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THE FORMATION AND THE RECLAMATION OF THUR LANDS IN THE PUNJAB.

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1. Introductory.

Although the problem of Thur or Kallar affected lands was brought to the notice of the Punjab Government as early as 1908, the extent of the damaged area and the fact that it was on the increase were not realised. It is possible the problem may have been masked on account of the rapid developments of new project areas. In the year 1915-16 the problem of waterlogging came to the forefront and threatened to seriously affect the prosperity of the Province. Government instituted a Waterlogging Enquiry Committee in 1925 to study the problem of waterlogging and classify waterlogged areas according to type. In the instructions issued not only were references to thur or kallar lands omitted but it was stated that areas in which thur or kallar was present were to be definitely excluded. At about the same time the Irrigation Research Laboratory was established and one of the main investigations that had to be undertaken was the study of the deterioration of land due to thur and the methods to be adopted for its reclamation. In the year 1927 a Revenue Officer was added to the Committee and he initiated regular surveys with the assistance of the revenue patwaris. After the very first reconnaissance made by the Revenue Officer, it was discovered that the problem of Thur was as serious as that of waterlogging. The same year instructions for the survey of waterlogged areas were modified and the damage to land was divided into damage due to sem or waterlogging and damage due to thur or salts. Fields were considered to be damaged if their cultivation had

been abandoned or they had deteriorated to such an extent that they could not produce a four anna crop. The presence of a white efflorescence over pulverised or swollen earth was the type of thur to be taken into consideration. It was further laid down that the revenue survey should be confined to those tracts in which the depth of the subsoil water had been diminishing and was at the time of the survey within 10 feet of the ground surface. This depth was later altered and the depth of water-table was fixed at 5 feet below the natural surface. Thur, therefore, was first recorded in areas of high water-table and from this the belief that a high water-table is essential for the formation of thur has probably arisen. From the year 1927 to the beginning of 1939 surveys had been made on the basis of a salt efflorescence at the surface and a 5 feet depth of water-table. It should, however, be remembered that revenue surveys have been in progress only in selected districts and in selected estates of these districts. These surveys, therefore, do not give a complete idea of the problem of thur in the Province as a whole or even in any one doab. Moreover, they represent a completely deteriorated condition and give no information regarding the extent of damage to fields which are in the process of deterioration but which have not yet passed the stage of 75% damage.

It will be indicated later in this paper that the damage due to salt can and does take place even when the water-table is deep. If damage in deep water-table areas is also taken into consideration the loss to the Province due to thur must be very considerable. For the present, however, basing arguments on the data collected for high water-table areas only, the rate of damage due to thur is plotted in Fig. 1. It will be seen that since the date of the institution of girdawris approximately 5 lakhs of acres have been abandoned for cultivation due to thur and that the rate of deterioration is on the increase, the present rate being approximately 25,000 acres per annum. These figures indicate that unless steps are taken to check the further formation of thur and to reclaim lands that have gone thur, the situation will become unmanageable in the next few years. To quote from a note by Mr. Kirpalani,

Settlement Officer, Lyallpur :—

> "Damage by Thur to culturable land in Lyallpur district has attracted increasing attention lately. I doubt, however, if the magnitude of the problem has been correctly ascertained. Probably the waterlogging Board has collected data which might show if the disease is decreasing, stationary or increasing in the province as a whole. Judging by conditions in Lyallpur district I should think it is rapidly increasing. A thur girdawri has been conducted recently in the Dangali Chaks of the Jaranwala tehsil, Lyallpur district. For various reasons such girdawris do not reveal the exact extent of damage. Owners of land are reluctant to give up cultivation until the process of deterioration makes germination of seed impossible. *Patwaris themselves find it difficult to judge whether the yield of a particular field is only four annas of what it should normally produce*".

Sir Malcolm Darling, Financial Commissioner, Development after an inspection of villages in the Sheikhupura and Gujranwala districts, in connection with the re-assessment of the Rakh Branch Area wrote :—

> "It will be seen that in both Par Massu and Par Lakhan the cultivated area available per head of the population in 1936, was well under an acre, which means that the villages must be very hard put to it to make a living. Moreover, it is clear from the figures given that their condition is steadily deteriorating. Their condition, indeed, when I saw it last year, was pitiable in the extreme ; their houses visibly crumbling, some already fallen, their land steadily going out of cultivation, most of the village servants fled, and the whole village set in the middle of a vast swamp. ....
> ....
> I would strongly recommend that all whose

means of livelihood have been destroyed or seriously impaired should be offered land in exchange .....

.....

For this purpose there is no need to recognise any legal claim to compensation, but there is, I submit, a clear moral obligation on Government to do what it can to put things right so far as its resources and the magnitude of the problem permit. This obligation is all the stronger as the people affected are too ignorant and helpless to make their sufferings strongly felt at Headquarters".

2. Acknowledgments.

The information given in this paper is largely the result of experimental work carried out under the guidance of Dr. E. McKenzie Taylor in the Land Reclamation and the Chemical Sections of the Irrigation Research Institute. The problem of salt and alkaline soils in the Punjab was an unsolved problem and the Province owes a deep sense of gratitude to Dr. McKenzie Taylor not only for having evolved the methods by which land can be permanently reclaimed but also for suggesting methods of developing new project areas so that land deterioration can be prevented.

The analytical work connected with the investigations has been largely carried out in the laboratory of Dr. Hoon in the Irrigation Research Institute.

