5.1. SOIL AND WATER CONSERVATION, RUN-OFF WATER HARVESTING AND EVAPORATION RETARDATION

5.1.1. Land Development Systems

In the black soil area of low rainfall tracts of Karnataka State, land development has been a problem. Many farmers follow block or compartment bunding with large cross section. The waste weir is provided to allow the run-off water out of the field. In this system, the water spread and silt deposition take place in a strip adjoining the bund. The upper portion of the field, in between two bunds constructed across the slope, virtually receives no advantage of land development.

The system of contour bunding was adopted on a large scale, by the then Bombay Department of Agriculture during 1942-1947 in the low rainfall areas of black soil. A contour bund with a cross section of 2.16 sq.m. did not prove to be very successful, due to the development of wide cracks and breaches in the bund. The contour bunding was therefore suspended for want of a better method suited to these black soils. Broad base bunds with a cross section of 2.07 sq.m. were tried. The farmers could not maintain them effectively, and also
no suitable method was there to dispose of the run-off water. Disposal of run-off water is a major problem in black soils. Run-off, if allowed to flow through the field, may cause considerable damage in the lower reaches of the terrain. Keeping these points in view, attempts were made in the present investigations to evolve suitable land development systems for the black soil region of North-East Karnataka.

At Saundatti, three systems of land development were compared with conventional compartment bunding on an area of 16 hectares.

In the study area, the highest intensity of rainfall was as high as 57 mm per hour (Table 3). The analysis of rainfall frequency distribution for Bijapur also showed that out of 14 years (1953-1966) eight times more than 137.5 mm and 28 times more than 75 mm and 63 times more than 50 mm rainfall was received at a time (Table 4). There was also 0.9 metre fall between two contour bunds with 90 metre distance. Owing to the above conditions, there was more run-off water
which when flowing downward along the slope gained higher velocity due to acceleration and as the water reached the lower bunds, it had gained enough force to cause breaches in the bunds. Contour bunding gave an increased jowar yield of 21.8 per cent over block bunding. This may be because of relatively better water spread. Patil (1969) reported a 22 per cent increase in grain yield of rabi jowar in plots where contour bunding was adopted at Raichur, and stated that in years of low rainfall, the increase in yield was to the extent of 44 per cent. Further at Bagari, rabi jowar and cotton yields increased by 24 and 14 per cent respectively due to contour bunding. The increase in land value due to contour bunding was about Rs. 1,000 for a block of four hectares. Considering 60 per cent increased income over investment from crop yields and 77 per cent from increased land value, benefit over cost of contour bunding in two years works out to 137 per cent.

The second system of land development included land grading to border strips with grassed waterways in addition to contour bunds. In this case, there was neither accumulation of water along the bunds
nor breaches in bunds. The soil erosion was reduced. This is because of the fact that by dividing the 4 hectare block into 40 border strips and levelling the land to 0.2 per cent slope the quantity of run-off water and its velocity were reduced considerably. The run-off water was let out of the field through grassed water ways, preventing rill erosion in between two bunds from one waste weir to another which was observed when contour bunding alone was adopted. This system has the advantage of land levelling as indicated by Little and Welch (1965) who developed a system of land development by levelling the land to precise slopes in two directions, in the United States of America. The second system gave 50.7 per cent higher jowar yield over block bunding. The higher jowar yield may be due to greater conservation of rain water. The cost of land development in the second system was 115.5 per cent more than that for contour bunding alone. The increase in land value due to second system of land development for contour bunding and border strip lay out was Rs. 2,500 for 4 hectare block. Considering 60.8 per cent increased income over investment from crop yields and 83.2 per cent from increased land value,
benefit over cost of contour bunding with border strip levelling, in two years works out to 144 per cent.

The third system of land development included, land levelling to border strip lay out with grassed water way and construction of farm pond to store run-off water. This system enabled better penetration and conservation of rain water. It was also possible to store run-off water in excavated pond for its reuse to irrigate a portion of the land. Although, the initial investment for adopting this method was 4.6 and 2.3 times more than the first and second systems of land development respectively, it was possible to get additional income due to use of stored water for raising a second crop of wheat on 0.8 hectare. The additional yield of 30.15 q/ha due to third system of land development in two years, was 167 per cent over block bunding as against 50.7 and 21.8 per cent in the second and first systems respectively. The increase in land value due to land development in the third system was about Rs. 5,000. Considering 59.8 per cent increased income over investment from crop yields and 83.2 per cent from increased land value, benefit over cost of contour bunding, in two years works out to
143 per cent. However, this system of border strip lay out with farm pond construction worked out to be more economical in the long run considering assured crop production and scope for double cropping. The storage of run-off water in farm ponds in this system may also help in recharging the subsoil water.

The three systems of land development were found superior to the local practice of block bunding. Among the three systems of land development, the border strip with farm pond enabled the utilisation of the rain water apart from its value as an effective way of conserving soil. There was increase in the yield of jowar crop by 53.3 per cent over simple block bunding from conservation of greater rain water. The farm pond water also helped in utilizing the run-off water for production of wheat crop during the rabi season. One supplemental irrigation, made possible from farm pond, yielded 10.6 quintals of wheat per hectare. Considering this extra yield with farm pond, the total production of grain could be doubled in the drought stricken areas of North-East Karnataka.

The next best system appears to be contour
bunding with border strip layout. There is increase in yield by 50.7 per cent over block bunding. In both the second and the third systems considerable amount of land levelling is involved.

The storage of run-off water in excavated ponds plays an important role in saving of water and its reuse later. It may be very effective to overcome the adverse effect of drought to a great extent. The analysis of climatic data made earlier has indicated that the rainfall pattern in the region follows usually two peaks, with one peak in May-June and the other in September-October. Often water could be collected in the farm pond from the rains in May-June and used for supplemental irrigation during drought spells of July-August. According to Quackenbush (1971), land levelling could be a success, when run-off is high, run-off storage and its use for crops is feasible and crops requiring least amount of water are grown. All these conditions do exist in the study area and the advantages of all these four factors were fully made use of in the third system of land development.
5.1.2. Land Development in Stages

Three units of block bunded area each of four hectares were selected at Gadag with the following treatments:

1. Land grading for border strip at one stage.
2. Land grading for border strip in two annual stages.
3. Control (No land grading).

Though land levelling is one of the most important pre-requisite in the land development systems, under dry farming conditions, it may not be sometimes feasible or necessary to take up the work in one stretch. The soil fertility status of the surface soil is likely to be reduced due to cutting and may call for extra addition of manures and fertilizers to get a normal yield. The power required for completing the operation at any one time is also very high. The farmers in the region usually own one pair of bullocks and may not find enough time to complete the levelling work in one year. Keeping all these in view, a stagewise development of land was compared with developing at one stretch.
During the kharif season sorghum crop was raised for two successive years. In the first year of study the block levelled for border strip at one stretch gave an increase of 1.5 quintals grain over the unlevelled field while in the block levelled in two annual stages the increase in yield was 8.75 quintals per hectare. Thus, it is evident that complete levelling of the land at one stretch may not be advantageous. The reduction of increase in yields due to extra water conservation after land levelling was probably because of disturbance in the surface soil. Several workers (Whitney et al., 1950; Burnett and Fischer, 1956; Hauser et al., 1962; Thomas et al., 1965 and Lyles, 1967) have noticed that the yield of wheat was reduced up to 70 per cent when land was levelled by cutting to a depth of 15 cm or more.

However, in the present investigations, there was only a slight increase in yield of 1.5 q/ha. Any how there was no reduction in crop yields, after levelling at one stretch. This may be due to better moisture status owing to very small cuts and fills involved due to smaller strip widths of 10 metres as compared to 30 metres and more.
in cases by other workers. Also the soils of the present study area were fairly deep. The differences in yield in plots levelled in one stretch and the plots levelled at two stages were brought on par after second year of cultivation. Mickelson (1968) reported similar trend in equalizing of yield levels between the differences in the cut and filled portion of lands levelled at one stretch. However, land grading in stages was advantageous as it also saved B. 44 per hectare in the cost of investment.

5.1.3. Water Conservation in Border Strips

The results of the present investigation indicated an increased infiltration of rain water with decreasing slopes from 1.0 to 0.2 per cent and also in level strips. The level and 0.2 per cent graded border strips recorded a total amount of 12.3 and 12.1 cm of water respectively to a depth of 60 cm whereas a corresponding figure for the unlevelled strip was only 7.6 cm indicating a better conservation of moisture in levelled strips. An increase of 6-8 cm of conserved rain water in level 3.3 metre wide strips not only resulted in higher yields of 4.51 q/ha of sorghum as
compared to 2.82 q/ha in unlevelled plot, it also left an extra amount (3 cm) of water in the soil at the time of harvest. Similar results are reported by Lyles (1967). Land levelling and grading in dry lands may thus facilitate raising of a second crop, in years of favourable distribution of rainfall. Frey et al. (1965) have also reported that level contour benches reduced run-off and conserved more rain water with lesser land slopes and eliminated the need for at least one irrigation.

