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Soil Erosion and Conservation of Moisture in Un-irrigated Black Soils

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Lecture No. 2*

The results of run-off experiments conducted at Hagari have shown that a large proportion of the rainfall is lost by surface flow. The greatest opportunity for conserving moisture in dry soils, therefore, lies in the reduction of losses due to surface run-off. It is naturally impossible to prevent run-off completely. It but a portion of it is saved, a substantial increase in the moisture supply is effected.

As mentioned already, in the black soils the main *hingari* crops, cotton and sorghum have to depend on the moisture that is stored in the soil by their sowing time. Rainfall during their growth period is poor and precarious. The effective rainfall for crop growth is that received in the period August to October, normal for August, September and October is 12·3 in. against an annual normal of 20·6 in. (for the last ten years). Conservation methods like bunding, scooping or listing, therefore, help in better utilisation of the rain water. They arrest run-off and allow the water to stand on the field for a longer time, giving greater chance for it to be absorbed by the soil. Ploughing, by throwing the land into better physical condition, helps in better absorption of the rain water by the soil, provided the furrows do not run along the slope. Any implement which cuts a furrow can be used for forming basins, if the furrower can be lifted at intervals. In the case of the basin-lister this is arranged by means of an eccentric cam. The local interculturing implements, *dhantulu* or blade harrows, can also be used for forming the basins by lifting the harrow at intervals.

As moisture is the limiting factor for crop growth in dry areas, a study of its movements under field conditions is essential.

Theoretical Before considering the movements of moisture in soils under field conditions, I shall briefly outline the theoretical aspect of the problem. The earliest hypothesis on the movements of moisture is familiarly known as the capillary tube hypothesis. It is based on the fact that if a capillary tube is dipped in water, the water level inside will be higher than that outside; the rise in the height is given by the equation:

$h = \frac{2T}{gdr}$; where h is the height of meniscus above the water level,
T is the surface tension between water and air,
g is the acceleration due to gravity,
d is the density of the liquid, which may be taken as unity for water, and
r is the radius of the tube.

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The height of rise is therefore proportional to the inverse of the radius of the tube. If r is very small, then h should be high. If we visualise the soil as consisting of a bundle of capillary tubes of varying cross-sections, r may be taken as the average effective cross-section. If r is very small then water should rise to great heights by capillarity. It follows that the soil between the water table and the water front should be saturated. Varying estimates to which water can rise by capillarity were made by different workers. Their range varies from 10 ft. in a year to about 200 ft. in a favourable term of years. Under laboratory conditions, the rise from a water table never reached these phenomenal heights; it rarely exceeded four feet. This was explained away by the fact that it is impossible to imitate the field structure under laboratory conditions. Dr. B A. Keen in his classical lysimeter experiments showed that the upward rise of water by capillarity occurs over only limited distances. Large cylinders with water-tight bottoms, 2ft. × 6ft, were used for the experiment; their tops were kept a little above the ground level. After the soil was refilled in the natural order, it was allowed to settle for a period of eight years. The level of free water surface was noted in a side tube. From these readings the depth of the free water level was plotted aginst time, during a period of severe drought. The curves obtained by him for the movement of the free water level from an initially saturated soil were very interesting. From these it is concluded that once the water recedes about 80 cm. in clayey soils, it is not drawn back to the surface by capillarity. For all practical purposes upward capillary movement is ineffective even over these limited distances. Dr. B. A. Keen, in a later work came to the conclusion that when water recedes 180 cm or 6 ft. it is not drawn back by evaporation. Dr. V. I. Vaidyanathan, working at the Irrigation Research Institute, Lahore, found that sub-soil water, in the month of June was drawn to the surface by evaporation from a depth of about 22 ft. But the amount thus reaching the surface is a negligible quantity, being 7 mm. for the whole month. This is a very minute fraction of the evaporation losses at the soil surface, much less is it of any use for cultivation. Thus the simple theory of capillarity could not explain the observed phenomena quite satisfactorily. The theory was also applied to the study of the rate at which water moves through soils. In explaining this the fundamental equation for the flow of liquid through a tube under a known pressure head is used:

V, the volume of liquid flowing out in time t, through a tube of length l, under a pressure head h, is given by:

$$V=\frac{\pi g h d t r^4}{8 n l}$$ where *r* is the radius of the tube, d, the density and n, the viscocity of the liquid.