3. The Formation of Thur Lands.

It has been stated already that as thur surveys were all made in areas of high water-table it was believed that the source of the salt responsible for the formation of thur was the water-table and that thur appeared as the result of the evaporation of water that is drawn from the water-table to the surface. Thur studies, therefore, were first confined to areas of high water-table and field observations indicated that when the water-table was 18 feet from the ground surface thur might be expected to form. (1) In America attention has been devoted to the

addition of salt made to the land by irrigation water and in that country Scofield (2) considers this to be an important source of salt. In order to investigate the effect of the rising water-table on the formation of thur proposals were made to institute special thur girdawris and soil surveys in that portion of the Lower Chenab Canal area where the water-table was at a depth of more than 18 feet and the rate of rise was approximately 1·6 feet a year. Two lines of villages (Fig. 2) lying between Pindi Bhatian and Qila Dharam Singh and between Chiniot and Sayedwala were selected. In these villages the water-table was known to vary considerably in depth. Some of these villages in which the water-table was situated near the surface were being surveyed for thur and sem by the Waterlogging Assistant to the Financial Commissioners, Punjab, but the deep water-table areas were not included. The results of the first special girdawri carried out in 1938-39 are given in Table 1. A soil survey of the areas has shown that the thickness of the soil crust does not exceed ten feet. From Table 1 it will be seen that land is going out of cultivation due to the appearance of thur at all depths of the water-table between 9 feet and 40 feet. From this it appeared that the water-table might not be an essential factor contributing to the formation of thur.

Having discovered that land is going out of cultivation on account of thur at water-table depths from 9 to 40 feet it was necessary to pursue the study further. During the same winter pits to expose soil profiles were dug in all the villages. The selected points for profile observations were:—

(*a*) fields where thur had appeared at the surface.

(*b*) the adjoining fields in which normal crops of cotton were standing or wheat had been sown.

The soil profiles remained exposed for some time so that the soil characteristics could fully develop and a visual examination became possible. The observations made are shown in coloured illustrations (Figs. 3 and 4) and the results of the analyses in Fig. 5. From the examination of Fig. 5 which relates to village 266, Rakh Branch, having a water-table at a depth of 38 feet from

the natural surface, it is clear that in the field (Pit No. 1), which was formerly under cultivation but had become thur, salt is present throughout the depth of the soil crust, *i. e.*, a depth of 10 feet from the natural surface, and that the main zone of the accumulation of salts, is 0 to 5 feet.

In one of the two fields (Pit No. 2) carrying a normal crop of cotton the salt content of the first three feet of soil is low. Between the third and the tenth foot the salt content is high and forms a zone of accumulation between these depths. Below the tenth foot, sand occurs and the salt content is low.

In another field (Pit No. 3) the salt content throughout the depth of the soil crust is low and no zone of accumulation of salts is present.

The three profiles represented in Fig. 5 and that illustrated in Fig. 3 were taken close together and were situated over similar water-tables at the same depth. Since soil profiles free from salt and containing salt occur under similar conditions regarding depth and quality of water-table it follows that the water-table is not responsible for the presence of the salt in the soil crust.

The examination of soil profiles was extended to the irrigated and the unirrigated areas of Chhaj, Rechna and Bari Doabs. These profiles demonstrated that both in the irrigated and unirrigated areas salts were generally present in the soil crust. Since the salts were present in the soil crust in the unirrigated areas their occurrence could not be due to additions made by irrigation water. In the irrigated areas it was found that the salts were usually present as zone of accumulation but in the unirrigated areas more even distribution of the salts through the soil crust was observed. It seems, therefore, that the irrigation may be responsible for the formation of the zone of salt accumulation. As these salt containing profiles were situated over varying depths of water-table and as the sand underlying them was dry there could be no moisture connection between the water-table and soil crust. It must, therefore, be considered that the formation of thur in such areas has no connection with the rise of water-table. From these investigations the con-

clusion has been drawn that salt is a characteristic original constituent of the soil crust in large areas of the Punjab and that the formation of thur is dependent upon the original salt content of the soil crust.

A recent soil survey of the Thal is of considerable interest in connection with the salt as an original constituent of the soil profile. Over large areas of the Thal no irrigation water has yet been applied. The water-table varies from 25 to 65 feet and the sand between the water-table and the soil crust is completely dry. Profiles dug in the Thal show that there is invariably a salt bearing layer of soil some distance below the natural surface. Should thur develop as a result of the irrigation of this area the obvious source of the salt would be the salt layer present in the profile.

Before proceeding further to discuss the factors that are responsible for the movement of the salt layer in the soil profile to the ground surface, two important observations must be mentioned. Investigations by Puri (3) indicate that in an area of rising water-table, if the soil crust is more than ten feet thick, the rise stops when the water-table touches the soil crust and no signs of waterlogging appear at the soil surface. In other words, areas in which the soil crust is more than 10 feet in thickness are usually free from the danger of waterlogging.

The second important observation is that various workers under laboratory and semi-field conditions have shown that the loss of water due to evaporation at the soil surface only affects the water in a limited depth of soil. Keen (4) states that water which has once reached a depth of 6 feet in a soil does not return to the surface by evaporation. The work of Veihnmeyer also supports the conclusion that the return of water to the surface of a soil occurs only from a shallow depth. More recently Ram Dass and Malik (5) using Punjab soils have shown that the amount of water lost by evaporation decreases as the water-table recedes below the surface. The results obtained by them have been plotted in the form of a curve (Fig. 6). From Fig. 6 it will be seen that when the water-table reaches a depth of 4 feet the loss of water by evaporation from the surface ceases. The

study of the evidence leads to the conclusion that the water-table is unlikely to contribute salts to the soil surface when it is situated at a depth of 10 feet.

When the water-table in the Punjab is within 10 feet of the surface it seems probable that it may supply water to the soil crust to replace that lost by evaporation. With soil crust less than 6 feet in thickness a water-table touching the bottom of this crust results in signs of waterlogging and water lost at the surface by evaporation is undoubtedly partially replaced by water from the water-table. Under these conditions of water-table it seems probable that the water-table may contribute to the formation of thur since there will be a tendency for the deposition of salts at the soil surface following the evaporation of the water. In areas of high water-table, therefore, the source of a portion of the salt causing thur may be the water-table. At the same time it would be expected that the greatest concentration of salt in areas of high water-table would always be at the surface if the water-table was the main source of salts since evaporation taking place at the surface of the soil results in the deposition of the salts. Profiles in high water-table areas that had not gone out of cultivation generally show a zone of salt accumulation below the surface indicating that even in high water-table areas the water-table itself is not such an important factor in thur formation as was once supposed.