The yield data of wheat recorded in all the three locations indicated that higher yields were obtained in slopes of 0.2 and near level plots as compared to 1.0 per cent followed by 0.6 per cent slope under border strip widths of 3.3, 6.6 and 10 metres. Though rain water conservation in the level plots is 0.19 cm more than that in the strip with 0.2 per cent land gradient, the yields of wheat in the level plots were less. This is because of the fact that in the level strips there was ponding of water due to lack of sufficient surface drainage.

Field experience had indicated, that level
closed and terraces create farm management problems and sometimes yields are reduced by water ponded in the channels, particularly on slowly permeable soils as reported by Hauser et al. (1962). In Great Plains due to flooding during excessive rains wheat yields were reduced (Harper, 1941). Saveson (1967) and Mickelson (1968) reported reduction in yields of sugarcane and grain crops due to lack of surface drainage and recommended 0.3 to 0.5 per cent slope in the terraces of 30 metre and more width. In the contour border strips of 10 metre width, in the present study, 0.2 per cent gradient was found necessary not only to conserve enough rain water but also to provide surface drainage necessary for high crop yields.

5.1.4. Harvesting of Run-Off Water and Retardation of Evaporation from Farm Ponds

The idea of collecting run-off water in the lakes and ponds is not a new technique. It is being done from ancient times. But the concept of collecting run-off water, from comparatively small catchment areas, that too from one's own holding, to provide supplemental irrigation, is new.
In the opinion of Myers (1969), the simplest method of water harvesting is the construction of ditches to collect run-off in grasslands of Australia. Another example is inducing run-off from a part of the land and taking crops on the remaining area where the run-off water is collected.

The idea of harvesting of run-off water from small catchment area was developed and tried in black soils region of North-East Karnataka. The soils in the area are fairly deep and about 20 per cent of water is lost as run-off.

In the present investigation, farm ponds in the black soil areas at Saundatti, Navalgund, Gadag and Bijapur with catchment areas ranging from 3.24 to 6.25 hectares under border strip layout received, 12.0 to 22.5 per cent of the rain water by way of run-off. The fifth pond at Dhavaleswar, in red soil, with a catchment area of 6.0 hectares, received only 10 per cent of the rain water by way of run-off during 1969-70 (Table 15). Again the percentage of run-off in the black soil areas, varied with antecedent water in the soil and amount and intensity of rainfall. The low
run-off at Dhavaleswar, can be attributed to the high infiltration rate of 2 cm per hour in these soils.

The information collected regarding run-off water from fifteen different locations at different times in black soils from 1968 to 1972 for catchment areas varying from 4 to 20 hectares also indicated that the annual average run-off was about 20 per cent of the rainfall.

The average annual run-off obtained for the period 1967-68 to 1972-73 at Nargund as calculation using the formula developed by Hauser (1965) (Table 15 b) and the actual run-off measured in the farm pond constructed at the Agricultural Research Station, Nargund are presented below.

### Run-off at Nargund

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall received</th>
<th>Run-off collected in the farm pond</th>
<th>Run-off calculated as per Hauser's formula</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>cm</td>
<td>Per cent</td>
</tr>
<tr>
<td>1966-67</td>
<td>71.27</td>
<td>14.30</td>
<td>23</td>
</tr>
<tr>
<td>1967-68</td>
<td>51.00</td>
<td>9.12</td>
<td>18</td>
</tr>
<tr>
<td>1968-69</td>
<td>75.82</td>
<td>15.02</td>
<td>20</td>
</tr>
<tr>
<td>1969-70</td>
<td>49.07</td>
<td>10.30</td>
<td>21</td>
</tr>
<tr>
<td>1970-71</td>
<td>56.00</td>
<td>13.60</td>
<td>24</td>
</tr>
<tr>
<td>1971-72</td>
<td>39.75</td>
<td>6.15</td>
<td>15</td>
</tr>
<tr>
<td>1972-73</td>
<td>32.90</td>
<td>5.25</td>
<td>16</td>
</tr>
<tr>
<td>TOTAL</td>
<td>375.81</td>
<td>73.74</td>
<td>19.6</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>53.70</td>
<td>10.53</td>
<td>19.6</td>
</tr>
</tbody>
</table>
The results indicate the feasibility of using Hauser's formula to calculate min-off at Nargund since the actual run-off and that calculated as per formula are almost equal. The results of the studies further indicate that about 80 per cent of run-off is often received in two peak periods of April-June and September-October months. On this basis the economic size of farm pond was worked out to hold 40 per cent of the total run-off water. Accordingly, the details of farm pond size for a catchment of 4 hectare is as below.

1. Run-off at 20 per cent of annual rainfall of 626 mm
2. Deduct 20 per cent rains received during the months other than two peak periods
3. Run-off expected in the two peak rainfall periods
4. Pond capacity required to collect run-off from one hectare area for each peak rainfall period
5. Area of catchment
6. Pond capacity required to collect run-off from 4 hectares catchment area
The farm ponds in the study area were designed to store about 8 per cent of annual rainfall. The required dimensions of pond sizes for different catchment areas, with a capacity equivalent to 8 per cent of the average annual rainfall, are presented below:

Details of suitable pond dimensions

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Catchment area (ha)</th>
<th>Pond capacity ha cm</th>
<th>Dimensions at top L x B metres</th>
<th>Depth of pond metres</th>
<th>Side slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>4</td>
<td>20</td>
<td>31 x 31</td>
<td>3</td>
<td>2:1</td>
</tr>
<tr>
<td>2.</td>
<td>6</td>
<td>30</td>
<td>31 x 31</td>
<td>4.5</td>
<td>2:1</td>
</tr>
<tr>
<td>3.</td>
<td>12</td>
<td>60</td>
<td>44 x 44</td>
<td>6</td>
<td>2:1</td>
</tr>
<tr>
<td>4.</td>
<td>20</td>
<td>100</td>
<td>53 x 53</td>
<td>6</td>
<td>2:1</td>
</tr>
</tbody>
</table>

These dimensions can be changed to suit soil depth, maintaining the pond capacity and side slopes.

The irrigation potential of each pond giving margin to vagaries of monsoon and evaporation and seepage losses, can be considered 1.5 times of its capacity, that is 30, 45, 90 and 150 hectares cm from 4, 6, 12 and 20 hectares of catchment area respectively. This may provide at least one irrigation for 50 per cent of the pond catchment in kharif and 50 per cent in rabi.
The investment on the construction of farm pond decreases with increase in the catchment areas, from Rs. 750 per hectare to Rs. 400 per hectare when catchment area increases from 4 to 20 hectares. The pond potential of one ha cm costs Rs. 150, Rs. 133, Rs. 93 and Rs. 80 for a farm pond with catchment areas of 4, 6, 12 and 20 hectares respectively when designed to hold 8 per cent of annual rainfall.

In the black soil areas, severe soil erosion is a common feature, leading to rapid silting up of farm ponds if there is no proper levelling of the catchment area of the pond. The studies taken up to evaluate the economic utility of farm ponds in both the black and red soils in relation to silting, indicated that by levelling in the catchment areas the life of the farm pond, could be prolonged to 15 years in black soils and 25 years in red soils. The average annual silting of farm pond in black soils was observed to be 0.9 to 1.7 per cent of the farm pond capacity in case of graded contour border strip where as it was 3.0 to 6.2 per cent in case of unlevelled fields. Smith and Henderson (1961) and Harrold (1960) observed similar trend of two and three times the soil erosion or siltation in the unlevelled fields in Loessial
region of Nebraska and in the black land soils of Texas respectively.

In order to conserve water in ponds it is necessary to reduce the loss of water by evaporation and percolation. An effective way to reduce the percentage of water loss due to these factors could be deepening of the ponds. When ponds are deep, the surface area exposed being less for the same amount of water stored, the rate of evaporation is considerably reduced. Studies conducted on prevention of percolation and evaporation loss with shallow and deep ponds indicated a saving of 35 to 45 per cent of water by increasing the depth of farm pond from 3.0 to 4.5 metres. These observations are in line with Geddes (1963) who reported evaporation reduction of 43 to 77 inches a year by storing water in deep Turkey-nest dams in Australia.

In the present investigations, attempts were made to reduce evaporation loss using three different alcohols, two types of floats and sheep manure pellets spread on the surface of water. Of these, the sheep manure pellets proved to be most effective. The water loss was reduced to an extent of 61 per cent by the
sheep manure pellets over that of control. This may be due to the shading effect of the floating materials in the beginning and the formation of a thin film when the pellets settle to the bottom.

