed with double length

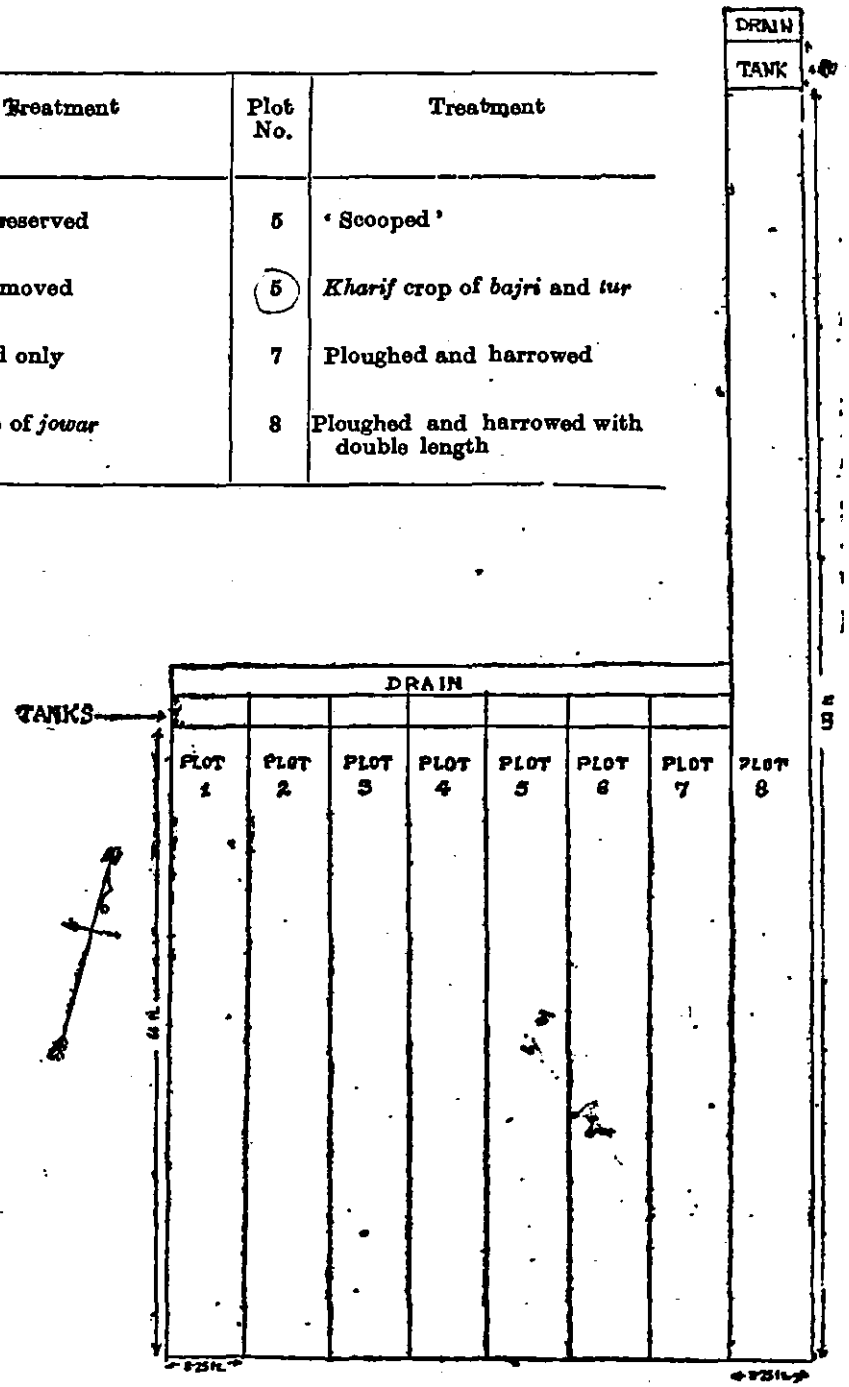


FIG. 2. Plan of the run-off and erosion experiments at Sholapur

Plot 2 : *Removal of natural vegetation by cutting* (*Treatment 2*)

The natural vegetation on this plot was superficially removed by cutting close to the ground without disturbing the surface soil. This was done annually, two or three times during the monsoon, whenever the vegetation had grown enough (one to two inches above ground) to interfere with the run-off.

Plot 3 : *Shallow cultivation by local harrow* (*Treatment 3*)

This plot received only such cultivation as is usually given by cultivators in the tract. Such cultivation is shallow and, for this purpose, the country blade harrow is the common implement used by the cultivator.. The plot was harrowed to a depth of 4 in. two or three times during the season, once in the hot weather before the monsoon (May-June) and twice during the monsoon (July-September) before the sowing season.

Plot 4 : *Cultivation of a* rabi *crop of* jowar (*Treatment 4*)

In this plot, ploughing was done in the hot weather and subsequent harrowing was done every month from May to September. In the first year, the ploughing was carried out with a CT2 plough but, in the succeeding four years, the plot was hand-dug in order to get the effect of ploughing as actual ploughing was found to be impossible on account of the iron sheets fixed along the borders of the plots. A *rabi* crop of *jowar* (*Andropogon sorghum*) was sown at the beginning of October and received about four interculturings at an interval of about three weeks during November-January.

Plot 5 : *Cultural treatment with a 'scooper'* (*Treatment 5*)

The 'scooper' is a specially devised bullock-drawn implement which makes a number of shallow hollows or pockets when worked over a well-prepared soil. By the use of this implement, about 150 'scoops' or hollows were made over the surface of the plot,. the intention being that the rain water should be held in these 'scoops' and run-off checked. The size of each hollow or 'scoop' was about 15 in. × 9 in. × 3 in. and the space between two 'scoops' was about 12 in. The scooping was done on two occasions, once early in July and again late in August.

Plot 6 : *Cultivation of a* kharif *crop of* bajri *and* tur (*Treament 6*)

After a thorough preparatory tillage consisting of one ploughing and two harrowings, this plot was sown with *bajri* (*Pennisetum typhoideum*) and *tur* (*Cajanus indicus*) mixture every year. In sowing this mixture either in June or July, the usual cultivators' practice of sowing three rows of *bajri* and the fourth row of *tur* was followed. The rows ran across the slope so as to obtain the fullest effect of the standing crop in checking rainfall run-off and soil erosion. Four to five interculturings were given to the standing crop at an interval of three or four weeks during July-October.

Plot 7 : *Thorough and intensive preparatory tillage* (*Treatment 7*)

In this plot, intensive preparatory tillage was given, which consisted of deep ploughing in the hot season and harrowing four times during the monsoon

from June to September. In the first year, the ploughing was done with a CT2 plough, but later on the plot was hand-dug to imitate ploughing. The furrows were made across the slope. No crop was cultivated.

Plot 8 : Treatment 7 on a plot double the length of plot 7 (Treatment 8)

This plot received similar treatment as was given to plot 7, i.e. intensive preparatory tillage consisting of ploughing and four harrowings. In this plot the effect of the greater length of the plot on the run-off and erosion was under study as the length of this plot was 132 feet, or double that of plot 7 and other plots.

NOTE.—Treatment 4 was carried out on plot 7 in the first year of the experiment and treatment 7 on plot 4 but, during the remaining four-year period, treatment 4 was continuously on plot 4 and treatment 7 on plot 7. The reason for this change was to avoid the sheltering effect of the standing crop of *bājri* and *tur* of plot 6 on the *jowar* crop of plot 7, as laid out in the first year. As plot 6 was to the west of plot 7, the standing crop on the former plot used to intercept the showers of the south-west monsoon and thus affect the growth of the *jowar* crop on plot 7.

IX. MEASUREMENT OF THE RUN-OFF WATER AND THE RESULTS OBTAINED FROM JUNE 1934 TO MAY 1939

The experimental work started on 1 June 1934, when the construction of the tanks and the lay-out of the eight plots were completed.

Whenever run-off of rain water took place, measurements of the depth of the accumulated water in each plot-tank were taken as accurately as possible, an average of six readings correct to a tenth of an inch being calculated. The volume of water was then calculated on the basis of the known tank dimensions after making correction for the rainfall received directly into the tank. The water in each tank was then thoroughly agitated by stirring, and allowed to escape through the outlet near the bottom of the tank. A sample of this water was taken in a Winchester bottle, care being taken to obtain a fair sample. The quantity of suspended silt was determined in the laboratory by filtering the water through a filter paper and then by drying and weighing the residual material. The actual volume of water was then calculated by deducting the calculated volume of silt from the combined volume of water and silt. The amount of run-off from each plot was calculated both as cubic feet of water collected in each tank and as inches of rainfall lost. The results obtained over five years are given in Table V, which shows the equivalent inches of rain water lost by run-off annually from each of the eight plots receiving the different treatments described above.

On account of the expensive nature of the lay-out required for these experiments, they were conducted on single plots only. It will be shown in Appendix II by the analysis of variance that variation between plots is extremely small when the data of plots similarly treated over some period are worked out statistically.

X. Rainfall at Sholapur during the period of the experiment

Before discussing the results of the experimental work on run-off, it is necessary to examine how the rainfall varied during the experimental period of five years and how far it represented the average rainfall obtained in this tract over a prolonged period, both with regard to the total annual rainfall and its monthly distribution.

In Table VI, data regarding monthly and annual rainfall at the Research Station along with the number of rainy days are given. In column 2 of this table, the average monthly and annual rainfalls for a period of 25 years from 1908 to 1933, i.e. just prior to the commencement of the experiments, are given. Columns 3-7 give similar data for the five years of the experiments, while in the last column, the average monthly and annual rainfalls and the number of rainy days for the whole period of five years (1934-39) are given along with their deviations from the annual average. It may be seen, by comparison of columns 2 and 8, that the average annual rainfall for the shorter period of five years was practically the same as the annual average over the longer period. The average distribution differed, however, in the two periods. The average rainfall of the three months from June to August was somewhat higher during the shorter period than during the longer period. On the other hand, the rainfall during September and October was somewhat lower during 1934-39 than during the previous 25 years' period, i.e. from 1908 to 1933. The number of rainy days per annum did not differ much. Curves showing the average monthly distribution during the two periods readily illustrate the above points (Fig. 3). If the individual years are considered separately, then it can be seen that the years 1934-35 and 1936-37 were years of drought when only 80 and 60 per cent, respectively, of the annual average rainfall were received. The year 1937-38 received very nearly the annual average rainfall. The remaining two years, viz. 1935-36 and 1938-39, were wet years and received rainfall higher than the annual average. This increase, however, was only 20 per cent in the former year but was nearly 40 per cent in the latter. In the year 1938-39, the number of rainy days was also much higher, viz. 57 as against the normal average of 41·2. It can be seen therefore that the period of experimentation may be taken as fairly typical in covering possible variations in individual years and, at the same time, giving approximately average rainfall conditions over the total period of five years similar to those experienced over a long period of 25-30 years. Fig. 4 indicates the variation in the monthly distribution of rainfall during the five years of the experimental work. It can be seen from the data in Table VI that no exact relationship appears to exist between the number of rainy days in a year and the total rainfall received during the same period. Although it is true that in general the higher the number of rainy days, the greater the total rainfall and *vice versa*, this is not always the case. Thus, in the year 1937-38, the rainfall was nearly 25 per cent higher than that of 1934-35, but the number of rainy days was smaller, viz. 42 in the former year as against 46 in the latter year. Again the year 1935-36 received nearly 40 per cent more rain than the year 1934-35, but the total number of rainy days in both the years was exactly the same.