Calculations have been made to estimate the amount of salt that would be added to one acre of soil crust 10 feet in thickness by the annual evaporation of 6 inches of water derived from the water-table. For a water-table containing 90 parts per 100,000 parts of water of total soluble matter the amount of salt added to the soil crust is found to be 0·5 ton per annum. Investigations of numerous soil profiles of land that has gone out of cultivation due to thur show that, on an average, about 100 tons of salts per acre are present in a 10 feet depth of soil crust. It will be seen, therefore, that a period of something like 200 years would be necessary, if the water-table were the source of the salt, to account for the presence of the quantity of salt present in thur land

when the land has gone out of cultivation. This is an additional reason for stating that there is little connection between the rise of water-table and the appearance of thur.

Having eliminated the water-table as a cause of the appearance of thur on the soil surface in areas of deep water-table, other factors that might be responsible were brought under examination. These factors are the intensity of irrigation and the system of cropping, which includes the use made of the irrigation water. An examination was made of the area irrigated during *kharif* and the average depth of water used for irrigating crops on all the branches of the Lower Chenab Canal where thur is on the increase. Taking as a particular instance of the Rakh Branch, the data obtained are shown in the form of curves in Fig. 7. At the bottom of Fig. 7 is shown the percentage area irrigated during *kharif* on the same water supply for the period 1907 to 1936. In the second curve is shown the average depth of water in feet per acre used for irrigating the *kharif* crops. In the top curve is shown the area under *banjar* (area gone out of cultivation) in village 266, Rakh Branch, the soil profiles of which have been described already. The record for the area that has gone out of cultivation is available for the last 12 years only. An examination of the three curves in Fig. 7 shows that the intensity of irrigation during *kharif* has increased from 26 per cent. in 1907 to 44 per cent. in 1936 which means approximately 70 per cent. more irrigation is being done now than previously on the same water supply. This increase in irrigation is reflected in the curve for the depth of water used. The depth of water used for irrigating *kharif* crops has decreased from 4·6 feet in 1907 to 2·5 feet per acre in 1936. These figures show that a much smaller quantity of water is being used now for maturing crops than formerly. Investigations carried out in the Irrigation Research Institute have shown that in *kharif* salts are either stationary or else there is a downward movement; an upward movement being confined to the *rabi* season. With the high delta of former years

the tendency would be for the movement of salts to be downwards. With the decrease in the delta the tendency for the movement of salts downwards will have been considerably reduced. The subsequent movement of salts upwards in the *rabi* is likely to be, therefore, a much easier process than formerly. Since thur is appearing it must be concluded that under the present delta the balance of the salt movement is in an upward direction. This probably means that the soil is drier at the present time than it was some years ago when the delta was higher. If, as is the case in Pit No. 2, Fig. 5, salts are present in excessive quantities in the soil crust the upward movement results in the zone of accumulation of salts approaching the surface. As soon as this upper limit of the zone of accumulation approaches such a depth from the surface that the concentration of salts can occur due to evaporation then the land becomes thur. The top-most curve in Fig. 7 shows that with the progressive increase in *kharif* irrigation and the decrease in the amount of water used per acre the area that has gone out of cultivation has consistently increased.

The monsoon is probably also a factor determining the position of the zone of accumulation of salts in the soil profile. If the monsoon is good then the zone of accumulation will be depressed to a much greater depth than if the monsoon is poor. During the past few years the monsoon in this area has been poor and hence the natural downward movement of the zone of accumulation of salts during the *kharif* season has not taken place for this reason.

Puri (6) has shown that while seasonal variations in salt content occur in a soil profile in an unirrigated land, in general, the total salt content in the first 5 feet of the profile is the same at the beginning and end of a complete cycle of seasons. From this the conclusion can be drawn that before the introduction of irrigation the soil is in a state of complete salinisation with reference to the climatic and other factors determining the salt distribution in the profile. It has also been shown by Puri (7) that soils contain-

ing sodium sulphate can absorb, under certain conditions of humidity and temperature, considerable quantities of moisture from the atmosphere. As a result of this absorption during a period of high humidity and low temperature, when conditions are again suitable for evaporation to occur, a moisture gradient is established in the soil and there is tendency for the movement of salt towards the surface. These observations account satisfactorily for the appearance of salts in the winter when humidity and temperature conditions at night are suitable for moisture absorption and in the day time for evaporation. In the summer either humidity or temperature or both are unsuitable for moisture absorption by sodium sulphate and, therefore, the auto-movement of this salt does not take place in the *kharif* season.

The absorption of moisture by the soils containing sodium sulphate affords an explanation of the zemindar's observation that the best yields of crops are obtained immediately before the land goes out of cultivation due to thur formation. Water is always the main factor limiting crop production in the *rabi* season in the Punjab. If a soil contains sodium sulphate, in an amount insufficient to be directly toxic water can be absorbed by the soil upto about 15% by weight. Under these soil moisture conditions, the crop is unlikely to suffer from water shortage at periods of high atmospheric humidity and, hence, the yield of the crop is unlikely to be limited by the water supply factor. Excellent crops of wheat have been observed growing on land during the *rabi* season and the land has gone out of cultivation within a year due to salt efflorescence.

To summarise the discussion in the preceding paragraphs it may be stated that, before the commencement of irrigation, salt is distributed throughout the depth of the soil crust and in the absence of irrigation water no movement takes place. With the introduction of irrigation the salts accumulate in the form of a solution at some depth below the surface forming a zone of accumulation. The subsequent position of this zone of

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accumulation in the soil crust depends on the intensity of irrigation and the agriculture, which means the use made of irrigation water. If the agriculture is of such a type that the amount of water used for irrigation is sufficient to counterbalance that lost by transpiration and evaporation, then the zone of accumulation will tend to remain stationary or to move to a greater depth. If, however, the quantity of irrigation water used is insufficient to balance the losses due to transpiration and evaporation and the zone of accumulation is within 10 feet of the surface then the tendency will be for the zone of accumulation to move upwards.

Experiments were started in the field to examine the effect of the introduction of irrigation on the salt content of the soil profile. An area of 15 acres of Government waste land which had never been irrigated was acquired near Jaranwala. Plots were laid to study the effect of different intensities of irrigation and different systems of cropping on the distribution of salt in the soil profile. The lay-out of the plots enabled the following to be examined :—

(*a*) the effect of perennial irrigation when such crops as cotton, rice, wheat and *senji* are included in the rotation;

(*b*) the effect of *kharif* irrigation only, when crops such as rice and cotton are grown.