Polyethylene sheet and bamboo mat floats provide shade to change the surface reflectance and thus reduced evaporation. The extent of reduction in water loss for polyethylene sheet and bamboo mat was 24 and 21 per cent less than the loss in control in the same order. These observations are in conformity with the findings of earlier workers (Genet and Rohmer, 1961; Crow and Ree, 1964; Rozitsky and Brashe, 1966; Cluff, 1966; Yu and Brutseart, 1967 and Myers and Prausier, 1970) who reported 20 to 85 per cent reduction in the loss of water due to polyethylene and other floats. The relatively better coverage in polyethylene float reduced evaporation to a greater extent compared to bamboo mat float. The relation between the extent of surface cover and the evaporation was identified by the earlier workers in this line (Lauritzen, 1967 and Cooley, 1969 and 1970).

The monomolecular films of long chain alcohol were effective to reduce evaporation from 2 to 6 percent. This observation is contrary to the earlier findings.
where the monomolecular films of alcohols were reported to reduce the evaporation loss in the ponds to an extent of 35 per cent (Ridhead, 1960; Mangan and Randall, 1950; Gruse and Harback, 1960 and Cluff, 1966). This contradiction is mainly due to movement of alcohols to one side of the pond due to strong winds.

Studies conducted on soil and water conservation, run-off water harvesting and evaporation retardation have indicated that in black soils of Karnataka the techniques investigated can be advantageously adopted to conserve increased rain water in the soil, collect run-off for supplemental irrigation and provide at least one irrigation to the crop in about 50 per cent of the catchment area from run-off water stored in excavated ponds.

5.2. IRRIGATION

5.2.1. Land Grading

The primary requirement of a successful irrigation system is land grading. Land grading to contour border strip with bullock power is more laborious and time consuming. By using machine power it is possible to
reduce the time gap that exists between the creation of irrigation potential and its efficient use. The investigations indicated that the cost of grading from existing land slope of 0.5 to required slope of 0.2 per cent was more or less same with bullock and machine power. More time than usual was needed for machines in carrying out mainly finer levelling required in land slopes of 0.5 per cent due to non-availability of suitable graders with automatic adjustments. In land slopes of 1.0, 1.5 and 2.0 per cent, the cost of land grading with bullock power was more by Rs. 40, Rs. 54 and Rs. 74 per hectare respectively compared to use of machine power for the same slopes.

The time required for land development was much less with the use of machine power in all the slopes compared to the use of bullock power. The time required by the machine power to grade the lands with 0.5, 1.0, 1.5 and 2.0 per cent slope to 0.2 per cent slope was 2.5, 2.22, 2.04 and 1.85 per cent of that of bullock power. Further, land grading for surface irrigation can be carried out only during six months in a year when there is no crop on the land. Under the circumstances land owners can grade only small acreages with a land slope of 0.5 per cent and less, using bullock
power. This calls for the use of machine power for land grading in the ayacut areas. In case of land slopes with less than 0.5 per cent, the bullock power may be used in the off season. This helps in the utilisation of bullock power during slack period even though the extra bullock power available is negligible compared to demand in the irrigated project areas for land grading. The machine power saves much time investment cost, prevents steep rise in wage structure and maintains cost of production of crops within the reasonable limit, as compared to use of bullock power.

5.2.2. Seepage reduction in earthen and lined channels

In the surface method of irrigation, water had to be conveyed from the farm headgate or farm source to the individual field, border strip, basin or furrow. Considerable quantity is lost due to seepage when the water is conveyed through open unlined ditches.

The problem of breaches and seepage in earthen field channels are serious. In the alluvial plains of the North India, the commonly accepted figures of seepage losses in water conveyance are 17 per cent for main canals and branches, 8 per cent for distributaries
and 20 per cent for water courses, which added up to a loss of 45 per cent of the water entering the canal head. In addition, in the field about 60 per cent or more of the supply reaching the field or 33 per cent of the head discharge is lost. This works out to the total water loss of 78 per cent due to seepage of water diverted into main canal. Angadi and Kalmattur (1969) considered 15, 8 and 22 per cent (total of 45 per cent) water losses to head discharge in unlined channels, for canal and breaches, distributaries and water courses respectively. Corresponding figures for the lined channels were 3.0, 1.5 and 4.5 per cent. (total of 9 per cent respectively. The excess seepage from unlined channels results in extensive water logging and development of salt affected lands along the canal distributaries, and water courses and even below the irrigation channels.

In the irrigated black soils of the study area, crop damage up to four metres from the farm ditch, due to seepage from unlined channels constructed in the embankment is a common feature. Under the existing practice of channel running in embankment (farmers' or local practice), the moisture content of the soil below the channel up to 15 cm depth was 5 per cent more due to
seepage at one metre distance in the stagnant water as compared to flowing water. In case of improved method where the channel was dug at 30 cm below the soil surface, the increase in soil moisture due to seepage was only one per cent more in the stagnant water compared to flowing water at the same soil depth, indicating the reduction in seepage. This was because, in the improved method excess seepage occurred only when water was headed up during the time of irrigation while excess seepage was a continuous process in the farmers' practice.

In the improved method below the channel the soil moisture content up to 15 cm depth at one metre distance was seven per cent less than that of when water was flowing in farmers' method (Table 20 a) and it was ten per cent less in case of stagnant water (Table 20 a). Further, by lowering the bed of the channel 30 cm below the ground surface the soil moisture content up to two metres on the lower side of the channel was maintained below the field capacity both under flowing and stagnant conditions, unlike in the farmers' practice.

In the farmers' method, because of seepage up to four metres on the lower side of the channel, there was dense weed growth and the jowar crop grown in the field
failed, while these adverse effects were not observed in
the improved method. The annual cost of removal of weed
and loss due to failure of jowar crop up to four metres
below the channel in the farmers’ method was Rs.4C and
Rs.25 per 100 metre of length of the channel, respectively
which is a recurring feature. As against this, the cost
of deepening of channel to 30 cm below ground level
along with fixing of RCC gates for every 15 cm fall in
the channel was Rs.25 per 100 metres. The cost benefit
ratio works out to more than 1:2.5 in the first year
itself.

It can be said that the improved method suggested
will be able to take care of only surface and lateral
seepage and not deep percolation losses that are bound
to occur with the continued use of unlined irrigation
channels, and this may eventually lead to the development
of water-logging and salinity. It is necessary to find
out a suitable lining material for the channels, for
effective control of seepage.

Channel lining materials

The purpose in using any lining material is to
reduce the seepage loss both lateral and deep percolation,
to the minimum and it has to be of low cost, durable and should not adversely affect the crop growth.

Considering the relative advantages of lined channels over unlined ones, for the study area of Ghataprabha irrigation project, Angadi and Koimattur (1969) reported that the cost per hectare of lined channel inclusive of expenditure on maintenance to be Rs. 472 compared to Rs. 509 per hectare for unlined channels, thereby saving Rs. 37 per hectare.

The lining materials viz., (1) clay with 6 per cent cement, (2) cement sand and gravel mixture, (3) paddy husk and cow dung with 6 per cent bitumin, (4) gunny cloth coated with bitumin, (5) sodium rosinate, (6) sodium methyl simulate, (7) bitumin powder, (8) calcium arsenate, (9) bitumin with coarse sand mixture, (10) rubber sheet, (11) becopan membrane and (12) becopan pannels were among the 20 lining materials tested in the present investigation. The loss of water due to seepage under the twelve different lining materials varied from 1,000 mm to 1,450 mm in 10 days compared to the loss of almost all the 1,500 mm of water in control without lining material. In the 12 lining materials the loss of water from the channel
was more than 66.6 per cent. Hence, it could be stated that none of the 12 lining materials stated above were effective. Apart from low efficiency in the reduction of seepage loss the durability of the 12 lining materials was also quite less. The seepage loss increased in the second year only. Warnick (1956), Zaheer (1963), Joseph (1968) and Sridharan (1968) have reported the failure of many of these materials for lining irrigation channels.

Out of the eight remaining lining materials tried polyethylene sheet of 400 gauge and buried asphalt membrane, reduced seepage loss to 44.2 and 52 per cent respectively as compared to no lining treatment. The polyethylene sheet was damaged due to hard clods while laying. The high contraction and expansion of clay caused punctures so also the roots of weeds. Corry and Fox (1959) also reported such mechanical damage to polyethylene sheet lining. Burried asphalt lining was also found to deteriorate by weathering, weed growth and soil cracking and hence was not durable. These results are in agreement with the findings of Warnick (1956) who reported the failure of asphalt lining after three years of construction under similar
soil conditions.

Size stone masonry, burnt clay flat tiles and hollow cement block channel linings reduced the seepage loss by 50, 50 and 36 per cent of the control respectively. The cost per square metre of these channel lining materials worked out to Rs. 6.50 for size stone masonry and Rs. 6 for the other two. The size stone has been used since ancient times in India as it provides a strong permanent lining. Its initial cost however is high particularly when the size stones are required to be transported from a long distance. Burnt clay flat tiles require frequent repairs resulting in high maintenance cost. The use of hollow cement blocks for lining was not only costly but the reduction in seepage was also comparatively low.