In the case of downward movement of water, as happens under irrigation or when a rain is received, suppose water is maintained to a constant depth 'a' above a soil column. If we assume that the capillary attraction also assists the forward motion of the liquid through the soil, the total pressure head at a point distant 'h' from the source is $a+h+k$, where k is the capillary attraction. The rate at which the water front moves can be shown to be:

$$\frac{dh}{dt} = \frac{P}{S}\,\frac{(a+h+k)}{h}$$

$$= \frac{P}{S}\left(1 + \frac{a+k}{h}\right),$$ for the downward motion, P, being the permeability, and S, the pore space.

When h is zero, $\frac{dh}{dt}$ is infinity and when h is infinity, $\frac{dh}{dt} = \frac{P}{S} =$ a constant. Thus in the case of downward movement of water, the rate is infinite in the beginning and tends to become a constant at great heights from the source of water.

In the case of vertically upward motion as happens in the case of the capillary rise from a water table, 'a' disappears and 'k' and 'h' act in opposition. Hence we have:

$$\frac{dh}{dt} = \frac{P}{S}\,\frac{(k-h)}{h} = \frac{P}{S}\left(\frac{k}{h} - 1\right)$$

When 'h' is zero, $\frac{dh}{dt}$ is infinity; and when $h=k$, $\frac{dh}{dt}$ is zero. The velocity of water decreases hyperbolically from infinity to zero at a certain height 'k' from the water table. This shows that $\frac{dh}{dt}$ should vary linearly with $\frac{1}{h}$. From experiments on the vertical rise of water through soils it was found that the expected linear relationship held good only for the first 15 to 20 minutes and there was a progressive decrease in the value of $\frac{dh}{dt}$ over the greater part of the experiment. This demonstrated the insufficiency of the capillary tube hypothesis.

In the case of the horizontal motion of liquid through a soil, 'k' alone acts; 'a' and 'h' disappear; we have $\frac{dh}{dt} = \frac{P}{S} \cdot \frac{k}{h}$ or the velocity is inversely proportional to the height, h.

In a qualitative manner all the above conclusions hold; but they fail to explain quantitatively the movement of water through soils.

When the capillary tube theory failed to explain the phenomena of moisture movements, the analogy of heat conduction and conduction of electricity through solids was applied to the case of movements of water through a porous substance like the soil. This also was not quite successful as the analogy implies that the capillary conductivity or the facility with which water moves through soils should be a constant of the substance, like electrical conductivity or heat conductivity.

It was next realised that a complete picture of the nature of the pore space in a soil was necessary before any correct hypothesis could be postulated. The geometry of the pore space existing in an ideal soil composed of spheres of uniform radius was investigated. The properties of liquid films were applied to moisture films existing round points of contact of the spheres. The pressure below a curved surface of the liquid is less than that above, the deficiency in pressure being given by the product of the surface tension, T and the curvature of the surface $\frac{1}{r}$, r being the radius of curvature of the particle P. D. is proportional to $\frac{T}{r}$. Different pressure deficiencies are associated with different values of $\frac{T}{r}$. The development of the subject is largely due to the work of Versluys, Haines and Fisher. Three stages in the distribution of moisture through the pore spaces of the soil are worked out.

Starting from dryness to saturation, the first one is the 'pendular stage' or the stage of discrete ring formation. As the moisture content is increased, the rings in adjoining cells meet and continuity is established in the moisture within the pore space. The pressure deficiency, which is very high at low moisture contents falls from infinity to $4{\cdot}1\frac{T}{r}$, when the upper limit of the pendular stage is reached. This has been determined as 24% of the pore space or 3·55% moisture content by weight of soil. This is the stage when the films within neighbouring cells meet and continuity in the film is established. It is the beginning of the 'funicular stage' of distribution, when the film thickens at the waist. Between 6% and 24% saturation, side by side with the pendular stage, the funicular stage also is possible. The funicular stage extends beyond 24% saturation; its upper limit is not yet determined. As the soil moisture is increased, saturation of the air cells commences, this being the commencement of the 'capillary stage'. In the capillary stage the soil suddenly passes from saturation to flooding. The capillary stage is complete only when all the pore space is filled with water.

At complete saturation the pressure deficiency is zero. But saturation can exist in certain portions of the cells down to a P. D. of $12{\cdot}9\frac{T}{r}$. Between 30% saturation and complete saturation regions of local saturation can exist side by side with regions of low moisture content.