(*c*) the effect of *rabi* irrigation only when crops such as wheat and *senji* are sown.

The water-table in the Jaranwala area is, on the average, situated at a depth of 16 feet from the natural surface and the soil crust has a thickness of 10—11 feet. Fig. 8 shows the distribution of salts in the soil profile before and after the growing of one cotton crop with irrigation. From Fig. 8 it will be seen that, before the commencement of irrigation, salts were distributed throughout the depth of the soil crust. With the irrigation applied to cotton, salts have been removed from the surface and have formed a zone of accumulation at a depth of 6—7 feet. Fig. 9 shows the distribution of salts in the profile before and after the growth of one rice crop.

The depth of water used for rice is approximately three times that used for cotton. From Fig. 9 it will be seen that with the heavy irrigation given to rice the salts have been almost completely removed from the soil crust and there is no zone of accumulation.

The differences in these profiles after irrigation have important applications. They indicate that unless salt is present in the soil crust, there is little danger of deterioration of the soil due to salt movement with a rising water-table. In the case of the profile under cotton, since the salts have not been removed from the soil crust, it would appear that there will be a tendency for the salts to again rise to the surface when conditions become suitable for this movement. In the case of the profile under rice, since the salts have been completely removed from the soil crust, deterioration in future is unlikely to take place.

The work at the Jaranwala Farm has indicated the lines on which the development of new project areas should be taken up and also the methods to be followed in the reclamation of salt affected lands. In an undeveloped area, if the soil has a salt bearing layer in the soil crust within 10 feet from the surface then it will be advisable to introduce a rice crop at the beginning of irrigation to remove the possibility of soil deterioration in the future. In the case of the reclamation of thur land it seems necessary to wash the salts to the sand layer to avoid the possibility of the return of the salts to the surface.

A question that may be asked is that in the case of well irrigation, if there is a salt bearing layer in the soil crust below the natural surface, why is it that no deterioration due to thur formation takes place ? In order to examine soil conditions under well irrigation pits were dug in recently irrigated fields under *bajra* and cotton. In the case of *bajra*, it was found that the maximum depth of penetration of the irrigation water was 6·5 inches (Fig. 10). Between this moist surface soil and the salt bearing layer 2·5 feet of completely dry soil existed. In the case of cotton (Fig. 11) the depth of the penetration of irrigation water was about 20 inches since

cotton receives twice the amount of water given to *bajra*. The moist soil under cotton was again separated from the salt bearing stratum by completely dry earth. The examination of these profiles has shown that under well irrigation no contact of the salt layer with the surface soil is established and, therefore, no rise of salts under well irrigation can take place.

Under canal irrigation much larger quantities of water are used which establish the connection between the surface soil and the salt bearing layer in the soil crust and help in the movements up and down of the moisture and salts in the soil crust ; hence the necessity for taking more precautions to avoid deterioration of land under canal irrigation than under well irrigation.

4. Deterioration due to Thur Formation.

From a study of the previous paragraphs one must not conclude that the flooding of salt affected land is all what is required for its reclamation. The presence of large quantities of certain soluble salts change the entire physical and chemical condition of the soil. Chemical reactions take place between the salt and the clay in the soil and the stage to which soil deterioration has taken place is determined by the extent to which the chemical reactions have advanced. On the physical side, by the continued action of the salt, the structure or the tilth of the soil is affected, colloidal substances are altered and changes in the moisture relationships occur. The clay in a normal soil is mainly present in the form of calcium clay. A soil containing calcium clay is permeable to water and air, the conditions in it are aerobic and the methods to be adopted in the cultivation of such a soil are known to the Punjab farmers. When a solution of sodium sulphate or sodium chloride is brought in contact with a calcium clay soil, base exchange takes place, the sodium replacing the calcium in the clay, resulting in the formation of a sodium clay. The reaction is shown in the following equation :—

$$Na_2\ SO_4 + Ca - clay = \quad Na_2 - clay\ (alkaline) + CaSO_4$$

It will be seen that there are two stages in soil deterioration, the first stage is the accumulation of salts which is

relatively harmless ; the second stage is the base exchange reaction given by the above equation, which renders the soil conditions much more difficult to ameliorate. The development of alkalinity is a gradual process and it follows that after the first stage of thur appearance has been reached the longer the land is left before reclamation the greater will be the approach to the second stage of alkalinity. As the alkalinity increases reclamation becomes more and more difficult and finally economically impossible.

In the Punjab the main salt present is sodium sulphate. Owing to the alternate dry and wet periods and the consequent movements of moisture and salts in the soil profile the reaction between sodium sulphate and calcium clay has taken place repeatedly. The result is that the Punjab plain soils tend to be sodium clays and are alkaline. In a very alkaline soil the clay becomes deflocculated and the soil is impermeable to water. This soil presents difficulties in leaching and is unsuitable for the growth of normal crops. Thus the main limiting factors, other than water, in crop production in the Punjab are the salt content and the alkalinity. From the point of view of reclamation it is essential to know the limits of both the salt and the alkalinity in the soil at which yields of crops begin to decline, the limits at which crop growth becomes impossible and also the limits when reclamation cannot economically be carried out. With a view to ascertain these limits two types of investigations have been carried out. Firstly, soil surveys of wheat and rice growing tracts have been made and, secondly, these crops have been grown at Chakanwali Reclamation Farm under controlled conditions on fields having different salt contents and varying degrees of alkalinity. McKenzie Taylor, Puri and Asghar (8) have shown that, providing the salt content is low, the yield of wheat is not affected until the *pH* value rises above 8·5.

Chakanwali Reclamation Farm experiments indicated that rice can stand a relatively high quantity of salt in the soil and a higher degree of alkalisation than most of the other crops grown in the Province. In the reclamation

of thur areas, it was noticed, that when the yield of rice was 18—20 maunds per acre the land can be made fit for growing normal crops by following a suitable rotation. No further leaching or any treatment with chemicals was necessary. The experiments at Chakanwali also showed that the rakkar lands were indicative of high alkalinity. They were very difficult and expensive to reclaim.