The lining of the channels with washing soda, common salt and clay reduced the seepage loss to 28 per cent as against 100 per cent of water in unlined channel. Similar results have been reported by Glenn (1968) with 70 per cent sodium saturation slurry and Myers and Reginato (1968) by using sodium carbonate. Though the treatment was highly effective in reducing the seepage, the germination, growth and yield of safflower crop was adversely affected up to a distance of two metres.
This may be due to accumulation of sodium salts in this area by lateral movement. The adverse effect on crop growth is a limitation on the use of this material for lining the channels.

Single burnt brick lining in cement mortar reduced the seepage loss to 38.6 per cent, as compared to unlined channel. This lining is commonly used for small channels in India. It provided almost the same degree of impermeability as that of concrete. It develops less cracks than the concrete and avoided the necessity of expansion joints.

Precast cement channels used for conveying water in the black soils reduced seepage loss to 52 per cent. The cost per square metre is low and works out to Rs. 3.50 that is about Rs. 500 per hectare.

Lauritzen (1957, 1961) has reported that in addition to reduction in seepage loss, comparative costs of different lining materials was generally a determining factor in the selection of lining material. In order to be comparable, costs should include the annual repairs, in addition to the initial cost, amortized over the expected service life. Considering the above aspects, precast cement channel followed by single burnt brick lining and size stone in cement mortar were found to be most suitable for black soils in the order of their ranking.
5.3. DRAINAGE

When black clay loam soils are brought under irrigation in semi-arid areas drainage can pose a very serious problem for successful crop production. Improper drainage results in water-logging and rise in water table and because of this, salt concentration in the upper layer tends to increase. In Tungabhadra and Ghataprabha ayacut areas, large patches have been affected by water-logging and salinity. Owing to the clayey nature of the soil and occurrence of saline and sodic soils in certain places, there is every danger that these areas may soon become unsuitable for a successful cultivation of crops.

In the present investigations the data on water table on 100 acre farm at Siruguppa (Tables 5 and 6) revealed that due to heavy rainfall, intensive irrigation, the water table remained usually at its highest during August to November. The rise in water table was maximum adjacent to the silted up natural water course in the first block. This is also the bottom land on the farm to which block much water moved through seepage from upper reaches. The study on spacing of drains was taken up in this block.

In the 2nd block of A.R.S. Siruguppa below the irrigation canal distributory, water table built up much
faster. It was due to excessive seepage from the distributory, saucer shape geological strata and anisotropic nature of the soil, impeding lateral drainage. This anisotropic nature of the black soil is reported by Inglis (1910 and 1928) and Thippennavar et al. (1972). Occurrence of this type of saucer shape geological strata and anisotropic soil condition that impede lateral drainage in the black soil area under irrigation, call for detailed water table investigations, soil profile studies by fixing batteries of piezometers and taking up of detailed soil profile analysis along with hydraulic conductivity before planning relief or lateral sub-surface drains. The study on depth of tile drains was taken up in the eighth block located in such soils. In the upper reaches of 100 acres catchment, light irrigated crops were grown in block II and VII whereas block IV was cultivated with paddy since the introduction of irrigation. In the IV block, adjacent to the ridge line, because of paddy cultivation with intense irrigation, water table had built up much faster than that in the II and VII blocks. In the VII block, water table was more than 200 cm below and was slowly building up. Study of different kinds of sub-surface drains was taken up in the VII block to find out the relative efficiency and cost and also the feasibility of laying sub-surface tile drainage as a preventive measure to check down rise of water table.
In block IV where paddy is grown continuously, a large amount of water is added to sub-surface soil due to deep percolation. Studies with drum culture technique of Achar and Dastane (1972) have shown that the percolation loss can be of the order of about 50 per cent of the irrigation water. However, the reason for build up of water table at Gangavathi where the experiment on depth and spacing of drains was laid out was topography. This patch of land is situated at the bottom surrounded by canal irrigated area. Thus, it is found that land topography, soil conditions, silting of natural water courses, water table fluctuation, seepage from the canal distributors, intensity of irrigation and rainfall have direct bearing in the severity of the problems of water-logging and salinity in the canal irrigated Tungabhadra project black soil areas. Hence, a series of investigations were undertaken to find out useful techniques and methods to reclaim the water-logged and saline lands and to plan drainage to the vulnerable lands as a preventive measure.

5.3.1. Depth and Spacing of Sub-surface Drains

Depth and spacing of tile drains is still largely determined based chiefly on experience and on studies of ground water level. The optimum tile depth for laterals
is influenced by soil permeability, tile spacing, fluctuation in depth of water table, impermeable strata in soil profile, depth of the outlet system and the crops proposed to be grown. Due to high intensity rains, temporary water table may develop in the root zone of crops. The tile lines laid should help in lowering water table to at least 30 cm in 24 hours and to 50 cm in 48 hours (Kidder and Lytle, 1949). When the water table rises to some 15 cm below ground surface, it should drop to 35 to 40 cm in one day (Neal, 1934; Walker, 1932).

Lowering the Water Table

Laying the tile at depth of 140, 120 and 105 cm lowered the water table to 60 cm in heavy black soils as seen from the results obtained with weekly water table readings of piezometers and observation wells recorded before and after laying tile drains at Siruguppa. During August to November usually the water table was at its highest level. Further, the day-to-day water table records indicated that 120 cm depth of placement of tile drain laid above the impermeable barrier was effective. But Hermsmeier (1968) in Minnesota silt clay loams reported success of 87 cm depth of tile placement. It is because of higher hydraulic conductivity of 12.5 mm/hr compared to 3 mm/hr in black soils of the study area. Sommerfeldt
(1971) reported success of perforated tiles laid at 120 cm depth in fine textured soils in Canada. Ferrari (1952), Van'twoudt and Hagan (1957), Van Hoorn (1956), Harris et al. (1962) and Goor (1972) have reported that for most of the light irrigated crops, highest yields were obtained with water table depth of 50 to 75 cm. In the present studies tile depths varying from 75 to 100 cm were not able to lower the water table below 60 cm, the normal root zone of the annual crops in black soils within two to three days after rain or irrigation.

In the studies on depth and spacing of tile drains carried out at Gangavathi, 75 cm depth tile drain failed to lower the water table below 60 cm from the ground level in all the four tile drain spacings of 12, 18, 24 and 36 meters. At 90 cm depth of drains, 12 meter spacing gave better results compared to other spacings. In 105 and 120 cm depths of drains, 12, 18, 24 metres spacings lowered the water table below 60 cm. It is observed that with the increase in depth of tile drainage the spacing may also increase to some extent. The results are in close agreement with Hermemeier (1969) who recommended design standards of 60 feet spacing for 6 feet depth and 40 feet spacing for 4 feet depth to provide good drainage in clayey soils.
At Siruguppa, in the studies on spacing of drains it was indicated that 12 metre spacing lowered the water table from 20 cm to 107 cm depth while it was lowered to 52 cm with 24 meters spacing. There was not much difference between 24 and 36 metre spacing. Water table recession rates were quite variable between soils, water table shapes and between tile systems having different lateral spacings (Pillsbury et al. 1965).

Hydraulic conductivity of soils vary greatly with texture. Soils of high hydraulic conductivity pass water rapidly to drains, than if the soil is tight. In black soils of very low hydraulic conductivity the wider spacings of 24 and 36 metre spacing did not have required water table recession unlike 12 m spacing of tile drains. Ineffective functioning of tiles at wider spacing is mainly due to the low permeability and restricted lateral movement of water. When the hydraulic conductivity is in the range of 35 to 50 mm/hr, much higher spacings have worked satisfactorily (Lamborn and Houston, 1966 and Hermsoever, 1969). In the black soil areas of Karnataka with the hydraulic conductivity of 3 mm/hr, the restricted lateral movement seems to be the major obstacle for increasing the spacing above 24 m.
In the studies on depth of drains with uniform spacing of 20 metres, 120 cm depth was found to be more effective in reducing the water table below 60 cm as seen from figure 10. In other treatments the water table depth was either within 60 cm from the ground level or it was lowered slowly taking more than two days to lower it to 60 cm depth.

The high water table due to shallow depths of tiles of 75 to 80 cm and wider spacings of 24 and 36 metres resulted in shallow root system, accumulation of salts in the surface soils, stunted crop growth, increased weed infestation, reduced crop yields. Van Hoorn (1958) in clay soils of Netherlands found that low crop yields under high water table conditions were due to insufficient aeration of the root zone leading to poor root development and inadequate nitrification. He also reported that high water table gradually caused the deterioration of soil structure. Hooghoudt (1952) also reported deterioration of soil structure to a more compact and sticky top soil with 40 to 60 cm depth of water table compared to soils with deeper ground water.