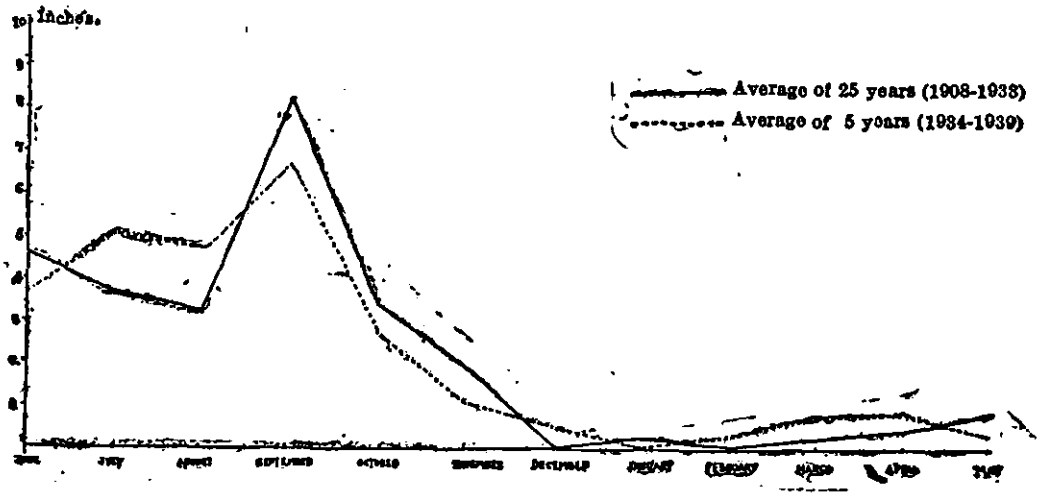


FIG. 3. Average rainfall at Sholapur

TABLE V

Quantities of water lost by rainfall run-off in inches from each plot during the five years of experiment

No. of plot	Treatment	Rainfall lost in inches				
		June 1934—May 1935	June 1935—May 1936	June 1936—May 1937	June 1937—May 1938	June 1938—May 1939
1	Retention of natural vegetation	0·21	4·02	0·07	0·65	0·64
2	Natural vegetation removed by cutting	1·37	5·80	1·06	6·36	9·48
3	Shallow cultivation by harrowing	1·24	5·70	2·22	8·36	9·51
4	Thorough and intensive cultivation by ploughing and harrowing and growing *rabi* crop of *jowar*	1·09	5·55	1·89	7·47	6·92
5	'Scooping' of the surface soil after thorough cultivation	0·02	3·83	0·19	4·32	2·01
6	Thorough cultivation by ploughing and harrowing and growing *kharif bajri* and *tur* mixture	0·58	4·62	1·58	6·99	4·41
7	Thorough and intensive cultivation by ploughing and harrowing	1·42	5·02	1·93	7·14	6·41
8	Thorough and intensive cultivation as in plot 7 with double length	1·21	5·31	2·19	7·74	6·39

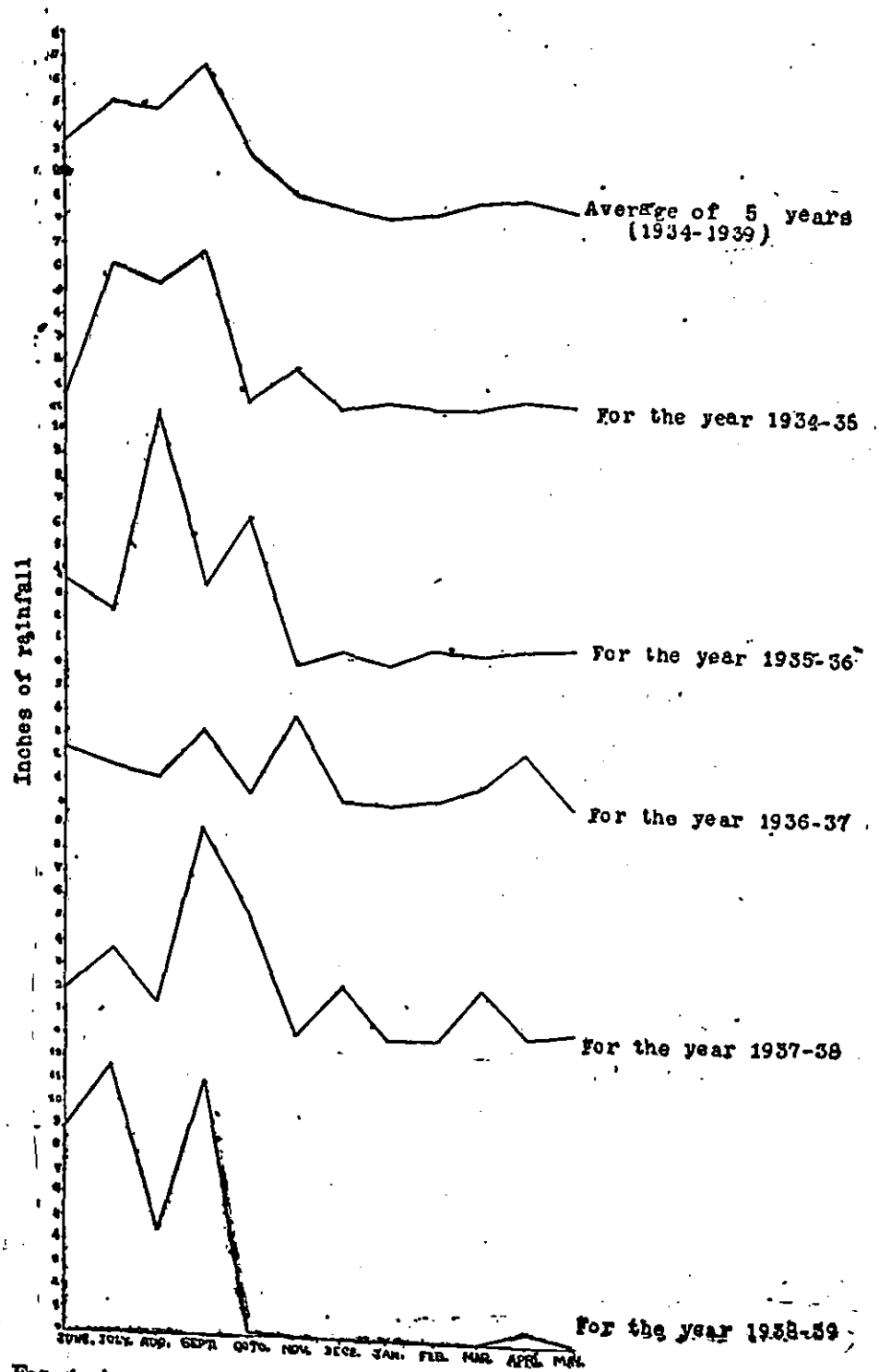


FIG. 4. Average monthly rainfall at Sholapur during the experimental period

TABLE VI

Rainfall and the number of rainy days at Sholapur

Calender months	Average for 25 years		1934-35		1935-36		1936-37		1937-38		1938-39		Average for the years 1934-39	
	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days
June	4·55	6·6	0·59	3	3·54	10	2·43	4	1·92	2	8·45	13	3·39	6·4
July	8·70	7·7	6·06	19	2·26	6	1·62	5	3·65	12	11·59	19	5·04	11·0
August	8·15	7·6	8·33	9	10·84	11	1·10	3	1·53	4	4·53	12	4·67	7·8
September	8·10	9·0	6·56	12	3·44	6	3·12	5	8·96	11	11·02	9	6·62	8·6
October	3·30	4·3	0·28	2	6·39	7	0·47	1	5·12	5	1·06	2	2·66	3·4
November	1·75	1·5	1·62	3	0·01	...	3·75	3	...	...	...	...	1·08	1·2
December	Trace	0·6	...	...	0·56	1	0·05	...	2·08	3	...	...	0·54	0·8
January	0·15	0·3	0·19	1	...	...	...	...	...	...	...	...	0·04	0·2
February	...	...	...	...	0·73	2	0·23	1	...	...	...	...	0·19	0·6
March	0·20	0·4	...	...	0·36	1	0·75	2	2·21	2	...	...	0·66	1·0
April	0·40	1·0	0·41	2	0·65	1	2·40	4	0·23	1	0·49	2	0·84	2·0
May	0·75	2·2	0·11	1	0·74	1	...	...	0·41	2	...	...	0·25	0·8
TOTAL	26·40 ±1·53	41·2	21·15	46	29·52	46	15·92	28	26·11	42	37·14	57	25·96 ±3·62	48·8 ±0·09

Similarly, monthly rainfall is not always proportional to the number of rainy days in the month. This is due to the fact that the intensity of rainfall is different in different months, as can be seen clearly from the figures given in the last column of Table VI. It can be stated in general that the intensity of rainfall is greater in the latter half of the monsoon, i.e. from September to November, than in the first half, i.e. from June to August. The month of July gave the largest average of rainy days but the intensity of rainfall in this month was the lowest. It should be noted that the rainfall during the period of September to November is generally received in the shape of stormy downpours lasting for only an extremely short period of one to two hours daily. The rainfall during the early period of the monsoon is generally received as small showers of a persistent and soaking nature, lasting over a large number of hours each day. This shows that the early monsoon rains are generally of low intensity while those of the later period are of great intensity. This intensity of rainfall has a very great bearing on the run-off of rain water and on consequent soil erosion.

XI. Temperatures, humidity and wind velocity at Sholapur

Mention has already been made of the influence of climatic factors, other than rainfall, on the run-off of rain water and on consequent soil erosion. In Table VII monthly average values for some of the more important meteorological observations taken during the experimental period of five years, i.e. 1934-35 to 1938-39 are given.

Table VII

Monthly averages of important meteorological observations at Sholapur Dry Farm

(Average of 5 years from 1934-35 to 1938-39)

Month	Maximum temperature (°F.)	Minimum temperature (°F.)	Mean temperature (°F.)	Relative humidity per cent	Wind velocity miles per hour	Evaporation from free water surface in inches
June	94·23	73·35	83·79	73·94	10·78	11·79
July	88·43	70·94	79·65	82·34	10·40	8·61
August	88·15	70·02	79·10	81·03	9·43	8·17
September	86·84	69·53	78·19	82·40	7·81	7·80
October	90·04	66·53	78·30	65·79	5·78	10·77
November	86·17	58·82	72·50	58·94	5·04	8·63
December	84·28	55·93	70·12	58·99	4·44	8·66
January	86·47	56·96	72·62	55·30	4·13	9·94
February	90·78	60·65	75·72	47·57	4·72	10·81
March	97·90	67·33	82·52	34·97	5·12	16·30
April	101·06	72·37	86·73	40·90	6·05	17·22
May	105·41	76·44	90·93	43·57	7·72	20·43

The data of monthly average maximum and minimum temperatures indicate the wide range of temperatures prevailing in this tract. The very high temperatures during April and May result in considerable sun-drying and baking of soils, which causes considerable cracking and fissure formation in the deeper types of soils. These cracks ultimately give rise to gully formation as a result of the run-off of heavy rains at the outbreak of the south-west monsoon. The higher temperature of the atmosphere, combined with the high wind velocity during the monsoon months, produces a highly desiccating effect on the soils. Slight showers are, at that time, ineffective as the soil moisture is largely lost by evaporation during the following 24 hours. The high rate of evaporation of water noted from free water surface indicates a similar trend of rapid evaporation of soil-moisture. These factors result in the surface soil remaining dry and pulverized, thus facilitating its removal by the run-off water resulting from the heavy showers commonly received in September and October in this tract. The knowledge of the influence of such climatic factors facilitates a clearer understanding of the experimental results on run-off and soil erosion which are discussed hereafter.

XII. Results of rainfall run-off experiments at Sholapur

(*A*) *Effect of experimental treatments*

The eight different treatments given to the eight plots in the experimental area have already been mentioned in detail. The main object of these different treatments was to ascertain whether any particular method of tillage or cultivation or the growing of any particular crop would have a controlling effect on the quantity of water lost by run-off. The results of the experiments given in Table V were obtained from the estimate of the actual volume of water lost from the area of 1/80th or 1/40th of an acre in cubic feet from year to year and are expressed in inches of rainfall thus lost. Table VIII shows the number of occasions upon which run-off of rain water took place in each year and also the total number of such run-offs during the five years under each plot treatment. The quantities of water lost from each plot in inches are also shown. Careful scrutiny of these results shows that the treatment on plot 1, viz. the plot with natural vegetation preserved *in situ* gave the lowest number of run-offs and lost the smallest quantity of rain water by run-off during the experimental period of five years. In this plot, there were, in all, 23 run-offs during the five years and the total quantity of rain water lost in this way amounted to 5·59 in. during the same period. This treatment was, therefore, the most effective in checking the loss of rain water by surface run-off. The treatment given on plot 5, which consisted of 'scooping', ranked second in effectiveness in controlling run-off. The number of run-offs on plot 5 during five years was 31 or nearly 25 per cent more than on plot 1, but the total quantity of rain water lost amounted to 10·37 in., which is nearly 85 per cent more than the loss on plot 1. Only one more treatment, viz. the cultivation of *bajri* and *tur* crops on plot 6 showed some appreciable effect in controlling rain water run-off. The number of run-offs in this plot was 43 and the water lost amounted to 18·28 inches. If, however, the results from plot 6 are compared with the results obtained on plot 1, i.e. vegetation cover, the number of run-offs on the former plot was nearly double

TABLE VIII

Number of run-offs from each plot and inches of rainfall lost from each plot in different years

Year of observation	Plot 1 Retention of vegetation		Plot 2 Removal of vegetation		Plot 3 Shallow cultivation		Plot 4 Cultivation of *rabi jowar*		Plot 5 'Scooping'		Plot 6 Cultivation of *kharif bajri* and *tur*		Plot 7 Thorough cultivation		Plot 8 Thorough cultivation and double-length	
	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)
1934-35 .	5	0·21	5	1·37	5	1·24	5	1·09	4	0·02	6	0·68	6	1·42.	5	1·21
1935-36 .	6	4·02	9	5·80	9	5·70	8	5·55	6	3·83	6	4·62	7	5·02	6	5·31
1936-37 .	3	0·07	5	1·06	5	2·22	4	1·89	3	0·19	3	1·58	4	1·93	4	2·19
1937-38 .	7	0·65	16	6·36	20	8·36	16	7·47	11	4·32	15	6·99	16	7·14	15	7·74
1938-39 .	2	0·64	15	9·84	15	9·51	13	6·92	7	2·01	13	4·41	13	6·41	13	6·30
Total in 5 years	23	5·59	50	24·43	54	27·03	46	22·92	31	10·37	43	18·28	46	21·92	43	22·75
Average per annum	4·6	1·12	10	4·88	10·8	5·40	9·2	4·58	6·2	2·07	8·6	3·65	9·2	4·38	8·6	4·55

that on the latter and the quantity of water lost more than three times. The *bajri* crop stands for 3-3½ months during the south-west monsoon period and the *tur* crop remains much longer. The combined effect of these standing crops in checking run-off can be seen in the results obtained on plot 6 if compared with those of plot 7.