These are some of the salient features of the theoretical studies on the movements of moisture in soils. The subject is still developing.

Experimental Coming to the practical aspect of moisture movements in soils, during the last five years, studies on the seasonal distribution of moisture in soils under field conditions were carried out at Hagari. The relative efficiency of cultural methods intended to conserve rainwater can best be seen only by a study of the moisture condition of the soil at the different depths before and after rainy periods. Soil samples were taken once a fortnight during the crop period in fields which differ in respect of the preparatory cultivation which they received, like bunding, bunding combined with ploughing once in two years and ploughing once in four years etc. Soil sampling was done by means of King's sampler of the tube type, consisting of a cylindrical brass tube about 6 ft long, having a steel end piece, with a sharp edge and marked every three inches.

Screw augers were not found of much use in these black soils as the soil is lifted in big clods and it is difficult to sample without loss of moisture. Every six inch layer of soil down to 3 feet was sampled and the moisture content for any layer is obtained as the average of about six individual determinations. After the first year, samples were taken for layers 0 to 6 in. 6 to 12 in., 12 to 24 in. and 24 to 36 in. The moisture content of the soil when plotted against the date of sampling gives the curve of seasonal fluctutations of soil moisture for the different layers. Thus the field distribution of moisture is obtained under different experimental conditions—rainfall being the only source of moisture. Figures 1, and 2 contain typical curves for the seasonal variation of soil moisture in a plot cropped with cotton and in one which was fallow. The curves for a plot containing sorghum were almost similar to those of the cotton plot except that they lie a little higher than the corresponding curves for the cotton plot.

The soil reaches its peak of moisture after the September–October rains. All layers reach their field capacity by the end of October. Cotton and sorghum during their growth period depend almost entirely on the moisture stored in the soil at the time of their sowing. During the dry period the amount of moisture lost by the different layers of the soil decreases with increasing depth. The curves for the fallow plot show that evaporation losses are confined practically to the top six inch layer of soil. The effect of the diurnal variations of temperature and circulation of air are a maximum in this layer. The absorption of soil moisture by the crops was effective only to a depth of 2 to 2½ feet, as seen from the differences in the moisture content of the different layers, between the moisture at the end of the rainy period and at the end of the growth period of the crops. The following table contains the differences in moisture content of the soil between 31st October 1935 and 6th March 1936, and shows the amount of moisture lost by the different layers of the soil during the period.

Loss of moisture from the soil during the dry period: (31–10–35 to 6–3–36)

Layer of soil	Cotton plot	Sorghum plot	Fallow
0 to 6 in.	17·5	16·9	14·3
6 to 12 ,,	15·5	15·1	5·9
12 to 18 ,,	13·0	11·2	3·9
18 to 24 ,,	10·6	10·0	2·9
24 to 30 ,,	6·4	6·9	2·8
30 to 36 ,,	1·5	0·5	0·2
0 to 36 in.	10·7	10 1	5·0
0 to 36 in.—in inches	5·1	4·8	2·4

The rate of evaporation being high at high moisture contents, the moisture in the top six inch layer of soil rapidly comes down to the hygroscopic moisture in the course of a few weeks after the rainy period. In the cropped fields the variations of moisture with season in the different layers become almost parallel to each other, losses in moisture gradually diminishing with depth. A clear indication that by fallowing the land moisture is carried over to the succeeding season is provided by the curves in fig. 2, where the moisture below the 12 in. depth was almost constant during the dry period. Curves of soil moisture variations obtained in succeeding years are in general conformity with those given in figures 1 and 2. The moisture in a fallow plot is steady below the 12 in. layer, during the dry period, when the distribution of moisture with depth becomes more and more regular as the dry season advances. It follows an exponential relationship of the type:

$Y = F - (A.\ b.\ 10^{-ax})$;

where Y is the moisture content at any depth x;

F, the Field capacity (equivalent to the moisture equivalent of the soil);

A, the maximum observed moisture at lower depths;

a and b are constants which can be evaluated from the observed moistures at a few depths.

Calculated and observed values of soil moisture, using the above relationship are given below:

Depth in inches	Observed moisture per cent	Calculated moisture per cent
3	8·1	11·4
9	19·1	19·3
15	25·0	23·9
21	26·8	26·5
27	27·5	28·0
33	27·0	28·8

Considering the variations in moisture which normally exist under field conditions, the agreement between the calculated and the observed values is fairly good.