From the studies conducted at Siruguppa and Gangavathla it was observed that the tile depths of 105
to 120 cm with a spacing of 12 to 18 metres was efficient in lowering the water table below 60 cm from the ground level in the black soils. The results are in agreement with the findings of Kirkham (1950 and 1960), Frevert et al. (1955), and Chauhan and Sewaram (1972) for drain spacing and with those of Hermmeier (1965 and 1969) and Hoover and Schwab (1969) for depth and spacing.

**Drainage Coefficient**

At Siruguppa, the water removed by tile drains was maximum with 120 cm depth of tile placement and least with 140 cm depth, in all the three years (as seen from Tables 24b, 25 and 26, and Fig. 10). One reason for low discharge of tiles placed at deeper depths could be development of a perched water table above the tile lines, at shallow depths due to compact soil layers like clay pans. Observation of Luthin and Robinson (1969) have clearly brought out that perched water table can develop when the hydraulic conductivity of a soil layer is less than 2.5 mm/hr. The percentage of rain water removed through the soil was 3.9, 11.9 and 15.35 per cent of rainfall with 120 cm depth in the first, second and third year after laying tiles, while it was 1.3, 4.2 and 5.7 per cent with 140 cm depth, respectively. Generally accepted drainage needs of clay soils vary between 6 to

In the present studies, it was observed that the extent of drainage was 8.5 per cent of the irrigation water and 15.35 per cent of rain water when tiles were placed at 120 cm depth whereas the corresponding figures for 140 cm depth were 4.32 and 9.35 per cent, respectively. These results establish the greater efficiency of 120 cm depth of tile drain over 140 cm depth. The greater efficiency of tile laid at 120 cm depth can be attributed to two reasons. First, the black soils crack heavily up to 1 metre depth, therefore, when tiles are placed nearer to this depth water can easily move into the soil, secondly the clay and sodium content of these soils increase with depth making the soil less permeable. Sommerfeldt (1971) reported success of tile drainage in slowly permeable soil in Canada laid at 120 cm depth. Hermesmeier (1969) reported that drains at 6 feet depth in clay soils did not function well due to low permeability of heavy soils. This was due to very slow water movement in the soil and insufficient water reaching the drain to provide good drainage (Hermesmeier, 1968). Tile depths of 80 and 100 cm did not drain as much rain water as the 120 cm depth because of comparatively less pressure
of quantity of water column above the tiles. The drain discharge of 8.5 and 15.35 per cent of irrigation and rain water respectively in the study was in agreement with the findings of Donnan et al. (1947) for heavy soils of Imperial Valley.

In the tile drain spacing study at Siruguppa, the data on drainage coefficient indicated that with 12 m spacing the average drainage coefficient in the two years were 0.328 and 0.879 inches. With 24 and 36 m spacing it was only 0.196 and 0.111 and 0.362 and 0.277 inches respectively, during the first and second year after laying tile drains. Thus, with a spacing of 12 m about twice as much water was drained as that of 24 m and thrice that of 36 m spacing. Chauhan and Sewa Ram (1972) reported 4.92 to 30.25 per cent removal of applied water as the tile spacing decreased from 35 to 15 m. Hoover and Schwab (1969) reported that narrow (30 feet) drain spacings resulted in a higher tile discharge (2.06 inches) than the wider (60 feet) spacing (1.32 inches). They further observed that narrow drain spacing brought about a faster removal of excess water, thereby reducing the moisture content of the soil to field capacity earlier in the growing season.
Similar trends have been observed by Kirkham (1945 and 1949) and Hermsmeier (1965). The percentage of rain water drained from each spacing was found to be inversely proportional to drain spacing working out to 36, 22 and 12 per cent for 12, 24 and 36 m spacing during the first year and 39.7, 16.4 and 12.5 per cent during the second year respectively.

The high clay content of the soil (50-70 per cent) coupled with low hydraulic conductivity (3 mm/hr) and stratified soil profile are the major causes for reduced drainage coefficient with increase in tile spacing from 33 to 66 m (Pillsbury et al. 1965). It may also be interesting to recall a study in Fargo Bearden soils where the hydraulic conductivity and other soil characteristics are almost similar to black soils of the study area. In that soil also, after tiling, the maximum tile out flow was 33 mm/day after 225 mm monthly rainfall. Average drainage coefficient was 6 mm/day and 28.5 mm in the season. After rainfall, usually water table built up suddenly to 0.8 feet depth and its draw-down with 6 and 27 m spacing was 27 cm and 9 cm per day and it was 102 and 69 cm after 11 days, respectively. These factors closely agree with the present findings in the black soils of the study area.
At Gangavathi, the average drainage coefficient of 12, 18, 24 and 36 m spacing was 0.102, 0.072, 0.068 and 0.032 inches, respectively, showing the suitability of 12-18 m and inefficiency of 36 metres tile drain spacing. In Landbouw Germany, Wesseling (1969) suggested a minimum drainage coefficient of 7 mm for clay soils while Hoover and Schwab's (1969) recommendation allows a variation of 5 to 12.5 mm. In the present study the drainage coefficient observations presented in table 35 support the results of piezometer readings given in table 34 and supplement the draw-down data shown in figure 12.

Narrow spaced tile drains resulted in higher steady discharge rate and total volume removed per unit area than the drains at farther spacing. Chauhan and Sewa Ram (1972) reported similar findings for the Terrai lands of Uttar Pradesh.

**Leaching of Salts**

In water-logged area, the rate of capillary rise and salinity of ground water decide the extent and depth at which salts accumulate. This is counteracted by the extent of leaching intensity by rain or irrigation water.

Studies at Siruguppa indicated that more salts were leached in tile drains of shallow depths of 80 and 100 cm as compared to 140 cm depth. The tile drain laid
at 120 cm depth leached almost double that of 140 cm and nearly two-third of 80 cm. A critical water table depth for checking the salt build up at the surface was found to be between 75 and 90 cm at which the upward flow rate was 0.1 cm/day and less (Talsma, 1963; Collis George and Evans, 1964 and Luthin and Robinson, 1969). In the present investigations the critical level was observed to be 60 cm from the surface and water table could be reduced to this depth only with 12 to 18 m spacing. Other spacings maintained water table above this depth and encouraged temporary salt build up at the surface. Similar observations of higher efficiency of shallow drains in removing the salts from upper layers of soil, on soils with high water table were also reported by Robinson and Luthin (1967) and Sommerfeldt (1971). These variations are observed due to higher concentrations of soluble salts in the upper layers of the soil profile. In the water-logged and saline areas, the upward rise of salts was more than the downward leaching, resulting in larger concentration of soluble salts in the surface.

The results of investigations indicated that 80 and 100 cm depths of tile drains, even though efficient in leaching greater amounts of salts were not suitable, as they were subject to resalinisation due to higher water
The tile depth of 140 cm leached least amounts of salts in water-logged and saline soils and the rate of lowering of water table was slower compared to 120 cm depth of tile drains.

The soil analysis data up to 90 cm depth before and after laying tiles indicated reduction in salt content in all the layers of soil profile in 12 meters spacing of drains. Layer-wise soil profile analysis for salt distribution indicated downward leaching of salts to lower layers in 12 meter spacing. In 24 m spacing, salt accumulation was observed in the top layers. The drainage coefficient in 36 m spacing and the total amounts of salts removed were also less.

In the study at Siruguppa the efficiency of the drains placed at different spacing in removal of salts from the profile as observed from the electrical conductivity of soil up to 90 cm depth indicated that the tiles spaced at 12 metre were very effective in leading of the salts bringing down the E.C. to 1.39 mmhos/cm during the second year as compared to 6.20 and 6.88 mmhos/cm with tile spaced at 24 and 36 metre respectively. Though the E.C. was found to be reduced due to tile drainage at all the spacings, it was reduced to 33 per cent with 12 m, as compared to 66 per cent of the initial E.C. in 24 and 36
metre spacing in the second year. But in the third year the reduction in E.C. with 12, 24 and 36 metre spacing was 57, 19 and 11 per cent, respectively. The difference in the efficiency of drains spaced at 24 and 36 metres in respect of salt removal was not appreciable.

The greater reduction in E.C. in 12 metre spacing compared to 24 and 36 metre spacing may be because of the lesser lateral permeability of black soils making wider spacing not only less efficient in drainage coefficient but also in the leaching of excess salts present in the soil.

The concentration of the salts in the effluent of the tile systems, in the three studies indicated gradual decrease from the time the tile systems were installed, year after year, in all the tile depths and spacings. In California Pillsbury et al. (1966) represented such a decrease in salinity of effluent from tile systems by regression equation.