A detailed soil survey of the rice areas of the Upper Chenab Canal was carried out in 1933 with the co-operation of the Executive Engineers in charge. The Executive Engineers placed the services of the zilladars and the canal patwaris at the disposal of the survey parties constituted for the purpose of taking soil samples. The zilladars and the patwaris had an intimate knowledge of the soils of the area and of the yields of rice obtained. Instructions were issued that fields giving varying yields of rice should be selected for sampling. In 1934, Mr. Cox verified the yields of rice by actual observations by the zilladars and the patwaris. A description of the investigation together with the results obtained has already been published (9). Samples of soils obtained from these rice areas were examined for their salt content and *pH* values. These results together with the yields obtained have been shown in the form of a solid curve (Fig.12). From an examination of this solid model the following standards were laid which have been verified by subsequent surveys :—

Type (i) Good land capable of carrying the normal crops and likely to give normal yields. Such soils are characterised by a soluble salt content of 0·2 per cent or below and a *pH* value not higher than 8·5.

Type (ii) Soils which have some limiting factor such as salts or alkalinity which will tend to reduce the yields of crops below the normal. The main characteristics of these soils are a salt content below 0·2 per cent and a *pH* value ranging between 8·5 and 9·0. Given proper cultivation and subsequent interculture etc., it is possible to obtain a yield of 18—20 maunds of rice in soils of this type. The rotation advocated for this type is rice followed by *berseem* or *senji* followed by sugarcane, followed by wheat or cotton. After cotton rice can be eliminated from the rotation.

Type (iii) Soils in which the influence of some limiting factor is very marked so that they are only suited for a limited type of cropping in the initial stages of irrigation. The salt content of this type is almost always less than 0·5 per cent. and the *pH* value ranges between 9·0 and 9·5. These soils belong to what is locally known as the "Mild Rakkar" type. Soils of this type are unfit for general cropping and need to be reclaimed. Reclamation experiments show that two rice crops enable this land to be reclaimed and made fit for normal cultivation.

Type (iv) Salt soils that can be economically reclaimed. In soils of this type the salt content is above 0·2 per cent while the *pH* value is below 9·0. Soils of this type are locally known as 'thur' soils. Usually one rice crop is sufficient to reclaim soils of this type. After the first rice crop it is possible to introduce gram, *berseem*, *senji* in the *rabi* and sugar-cane or cotton in the following *kharif*.

Type (v) Salt and alkaline soils that are difficult and at the same time expensive to reclaim. These soils may or may not have a high salt content but their *pH* value is always higher than 9·5. These soils are locally known as 'rakkar' soils. The reclamation of this type takes a much longer period than is the case with types (*iii*) and (*iv*). The reclamation of the 'rakkar' type is not a commercial proposition. It is advisable to exclude soils of this type from reclamation or new irrigation projects.

From the soil classification given above it will be seen that type (*ii*), *i. e.*, soils containing salt content less than 0·2 per cent. and *pH* value ranging between 8·5 and 9·0 can be reclaimed with one rice crop only. Types (*iii*) and (*iv*) sometimes require more than one rice crop to be grown before they are fit for growing normal crops.

5. Reclamation of Thur Lands.

It has been mentioned already that, until last year, the study of thur soils was confined to high water-table areas. The first experiments on reclamation were, therefore, located in such areas. The Chakanwali Reclamation Farm, where water-table varies from about 6 inches to about 5 feet from the ground surface and where fields in all stages of thur formation were available, was made

the centre of all experimental work on reclamation. A detailed description of the experiments carried out and the results obtained is given in the Annual Reports of the Punjab Irrigation Research Institute for the years 1935 and 1936. As a result of the experimental work at Chakanwali the methods for the reclamation of the various types of soils were fixed. The main conclusions arrived at are given below :—

(*a*) That the most suitable type of drain suited for areas of high water-table in the Punjab is the open drain type. The section of the drain is governed by the nature of the soil and the cropping system.

(*b*) That the open drains were unable to reduce the water-level in the plot to the level to which they themselves were dug. It was observed, however, that they kept the water-table in motion which in turn removed the salts from the fields to the drains, increased soil æration, and thus allowed crops to grow. Rice, sugarcane, wheat, *berseem*, *senji*, barley were successfully grown in land reclaimed from thur. In fields where the water-table was situated below three feet from the natural surface cotton was also successful.

(*c*) That the thur type of soils could be reclaimed with one or two rice crops but the rakkar type could not be reclaimed in less than four *kharif* seasons.

As the work at Chakanwali was mostly experimental and was mixed up both with the study of the physico-chemical changes taking place during the process of thur formation and the supervision of a large area under cultivation otherwise it was impossible to work out costs of reclamation from the total expenditure incurred. An attempt was made to keep separate accounts for individual plots and it was found that, spread over a period of four years, thur land could be reclaimed at a cost not exceeding Rs. 42/- per acre.

Government issued orders that the further reclamation of thur land should be carried out on big zemindars' estates at their cost and with their own labour. The first area taken up was Dr. Kapur's land on the Lower Chenab Canal. The results obtained showed that thur land could be reclaimed in two *kharif* seasons.

Costs were worked out and it was shown that spread over a period of three years the total expenditure on an area of 25 acres of thur land was Rs. 1,872/- whereas the income during this period was Rs. 2,669/-.

The yields of rice from the reclaimed area were compared with those obtained from the good land which was under cultivation by the landlords' tenants. The yields obtained are given below :—

	Thur area under reclamation or reclaimed.	Good land under cultivation by tenants.
	Average yield of rice per acre.	
1933 ...	23·8 maunds	12·0 maunds
1934 ...	18·3 ,,	11·5 ,,
1935 ...	24·8 ,,	12·2 ,,

It may be mentioned here that in 1935 the whole of the reclaimed land was cultivated by the same tenants who were cultivating good land belonging to the landlord. These yields indicate that reclaimed land gives higher yields than the normal soils of the locality.