The treatment given in plot 2, where the natural vegetation was removed by cutting close to the soil surface without disturbing the soil itself, showed by contrast the great preserving effect on soil erosion of the plant cover on plot 1. The soil in both cases was undisturbed, but there was a vegetation cover in plot 1 and no such cover in plot 2. Treatment on plot 2 gave in all 50 run-offs and lost a total of 24·43 inches of water during the five years. The number of run-offs was more than double that on plot 1 during that period and the rain water lost by run-off on plot 2 was more than four times that lost on plot 1 which had plant cover. It was observed that this plot used to get dry and crack extensively during the hot weather. This cracking facilitated the vertical percolation of rain water and thus reduced the loss of rain water by surface run-off.

The treatment on plot 3 consisted of shallow cultivation, viz. two or three harrowings during the monsoon months done with a blade harrow. This plot gave the largest number of run-offs, viz. 54 and also lost the largest total quantity of rain water, viz. 27·03 in., during the complete period of five years. The difference of 2·6 inches in the total water lost by run-off between plots 2 and 3 was mainly due to higher loss from plot 3 in one year. During the year 1937-38 which gave a greater number of intensive showers, there were four additional run-offs and 2 in. excess loss of rain water from plot 3 as compared to plot 2. That the difference between the treatments on plots 2 and 3 is not statistically significant, is shown later on in another statement.

The treatment on plots 7 and 8 consisted of thorough and intensive cultivation of the land by one deep ploughing in the hot season, followed by four or five harrowings during the monsoon months. The length of plot 8 was double that of plot 7. The total number of run-offs during five years was 46 from treatment on plot 7 and 43 from treatment on plot 8. The total quantity of water lost was 21·92 in. and 22·75 in. from plot 7 and plot 8 respectively. As compared to no cultivation on plot 2, or shallow cultivation on plot 3, the run-off was somewhat lower in the case of the deeper cultivation on plots 7 and 8. There was no noticeable difference due to the different lengths of the two plots. This is contrary to the result obtained by Duley and Ackerman [1934] in the U. S. A. They found that the shorter plots gave a larger percentage of surface run-off than longer plots. Thus, although the thorough and deep cultivation given effected a slight reduction in the number of run-offs, and in the quantities of water lost by run-off, when compared with the treatment on plot 3 which received shallow cultivation and also with treatment on plot 2 which received no cultivation, the difference was not statistically significant. Miller and Krusekopf [1932] found no benefit as a result of deep ploughing in checking the surface run-off of rain water.

The remaining treatment on plot 4 consisted of thorough and intensive cultivation, as in plots 7 and 8, and had in addition a *rabi* crop of *jowar* from

October to February. The total number of run-offs during the five years from the plot was 46 and the total quantity of water lost amounted to 22·92 in. Thus there was no apparent influence of the cultivation of a *jowar* crop on the rain-water run-off. This may be attributed to the fact that most of the rains were received before the sowing of the crop and only a small amount during the very early stage of the crop when the young seedlings could not in any way influence the run-off. Fig. 5 illustrates the comparative losses of water every year under different treatments.

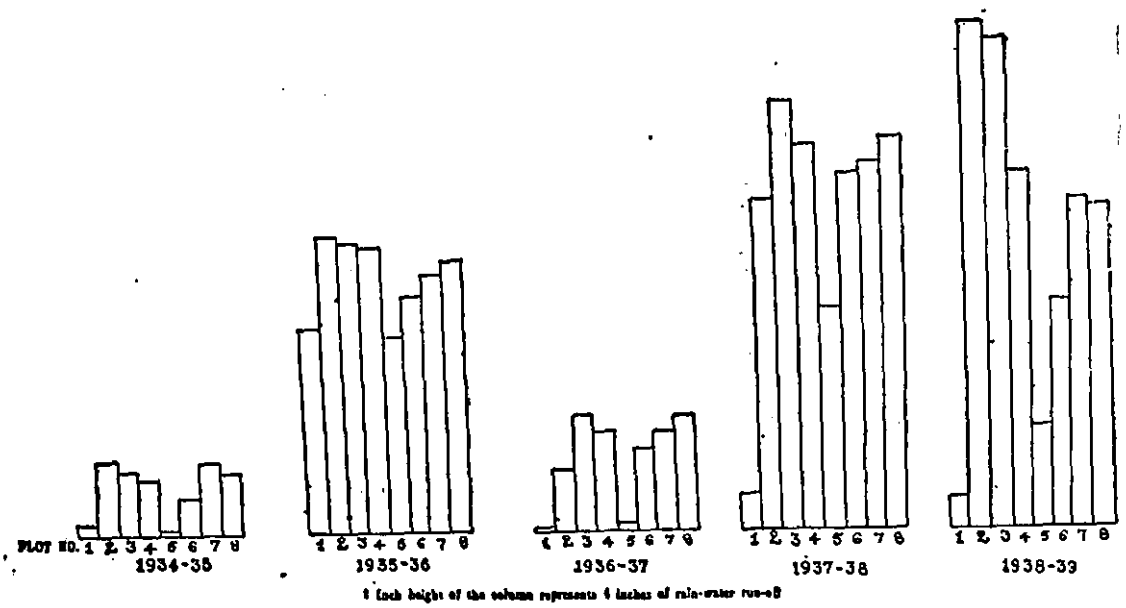


FIG. 5. Relative quantities of rain water in inches lost by run-off from plots under different treatments

[Plot 1, weeds preserved; plot 2, weeds removed; plot 3, harrowed only; plot 4, *rabi* crop of *jowar*; plot 5, scooped; plot 6, *kharif* crop of *bajri* and *tur*; plot 7, ploughed and harrowed; plot 8, ploughed and harrowed with double length]

Thus, to sum up the results of the experimental work on the effect of the different treatments on rain-water run-off, it can be stated that: (1) There is some reducing effect resulting from deep cultivation on the number of run-offs and on the quantity of rain water lost by run-off as compared to the effects of shallow or no cultivation. The results of treatments on plots 2, 3 and 7 suggest the above conclusion. (2) The length of the plot does not affect the run-off materially as seen from the comparison of the results of treatments on plots 7 and 8. (3) The cultivation of *rabi jowar* also had no influence on the run-off. (4) The cultivation of a mixed crop of *bajri* and *tur* in the *kharif* season reduced the quantity of water lost by run-off. (5) The special cultural treatment of 'scooping' reduced both the number of run-offs and the total quantity of water lost by run-off. (6) The most effective treatment in controlling and reducing the rainfall run-off was found to be the conservation of the natural vegetation on the untouched surface of the soil.

(B) The total annual rainfall, the number of days on which run-off occurred and the quantity of rain water lost by run-off during the experimental period of five years

Having considered the effect of different cultural treatments and systems of cropping on the quantity of rain water lost by run-off in the preceding paragraphs, it will be interesting to see whether any relationship can be traced between the total annual rainfall and the number of days on which run-off occurred as well as the total quantity of rain water lost by run-off during the same period.

TABLE IX

Total annual rainfall, the number of days on which run-off took place and the total quantity of rain water lost by run-off

Year	Total rainfall during the year in inches	The number of days on which run-off occurred	The total quantity of rain water lost by run-off in inches
1934-35	21·15	5	1·24
1935-36	29·52	9	5·70
1936-37	15·92	5	2·22
1937-38	26·11	20	8·36
1938-39	37·14	15	9·51

The data presented in Table IX are for treatment 3, i.e. shallow cultivation by harrowing on plot 3. The data from this plot are selected for consideration as this treatment represents closely the usual cultivation followed by the cultivators in the tract.

Careful scrutiny of the figures in columns 2 and 3 would indicate that no relationship can be established between the total annual rainfall and the number of days on which run-off occurred during the year. This is illustrated by the fact that the year 1938-39, with the highest total rainfall (37·14-in.), was not the year which recorded the largest number of run-off days. On the other hand, the year 1937-38, with only 26·11 in. total rainfall, recorded the largest number of days on which run-off occurred. Similarly the total quantity of rain water lost by run-off during the year is not proportional to the total rainfall received during the same period. This can be clearly seen by comparison of the data for the year 1934-35 with those for 1936-37 and again the data for the year 1935-36 with those for 1937-38. Thus the number of days on which run-off occurred and the total quantity of water lost by run-off bear no definite proportional relationship to total annual rainfall. Other factors in this connection are considered later.

(C) Monthly rainfall, number of days on which run-off occurred and the total rainfall run-off from month to month during the experimental period

The average number of days upon which run-off occurred in each month is shown in Table X for the whole period of five years for the treatment on plot 3, i.e. treatment 3, viz. shallow cultivation by harrowing. It will be seen that the maximum number of days of run-off was recorded in the month of September with an average of 3·2. July stood second with 2·2 days of run-off and August third with 1·8. The month of June recorded 1·6 days of run-off followed by October with an average of one day of run-off. The remaining seven months together recorded only 1·2 days of run-off. The average quantity of water lost generally increased from June to September and rapidly decreased from October to December. The remaining months. except March, recorded no run-off. The quantity of water lost by run-off was much higher in September and was equal to the total quantity lost during the three months of June, July, and August. The differing effects on rainfall run-off of the early rainfall (June-August) and the later (September and October) can be seen from the detailed consideration of the data presented in Table X. Thus, in the year 1934-35, the month of July recorded 6·06 in. of rainfall and the month of September, 6·56 in. But there was only very slight run-off equal to 2 cents of rainfall in July, while in September a loss of 1·20 inches occurred on three occasions. Examples can be multiplied to show that there is no exact relationship between the monthly rainfall and the quantity of rain water lost by run-off during the month. Detailed considerations of the experimental data for five years indicate that, for a given slope and type of soil, the most important factors that influence rainfall run-off appear to be : (1) the intensity of individual showers and (2) the moisture-status of the soil previous to the rainfall resulting in run-off. Both these factors are considered in detail in Table X.

(D) Intensity of showers and rainfall causing run-off

Appendix I-*a* shows the rainfall recorded on all rainy days in each month. The figures representing rainfalls that caused surface run-off from any of the experimental plots have been shown in italics. The data for all the five years of the experiments have been included in that table. In addition, the rainfalls have been grouped into four classes indicating varying intensities according to the quantity of rainfall received during a day or 24 hours. These data have been summarized in Table XI, which gives the total number of rainfalls in each class for each year and the number of rainfalls in each class which caused surface run-off.

It can be seen from Table XI that the total number of rainy days was 218 during the whole period of five years. Out of this total 55, or nearly 25 per cent of the total number, caused surface run-off. Only nine, or nearly 4 per cent of the total number, exceeded 2 inches of rainfall. Twenty-five, or 11·4 per cent varied from 1 in. to 2 in. Forty, or 18·3 per cent, varied from ½ in. to 1 in., while the remaining 144, or nearly 66 per cent, represent less than ½ in. rainfall in a day. Detailed examination of these data as presented in Table XI reveals an interesting relationship between the intensity of rainfall and the occasions of rainfall run-off.