Further, it was found that the salts leached under rainfed conditions per unit of water was much more compared to that under surface irrigation. Rainfall of 16 cm had leached 1.4, 1.28 and 0.61 tonnes of salts from
2 hectares area, while 15 cm irrigation water had removed only 0.668, 0.420 and 0.033 tons of salts under 12, 24 and 36 m tile spacing respectively. Nielson et al. (1965) found that when water is ponded on the soil surface, soil cracks provide the main avenue for water and salt transmission in heavy soils. While leaching with surface irrigation when water is ponding on the soil surface, water passes rapidly through the cracks to the tile line as compared to that through the soil block. As a result the main soil body is not effectively leached and the salt diffusion from the interior of the blocks to the cracks is too slow to result in an efficient leaching. Under rainfall, in a non-ponded system, water moves through the smaller pores and unsaturated large pores at about the same rate making the leaching process more efficient. Further, the soil surface is maintained in a more favourable condition for gaseous exchange and water penetration as there is no surface sealing.

In the study on depth and spacing of tile drains conducted at Gangavathi the salts leached in two years from 0-90 cm depth of the soil in 12 and 18 m spacings worked out to 66 and 75 per cent of the original salt content. The electrical conductivity was comparatively more in tile depths of 75 and 90 cm compared to 120 cm and
105 cm depths of drain. The data on effluent analysis indicated that 120 and 105 cm tile depths with 12 and 18 m spacing were efficient in leaching excess salts as compared to 75 and 90 cm depths and 24 and 36 m spacings. Further, leaching per unit of water was more efficient with rainfall compared to surface irrigation.

**Infiltration Rate and Hydraulic Conductivity**

The basic infiltration rate in black soils is 2-3 mm/hr. In heavy clay soils, where development of deep crack is common, cracks help to increase movement of water through the soil profile in the initial stages (Wilson et al. 1960 and Allen and Braud, 1966). Water drained under rainfall was much more than the results that could be obtained from infiltration rings or under flood irrigation. Under rainfed conditions there is less surface sealing, in addition to more effective functioning of micropores under unsaturated flow which is not the case under infiltration rings or flood irrigation where water is ponded in between the two rings or on the soil surface. In the silt clay loamy soils of Minnesota the hydraulic conductivity measured by four different methods viz., Piezometer tube, auger hole, core sample and tile out-flow and depth of water table by Schilfgaarde's equation, never tallied. The core sample method indicated 1/8 of
the hydraulic conductivity as measured by the tile outflow and depth of water table measured by Schilfgaarde equation and Piezometer tube methods (Hermsmeier, 1968). The avoidance of ponding, when water is applied to surface of the soil (under rainfall condition) has two obvious advantages. First the larger pores never become saturated. Water moves through the smaller pores and unsaturated larger pores, at about the same rate making also the leaching process more efficient. Second, the soil surface is maintained in a more favourable condition for gaseous exchange and water penetration. Conditions prevailing during rainfall can provide the same two advantages described above, resulting in higher infiltration rate unlike under flood irrigation or in the infiltration ring where water is ponded (Bigger and Nielson, 1962). This fact is also reported by Nielsen and Bigger (1961), Allen and Freud (1966) and Bouwer (1969).

In the studies carried out at Gangawathi, the infiltration rate of soil during 1969, before laying the tile drain and after two years of leaching during 1971 indicated that there was general reduction in infiltration rate in all the spacings of tile drains. This was later improved in 12 and 18 metre spacings as compared to
wider spacings of tile drains because of greater lowering of water table resulting in better aeration, soil structure and deeper root development due to slow and steady leaching of salts in the calcareous black soils rich in organic matter and also additional application and incorporation of the same in the soil.

**Crop Yields**

In the studies carried out on depth of drains at Siruguppa the cotton crop grown before laying tile drains during 1969-70 failed due to high water table at 30 cm depth and high salt concentration. After laying tiles, Setaria, Hampi cotton, D-340 Jowar and UP 301 wheat grown during 1970-71 to 1972-73 gave increasing yields from year to year. Among the four depths of tile drains the crop yields were highest with 120 cm depth of tile drain followed by 140, 100 and 80 cm in the decreasing order (Table 27).

The yield data of Kharif crops of setaria and D-340 jowar grown during the months of June to October indicated that there was no much difference in yields between the tiles placed at 120 and 140 cm depths. The yield was slightly reduced in 100 cm depth while there
was drastic reduction in yield at 80 cm depth. Similar trend was noticed in the yields of Hampi cotton grown during August to March. This was mainly because of the shallow water table within the rooting depth of the crops in 80 cm depth of tiles where water table was within 60 cm from the ground surface for more than two days. The high water table restricts plant growth, because of poor aeration and salinity (Russel, 1953; Van't twoudt and Hagan, 1957 and Pearson et al., 1957). Van Hoorn (1958) has reported decrease in percentage of large pores with shallow water table and also of hydraulic conductivity of the 50 to 90 cm layer from 2.5 to 0.35 inches per day. Willardson et al. (1963) found that low crop yields in shallow water table was due to low rate of diffusion of oxygen. Goor (1972) reported 70 per cent of the roots of great number of annual crops are found in the 30 to 60 cm depth of soil surface. Highest crop yields of arable crops are reported with water table depth of 50 to 76 cm by Ferrai (1952), Van Hoorn, (1955) and Harris et al. (1962). In case of wheat, however the reduction in the yield at 80 cm depth was not as drastic as the other crops because during the major period of crop growth that is, November onwards the water table receded along with increase in the rooting depth of the crop with its age. It is, thus indicated that the depth
of placement of tiles should be at 105 or 120 cm. The
tile depths of 105 or 120 cm however, will have to be
varied, in individual cases, depending on the occurrence
of impermeable layer, if any, in soil profile and
hydraulic conductivity of the soil. The root system
of the crop to be raised on the field is another consi-
deration.

In the studies carried out at Siruguppa, crops
had failed during the preceding four to five years. The
SR 26 B variety of paddy grown during the first year
after laying tiles in the plots at 24 and 36 metres
spacing gave an yield of 136 and 41 kg per hectare. This
low yield was probably because of the incomplete leaching
of salts and higher water table. In the second year,
safflower was grown. Even though the crop growth was
stunted the yield was 631, 412 and 134 Kg per hectare
with 12, 24 and 36 metre spacing respectively. During
1972-73 Hampi cotton established well. Due to very low
rainfall during the year, there was general lowering of
water table. The yield difference between 12, 24 and 36
metre spacing were therefore not marked. The relatively
low yields of all the crops in 24 and 36 metres spacing
of drains were due to inadequate removal of salts and
inadequate lowering of water table as discussed earlier.
At Gangavathi, sugarcane and daingha crops failed to establish before laying tile drains because of water-logging and salinity. After laying the tiles, at 12 metre drain spacing and 120 cm depth, the yield of safflower in the first year (1971-72) was 820 Kg/ha closely followed by 715 Kg/ha in 18 metre spacing and 120 cm depth. The yield data of safflower and wheat crops indicated that the crop yields were lower when the tiles were placed at 24 and 36 metres apart as compared to 12 and 18 metre spacing during both the years. It was further observed that the yields increased in 12 and 18 metre spacing as the depths of tile placement increased from 75 to 120 cm. However, it was observed that there was not much difference in yields of plots in 18 metre spacing with tile depths of 105 and 120 cm as compared to 90 and 105 cm depths with 12 metre spacing. This indicated that it is possible to increase the spacing between tile drains from 12-18 metre by placing the tiles deeper.

The investigations on depth and spacing of drains which involved studies on water table recession, drainage co-efficient leaching of salts and crop yields
indicated that tile depths of 105 to 120 cm at spacings of 12 to 18 metre are suitable for annual crops in black soils.

5.3.2. Kind of Sub-surface Drains and Tiles

The solution of a drainage problem may require the installation of one or more types of drain devices such as open drains, covered rubble or tile drains. The greatest advantages of open drains are the low initial cost and their ability to convey large quantities of water. The cost factor is partially offset by high maintenance costs. The open drains are found efficient to intercept seepage water from upper reaches. Covered drains take many forms and are built with various types of materials. The common types are rubbles and tile line.

The performance of different kinds of sub-surface drains and tiles was compared with open drain, both at Siruguppa and Dharwar. The sides of open drains slid into the centre after each rain, resulting in water stagnation and consequent blocking of the drain. There was weed growth in the drain which had to be
removed. This resulted in gradual lowering of the bottom of the open lateral drain, below that of main drain in two to three years time. Thus, the open drains were found unsuitable for deep black soils. The results both at Dharwar and Siruguppa agree with the findings of Wilson et al. (1960) and Hagan et al. (1967). The open drains were ineffective in lowering water table and in leaching of excess salts (Tables 40, 44-47). In the Minnedota Irrigation Project a system of open drains on 65,500 acres has only a limited effect upon the water table and salinity conditions (Worstell, 1968). It was observed that open drains took three months to lower water table to return to the original level, while the tile lines lowered water table to three feet in three to five days (Wilson et al. 1960).

Sub-surface drains with boulders or rubbles were less efficient to remove excess water and salts compared to tile drains. This was due to clogging of interspaces in the boulders by clay and silt particles resulting in lower percolation and lesser removal of drainage water. The results agree with the findings
of Donnan and Houston (1967). The cost of drain with boulders was six times than that of open drains. The life of rubble drains is usually 5 to 10 years and that of tile drains is more than 25 years.