In 1931 Mr. Jesson, Superintending Engineer, Lower Jhelum Canal, started two experiments in that colony in co-operation with the Irrigation Research Institute. In Chak 188 N. B. Faruka Distributary he took an area of 11·2 acres and provided an independent supply of water. This area was kept under direct cultivation and after reclamation was handed over to tenants on the zemindari supply of water. The yields of crops obtained by the tenants on the zemindari supply of water are given in Table 2. These results show that the yields of crops seven years after reclamation are above normal. Figs. 13—16 illustrate the type of land before reclamation, the condition of crops obtained during reclamation, and the condition of cotton during *kharif* 1939, *i.e.*, seven years after reclamation.

In Chak 187 N. B. Faruka Distributary 75 acres of thur land were distributed amongst tenants for a period

of three years. An independent supply of water was given and a trained *muqaddam* was posted to guide and supervise the reclamation operations. No water rates and land revenue were charged but the cultivators carried out all the operations at their own cost. In Table 3 is given the progress of reclamation. In the first year reclamation was not successful on account of the *jangli* type of tenants who take little interest in the cultivation of land. During *kharif* 1933 tenants from rice growing tracts were imported. During the period of three years they reclaimed the whole of the land. This area has been cultivated on lease on the zemindari supply of water since 1935 and the yields of crops have been good. The two experiments carried out by Mr. Jesson in the Lower Jhelum Colony were again unable to afford data for true costs of reclamation. In the case of 188 N. B. the area taken up was too small to be considered as a commercial undertaking. In 187 N. B. the lessees did not maintain any accounts. The yields of crops obtained seven years after reclamation on the zemindari supply of water, however, showed that the land once reclaimed would remain fit for cultivation for a period of seven years at least. Mr. Bigsby at this stage issued orders that a scheme for commercial reclamation, based on the experimental work at Chakanwali and seven years' data in zemindars' fields, should be worked out. At the same time he wished that reclamation of thur land by big landlords should be carried out on a larger scale than hitherto to get some idea of the actual costs involved.

A scheme for commercial reclamation was prepared and was submitted to Government in September 1937. The financial aspects of this scheme are given in Tables 4 to 11. The figures given in these tables have been worked out on the following assumptions :—

(*i*) that the gross culturable commanded area of the block to be reclaimed is 5,000 acres ;

(*ii*) that this area has deteriorated to the extent of 75%, *i.e.*, it is incapable of giving more than a four anna crop ;

(*iii*) that reclamation will be taken up in one-fourth of the area at a time ;

(*iv*) that a capital of Rs. 1,00,000/- at the rate of Rs. 20/- per acre would be borrowed at the rate of 4 per cent. interest;

(*v*) that payments on account of interest will be suspended till the 6th year of operations;

(*vi*) that Rs. 1,000/- a month for superior staff will be drawn from Government monthly as needed and will be repaid together with interest at the end of the reclamation period when the land is sold;

(*vii*) interest will be charged on arrears of interest at 4 per cent;

(*viii*) that full *abiana* will be paid but no land revenue;

(*ix*) that any expenditure required on Government channels to deliver the extra quantity of water needed for reclamation is not charged to the reclamation project;

(*x*) that the work is done on zemindari lines;

xi) that the block of 5,000 acres would be available without incurring any expenditure on the transfer of the existing population elsewhere or for the value of any land given in exchange by Government; and

(*xii*) that the whole of 5,000 acres will remain with the Reclamation Agency for a period of 10 years.

Turning now to Table 11 it will be seen that if there are no calamities, such as hail or crop disease, there will be a net profit of Rs. 30,172/- at the end of the operations. Allowing 10 per cent. reduction in income on account of possible calamities and drop in prices and 10 per cent. increase of expenditure the account will balance if capital appreciation of the land amounts to Rs. 24/8/- per acre.

Assuming that land before reclamation was worth Rs. 80/- per acre and that, after reclamation, it could be

valued at Rs. 200/- the profit on the sale of reclaimed land is given below :—

Price of land before reclamation 500×80	...	Rs. 4,00,000
Cost of reclamation (Table 11)	...	Rs. 1,21,900
Total cost	..	Rs. 5,21,900
Price of land after reclamation allowing for land taken up by drains $5000 \times \cdot 9 \times 200$	...	Rs. 9,00,000
Therefore profit on reclamation	...	Rs. 3,78,100

While the scheme outlined above was still being considered, important results bearing on the subject of reclamation were achieved at Renala and in the Irrigation Research Institute. As already mentioned, Puri in 1937, in connection with his investigations on the influence of the soil crust on the rise of water-table established that, when the rising water-table touched the soil crust, the rise stopped. If a hole were made in an area where the soil crust was 10 feet or more in thickness and where the further rise of the water-table had stopped he found that when the hole pierced the soil crust and reached the sand stratum then the water rushed through the bore and after a time attained a steady level. From this he drew the conclusion that the water-table underneath a soil crust of 10 feet thickness was under pressure. The records of the open wells which all pierce the soil crust and enter the sand stratum, therefore, indicate fictitious water-table.

Soil surveys of areas taken up for reclamation have shown that although the water table as observed in an open well may indicate the necessity of a drainage system the construction of fresh bores enabled soil samples to be taken from depth as much as 12 feet without encountering the water-table. At Renala, where land deterioration due to thur formation is taking place at a very rapid rate, an experiment on reclamation was started by Colonel Bruce on a fairly big scale not only to work out the costs but also to ascertain the drainage that would be necessary on account of the rise in water-table with rice irrigation

in areas of high water-table. Observation pipes were sunk in area under reclamation and also in the lowest point of the trough in which thur was prevalent. The water-table in this area was situated at a depth of 7 feet from the natural surface. The data obtained is plotted in the form of a curve in Fig. 17. With the heavy irrigations given for leaching and the growth of rice the water-table in the area under reclamation rose from 7 feet to about 5·2 feet. When, however, irrigation was stopped and rice was harvested the water level fell to its original level. The records for the pipe sunk in the lowest portion of the trough showed that the water level in the pipe was not affected by the heavy irrigations given to the neighbouring thur land or the land on the dhaya.