TABLE X

Monthly distribution of rainfall, the number of days of rainfall run-off, and the quantity of water lost by run-off

(Plot 3)

Month	1934-35			1935-36			1936-37			1937-38			1938-39			Average of 5 years		
	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches
June	0·59	...	...	3·54	1	0·05	2·43	...	...	1·92	2	0·69	8·45	5	2·56	3·38	1·6	0·66
July	6·06	1	0·02	2·26	1	0·01	1·62	1	0·04	3·65	3	0·23	11·59	5	2·39	5·07	2·2	0·54
August	5·33	2	0·02	0·84	6	4·34	1·10	...	...	1·53	1	0·08	4·53	...	...	4·56	1·8	0·89
September	6·56	3	1·20	3·44	...	...	3·12	2	0·76	8·96	6	3·93	11·02	5	4·56	6·62	3·2	2·09
October	0·28	...	...	6·39	1	1·30	0·47	...	...	5·12	4	1·78	1·86	...	...	2·66	1·0	0·61
November	1·62	...	...	0·01	...	...	3·75	2	1·42	...	...	...	...	...	...	1·08	0·4	0·28
December	...	...	...	0·56	...	...	0·05	...	...	2·08	3	1·07	...	...	...	0·54	0·6	0·22
January	0·19	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0·4	...	...
February	...	...	...	0·73	...	...	0·23	...	...	...	...	...	...	...	...	0·19	...	...
March	...	...	...	0·86	...	...	0·75	...	...	2·21	1	0·58	...	...	...	0·66	0·2	0 11
April	0·41	...	...	0·55	...	...	2·40	...	...	0·23	...	...	0·49	...	...	0·84	...	...
May	0·11	...	...	0·74	...	...	...	...	...	0·41	...	...	...	...	...	0·25	...	...
Total	21·15	6	1·24	29·42	9	5·70	15·92	5	2·22	26·11	20	8·36	37·14	15	9·51	25·96	11	5·40

TABLE XI

Classification of rainfall according to intensity and the number of rainfall run-offs in each class, during the experimental period

Year		0—50 cents	50—100 cents	1—2 inches	More than 2 inches	Total	Remarks
1934-35	No. of rainfalls in each class	36	4	4	2	46	
	No. of rainfalls that caused run-off	2*	...	2	2	6	*Sharp showers on previously saturated soil
1935-36	No. of rainfalls in each class	28	12	3	2	45	
	No. of rainfalls that caused run-off	1*	2†	3	2	8	†Showers were either of great intensity or were received on saturated soil
1936-37	No. of rainfalls in each class	18	7	2	1	28	
	No. of rainfalls that caused run-off	1*	2†	1	1	5	
1937-38	No. of rainfalls in each class	26	8	6	2	42	
	No. of rainfalls that caused run-off	6*	6	6	2	20	
1938-39	No. of rainfalls in each class	36	9	10	2	57	
	No. of rainfalls that caused run-off	2*	3	8	2	15	
Total for five years	No. of rainfalls in each class	144	40	25	9	218	
	No. of rainfalls that caused run-off	12*	14	20	9	55	
	Percentage of the number of rainfalls that caused run-off	8·3	35	80	100	25·2	

It can be seen that: (*a*) all the nine showers of more than 2 in. resulted in surface run-off of rain water; (*b*) 20 rainfalls, or 80 per cent of the rainfalls varying from 1 in. to 2 in., also resulted in surface run-off. Five rainfalls belonging to this class, which did not result in run-off, were received as 'soaking' and intermittent rainfalls spread over the 24 hours. In some cases, however, they were solitary showers during the dry season from November to May; (*c*) about 35 per cent, or 14 out of 40 rainfalls belonging to the class of ½ in.-1 in., resulted in surface run-off. These were sharp showers of considerable intensity usually precipitated in less than one hour; (*d*) of the remaining 144 rainfalls (belonging to the class with less than 50 cents a day) only 12 rainfalls, or 8·3 per cent, resulted in run-off. The average rainfall of the 12 showers causing run-off in this class was, however, 35·8 cents. All these showers were of great intensity and were received on already saturated soil surface. The smallest shower producing run-off in this class was one of 17 cents, and was received in continuation of the previous day's rainfall on an already saturated soil surface.

E) Moisture status of the soil previous to the occurrence of rainfall run-off

Consideration of the data given in Appendix I-*a*, in addition to those summarized in Table X, reveals that, in general, the number of days of run-off was higher in the latter part of the monsoon season. But, more particularly, the quantity of water lost by run-off was distinctly greater during the period from September to November than during the period of June to August. It has been shown in the preceding paragraph that this is due partly to the greater intensity of the showers in the latter part of the monsoon. But another very important factor which contributes to

run-off is the moisture status of the soil previous to the rainfall causing such run-off. At the commencement of the monsoon in June, the surface 12 in. layer of soil of the arable lands in the tract is very dry. Moisture in such soils gradually increases from June to August and usually reaches saturation point in August or September. This may be seen from the data of soil-moisture content for the two seasons of 1934 and 1935 given in Table XII.

TABLE XII

Change of soil moisture from month to month (per cent)

1934			1935		
Dates	Surface layer 0—6 in.	Sub-surface layer 6 in.—12-in.	Dates	Surface layer 0—6 in.	Sub-surface layer 6 in.—12 in.
5 March	12·45	21·61	4 May	7·76	20·14
9 April	29·92	23·04	4 June	6·60	19·33
4 July	23·85	25·47	5 August	19·89	16·29
4 August.	41·43	39·49	5 September . . .	38·14	39·41
13 September	36·80	41·44			

When the land is fairly level and the soil is dry and porous, the rain water first moistens the dry soil and then percolates vertically downwards. When the surface-soil layer has become saturated, the rain water begins to run over the surface along the direction of the slope. The deeper types of soil in the Sholapur district have a high field capacity or a high saturation point, holding nearly 40-44 per cent moisture by weight. The surface layer of 12 in. can easily hold 6-7 in. of rain water and run-off would generally begin only after this saturated condition has been reached at least in the surface layer. Hence the number of run-offs in June, July and August is usually very limited. But this normal behaviour is often upset by other factors, viz. the intensity of the showers, the slope of the land and the impervious nature of the soil. When showers of great intensity, such as those which yield 1-2 in. of rain in an hour, are received, run-off of rain water may take place even before the saturation of the surface layer. Similarly, when the slope of the land is relatively greater, the rain water may begin to move along the slope before the saturation of the surface layer is complete. The effect of intensive showers, especially on impervious soils, is to saturate and compact a thin layer of 1-2 in. on the surface and thus to obstruct vertical penetration of rain water, causing lateral movement of water along the sloping surface. The data of soil-moisture contents for 1934 and 1935, given in Table XII, show how the soil-moisture normally increases during the monsoon and saturates the soil either in August or in September, after which period by far the greatest quantities of rain water are lost as a result of surface run-off.

(*F*) *Percentage of the annual rainfall lost by run-off*

The quantities of rain water lost by run-off from year to year for any of the eight treatments indicated in Table VIII show tremendous variations from year to year. This variation has been shown to be due to the variation

in the annual rainfall, difference in monthly distribution of rainfall and variation in the intensity of showers. The same data are calculated as per cent of the total annual rainfall and are given in Table XIII.

TABLE XIII

Rainfall lost by run-off as per cent of the annual total for 1934-39

Year	Rainfall in inches	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35	21·15	0·99	6·47	5·86	5·15	0·09	3·21	6·70	5·70
1935-36 . . .	29·52	13·60	19·60	19·32	18·84	12·90	15·64	17·00	17·00
1936-37 . . .	15·92	0·43	6·60	13·94	11·85	1·19	9·92	12·12	13·70
1937-38 . . .	26·11	2·48	24·35	32·01	28·66	16·54	26·77	27·34	20·64
1938-39 . . .	37·14	1·72	26·40	25·60	18·63	5·41	11·86	17·24	16·02
Average of five years .	25·96	3·44	15·50	18·34	16·61	7·22	13·48	16·08	16·71

The examination of these figures indicates fairly consistent behaviour of most of the plots under different treatments in the majority of seasons. The average results of five years show that the percentage losses of rain water in two treatments, viz. that of untouched vegetative cover (plot 1) and of 'scooping' (plot 5), are distinctly lower, viz. 3·44 and 7·22 per cent of the average total annual rainfall although there is considerable seasonal variation. In the remaining six treatments, the average percentage losses vary from 13·48 to 18·34. The lower figure was obtained with the treatment of *bajri* and *tur* cropping (plot 6) and the largest for the treatment of mere shallow cultivation without any crop (plot 3). Miller and Krusekopf [1932] in their experiments found the run-off to vary from 12 to 30·7 per cent of the total rainfall. The percentage losses found at Sholapur appear therefore to be comparatively smaller than those recorded in the U. S. A.

(*G*) *Loss of rain water by run-off as per cent of the rainfall causing run-off*

It has already been shown that all rainfalls are not capable of producing run-off. Most of the run-offs are produced by rains of more than ½ in. in intensity. As the important crop in this tract (*jowar*) is grown in the *rabi* season on moisture resulting from the rainfalls during the early monsoon and conserved in the soil, only such of the rainfalls as can penetrate down into the lower layers of the soil can be considered as useful from the point of view of *rabi* cultivation. It has been observed that rainfalls of more than one inch received in 24 hours are of this type and nearly 80 per cent of such rainfalls usually produce run-off. Therefore, if the amounts of the rain water lost by run-off are calculated as percentages of the rainfalls causing run-off, the figures obtained indicate that a very high proportion of the agriculturally useful rainfalls are lost by run-off. Calculations on these lines, along with their deviations, are given in Table XIV.

Examination of the figures in Table XIV indicates more consistent behaviour as regards run-off of most of the plots in the majority of years. It can be seen that only two plots, viz. 1 and 5, which had the lower run-offs, show wide fluctuations. With the remaining plots under different treatments, the annual figure of run-off in four years out of five shows a close agreement

with the average figure computed for the total period of five years. In the first year of the experiment only, the results were much lower than the average figure on account of very favourable distribution of rainfall during that year. The average proportion of the water lost to the total rainfall causing run-off under most of the treatments is very high varying from 26 to 38 per cent in the six cultural treatments used in the experiments. This proportion in some years and under some treatments exceeded 44 per cent. This high loss of useful rainfall assists in explaining the occurrence of crop failures even in years with a total average rainfall.

TABLE XIV

Rainfall lost by run-off as per cent of the total rainfall causing run-off

Year	Total rainfall causing run-off	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35 . . .	8·11	2·59	16·96	15·31	13·45	0·25	8·39	17·53	14·04
1935-36 . . .	14·77	27·21	30·26	38·59	37·58	25·93	31·37	33·98	35·95
1936-37 . . .	5·93	1·18	17·87	37·44	31·87	13·20	26·65	32·55	36·93
1937-38 . . .	19·38	3·35	32·82	43·13	38·54	22·29	30·07	37·10	39·93
1938-39 . . .	22·30	2·88	44·32	42·83	31·17	9·05	19·86	28·87	28·37
Average . .	14·09	7·93	34·65	38·34	32·51	14·71	25·93	31·09	32·27
	±3·15	±4·96	±5·97	±5·36	±4·62	±5·28.	±4·88	±1·79	±4·53

XIII. LOSS OF SOLUBLE SALTS FROM SOILS IN RUF-OFF WATER

The quantities of the fertility elements removed in solution by run-off waters were determined in some years. The total salts and lime thus lost in run-off waters were determined in all years after every run-off. These data are given in Appendices I-*c* and I-*d*. Considering the data for plot 4, i.e. treatment 4, viz. cultivation of *rabi jowar* after intensive preparatory cultivation, the total soluble salts lost in a year show a variation of from 26·06 lb. to 234 lb. per acre during the five years. Soluble lime forms quite a substantial proportion of the total salt. This can be seen from data in Appendix I-*d*. The quantity of lime removed has varied, indifferent years, from 9·22 lb. to 91·18 lb. per acre, showing that it forms nearly 35-39 per cent of the total soluble salts.

The nitrogen content of all the run-off waters, both as nitric nitrogen and as ammoniacal nitrogen, was also determined in three seasons. The total quantity of nitrogen thus removed in solution was found to be very small in each of these years. The average quantity lost every year during this period varied in different plots from 0·13 lb. to 0·53 lb. per acre. The nitric and the ammoniacal forms of nitrogen were found in nearly equal proportions. The nitrogen received in the rain water every year was separately determined and deducted from the nitrogen obtained from the run-off waters.

Phosphoric acid removed in solution in the run-off waters was determined during 1936. The total quantity lost during the whole year was found to be very low, being only about ½ lb. per acre from plot 4, i.e. *rabi jowar* cultivation (treatment 4).

If the quantities of nitrogen and phosphoric acid lost in solution in run-off water are compared with similar figures for other countries, the Sholapur figures are found to be very low indeed. The quantities of phosphoric acid lost in similar experiments at the Missouri Experiment Station are much higher, viz. 47 lb. per acre in the uncultivated plot as compared to less than ½ lb. at Sholapur. Even the nitric nitrogen lost at Missouri exceeded 6 lb. per acre in the uncultivated plot. These low values at Sholapur are mainly due to the low initial fertility of the Sholapur soils, with regard to both nitrogen and phosphoric acid.

XIV. Results of soil erosion experiments at Sholapur

The loss of rain water by surface run-off is no doubt a considerable factor contributing towards crop failures in the Deccan tracts of precarious rainfall, but such loss of water is only temporary, being restricted in its effects to the season only. The con-comitant loss of soil that takes place with every run-off of rain water causes a serious permanent and accumulative damage to the land. The soil lost is lost for ever. The same factors which influence the run-off of rain water also influence soil erosion. Thus the cultivation given to the land, the total annual rainfall, the intensity of successive showers, the moisture-status of the soil, all have a direct influence on soil erosion as on rainfall run-off. It is not therefore necessary to consider these factors again in detail. The experiments to determine the losses of rain water by run-off, described hitherto, were simultaneously utilized to determine the quantities of silt lost under different methods of cultivation or treatment. The exact quantities of silt lost during the five years from the plots under varying treatments are given in Table XV.