Drainage Coefficient

Studies using different kinds of tiles indicated that holes in the tiles are better suited for drainage purposes than slits in bell and spigot type of tiles. Further, the quantity of water drained was found to be greatly influenced by the total area of opening. It was found that sufficient increase in discharge of drainage effluent was obtained when the proportion was three to six per cent of the external surface area of the tiles.

At Dharwar, butt-end tiles with 15 slits and rubbles with an opening below, gave the highest drainage coefficient compared to other types of tile drains. At Siruguppa clay tiles with holes which have greater openings into tiles, (13.2 cm\(^2\)/60 cm length) proved superior to those with lesser openings into tiles with slits (77.8 cm\(^2\)/60 cm length) even though the diameter of the tile used was same. Several other research
workers (Kirkham (1950) Schwab and Kirkham (1951) and Luthin, 1966) have reported that an increase in the area of opening into tiles due to perforation and slits increased the drainage coefficient. Further, Kirkham (1949) has also reported that the diameter of the tiles had little effect on the flow rate.

The performance of tiles with longitudinal or horizontal slits with equal opening on the surface of tiles, did not differ markedly. The total area of opening was much more in the clay tiles with holes and very much less with those having slits. The 5 cm diameter clay tiles with holes gave almost equal effluent flow as that of 10 cm diameter slit clay tiles. It is of interest to note that the total area of opening in these two cases is almost the same. The results agree with the findings of Houston (1966) who reported that two inch plastic line functioned as efficiently as six inches concrete and four inch bituminised fibre tile lines, when the area of opening was same.

The clay tiles of 10 and 15 cm diameter with slits had a total slit opening area of 91.8 and 77.8 square cm respectively. Even though the 15 cm diameter
clay tile with slits is \( \frac{3}{4} \) times that of 10 cm and external surface area is almost double, the increased effluent flow is only 10 per cent and is very negligible. This may be because the opening into tile is not increased in the 15 cm diameter tiles. The data indicates that increase in diameter of tile had no proportional effect on increased entry of water into tiles. When hydraulic conductivity was 35 mm/hr, 5 cm diameter tile line seemed to function as efficiently as 10 and 15 cm diameter tile lines with drain spacings of 48 to 144 m (Lamborn and Houston, 1966). These findings were later confirmed by Hermseier (1969) in Imperial heavy clay soils on 80 acre farm. Considering the 3 mm hydraulic conductivity of the black soils with 120 cm tile depth there cannot be much increase in tile outflow due to increase in diameter of the tiles from 10 to 15 cm. But the increase in area of opening into tiles by holes increased effluent discharge from three to nine times. Schwab and Kirkham (1951) found that doubling the diameter of perforations from \( \frac{3}{4} \) inch to \( \frac{7}{8} \) inch increased the flow by 69 per cent for 4 holes per foot and 46 per cent for ten holes per foot. The 10 cm diameter cement tiles with holes had nearly half and two-thirds area of opening into tiles compared
to 10 and 15 cm diameter clay tiles with slits. The drainage coefficient of cement tiles with holes was 2 to 3 times more, thereby indicating the superiority of holes as opening into tiles compared to slits.

**Leaching of Salts**

Leaching of the salts while growing paddy at Dharwar, was possible by giving irrigation of 75 mm in addition to 75 mm of rain. The E.C. of the soil was reduced from 1.8 to 0.8 mmhos/cm by using tank water for leaching which had E.C. of 0.8 mmhos/cm. At Siruguppa, the leachate analysis from different kinds of drains showed removal of greater amounts of salts with increase in the flow of drainage.

The soil temperature measured at 15 and 30 cm depth in different treatments did not show any marked change. This is perhaps due to the fact that the water in the soil profile, was near about saturation during the period of study which does not allow a sudden change in temperature due to high specific heat of water. Goor (1972) observed that water logged soil with 50 per cent moisture and paddy lands with standing water require about 2.5 and 5 times more heat to warm up than dry soil does. Thus, even though there was
an improved drainage, temperature changes were not observed in the paddy soils, at Dharwar.

Water Table

The water table at Siruguppa in the unirrigated catchment area was at a depth of 12 metres. Due to the introduction of irrigation, the water table in some areas rose to a range of 0.5-3.00 metres from the surface during monsoon. This rise of water table from 9-12 metre occurred over a period of 20-25 years with the introduction of irrigation on the Research Station. The water table readings in the piezometers before laying drains in the study plot during 1970 varied from 93 to 212 cm below ground level. After laying tile drains the water table was lowered by 6 to 55 cm in piezometers and 6-57 cm in observation wells. The soil analysis data indicated a reduction in salt content in the profile. Mann and Tamhane (1910), reported that heavy irrigations to black soils with insufficient drainage to be the main cause for high water table and consequent salinity problems in Nira Canal area of Maharashtra.

Crop Yield

At Dharwar, the paddy crop grown after laying subsurface drains gave 33 q/ha yields in the plots where
drainage coefficient after cessation of rain was 0.77 mm (not too high) that is, where there was standing water in the paddy fields. In the treatments where drainage coefficient was maximum (i.e., 2.000 and 3.076 m/day) crop yields were reduced by 8 to 12 quintals per hectare. However, the yield obtained in plots with subsurface drainage was 3.5 to 15 q/ha higher than the yields in plots with open drains and control where no drainage was provided.

From the study, in paddy crop it was evident that provision of sub-surface drains is a necessity in irrigated lands. Among the different kinds of sub-surface drains, it was found that the bell and spigot type of clay tiles with 8 slits for 45 cm length of 10 cm diameter tile line provided an optimum outflow of 0.7 mm/day after the cessation of heavy rain or irrigation whereas the corresponding maximum tile outflow for other types of drains was 1.93 mm/day. As a result, it was difficult to provide a standing water in the field until next irrigation and the yields of paddy were reduced. Further, during continuous ponding there is always a downward gradient so salt is leached from and not moving by capillary into the root zone. Since the basic function of tile drainage in irrigated lands of the arid and semiarid regions is to
provide for maintenance of a low salt balance in the plant root zone there is argument that tile systems need not be designed for the peak flows resulting from rice flooding (Pillsbury et al. 1965).

5.3.3. Filter Materials for Tile Drains

Studies on filter materials for tile drains of bell and spigot type with slits were conducted at Siruguppa. The tiles were laid, slits facing downward. The results under rainfed condition showed 18.7 per cent discharge of rain water in tile drain without any filter material, followed by 25.0, 14.2, 13.5, 10.9 and 10.4 per cent in pebbles, sand, paddy husk, coconut fibre and groundnut husk respectively. The trend was almost similar under irrigation except for the change where effluent discharge in the tiles without filter material was more than that with pebbles. In Coachella valley pea size pebbles functioned more efficiently and lowered water table to a greater depth compared to pit run sand (Halsey and Marsh, 1967). In heavy texured soils movement of water through soil is restricted due to soil permeability and not because of the ability of drains to remove water. Further, the use of pebbles as filter materials in Sanjoaquín Valley has indicated that the effectiveness of the material is largely due to the
gravel with respect to the tile line. When the gravel envelope was placed below and at the sides of the tile, more water entered the tile line (Debruyn et al. 1970). Many of the drains currently being installed operate satisfactorily without the use of special protection of envelope or filter materials, to prevent entry of sediment with the inflowing water. For the most part, these drains are successful because of the stability of soil aggregates in the material surrounding the drain. In the opinion of Sisson and Jones (1962) the cohesiveness of soil particles limit their entering the drain pipe openings, even though water flow velocity and potential gradients adjacent to the drain may be high. If a filter functions properly it loses its permeability with time because it is plugged with the material. To function properly a drain should admit water continuously without an increase in resistance to water entry. Willardson et al. (1969) also reported that filter materials are likely to offer resistance to the entry of water into the tiles. Under rainfed conditions water moves through the soil profile both in the micro and macro pores in the soil blocks in addition to soil cracks in the beginning. This has resulted in greater percentage of rain water removal through tile flow compared to that under irrigation in all the treatments. This is because water moves through the soil profile slowly under irrigation.
because of surface sealing and functioning of only macropores in the soil unlike under rainfed condition. Often, deep percolation is likely to occur because of the resistance offered by filter materials for water entry into tiles. In black soils, it may not be necessary to use filter materials for clay tiles. The black soils containing 40-70 per cent clay with high cohesiveness are stable at 100 to 120 cm depth from the ground surface and are of low permeability. This also results in low entry of water into the tiles, at a minimum velocity. This low velocity will not be able to carry silt or clay into the tiles so as to seal and block the holes and/or reduce the tile capacity. Perhaps this may be the reason, why the filter materials were not of much use in black soils. Luthin (1966) reported that in Ohio, for 20 per cent of farm lands, filter materials were not used while laying tiles. He added that those tiles without filter materials are functioning successfully. The greatest danger occurs immediately after installation of the tiles since at this time the soil in the back filled trench is in an unstable and fluid condition. Usually fine sand and silt enter into tiles when the soils around are unstable. In the present study these drawbacks were overcome by laying bell and spigot type of tile drains with slits or holes facing
the ground when soil is not in fluid state due to rains or irrigation, thus avoiding the need for filter materials.