The moisture content of fields which differ in respect of preparatory cultivation was next studied. The effect of bunding, and bunding combined with deep ploughing was investigated. Scooping by various implements like basin lister, *dhantulu* etc. was also studied in regard to its effect on the conservation of moisture. The curves of moisture distribution similar to those given in figures 1 and 2 have been obtained, extending over different seasons, in an experiment where the treatments are as follows:

(a) Control: preparatory tillage consists of working the *guntaka* or the blade harrow three times before the rainy season;

(b) Bunded;

(c) Bunding combined with deep ploughing by Cooper No. 21 plough, once in two years; and

(d) Bunding combined with deep ploughing once in four years. Ploughing, in these soils is done after the harvest of a cereal. As the rotation is sorghum—cotton, the earliest interval of ploughing is once in two years.

These studies have definitely shown that under the *ryots'* method of cultivation, large quantities of rain water are lost by surface flow without being absorbed by the soil, during the short but heavy period of rainfall, usually September—October It has been shown that ploughing and erection of bunds about 7 in. high help considerably in the absorption of rain water by the soil. From the seasonal curves of moisture it was found that the summer showers are just sufficient to compensate for losses due to evaporation. Although ploughing involves some loss of moisture, all such losses occur in the fallow period when no crop is on the land. With the commencement of the monsoon the ploughed plots are quick to absorb the rain water. Similarly scooping the land by the basin lister or by the local interculturing implements like *danthulu* (blade harrows) has checked erosion and increased the powers of absorption of rain water by the soil. The following are a few typical instances to illustrate the beneficial effects of these cultural treatments on the conservation of rain water, when it is received in heavy instalments.

Trial of Improved Dry Farming Methods

Treatment	Moisture per cent in the layer 0 to 3 ft.		Difference	Rainfall absorbed in inches
	on 16-8-38	on 31-8-38		
	(Rainfall between the dates – 6·2 in.)			
Control	18·1	22·1	4·0	1·9
Bunded	19·0	24·1	5·1	2·5
Ploughed once in 2 years and bunded ...	17·2	25·1	7·9	3·8
Ploughed once in 4 years and bunded ...	17·3	26·4	9·1	4·4

Scooping Trials

Treatment	Moisture per cent in the layer 0 to 3 ft.		Difference	Rainfall absorbed in inches
	on 16-8-38	on 1-9-38		
	(Rainfall between the dates – 6·2 in.)			
Control	15·3	21·2	5·9	2·8
Bunded	15·4	24·8	9·4	4·5
Scooped with basin lister and bunded ...	16·6	26·8	10·2	4·9
Scooped with *danthus* and bunded ...	15·7	26·4	10·7	5·1

The effect of any particular treatment on the absorption of rain water depends also to a large extent on the initial moisture condition of the soil; the drier the soil the greater is its capacity to absorb moisture. The treatments are found to be most effective in checking erosion during the first spell of heavy rains and particularly in years of low rainfall. In years of very good rainfall, however, the effect of the treatments is not so conspicuous in the conservation of rain water, as there is a tendency for the different plots to attain the maximum field capacity; yet there is the lasting benefit of saving the soil, which is otherwise washed off in large quantities as shown by studies on surface run-off.

Figures 3 and 4 contain curves of the seasonal variations of soil moisture, for the first and second foot layers of a control plot, during four years, including a famine year In a famine year like 1937-38, when only 15 in. of rainfall was received the moisture condition of the soil below the first foot was very low; the maximum moisture attained by the second foot layer was 22 per cent during 1937-38, while the corresponding figures for 1936-37, 1938-39 and 1939-40 were 28·3, 28·5 and 28·2 per cent respectively. The available range of moisture which is the difference between the maximum moisture and the wilting point (about 18 per cent) was very low during the famine year. It was found during the course of these studies that the moisture content in the second foot layer has a decisive effect on the yield of crops, which are also influenced by the moisture content of the soil at the sowing time to a large extent.

Percolation of rain water to the lower layers of the soil was found to be very slow due to the heavy nature of the soil and there is consequently a lag in the attainment of moisture by the lower layers. Once the moisture content of any layer reaches about 25 per cent, the percolation to lower layers is improved, due to the continuity of moisture films established within the pore spaces of the soil.

The gradual percolation of rain water to lower layers is illustrated by the figures in the following tables, giving moistures before and after periods of rainfall.