The observations are important as they indicate that :—

(*i*) the leaching of thur land is not likely to cause any damage to other lands in the locality ;

(*ii*) the local rise in water-table in areas under reclamation is a temporary phase. The salts and water-table move along with it and join the main subsoil water stream;

(*iii*) that in areas where the water-table is as high as 7 feet from the natural surface no field drains are necessary during the period of reclamation.

Actual costing accounts are being maintained by Colonel Bruce at Renala. It is, however, not possible to deal with them in this paper on account of the following reasons :—

(*a*) Reclamation was started very late at Renala in the year 1938. It was, therefore, impossible to prepare the whole of the area for reclamation and utilise the whole of the water supply that had been made available. In addition the rice crop was attacked by the rice borer.

(*b*) In 1939, whereas the early crop of rice matured and gave a reasonable out-turn, the attack of the rice borer on the *jhona* and other varieties of rice was more severe resulting in a considerably decreased yield.

(*c*) The harvesting of the *jhona* variety of rice is not finished.

(*d*) Expenditure has been incurred on areas reclaimed and those still under reclamation.

Basing figures on estimates and allowing full value for water taken on volumetric system Colonel Bruce's calculations show that the total net cost incurred on reclamation is Rs. 5,126.

Two hundred and seventy-five (275) acres have been taken up for reclamation out of which 135 acres at least have been completely reclaimed and are fit for the cultivation of normal crops.

Major Prideaux who started reclamation on an area of 50 acres of thur land on one cusec supply of extra water during the *kharif* has also maintained an accurate account. This is given in Table 12.

An extract from his report is reproduced below :—

"You will remember that *jhona* was estimated to give an out-turn of 8 maunds per acre. The attack of borer was so heavy, however, that under 2 maunds per acre has been received. This will upset my former calculation and so far as we can see at present the loss per acre in the *kharif* will amount to Rs. 13/10/7 per acre. This will, of course, be covered by the sowings in the *rabi* but it is not possible to forecast at present.

Jhona has *let* us down otherwise the experiment would have been a great success."

My comment on this is that the rice borer let us down otherwise *jhona* would have been a great success.

The costs obtained from the Renala and the Okara experiments indicate that the estimates provided in the scheme for commercial reclamation are on the safe side.

In *kharif* 1938, a suggestion was made to Mr. Cox that an experiment should be made with a variety of rice which can mature earlier in the season. The Sathra variety of rice was selected for the purpose and Mr. Cox arranged that the experiment should be carried out at the Rice Farm, Kala Shah Kaku, under the advice of the Irrigation Research Institute. The Sathra variety of rice was transplanted on two dates, *viz.*, 5th May and 14th May 1938. The crop made excellent growth. Irrigation to the crop sown on the 5th May was stopped on 15th July and that sown on 14th did not require any canal irrigation after the 20th July. On harvesting, the crop gave a yield of 44·66 maunds per acre of rice which usually sells at Rs. 1/12/- per maund.

During *kharif* 1938 the weather remained dry almost from the 1st of July to the date of stoppage of irrigation which means that the water requirements of the Sathra crop for that year were the heaviest likely to be experienced. In other years when rain is received during the period 1st to the 20th of July it will require less canal water than was applied in the year 1938. From the experiment carried out, during *kharif* 1938, it became evident that for the ordinary zemindar, in whose land thur has started, the 'Sathra' variety of rice fits in well with the use he makes of his allotted water supply. For commercial reclamation on a contract supply of water double the area can be put under rice, half the area being sown with the 'Sathra' variety at the beginning of May and the other half sown about the 20th of July which is the normal planting season for other varieties of rice. Two 'Sathra' crops are also possible.

The 'Sathra' variety of rice was introduced into reclamation in *kharif* 1939 on the Lower Chenab and the Lower Bari Doab Canals. In spite of the severe attack of rice borer, the crop gave normal yields and enabled a crop of *jhona* to be sown in adjoining fields. As a result of the two years' experience with the 'Sathra' variety of rice it can be stated that :—

(*a*) the 'Sathra' variety can be transplanted any time between the 1st of May and the 20th of July,

(*b*) it requires irrigation for about 65 days during its growth,

(*c*) compared with other varieties it can stand a relatively higher salt content in the soil,

(*d*) it is a heavy yielder,

(*e*) fields that carry a crop of 'Sathra' become vacant by the end of July or the beginning of August and can be more conveniently prepared for a *rabi* crop during the following winter,

(*f*) for its water supply it does not compete with more valuable crops like cotton, sugarcane, wheat, *toria* and *berseem*, and

(*g*) if 'Sathra' is introduced the area under rice on *kharif* distributaries can be doubled on the existing water supply. This will increase the zemindar's income as well as revenue from canal water.

The experiments at Renala and the inclusion of the 'Sathra' rice in reclamation enable us to introduce two modifications in Table 11 which gives the financial results of commercial reclamation. If field seepage drains are omitted in a reclamation project and two crops of rice are raised on the water supply sanctioned, the costs of reclamation will decrease and the profit on reclamation will increase.

It is a matter of common observation that in a village or in an irrigation chak thur fields and those growing normal crops exist side by side. In *kharif* 1939 Government issued orders that an experiment on reclamation should be started in one such area to study the difficulties in the distribution of extra water for reclamation and also the behaviour of the cultivating classes in bringing their abandoned lands back to fertility. An area of 500 acres of thur land lying in Chaks 112, 113, 114 and 115, Rakh Branch of the Lower Chenab Canal in the Sheikhupura district was selected. The situation of the reclamation areas in Chak 112 R. B. and block A of chak 113 R. B. was such that a separate outlet and a separate watercourse could be constructed to feed these areas. The distribution of water in these areas was,

therefore, a simple matter. For the other three blocks extra water for reclamation has been added to the existing watercourses, the old *warbandi* has been discontinued and a new *warbandi* framed in which areas under reclamation get an increased *wari* at the rate of 50 acres per cusec of extra supply. As the discharge of the watercourse increased the *wari* for land not under reclamation has been correspondingly decreased. So that land that is still good and has not been taken up for reclamation receives the same quantity of water as it used to get before starting reclamation. As an inducement Government gave concessions and remitted water-rate and land revenue for the thur areas taken up for reclamation for a period of four crops. Seed was advanced as *taqqavi*. The yields of rice are not yet all available and the *rabi* crops have just been sown. The attack of the rice borer was very severe and the yield of rice on the average has been reduced to only one-fourth of the yield expected. The early variety of rice was sown after leaching 138 acres of thur area and in spite of the attack of the borer gave an average yield of 22 maunds per acre. The attack of the borer on the *jhona* variety was still worse. The harvesting of this variety of rice is in progress. The zemindars, however, feel so convinced now of the possibility of reclaiming thur land that they are not only willing to put in all the work necessary in their thur areas but they are also most anxious that the rest of the thur land should be reclaimed by the same method. The experiment in these chaks has been a demonstration to the other chaks as well. Applications for reclamation are pouring in large numbers.