(*A*) *Effect of varying plot treatments on soil erosion*

When the quantities of soil carried by run-off water from the eight plots under different treatments are considered, as shown in the data in Table XVI, it can be seen that each plot shows a similar trend from year to year. Thus, plot 1, where the natural vegetation of grasses and weeds were preserved, showed the smallest degree of soil erosion in each year. Plot 5, which received the special cultural treatment of ' scooping ', stood next lowest though it lost comparatively higher quantities of silt when compared with plot 1. Plot 2, which was uncultivated but from which the weeds were removed by cutting close to the surface, stood third lowest in the total quantity of silt lost during the experimental period of five years. Plot 6, which had a mixed crop of *bajri* and *tur* every year, ranked fourth in its effect on checking soil erosion. Plot 3, which received only shallow cultivation every year and carriod no crop, is next in order. Plot 8 had double the length and hence double the area as compared to the rest of the plots. But, when calculated on the basis of area, the quantity of silt removed was lower than that of plot 7 with which it is otherwise comparable. Plot 7, with thorough and intensive cultivation but with no crop, lost nearly 35 per cent more silt than plot 3 with shallow cltivation. Plot 4, with thorough and intensive cultivation and carrying a crop of *jowar* during the *rabi* season, lost the highest quantity of silt during the period of five years, probably on account of the coincidence of the interculturing operations given to the plot and the occurrence of some of the heavy rainfall showers. The surface 2-inch layer of

TABLE XV

Quantity of silt in pounds carried by run-off water from each plot

Year	Total rainfall during the year (inches)	Rainfall causing run-off (inches)	Plot 1 Retention of natural vegetation	Plot 2 Natural vegetation removed by cutting	Plot 3 Shallow cultivation by harrowing	Plot 4 Thorough and intensive cultivation by ploughing and harrowing and growing *rabi* crop of *jowar*	Plot 5 'Scooping' of the surface soil after thorough cultivation	Plot 6 Thorough cultivation by ploughing and harrowing and growing *kharif bajri* and *tur* mixture	Plot 7 Thorough and intensive cultivation by ploughing and harrowing	Plot 8 Thorough and intensive cultivation as in Plot 7 with double length
1934-35	21·15	8·11	0·73	25·61	14·28	27·83	0·20	28·66	37·02	2·29
1935-36	29·52	14·77	16·24	698·88	1,679·16	3,235·48	1,099·09	1,232·28	2,654·96	2,591·12
1936-37	15·92	5·93	2·02	30·56	81·87	120·76	9·86	230·38	493·85	63·45
1937-38	26·11	19·38	6·44	2,459·52	3,185·28	2,727·24	1,411·76	3,311·56	3,291·23	6,895·09
1938-39	37·14	22·30	4·62	572·38	503·02	933·32	379·90	394·02	845·77	1,562·57
Total .	129·84	70·49	30·05	3,786·95	5,463·61	7,044·63	2,900·81	5,196·90	7,322·83	11,114·52

the soil became loose and dry as a result of these interculturing operations and a large quantity of soil from this layer was removed with the run-off water after the heavy showers of October, November, or December.

In Table XVI, the soil erosion data for five years are given as tons of silt lost per acre. The seriousness of this problem of soil erosion is brought out very markedly by these figures. Natural vegetation appears to be the most effective means of checking soil erosion. The special treatment of 'scooping', though effective in reducing erosion, still resulted in a loss of nearly 100 times the quantity of silt lost from plot 1 with natural vegetation cover. Shallow or deep cultivation proved even more harmful and resulted in the loss of still more silt as can be seen by comparing the data of plots 2, 3 and 7. Shallow cultivation resulted in an increased loss of silt by about 40 per cent, and deeper cultivation by about 90 per cent as compared with the loss of silt from plot 2 with no cultivation. Increase in the length of the plot did not increase the extent of erosion, as may be seen by comparing the results of plots 8 and 7. In fact, there seems to be a tendency to deposition of suspended silt when the distance over which the run-off water has to travel increases. The results obtained by Duley and Ackerman [1934] on this point were not conclusive. But, in general, they found that light showers caused more erosion on shorter plots, while heavy showers caused more erosion on longer plots. Fig. 6 illustrates the comparative quantities of silt lost during the five years under different treatments.

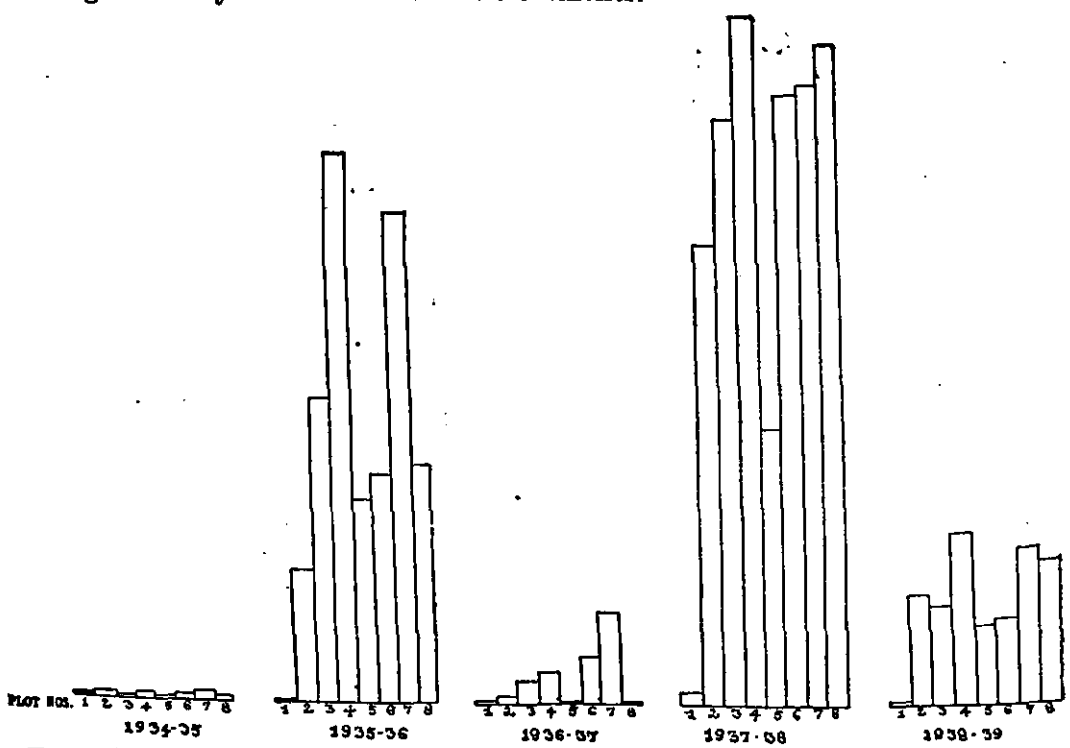


FIG. 6. Relative quantities of soil lost by erosion from plots under different treatments

[Plot 1, weeds preserved; plot 2, weeds removed; plot 3, harrowedonly; plot 4, *rabi* crop of *jowar*; plot 5, scooped; plot 6, *kharif* crop of *bajri* and *tur*; plot 7, ploughed and harrowed; plot 8, ploughed and harrowed with double length]

(1 inch height of col. = 40 tons.)

TABLE XVI

Silt carried in run-off water calculated as tons per acre from plots under different treatments during five years of experiments

Year	Total rainfall during the year (inches)	Rainfall causing run-off	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35	21·15	8·11	0·026	0·916	0·510	0·993	0·007	1·023	1·322	0·576
1935-36	29·52	14·73	0·580	24·960	59·970	115·660	39·250	44·010	94·820	46·270
1936-37	15·92	5·93	0·072	1·092	2·924	4·310	0·352	8·220	17·630	1·13
1937-38	26·11	19·38	0·230	87·840	113·760	133·480	50·420	118·270	117·540	127·680
1938-39	37·14	22·30	0·165	20·442	17·960	33·330	13·570	14·070	30·210	27·900
Total during five years .	129·84	70·45	1·073	135·250	195·124	287·773	103·599	185·543	261·522	203·556
Average of five years .	25·97	14·09	0·215	27·05	39·02	57·55	20·71	37·12	52·30	40·71
Number of years required to erode 8 inches of cultivated layer of surface soil			4,146·0	32·92	22·84	15·48	43·01	24·01	17·04	21·90

On the basis of the data of five years' experimental period, the average loss of silt per year from the plot cultivated with *rabi jowar*, i.e. plot 4 was 57·55 tons per acre. This indicates that nearly ½ in. of the surface layer of soil is liable to be lost by erosion each year. If the weight of the first acre-foot surface soil is taken as three million pounds, the cultivated surface layer of 8 in. could be lost in about 15½ years if no attempt be made to check erosion by proper levelling, terracing, or bunding of the fields. This rate of erosion seems to be much greater than that found elsewhere, as in the U. S. A. It was found by Duley and Miller [1923] in their experiments in the U. S. A. that it would take 28 years to erode the cultivated surface layer of 7 in. The slope of their experimental plot was much greater, viz. 3·75 per cent, than the moderate slope of 1·18 per cent of the Sholapur experimental plots. The average rainfall at the American experimental station was also higher, viz. 35·87 in. instead of 25·96 in. at the Sholapur Experimental Station.

Accordingly tropical conditions seem to be more favourable for heavy erosion. The rate of erosion under Deccan conditions is extremely high, as may be seen by examination of the figures in the bottom line of Table XVI. The surface 8-in. layer is taken as the cultivated layer of the soil and is known to weigh about 2 million pounds per acre. From the average quantity of soil lost per year under each plot treatment, the number of years required to erode completely the cultivable layer of the surface soil has been calculated. As already pointed out, plot 4, which represents the normal cultivation of *rabi jowar* followed by a few good cultivators in this tract, shows that the surface layer is liable to be lost in an extraordinarily short period. Other methods of cultivation tried in these experiments also indicate similar high rates of erosion, requiring only 17-43 years for the removal of the cutivated layer of the surface soil. The only effective treatment for checking soil erosion was the preservation of the natural vegetation on the surface soil as represented by the treatment in plot 1.

(*B*) *Relationship between total annual rainfall and soil erosion*

The total annual rainfall during the five years during which the experimental work has been in progress has varied from 15·92 to 37·14 inches, while the total rainfall causing run-off and producing soil erosion has varied from 8·39 to 22·30 in. in the five years. It has been already shown that the total run-off is not always proportionate to the total rainfall of the year. The intensity of the showers and the moisture-status of the soil have more influence on the extent of run-off than the total rainfall. The same finding holds good in the case of soil erosion. The year 1936-37, which recorded the lowest rainfall (Tables XV and XVI), was not the year of the lowest soil erosion. In the same way the year 1938-39 with the highest total rainfall was not the year of the highest soil erosion. The year 1937-38 with only an average annual rainfall had the highest number of rainfalls causing run-off and erosion. This year, therefore, proved most damaging in that it gave the highest erosion.

(*C*) *Effect of the intensity of showers on soil erosion*

Out of the total amount of soil lost during each year by erosion, the reater proportion was lost during one to three intensive rainfalls only. The

term 'intensive' implies either a high total rainfall or rainfall that is received as stormy showers, within a short period of time, e.g. 1-2 hours. Thus, in the first year only one rainfall on 7 September amounting to 2·67 in., received overnight, resulted in the loss of 89 per cent of the total silt removed during the year from plot 4 (Appendix I-*b*). In the second year, out of nine rainfalls causing erosion, two only accounted for 90 per cent of the total soil lost by erosion in that year. In the third year, two rainfalls out of five were responsible for the greater part of soil loss. In the fourth year, out of 20 rainfalls, three intensive falls only resulted in the loss of nearly 80-90 per cent of the total silt lost during the whole year. In the fifth year again, only two rainfalls out of 15 falls resulting in erosion caused the greater proportion of soil loss.

Thus, out of the large number of rainfalls (55) causing erosion (Table XI) during the five years, only 10 rainfalls could be termed intensive and these resulted in the loss of 80-90 per cent of the total soil lost from the seven plots under different treatments, during the experimental period of five years, as shown in Table XVII. In this respect, the data regarding run-off of rain water alone are somewhat different. In the case of run-offs, a greater number of total rainfalls is required to make up 80-90 per cent of the total loss of rain water. This indicates that the intensity of a shower has a greater influence on erosion than on run-off.