Soil Moisture in a fallow plot, 1935-36

Moisture % on the dates	0 to 1 ft.	1 to 2 ft.	2 to 3 ft.	Rainfall between the dates of sampling	
				Rainfall in inches	No. of rainy days
23-9-35	22·6	22·9	21·4	2·41	3
4-10-35	29·6	23·5	21·6	0·19	1
14-10-35	24·9	26·3	22·4	3·62	6
31-10-35	27·5	30·6	28·6		

Trial of Improved Dry Farming Method, Soil moisture in control plot, 1938-39

Moisture % on the dates	0 to 6 in.	6 to 12 in.	12 to 24 in.	24 to 36 in.	Rainfall between the dates of sampling	
					Rainfall in inches	No. of rainy days
12-7-38	9·4	13·5	15·5	20·7	3·89	6
16-8-38	20·4	15·1	16·5	20·0	6·15	8
31-8-38	21·9	29·2	21·5	19·1		

It is seen that a rainfall of 2·41 in. increased the moisture content of the first foot layer alone by 4th October 1935 and thereafter slowly percolated to the second foot layer and increased the moisture content of that layer only after a lapse of about 10 days. The second instalment of 3·62 inches of rain immediately soaked even to the third foot layer owing to the better conductivity for water at high moisture contents. In the second table it is seen that a rainfall of 3·98 in. received on six rainy days increased the moisture content of mostly the top six inch layer only. The moisture content of this layer was initially very low, being the end of the hot weather period. The next instalment of 6·15 in. of rain enhanced the moisture content of the top two feet of soil.

Towards the end of the crop period, *i. e.*, at the time of harvest of the crops, the moisture in the differently treated plots tends to come to the same level, though the maximum moisture at the end of the rainy period may be different.

Fallowing the land naturally leaves a large reserve of moisture for the succeeding crop, in the lower layers (Vide figure 2). It is seen from the following table how a crop after an year of fallow absorbs the moisture from the third foot layer also, while in plots which are continuously cropped, absorption of moisture is negligible in the third foot layer.

Moisture absorption in plots having a crop after a fallow and having a crop after a crop

Losses in moisture per cent between 15—10—40 and 16—1—41, difference in the moisture content between the dates

	0—6 in.	6—12 in.	12—24 in.	24—36 in.	0—36 in.
					in inches.
Sorghum (40-41) after cotton	19·4	13·1	12·2	2·1	4·90
Sorghum (40-41) after fallow	21·1	14·2	11·5	10·1	6·29
Fallow (40-41) after sorghum	18·3	2·6	1·7	1·0	1·92

The extra moisture is utilised in the production of additional dry matter in the plots after fallow. In view of the uncertainty of the seasons, however, fallowing of a large area cannot be recommended to the cultivators

Fallowing a small proportion of the holding as an insurance against famine is feasible.

Indirect influence of conservation of water (a) Conservation of moisture reduces the shrinkage and consequently the amount of cracking during the period of crop growth. It has already been mentioned that clayey soils swell when wet and shrink very much on drying. The changes in the volume of the soil due to wetting and drying are large and with the advance of the dry season numerous cracks are formed It was found that the black soil of Hagari has a shrinkage coefficient of about 65% by volume, when passed through a sieve of 100 mesh to the inch; *i. e* when 165 c. ft of soil are dried from sticky point (about 40 per cent moisture) to dryness, the volume will be reduced to about 100 c. ft. In the field the shrinkage will naturally be less than this owing to the presence of coarse particles and as the range of moisture the soil has to pass through in one season is limited. If, however, we can succeed in reducing the desiccation of the soil during crop growth, the shrinkage will be less and there is less possibility of wide cracks developing during the crop period.

(b) A second and more interesting effect of conservation of moisture in heavy soils is that on soil hardness. Losses of soil moisture by evaporation have been shown to be most effective in the top 12 in. layer of soil. This layer, after reaching the maximum field capacity for moisture during the rainy period, is subjected to sudden drying thereafter. The layer of soil between 3 to 12 in. thus becomes very hard, if the desiccation is rapid—the top 3 in. of soil remaining in a loose and friable condition, being disturbed by interculturing and exposed to alternate heating and cooling, on account of the diurnal fluctuations of temperature. If the hardness sets in later in the life of the plant, when it has established itself well, it may not affect the crop growth, but, if by adverse conditions, the hardness sets in early, the crop suffers on this account badly By conserving moisture, the setting in of the hard layer may be postponed to a stage when it is of no consequence to the growth of the plant.