According to Muth (1962), the filter materials prevent choking due to plant roots growing into the drains. Observations made by Luthin et al. (1966), Evans (1936), Taylor and Goils (1967) and Houston (1966) showed that sand and gravel filter, prevented entry of floating fine soil particles into tiles. In black soils, in view of its properties of high cohesiveness and low permeability this problem may not arise. Further, the entry of clay particles while back filling the excavated earth is avoided by placing the tiles with slits or holes facing the ground. This facilitates efficient entry of soil water into tiles through slits or holes from the bottom of the tiles much faster.

5.3.4. Economics of Tile Drainage

The data on cost of tile drainage collected from different places in the study area during 1969-70 for spacings 12, 18, 24 and 36 metres, worked out to Rs.2,298, Rs. 1,780, Rs. 1,463 and Rs. 1,225 per hectare respectively by using 10 cm diameter tiles for laterals for relief and 15 cm for main drains. In these studies the depth of tile placement was 1.0 to 1.2 metres. In some of the drainage
investigation studies, in black soils, even five cm diameter tiles with holes for laterals and 10 cm diameter tiles with holes for mains were used in place of 10 and 15 cm diameter clay tiles with slits respectively. These were also found to be effective to maintain the dynamic equilibrium of the water table at safer depths, in addition to leaching salts effectively. As such, it would appear that under black soils using of 5 and 10 cm diameter clay tiles with holes or laterals and mains, the cost of tile drainage can be reduced by about Rs. 500/- to Rs. 1000/- per hectare for 18 and 12 metre spacing respectively. These figures are in agreement with Sewa Ram and Chauhan (1972), who found that the cost of tile drainage in Uttar Pradesh to be Rs. 2000/- per hectare.

It is however to be stated that the cost of tile drainage varied with the spacing, terrain of the area, availability of suitable outlet, cost of labour, transport and watershed area. The cost of tile drainage mainly depends on the intensity of the tile system, the spacing or length of tile per acre. In San Joaquin valley the tile intensity was 30 m/acre while the usual average elsewhere would be (Pillsbury et al. 1965). 60-75 m/acre. In the present study area, it is very high (217 and 327 m/acre for 18 and 12 m tile spacing. The very low tile intensity in San Joaquin Valley of California is because of uniform soil texture without any pans in addition to relatively higher hydraulic conductivity.
But in the other areas, it is only due to higher hydraulic conductivity. Soils of high hydraulic conductivity pass water rapidly to drains and if that high hydraulic conductivity occurs near the surface, a much higher percentage of applied water gets to the drains than if the soil is tight. Further, the relationship of vertical to horizontal is much higher than the vertical because of nature of placement of the soil stratification and profile development accentuate this. The investment of Rs. 100 on reclamation of water-logged and saline soils in the present investigations, pays Rs. 165/-, Rs. 335/- and Rs. 550/- respectively in the I, II, and III year in the form of increase in land value due to improvement in its productivity, in addition to increased income from crop yields. The investment of Rs. 100/- for reclamation of water-logged and saline lands repays Rs. 30/-, Rs. 70/- and Rs. 100/- additional net income through increased crop yields in the first, second and the third year after laying tiles, respectively. From the fourth year onwards the same investment of Rs. 100/- on reclamation brings back annually Rs. 100/- net profit or more from additional crop yields depending upon the management practices.
5.3.5. Testing of Hooghoudt's Drain Spacing Formula under Irrigated Black Soils of North-East Karnataka

Laying tile drainage at a depth of 120 cm with a minimum drainage coefficient of 0.001 m/day (1 mm/day) and a permissible water table depth of 60 cm at the midpoint of two tile lines was found to be suitable drainage system in black soils. Hooghoudt (1940) has developed an empirical formula for heavy soils of Netherlands, to find out the spacing of drains, provided the data on hydraulic conductivity and depth to barrier are known.

Hooghoudt's drain spacing formula was tested and compared with field results, for fixing of sub-surface tile drain spacing, under different soil conditions starting from normal black soil with hydraulic conductivity of 0.135 to adversely affected black soil with hydraulic conductivity of 0.035 metres per day.

For using the drain spacing formula, Donnan and Houston (1967) reported that one must first determine the optimum depth at which the drains are to be installed. Then the spacing between drains will depend on:

1. The permissible water table depth between drains.
2. The hydraulic conductivity of soil to be drained.
3. The quantity of water to be drained which is influenced by quantity and distribution of precipitation or irrigation.
4. Water holding capacity of the soil and evapotranspiration.

Hooghoudt (1940) reported that the position of the water table will depend on the following factors:

1. The rainfall rate or the rate at which irrigation water is applied.
2. The soil hydraulic conductivity.
3. The depth and spacing of the drains.
4. The depth to an impermeable layer.

In the black soil areas of North-East Karnataka where drainage studies were taken up, the four parameters needed to test the utility of the Hooghoudt's drain spacing formula, were arrived at as under.

1. **The Optimum Depth of Tile Drain**

   Investigations with four depths of tile drainage at Siruguppa (80, 100, 120 and 140 cm depths) and at Gangavathi (75, 90, 105 and 120 cm depths) indicated the
superiority of the 120 cm followed by 105 cm depth of tile drainage over the other depths. Hence, for black soil areas, the suitable tile depth was considered to be 120 cm from the ground level since there were no barriers up to 120 cm in study areas. This finding is in conformity with those of Maasland (1959), Kovda (1961), Talsma (1963), Luthin (1966) Wesseling (1969), Hermersmeier (1969) and Sommerfeldt (1971).

2. The Permissible Water Table Depth

The studies on the optimum spacing and depth of drains indicated that water table depth of 60 cm was to provide enough to prevent resalinisation and aeration required for crop root growth thereby giving high crop yields. Hence, the maximum depth of water table that can be temporarily permitted was taken as 60 cm from the ground level for testing the formula under similar soil conditions. Van't Woudt and Hagan (1957), Luthin et al. (1967) and Goor (1972) reported 50 to 75 cm as safe water table depth for most of the arable crops.

3. Hydraulic Conductivity

Since the hydraulic conductivity varied with soil structure, moisture content, texture, salt content in addition to development of cracks, the average hydraulic
The average hydraulic conductivity of good, slightly affected, badly affected and adversely affected soils were 0.135 and above, 0.1 to 0.134, 0.081 to 0.099, and 0.035 to 0.08 metres per day respectively.

4. The Quantity of Water to be Drained

In the black soil areas of North-East Karnataka where water table is fluctuating, it was essential to provide subsurface tile drainage with a suitable drainage coefficient that kept the water table below 60 cm from ground level. The studies indicated that 3-12 per cent of rain or irrigation water if drained through soil profile, will keep the water table below 60 cm depth. Similar results were reported by Dumm and Winger (1963) under fluctuating water table. Based on these findings, 0.001 metres per day has been assumed as the drainage coefficient for testing the Hooghoudt's drain spacing formula in the black soils of Karnataka State. The major change incorporated in the formula developed by Hooghoudt's is in considering removal of leaching requirements of black soils for drainage coefficient and lowering water table to 60 cm from ground level within 48 hours after rains or irrigation along with surface drainage which
is found sufficient in the present investigations instead of excess rain water or irrigation water to be drained as considered by Hooghoudt in the Netherlands because of the special conditions that exist in that country.

In the drainage studies at four locations hydraulic conductivity rates were different in the ranges described above. Accordingly Hooghoudt's formula was tested under these four soil situations and compared with the field results.

For good soils, according to Hooghoudt's formula the drain spacing worked out to 86.64 metres. A spacing of 25 metres was found to work satisfactorily as a preventive measure against rise of water table as per field investigations. It was also possible to leach excess salts from the root zone of crops. The drain spacing calculated as per Hooghoudt's formula was 20 metres in slightly affected water-logged and saline soil and was equal to that obtained in the field investigations in similar soil conditions of depth of drains studies at Siruguppa, and was found to work satisfactorily. The spacing of drain was worked out by using the formula was 18.33 metres in badly affected soil as against 18 metres obtained through field investigations in the studies on depth cum spacing of drains at Gangavathl where soil was
badly affected due to water-logging and salinity. Even under the adversely affected soil conditions the drain spacing as per Hooghoudt's formula was 12.28 metres as compared to a spacing of 12 metres arrived at through field investigations.

Hooghoudt's formula can be conveniently adopted for determining the spacing of drains in different conditions of the black soil areas of North-East Karnataka State. The theoretical equations can be used for tile drain design, if correct values of soil hydraulic conductivity and drainable porosity can be determined for the area to be drained (Pillsbury et al. 1965).