TABLE XVII

High proportion of silt lost in five years by ten intensive rainfalls

Plot No.	Treatment	Total pounds of soil lost during the 5 years	Total pounds of soil lost during the 10 intensive rainfalls	Percentage of total soil lost by ten rainfalls
1	Retention of vegetation	30·05	16·08	53·52
2	Removal of vegetation	3787·01	3437·61	91·07
3	Shallow cultivation	5463·61	5055·45	92·55
4	Cultivation of *rabi jowar*	8054·83	7367·47	91·47
5	'Scooping'	2900·72	2601·96	89·71
6	Cultivation of *kharif bajri* and *tur* . . .	5196·90	4206·98	80·93
7	Thorough and intensive cultivation . . .	7422·83	6547·24	88·22
8	Thorough cultivation and double length . .	11144·52	10234·37	91·83

(*D*) *Moisture-status of the soil previous to soil erosion, and its effect on soil erosion*

As the type of soil erosion considered here is dependent upon the run-off of rain water, all the factors that affect rainfall run-off also affect soil erosion. The moisture-status of the soil, previous to rainfalls causing run-off of rain-water has been shown to influence the quantity of rain water lost by such run-off. A similar influence of this factor on soil erosion can be seen from the detailed data of soil lost by erosion given in Appendix I-*b*. Comparatively greater losses of soil take place from erosion after the surface soil attains moisture-saturation which does not usually happen before August or September.

(E) Relative proportion of water and silt lost by run-off and erosion

It will be interesting to examine whether any relationship exists between the quantity of water lost by a run-off and the amount of silt carried away by such run-off water. The comparative quantities of water and silt lost in pounds from each plot during the five years of experiments are given in Table XVIII. In the last line of this table, the ratio of the total water lost to the total soil removed is shown for the whole period of five years. It may be said in general, that the greater the amount of water lost, the greater is the amount of silt removed. But the ratio of losses of water to losses of soil differs widely, e.g. from 7·96 to 520·8, according to the varied treatments given to the plots. The plot with vegetation cover gives the widest ratio of 520·8 and differs entirely in this respect from the other treatments. The remaining seven treatments show a ratio ranging from 7·96 to 18·07. This would indicate that the capacity of run-off water to remove soil under the experimental conditions at Sholapur is very high when compared with the results obtained in similar experiments conducted in the U. S. A. The curve showing the relation of water lost to soil eroded shows a general relationship between run-off and erosion under different treatments (Fig. 7). Under tropical and arid conditions, the rate of soil erosion appears to be very high. It may be pointed out that the soil type in the present experiment cannot be considered as erodible according to Middleton as it belongs to the heavy clay type but the results obtained in the experiments at Sholapur agree with the views of Bennett who considers sticky soils with high swelling and shrinkage capacity as very erodible.

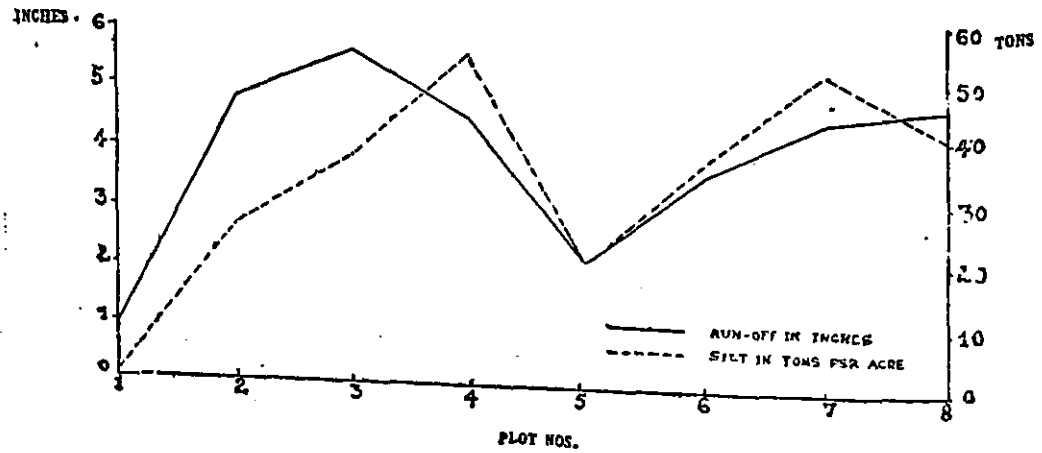


FIG. 7. Relative proportion of water and silt lost by run-off and erosion under different treatments

[Plot 1, weeds preserved ; plot 2, weeds removed ; plot 3, harrowed only ; plot 4, *rabi* crop of *jowar* ; plot 5, scooped ; plot 6, *kharif* crop of *bajri* and *tur* ; plot 7, ploughed and harrowed ; plot 8,-ploughed and harrowed with double length]

TABLE XVIII

Comparative quantities of water lost by run-off and silt carried in pounds per acre

Year	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt
1934-35	588	0·7	3,836	26	3,472	14	56	28	1,904	0·2	1,904	29	3,976	37	6,776	32
1935-36	11,256	16·3	16,240	699	15,960	1,679	15,540	3,235	10,724	1,099	12,936	1,232	14,056	2,655	29,736	2,591
1936-37	196	2·0	2,068	31	6,216	82	5,292	121	532	9·9	4,424	230	5,402	494	12,264	63
1937-38	1,820	6·4	17,808	960	23,408	3,185	20,916	3,737	12,096	1,412	19,572	3,312	19,092	3,291	43,344	6,895
1938-39	1,792	4·6	27,552	572	26,628	503	19,373	933	5,628	380	1,234	846	17,948	845	35,280	1,563
Total for five years, (From 1 June 1934 to 31 May 1939)	15,652	30·0	68,404	4,288	75,684	5,463	61,177	8,054	30,884	2,901	40,070	5,649	61,374	7,322	1,27,400	11,144
Pounds of water required to carry 1 lb. of silt in the run-off water	520·8		18·06		13·86		7·96		10·01		9·85		8·27		11·44	

Although the ratios of soil removed to rainfall run-off for the whole period of five years under seven different treatments show a limited variation, the actual day-to-day ratios have been found to show extraordinary variation. A litre of water could carry silt in suspension varying from less than 1 gm. to more than 400 gm. on different days, depending upon various factors, such as the total quantity of rainfall, intensity of showers, and the moisture-status of the soil previous to run-off.

(*F*) *Effects of soil erosion*

(*a*) *Increase in the slope of land*

Before the commencement of the experiments at Sholapur in 1934, accurate levels of the experimental plots were determined by a dumpy level along three lines in each plot at every 5 ft. distance. From the difference between the average levels at the top and at the bottom, the percentage slope of each plot was determined. The average slope for all the plots was 1·18 per cent or a fall of 1 in 85, in 1934. At the end of the period of five years, levels were again determined by the same method in all plots. The average slope for all plots was found to have increased to 1·68 per cent or a fall of 1 in 60, in 1939.

Thus, the accumulated loss of soil from the plots due to erosion during a period of five years had resulted in increasing appreciably the original slope of the plots. Such an increase in gradient is likely to accelerate the rate of run-off and also of erosion. This change in level is illustrated in the vertical section of plot 4, along the length, in Fig. 8.

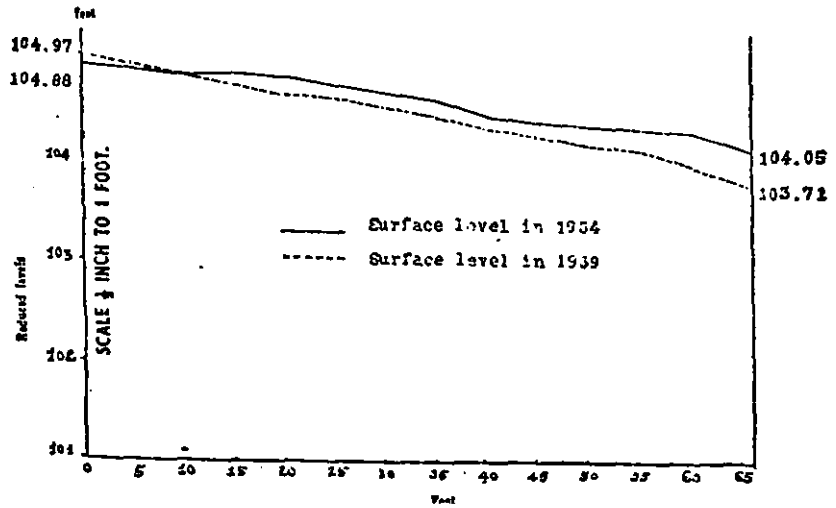


FIG. 8. Change in gradient of plot 4 by soil erosion

(*b*) *Loss of fertility elements*

The soil lost by erosion after each rain-fall resulting in run-off of rain water from the eight different plots was collected for a period of three years, viz. 1934-35, 1935-36 and 1937-38. A composite sample was prepared each year for each plot by taking a proportionate quantity from each bulk of eroded material and these samples were analysed for total nitrogen.

TABLE XIX

Percentage of nitrogen in silt obtained in run-off waters and pounds of nitrogen lost per acre from different treatments

Plot No.	1934-35		1935-36		1937-38		Average for 3 years	
	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre
1. Retention of vegetation . . .	0·133	0·07	0·109	1·41	...	...	0·082	0·74
2. Removal of vegetation . . .	0·059	1·21	0·047	26·27	0·051	107·51	0·052	44·99
3. Shallow cultivation . . .	0·069	0·79	0·050	67·26	0·056	142·70	0·058	70·21
4. Cultivation of *rabi jowar*. . .	0·052	1·15	0·049	126·95	0·055	184·47	0·052	104·19
5. 'Scooping'	0·068	0·01	0·042	36·92	0·052	58·73	0·054	32·88
6. Cultivation of a *kharif crop* of *bajri* and *tur*	0·046	1·05	0·050	49·28	0·062	175·98	0·053	75·44
7. Thorough cultivation . . .	0·052	1·54	0·046	97·70	0·059	155·34	0·052	84·86
8. Thorough cultivation with double length	0·087	1·15	0·056	58·04	0·070	200·20	0·071	86·46

TABLE XX

Chemical analysis of silt lost from surface run-off plots during 1935-36

(Expressed on per cent dry matter)

Plot No.	Loss on ignition	Sand	Fe_2O_3	Al_2O_3 and TiO_2	CaO	MgO	K_2O	P_2O_5	Nitrogen	Stone per cent on original
1. Retention of vegetation	10·51	55·18	10·10	12·95	1·80	1·28	0·59	0·06	0·109	6·65
2. Removal of vegetation . . .	7·35	55·47	10·73	11·10	4·69	1·38	0·47	0·05	0·047	23·42
3. Shallow cultivation	7·23	55·76	10·88	12·60	3·43	1·58	0·48	0·06	0·050	12·53
4. Cultivation of *rabi jowar*	7·30	54·59	10·66	13·42	3·28	1·64	0·49	0·05	0·049	15·09
5. 'Scooping'	7·71	56·46	11·21	12·07	3·59	1·54	0·53	0·05	0·042	7·90
6. Cultivation of *kharif bajri* and *tur* . .	6·83	56·66	11·90	12·57	2·72	1·33	0·51	0·06	0·050	7·38
7. Thorough cultivation	7·73	56·46	11·53	12·12	2·80	1·24	0·57	0·06	0·046	11·16
8. Thorough cultivation with double length .	8·02	59·53	11·69	12·55	1·61	1·32	0·50	0·06	0·056	3·43

The percentage of nitrogen present in the eroded soils obtained each year was distinctly higher than that found in the original soil which was only 0·039 per cent. The presence of vegetation on plot 1 naturally increased the nitrogen content of the soil from that plot. Table XIX shows the percentage nitrogen in soil and estimated quantities of nitrogen lost per acre under different experimental treatments during the three years. It may be seen that the quantity of nitrogen lost has varied according to the quantity of silt carried off by the run-off water from the plots under different treatments.

The average annual loss of nitrogen per acre during the three years was found to be very high from all cultivated plots, whether with or without crops, although that loss varied considerably from year to year. Only in the case of the plot with natural vegetation-cover, was the loss very low due to low loss of soil. The average loss of nitrogen per year is equivalent to nitrogen removed by 8 or 10 crops of *jowar* or *bajri* when cultivated on this type of soil in this tract. These losses are higher than the results of similar estimation made by the American workers [Miller and Krusekopf, 1932].

Complete chemical analysis of the eroded soils from different plots was made in the year 1935-36, by the method of hydrochloric acid digestion. The results of these analyses indicated that soils removed were richer in important fertility constituents than the original soil (Table XX).

XV Summary of the experiments at Sholapur

Rainfall run-off

1. Experiments conducted at Sholapur for a period of five years from 1934-35 to 1938-39, to determine the loss of rain water by surface run-off, are described.

2. The soil type upon which these experiments were conducted belongs to the Chernozem group derived from the Deccan trap. It has a high clay content and is rich in potash and lime but comparatively poor in nitrogen and phosphoric acid.

3. Eight unit plots were laid down under the following treatments* respectively :—

(1) Preservation of natural vegetation—no crop.
(2) Natural vegetation above soil surface level removed by cutting—no crop.
(3) Shallow cultivation by harrowing—no crop.
(4) Thorough and intensive cultivation with subsequent cultivation of *rabi jowar* crop.
(5) Special cultural treatment with a 'scooper'—no crop.
(6) Thorough and intensive cultivation followed by a mixed crop of *bajri* and *tur*.
(7) Thorough and intensive cultivation only—no crop.
(8) Thorough and intensive cultivation on a plot length double that of plots 1 to 7—no crop.