In these chaks again, as the soil crust was deep, reclamation has been attempted without a system of field seepage drains. During the course of reclamation, however, it was found that during the monsoon the run-off from the adjoining crown waste and proprietary thur area entered the area under reclamation and added considerable quantities of salt. The matter was brought to the notice of Mr. Mcleod, Superintending Engineer, Drainage Circle, who agreed to the construction of a branch drain. Field surface drains were constructed by the zemindars themselves and were connected with the branch drain.

The construction of the Vanir Branch Drain not only enabled the area to be reclaimed but it also saved a much larger area from further damage. The construction of other branch drains is in progress.

6. Permanency of Reclamation.

It has been frequently asked whether reclamation once affected is permanent. In order to decide this question we must split up the discussion in two parts, *viz.*, reclamation of thur areas where the soil crust is thin and the water-table high, say, within 6 feet from the natural surface, and those where the water-table is deep and the soil crust 10 feet or more in thickness. Describing briefly, the land to be reclaimed is levelled if necessary and is divided into $\frac{1}{4}$ acre plots with the main watercourse in the centre. If the water-table is below 6 feet from the natural surface no field seepage drains are provided but if the water-table as indicated by a fresh bore is above 6 feet then it is necessary to provide either a system of field drains or means for pumping drainage water. In the first week of April, when extra water for reclamation becomes available, water is allowed to stand in the fields to a depth of four inches until about the beginning of May when areas, where percolation has been quick and salts washed down, can be put under the 'Sathra' variety of rice. The heavy irrigations given during the growth of the rice crop eliminate the salt from the soil crust and the alkalinity which develops on the removal of salt appears to be removed by the action of the roots of the rice plant. The carbon dioxide formed by the roots converts the sodium of the sodium clay into sodium bicarbonate and the soil becomes permeable.

Fields under 'Sathra' do not require irrigation after the 20th of July and other fields which have been under leaching are planted about this time with either this or the *jhona* variety of rice. In order to re-establish the nitrogen balance in the soil a leguminous crop, such as, san hemp, gram, *berseem* or *senji*, follows rice. At about this time an examination of the soil profile is made.

In a *deep* water-table area if the salts have been washed either to the sand layer or from a depth of 10

feet of the soil crust, it is considered that the land has been permanently reclaimed. If there is still an accumulation of salts at some depth in the soil crust within 10 feet of the surface, then the reclamation should be regarded as temporary since there will be a possibility of the return of salts to the root zone. In this case the reclamation process under rice is continued until the conditions necessary for permanent reclamation are attained.

An instance of what appears to be permanent reclamation is afforded by the example of Chak 188 N. B. the results of which are given in Table 2 and discussed earlier in this paper. An examination of the soil profile from one of the cotton fields in reclaimed land was made in December 1938. The results of analyses are given in Table 13. These results show that both the salt content and the *pH* value throughout the depth of the soil profile are low. The depth of the water-table in this area is 11 feet below the natural surface. The low salt content of the soil profile also indicates that there has been no tendency for the salts to rise from the water-table to the surface. This land has been leased at Rs. 9 per acre which is the rent for good land in the locality.

An example of complete reclamation in a high water-table area is that of Chakanwali. A description of the work carried out at the Chakanwali Reclamation Farm has already been given. In the year 1936 Government issued orders to close down the farm and hand over the area reclaimed to a lessee. This was done by the Civil Department. As the terms of the lease were very mild, the lessee neglected the drainage system and also the cultivation of some of the reclaimed land.

Under instructions from the Chief Engineer a soil survey of the abandoned farm was carried out during the cold weather of 1938-39 to determine whether any soil deterioration has taken place. The results of the soil survey are given in Table 14. The soil crust in the Chakanwali area is not more than 3 feet thick and the water-table in the underlying sand is touching the soil crust. The water-table has a conductivity of 1250; which means the salt content is high. The field and the

subsidiary drains had ceased to function while the land was under the control of the lessee. The area had formerly been irrigated but no irrigation had been given by the lessee to Plot *A*-1. As no irrigation had been given there would be little tendency for salt movement downwards but rather for salt movement upwards. Since the analyses given in Table 14 do not show any accumulation of salts in the surface layer in any of the plots the conclusion can be drawn that the reclamation, once the salts have been removed from the soil crust, is likely to be permanent even under the worst agricultural and subsoil water conditions.

7. Difficulties Encountered in the Reclamation of Thur Land.

One of the main difficulties encountered is the lack of belief in the methods of reclamation. The zemindars' conviction that land that is once thur is always thur is also responsible for the lack of interest that the zemindars have taken in handling this problem. No doubt they realised that if rice were sown the land would improve but the fear that when rice cultivation ceased the land would return to the thur state prevented much progress from being made.

From the investigations described in this paper it is evident that if reclamation is taken up on lines developed in the Irrigation Research Institute and the salts are completely removed from the soil crust, the fears of the zemindars will not materialise. Areas reclaimed at Sukheki, Renala, Okara, Shergarh and 188 N.B. have been useful demonstrations and applications for further reclamation are being received in large numbers.

It has been mentioned that extra water is required for leaching and the growing of rice crop during the process of reclamation. Two difficulties have to be considered in this connection :—

(*a*) the provision of this extra supply in the distributary during the *kharif* season ;

(*b*) if extra water is let in at the head of the channel and the area to be reclaimed is at the