In this lecture, I have placed before you certain facts in regard to the movements and conservation of moisture in black soils, which have emerged as a result of the studies conducted during the last six years at Hagari.

Before concluding I wish to record my grateful thanks to the University of Madras for inviting me to deliver "The Maharajah of Travancore Curzon (Endowment) Lecture" in agriculture this year. My thanks are due to the Imperial Council of Agricultural Research, which is financing the Dry Farming Scheme at Hagari, jointly with the Local Government. I must record my grateful thanks to Mr P. H Rama Reddy, I. A. S., the Director of Agriculture and to Mr. P. V. Ramiah, M. A, B Sc. (Edin.), Government Agricultural Chemist, for their continued interest in the work. My thanks are also due to the Superintendent, Dry Farming Station, Hagari, for the

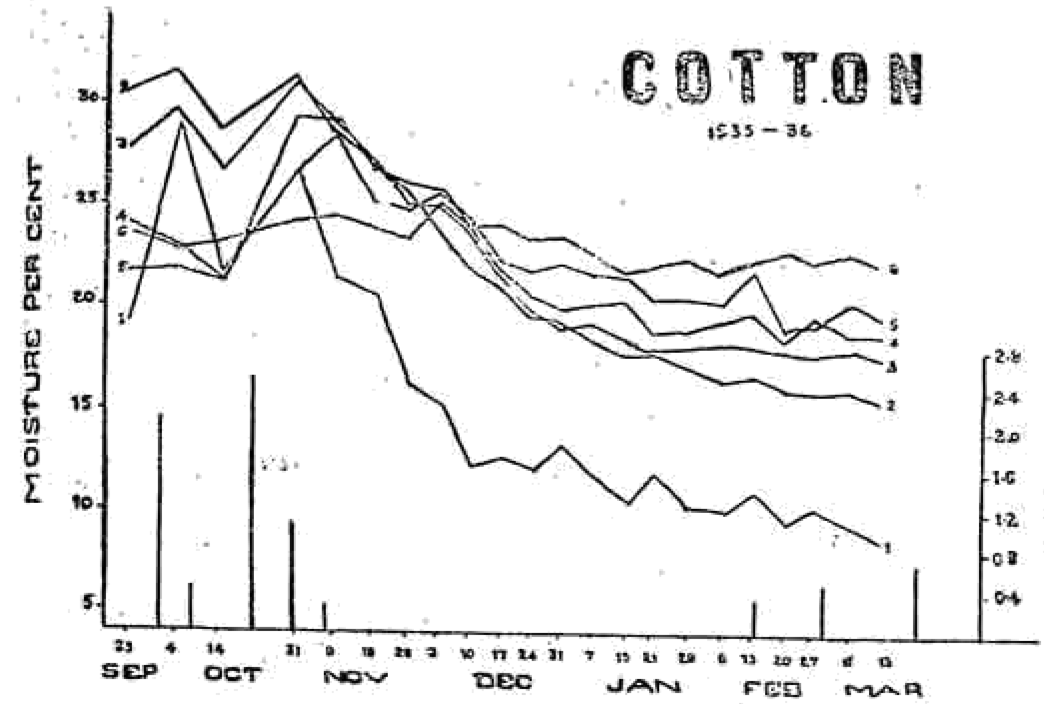

Fig 1. Soil Moisture curves in a Cotton plot.