*It will be noted that crop cultivation was carried out on plots 4 and 6 only. Intensive cultivation implies deep ploughing in the hot weather season followed by several harrowings during the monsoon period and several interculturings during the normal period of crop growth. Ploughing was done across the slope of the plots.

4. The shape of the plots was a rectangle having the dimensions 66 ft. length × 8·25 ft. width in the first seven plots and 132 ft. length × 8·25 ft. width in the eighth, with an average one way slope of 1·18 per cent along the length of the plots.

5. The average annual rainfall during the experimental period of five years corresponded closely with the average annual precipitation in the tract during the past 25 years. The monthly distribution of rainfall, however, showed some deviation from the average. The average number of rainy days* per year during the experimental period of five years and the past 25-years period was also similar.

6. The annual number of rainfalls causing run-off of rain water during the five-year period varied from 5 to 20, the annual average for the whole period being 11.

7. These run-offs of rain water were mostly restricted to the period from June to October. The month of September recorded the highest number. The average annual loss of water by run-off varied from 1·12 in. to 5·40 in. under the different treatments under experiment.

8. All the rainfalls received during the experimental period of five years have been grouped into four classes according to their intensities, i.e. according to the quantity of rainfall received during a day, i.e. 24 hours. It is found that all rainfalls exceeding 2 in. during a day resulted in run-off of rain water. There were nine such rainfalls during the experimental period of five years. The total number of rainfalls in class 2, i.e. rainfalls varying from 1 in. to 2 in. during a day, was 25 and, of these, 20 rainfalls or 80 per cent of the total caused run-off of rain water. There were 40 rainfalls varying from ½ in. to 1 in. received in a day in class 3. Of these, 14 rainfalls or 35 per cent caused rainfall run-off. The last class consisted of 144 rainfalls of less than ½ in. recorded during a day. Of these, only 12 rainfalls or 8 per cent of the total of this class resulted in run-off of rain water.

9. The previous moisture-status of the soil influenced the occurrence and extent of run-off very greatly.

10. The number of rainfall run-offs appeared to depend more on the number of heavy showers received during the year rather than on the total annual rainfall. Rainfalls exceeding 1 in. received during a day, i.e. 24 hours, are reckoned as heavy showers.

11. The treatments which appear to have the greatest effect in checking or reducing the run-off of rain water are :—

(1) the preservation of the natural vegetation,

(2) the special treatment of 'scooping',

(3) the presence of a mixed crop of *bajri* and *tur* after intensive cultivation.

12. Thorough and intensive cultivation alone showed a more restricting influence on the number of rainfall run-offs and on the quantity of water lost by such run-offs, when compared with shallow cultivation or no cultivation.

* A 'rainy' day indicates a day of 24 hours upon which 10 cents or more of rainfall were received.

13. The doubling of the length of the plot, or the growing of a *rabi* crop of *jowar*, showed no noticeable difference in influencing the number of rainfall run-offs or the quantity of water lost by such run-offs.

14. Appreciable quantities of soluble salts are removed from soils in rainfall run-off, lime forming a considerable proportion of such losses. The loss of nitrogen and phosphoric acid in solution was however found to be very small.

SOIL EROSION

I. The extent of soil erosion was determined annually by measuring the quantities of soil carried away by run-off of rain water from the same eight unit experimental plots under different treatments (para. 3 above) upon which the run-offs of rain water were determined during the five years of the experiments.

II. The same eight different plot treatments as mentioned in para. 3 above were compared to see their comparative effect on soil erosion.

III. The annual average loss of soil by erosion varied from 0·215 tons per acre in plot 1, i.e. the plot with natural vegetation preserved, to 57·55 tons per acre in plot 4, i.e. the plot with the *rabi* crop of *jowar* following intensive hot weather cultivation. The special treatment of 'scooping', i.e. plot 5, gave an average loss of 20·71 tons per acre, showing some checking effect of this treatment on soil erosion. Plot 2 with vegetation removed and without cultivation showed less erosion, viz. 27·05 tons per acre, than plots with shallow and intensive cultivation, i.e. plots 3 and 7 respectively, which showed 39·02 and 52·30 tons per acre respectively. The standing crop of *bajri* and *tur* mixture after intensive hot weather cultivation, i.e. plot 6, had some effect in reducing soil erosion, this plot giving an average loss of 37·12 tons per acre. Increase of the length of the plot, i.e. plot 8, showed an average loss of 40·71 tons per acre, and the tendency to the deposition of silt along the plot surface reducing the erosion to some extent.

IV. Except on the plot with natural vegetation preserved, i.e. plot 1, the average quantity of run-off water required to remove 1 lb. of soil showed a variation of from 0·796 to 1·806 gallons under different treatments. These figures indicate an extremely high rate of erosion under the Deccan conditions.

V. The average number of occasions upon which soil erosion was found to take place was 11 per annum. Of these, only two per year, on an average, are responsible for causing 80-90 per cent of the total loss of silt by erosion during the year. The rainfall on these two occasions was very heavy and intensive, usually more than 2 in. received in a few hours on an already saturated soil surface.

VI. As a result of soil erosion during five years, the original slope of the plots was found to have appreciably increased.

VII. The soil removed by rainfall erosion is richer in all plant food ingredients than the original soil. The average quantity of nitrogen lost in such eroded soil in a year is equivalent to that removed by 8-10 *jowar* or *bajri* crops.

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APPENDIX I

(*a*) *Rainfall received on rainy days classified according to intensity, during the experimental period of five years*

Class	Rainfall in inches*	June	July	August	September	October	November	December	January	February	March	April	May
					(1934-35)								
1	0—½ . .	0·10	0·17	0·17	0·11	0·10	0·18	...	0·19	...	...	0·23	0·11
		0·25	0·10	0·39	0·35	0·13	0·20	...	...	...	...	0·12	...
		0·11	0·17	0·31	*0·17*	...	...	...	...	...	...	...	...
			0·25	0·12	0·29								
			0·10	*0·36*	0·18								
			0·25	0·24	0·30								

APPENDIX I—*contd.*

Class	Rainfall in inches	June	July	August	September	October	November	December	January	February	March	April	May
					(1934-35)—*contd.*								
			0·49		0·20								
			0·40		0·14								
			0·31		0·14								
			0·13										
2	½—1 . . .		0·93	0·95	0·75								
			0·50										
3	1—2 . . .			1·13	*1·22*		1·24						
				1·52									
4	Above 2 . .		*2·17*		*2·67*								
					(1935-36)								
1	0—½ . . .	0·17	0·16	0·38	0·24	0·15	...	0·43	...	0·47	0·36	...	...
		0·20	0·12	0·14	0·41	0·43				0·26			
		0·16	0·13	*0·48*	0·29	0·23							
		0·34	0·12	0·47	0·25	0·42							
		0·13		0·23		0·13							
		0·20											
		0·26											
2	½—1 . . .	0·75											
		0·54	*0·78*	0·50	0·96	0·51						0·65	0·70
		0·69	0·65	*0·54*	0·99								
3	1—2 . . .			*1·57*									
				1·03									
				1·86									
4	Above 2 . .			*3·52*		*4·30*							
					(1936-37)								
1	0—½ . . .	0·18	0·16	0·25	0·14	0·37				0·21	0·49	0·22	
			0·25	0·35	0·47						0·20	0·41	
			0·10	0·16	*0·42*								
			0·10		0·13								
2	½—1 . . .	0·84	*0·35*				*0·90*					0·56	
		0·70					0·69						
		0·56											
3	1—2 . . .				*1·73*							1·03	
4	Above 2 . .						*2·03*						

APPENDIX I—*contd.*

Class	Rainfall in inches	June	July	August	September	October	November	December	January	February	March	April	May
					(1937-38)								
1	0—½ . . .		0·16	0·15	0·80	0·39		*0·39*				0·11	0·31
			0·27	0·14	*0·38*			*0·34*					0·10
			0·47		0·32								
			0·33		*0·44*								
			0·42		0·28								
			0·17		0·12								
			0·14		0·26								
			0·24										
			0·21										
			0·22										
			0·14										
2	½—1 . . .	*0·98*	*0·63*	*0·54*		*0·67*					0·81		
		0·80		0·52		*0·62*							
3	1—2 . . .				*1·30*	*1·97*		*1·35*			*1·40*		
					1·15	*1·44*							
4	Above 2 . .				*2·13*								
					2·05								
					(1938-39)								
1	0—½ . . .	0·34	0·25	0·16	0·31	0·23						0·25	
		0·10	0·44	0·19	*0·26*							0·18	
		0·31	0·10	0·28									
		0·15	0·11	0·10									
		0·30	0·30	0·10									
		0·18	0·42	0·16									
		0·10	0·27	0·24									
		0·16	*0·34*	0·10									
			0·15	0·26									
			0·33										
			0·30										
			0·11										
			0·41										
			0·10										
2	½—1. . .	*0·94*	*0·96*	0·65	0·66	0·75							
		0·60		0·59	0·79								
					0·56								
3	1—2 . . .	*1·90*	*1·72*	1·60	*1·14*								
		1·50	*1·78*		*1·76*								
		1·78	1·13		*1·14*								
4	Above 2 . .		2·32		*4·06*								

* The figures in *italics* indicate the rainfall that caused run-off of rain water and soil erosion.

APPENDIX I—*contd.*

(b) *Loss of rain water by run-off in inches and loss of soil by erosion in pounds per acre on each day of run-off during the experimental period of five years*

(1934-35)

Plot	Treatment	Dates / Rainfall	30-7-34	2-8-34	26-8-34	4-9-34	7-9-34	8-9-34
		Dates						
		Rainfall	2·17	1·52	0·36	1·22	2·67	0·17
1	Retention of vegetation	Run-off water	0·006	...	0·006	0·004	0·190	0·003
		Silt lost	1·15	...	7·69	0·70	48·50	0·83
2	Removal of vegetation	Run-off water	0·037	...	0·024	0·148	1·105	0·061
		Silt lost	13·69	...	107·72	239·55	1,648·03	45·29
3	Shallow cultivation	Run-off water	0·019	...	0·023	0·097	1·040	0·063
		Silt lost	3·54	...	47·37	59·62	975·86	56·48
4	Cultivation of *rabi jowar*	Run-off water	0·018	...	0·025	0·099	0·896	0·053
		Silt lost	6·39	...	12·60	160·81	1,979·25	67·90
5	'Scooping'	Run-off water	...	...	0·003	0·003	0·015	...
		Silt lost	...	...	8·38	1·73	6·17	...
6	Cultivation of a *kharif* crop of *bajri* and *tur*	Run-off water	0·037	0·032	0·011	0·053	0·505	0·043
		Silt lost	24·29	13·82	125·03	185·08	1,883·97	61·17
7	Thorough cultivation	Run-off water	0·123	0·021	0·023	0·145	1·067	0·042
		Silt lost	126·09	4·66	212·81	559·14	2,004·31	55·14
8	Thorough cultivation with double length	Run-off water	0·046	...	0·006	0·108	1·000	0·053
		Silt lost	6·05	...	44·45	78·74	1,130·66	31·78

APPENDIX I—*contd.*

(1935-36)

Plot	Treatment	Dates / Rain-fall	26-6-35	5-7-35	24-8-35	25-8-35	27-8-35	28-8-35	29-8-35	30-8-35*	24-10-35*
		Dates . . .									
		Rain-fall . .	0·69	0·78	3·52	0·48	1·57	1·03	0·54	1·86	4·30
1	Retention of vegetation	Run-off water .	...	...	1·13	...	0·35	0·32	0·16	1·02	1·03
		Silt lost . .	...	...	419·0	...	145·4	201·4	92·0	7·5	453·9
2	Removal of vegetation	Run-off water .	0·019	0·011	1·54	0·003	0·67	0·56	0·24	1·29	1·46
		Silt lost . .	9·3	5·80	3,697·0	1·4	898·0	1,585·0	1,461·0	31,940·0	16,365·0
3	Shallow cultivation .	Run-off water .	0·051	0·011	1·52	0·007	0·73	0·59	0·22	1·17	1·39
		Silt lost . .	40·4	3·9	5,217·0	2·6	971·6	1,635·5	878·0	85,570·0	40,000·0
4	Cultivation of *rabi jowar*	Run-off water .	0·011	...	1·51	0·024	0·76	0·55	0·22	1·18	1·29
		Silt lost . .	2·7	...	11,140·0	18·7	4,325·0	6,800·0	2,544·0	137,800·0	97,160·0
5	'Scooping' . .	Run-off water .	...	...	1·51	...	0·19	0·33	0·03	1·02	0·73
		Silt lost . .	...	...	5,966·0	...	464·7	1,105·0	336·5	43,120·0	36,870·0
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water .	...	...	1·46	...	0·51	0·50	0·16	1·14	0·83
		Silt lost . .	...	...	38,635·0	...	1,726·6	14,890·0	846·1	36,100·0	6,461·0
7	Thorough cultivation	Run-off water .	...	...	1·37	0·006	0·63	0·38	0·22	1·25	1·15
		Silt lost . .	...	...	21,460·0	3·8	4,689·0	6,586·0	1,735·0	53,510·0	124,400·0
8	Thorough cultivation with double length	Run-off water .	...	...	1·51	...	0·51	0·29	0·20	1·24	1·54
		Silt lost . .	...	...	11,570·0	...	626·4	2,264·0	729·3	48,770·0	39,680·0

* Shows rainfall of great intensity mentioned in Table XVII

APPENDIX I—*contd.*

(1936-37)

Plot	Treatment		23-7-36	26-9-36	28-9-36	13-11-36*	14-11-36*
		Date					
		Rainfall	0·85	1·73	0·42	2·03	0·90
1	Retention of vegetation	Run-off water	...	0·05	...	0·02	...
		Silt lost	...	92·6	...	69·49	...
2	Removal of vegetation	Run-off water	0·09	0·48	0·04	0·27	0·18
		Silt lost	101·6	775·3	65·0	592·6	911·0
3	Shallow cultivation	Run-off water	0·04	0·70	0·06	1·02	0·40
		Silt lost	57·9	909·5	84·5	2,381·0	3,775·0
4	Cultivation of *rabi jowar*	Run-off water	...	0·69	0·01	0·82	0·37
		Silt lost	...	1,051·0	22·3	3,514·0	5,174·0
5	'Scooping'	Run-off water	...	0·09	...	0·10	0·005
		Silt lost	...	433·0	...	291·6	64·59
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water	...	0·48	...	0·76	0·34
		Silt lost	...	596·9	...	11,690·0	6,144·0
7	Thorough cultivation	Run-off water	...	0·68	0·03	0·83	0·39
		Silt lost	...	969·8	47·2	37,190·0	1,301·9
8	Thorough cultivation with double length	Run-off water	...	0·78	0·02	0·90	0·49
		Silt lost	...	688·0	25·7	1,151·0	673·3

* Shows rainfall of great intensity mentioned in Table XVII

APPEN

(1937-

Plot	Treatment	Date / Rainfall	17-6-37	19-6-37	6-7-37	10-7-37 / 11-7-37	5-8-37	2-9-37	3-9-37
		Rainfall	0·98	0·80	0·47	0·96	0·54	1·30	0·38
1	Retention of vegetation	Run-off water	...	...	...	...	...	...	...
		Silt lost	...	...	...	...	...	...	...
2	Removal of vegetation	Run-off water	...	0·22	0·07	0·13	0·03	0·28	...
		Silt lost	...	323·4	278·8	198·1	64·8	203·0	...
3	Shallow cultivation	Run-off water	0·26	0·43	0·08	0·15	0·08	0·61	Trace
		Silt lost	371·5	902·4	362·1	267·7	121·5	388·8	14·56
4	Cultivation of *rabi jowar*	Run-off water	0·21	0·42	Trace	0·08	...	0·38	...
		Silt lost	373·0	1,614·0	87·32	124·6	...	280·0	...
5	(Scooping)	Run-off water	0·19	0·37	...	...	...	0·24	...
		Silt lost	358·8	1,788·0	...	...	...	232·7	...
6	Cultivation of *khari*, crop of *bajri* and *tur*	Run-off water	0·18	0·40	Trace	0·07	...	0·45	...
		Silt lost	287·1	1,806·0	85·6	146·5	...	220·2	...
7	Thorough cultivation	Run-off water	0·03	0·39	Trace	0·08	...	0·41	...
		Silt lost	121·1	1,381·0	79·40	150·3	...	497·2	...
8	Thorough cultivation with double length	Run-off water	0·05	0·36	...	0·06	...	0·50	...
		Silt lost	103·7	438·8	...	91·4	...	336·9	...

(1938-

Plot	Treatment	Date / Rain-fall	7-6-38 / 8-6-38	19-6-38	20-6-38 / 21-6-38	22-6-38
		Rain-fall	2·0	1·50	2·72	0·60
1	Retention of vegetation	Run-off water	...	...	0·15	...
		Silt lost	...	...	66·9	...
2	Removal of vegetation	Run-off water	0·38	0·56	1·59	0·15
		Silt lost	229·5	1,154·0	1,986·0	88·0
3	Shallow cultivation	Run-off water	0·28	0·57	1·55	0·16
		Silt lost	173·2	865·4	2,187·0	83·8
4	Cultivation of *rabi jowar*	Run-off water	...	0·35	1·27	0·12
		Silt lost	...	441·0	2,010·0	78·4
5	'Scooping'	Run-off water	...	...	Trace	...
		Silt lost	...	....	106·2	...
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water	...	0·34	1·09	0·08
		Silt lost	...	533·8	3,960·0	55·38
7	Thorough cultivation	Run-off water	...	0·41	1·28	0·011
		Silt lost	...	448·8	3,359·0	67·0
8	Thorough cultivation with double length	Run-off water	...	0·04	1·19	0·08
		Silt lost	...	90·6	660·1	46·6

DIX I—*contd.*

38)

21-9-37	22-9-37	*24-9-37	*25-9-37	2-10-37	3-10-37* / 4-10-37	5-10-37	13-12-37	14-12-37	24-12-37	26-3-38
1·15	0·44	2·13	2·05	0·67	2·59	1·44	0·39	0·34	1·35	1·40
...	...	0·24	0·31	...	0·10	...	...	...	Trace	...
...	...	145·1	185·6	...	73·63	...	...	...	100·9	...
0·29	0·06	1·20	1·42	0·30	1·26	0·61	...	...	Trace	0·49
394·1	95·8	58,650·0	75,010·0	78·2	55,650·0	4,109·0	...	...	942·3	712·2
0·48	0·08	1·39	1·37	0·22	1·08	0·48	0·01	0·01	1·05	0·58
589·4	107·4	79,930·0	89,300·0	1,294·0	72,810·0	3,075·0	31·02	47·2	4,435·0	739·2
0·46	Trace	1·38	1·39	0·16	1·07	0·48	...	...	1·07	0·37
349·4	11·82	116,500·0	115,000·0	805·0	44,230·0	3,256·0	...	...	15,410·0	838·1
...	...	0·55	0·96	0·15	0·87	0·40	...	...	0·57	0·02
...	...	35,130·0	40,100·0	799·1	22,720·0	8,782·0	...	...	2,885·0	168·7
0·18	...	1·42	1·28	0·19	1·08	0·62	...	...	0·78	0·34
215·3	...	117,300·0	93,670·0	1,172·0	34,040·0	6,816·0	...	...	5,331·0	854·3
0·40	0·04	1·27	1·29	0·27	1·23	0·46	...	...	0·92	0·35
549·3	73·60	113,200·0	94,450·0	3,390·0	35,850·0	9,397·0	...	...	3,533·0	582·9
0·42	0·03	1·40	1·22	0·26	1·35	0·50	...	...	1·13	0·46
417·8	40·30	76,470·0	134,000·0	3,125·0	55,440·0	10,810·0	...	...	4,255·0	501·4

39)

*3-7-38	6-7-38	8-7-38	13-7-38	16-7-38	3-9-38	10-9-38	21-9-38	*24-9-38 / 25-9-38
2·32	1·72	1·78	0·34	0·96	1·14	1·76	1·14	4·82
Trace	...	...	...	...	...	...	...	0·49
47·4	...	...	...	...	...	...	...	254·6
1·59	0·48	0·36	0·02	0·24	0·48	0·96	0·49	2·74
12,310·0	799·7	626·2	42·0	360·2	792·3	1,810·0	2,019·0	23,560·0
1·40	0·47	0·31	0·01	0·20	0·43	0·89	0·49	2·75
12,640·0	11,49·0	226·8	27·8	269·3	313·4	1,521·0	3,796·0	16,990·0
1·15	0·03	Trace	...	0·06	0·31	0·60	0·42	2·61
13,650·0	44·8	10·7	...	39·4	195·2	729·5	2,446·0	54,920·0
0·02	...	...	...	...	...	0·17	0·04	1·78
130·4	...	...	...	...	...	176·7	230·4	29,730·0
0·62	0·10	0·07	...	0·08	0·11	0·13	0·04	1·75
1,916·0	120·4	91·0	...	73·3	98·9	116·1	229·2	24,340·0
0·63	0·20	0·03	...	0·07	0·31	0·64	0·38	2·35
21,330·0	189·2	29·0	...	74·8	175·1	416·5	1,090·0	40,480·0
1·16	0·13	Trace	...	0·05	0·38	0·67	0·41	2·19
2,034·0	86·7	23·3	...	9·5	216·7	523·4	753·6	58,060·0

* Shows rainfall of great intensity mentioned in Table XVII

APPENDIX I—*concld.*

(c) *Total soluble salts in run-off water*

(Expressed in pounds per acre)

Plot No. and treatment	1934-35	1935-36	1936-37	1937-38	1938-39	Total during 5 years 1934-35 to 1938-39	Average per annum
1. Retention of vegetation .	11·18	75·09	5·57	16·45	23·32	131·61	26·32
2. Removal of vegetation .	53·31	101·70	24·39	138·87	255·70	573·97	114·79
3. Shallow cultivation . .	43·43	124·51	36·90	174·48	297·70	677·02	135·40
4. Cultivation of *rabi jowar* .	48·31	104·41	26·06	148·06	234·02	560·86	112·17
5. 'Scooping' . . .	6·06	81·00	2·28	101·51	71·08	263·53	53·70
6. Cultivation of *kharif bajri* and *tur*	36·12	83·27	28·29	143·66	155·59	446·23	89·38
7. Thorough cultivation . .	37·81	93·07	30·84	143·74	175·17	490·63	98·12
8. Thorough cultivation with double length	41·68	88·48	33·22	130·55	171·54	465·27	93·05

(d) *Total soluble lime (CaO) in run-off waters*

(Expressed in pounds per acre)

Plot No. and treatment	1934-35	1935-36	1936-37	1937-38	1938-39	Total during 5 years 1934-35 to 1938-39	Average per annum
1. Retention of vegetation .	3·18	31·83	1·31	6·58	6·95	49·85	9·97
2. Removal of vegetation .	15·06	42·74	6·27	48·83	98·86	211·76	42·35
3. Shallow cultivation . .	15·75	51·09	10·57	71·43	101·87	250·71	50·14
4. Cultivation of *rabi jowar* .	18·62	44·42	9·22	62·44	91·18	225·88	45·17
5. 'Scooping' . . .	1·43	24·62	2·42	37·67	30·46	96·60	19·32
6. Cultivation of *kharif bajri* and *tur*	8·43	36·36	9·76	64·14	64·94	182·63	36·52
7. Thorough cultivation . .	7·87	37·09	9·10	57·57	74·55	186·27	37·25
8. Thorough cultivation with double length	10·31	30·24	9·45	57·36	72·63	179·99	35·99

APPENDIX II

STANDARD ERROR OF THE TWO RUN-OFF PLOTS RECEIVING SIMILAR TREATMENTS

An attempt is made here to answer any possible objection regarding the single-plot lay-out mentioned earlier. Fortunately we have some data to throw light on the possible variation between two similar plots. Plots 4 and 7 were practically the same. Plot 4 had a *rabi* crop of *jowar* from October onwards, but most of the run-offs took place before the sowing of the crop, and therefore both the plots can be considered as comparable. The data of quantities of water lost by run-off as calculated in inches from these plots during the five years are as follows.

Inches of rainfall lost by run-off

	1934-35	1935-36	1936-37	1937-38	1938-39	Total for five years
Plot 4 . .	1·09	5·55	1·89	7·47	6·92	22·92
Plot 7 . .	1·42	5·02	1·93	7·14	6·41	21·92

The results in all the years show such a great agreement between the two plots that no objection may be raised regarding the single-plot lay-out. Further, in order to find out the probable variation in the two plots receiving exactly the same treatment, the results of run-off during five years are again compared, after omitting the run-offs obtained after sowing of the *rabi jowar* in October. The following table shows the actual figures thus obtained for the two plots for five years.

Years	Plot 4	Plot 7	Total
1934-35	1·09	1·42	2·51
1935-36	4·26	3·87	8·13
1936-37	0·70	0·71	1·41
1937-38	6·14	5·87	12·01
1938-39	6·92	6·41	13·33
Total .	20·54	19·85	40·39

Analysis of variance

Due to	Degrees of freedom	Sum of squares	Mean square	*Z* theo.
Treatments . . .	1	0·07	0·07	Not significant for 5 per cent
Season	4	58·36	14·59	Significant for 1 per cent
Error	4	0·22	0·055	
Total .	9	58·65	..	

The analysis of variance clearly indicates that the variation between plots is very small and is not statistically significant.

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