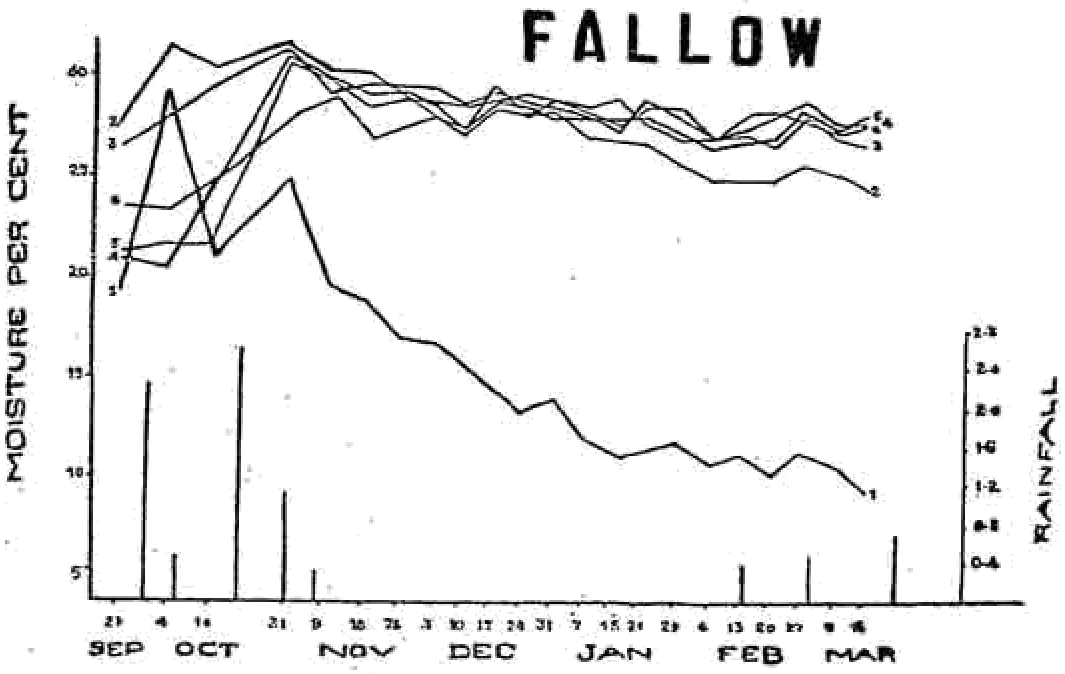

Fig. 2. Soil Moisture curves in a Fallow plot.

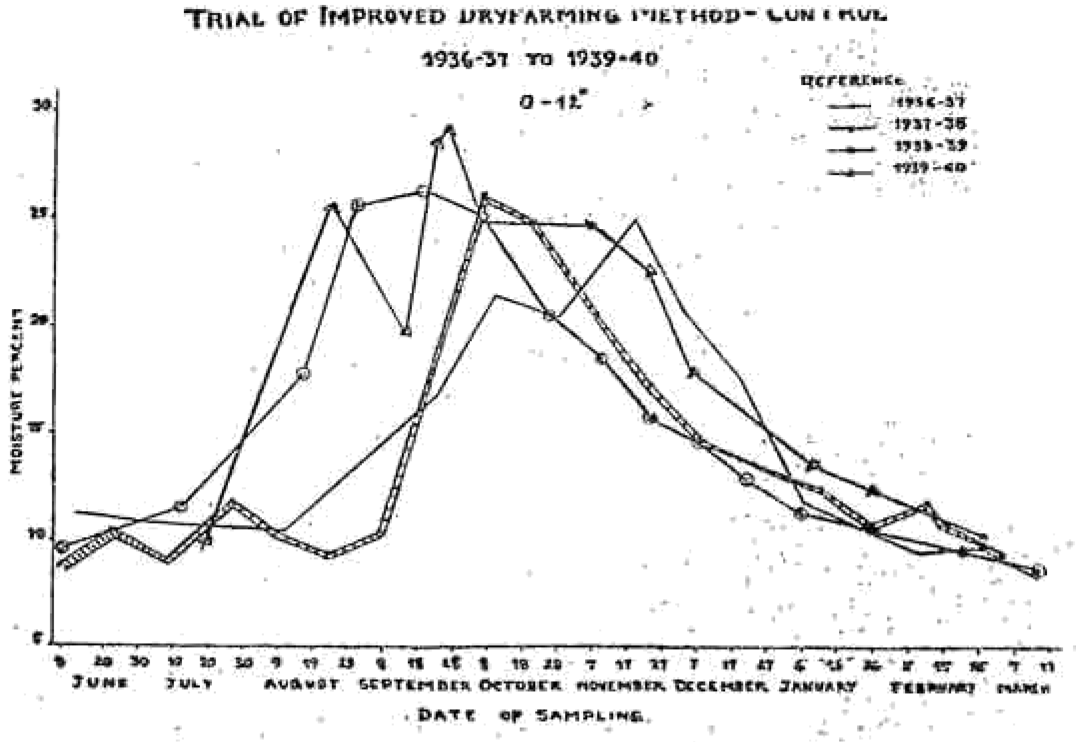

Fig. 3. Soil Moisture curves for four years for the first foot layer. (Double line : Famine year).

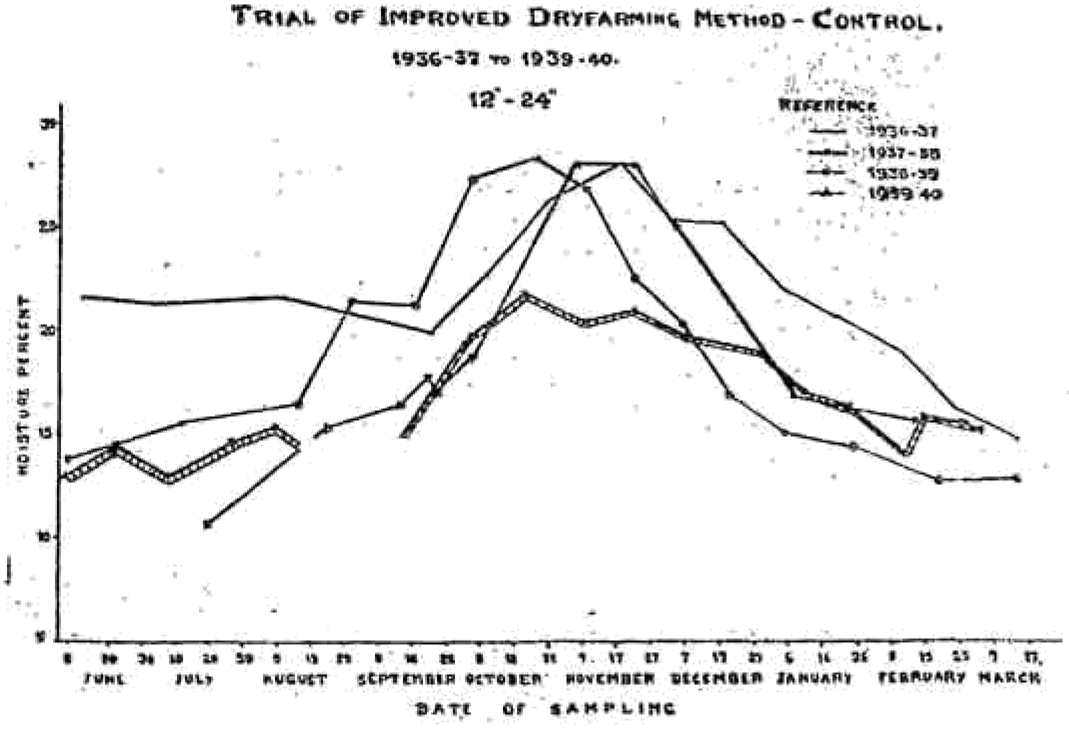

Fig. 4. Soil Moisture curves for four years for the second foot layer. (Doule line : Famine year).

agronomic work done in these experiments, to my staff who assisted me in the collection of the data, to Mr T. R. Narayanan, for valuable help in taking the pictures for epidioscopic projection and to Mr. T. Natarajan for help in projecting the pictures during the lectures. Finally I have to thank Mr. R. C. Broadfoot, I. A. S., Principal of the Agricultural College for kindly making arrangements for the lectures, besides presiding over the same.

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A cheap process of preparing charcoal for activated carbon

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In the manufacture of activated carbon from paddy husk, as carried on at present, the ignition of the first char at high temperature is done in thick iron tubes about 4 ft. in length and 8 in. in diameter. These tubes, to make them fairly airtight, have to be provided with lids hinged to both ends. Such iron pipes at the present market rate will cost anything from Rs. 30 to Rs. 40 each and even at that high cost are not easily obtainable. As these iron pipes have to be subjected to very high temperature, each time a charge of carbon is ignited they get fire-eaten after 50 to 60 charges and have therefore to be discarded, and new ones substituted. And for the ignition of carbon in such tubes under high temperature it is also necessary to build elaborate and costly furnaces with brick in-mud with the provision of iron gratings, ash pit, etc. To build a furnace of the kind designed by the Government Agricultural Chemist to take in three iron tubes of the dimensions mentioned above, it costs roughly Rs. 130. Because of such high cost and intricacy of building such furnaces, it is not possible for the majority of cane growers to prepare their own carbon to clarify their cane juice.

The new simplified method. With a view to simplify and cheapen the process of carbon making and to eliminate iron tubes and elaborate