4.1 INTRODUCTION

Soil is comprised of minerals, soil organic matter, water and air. The composition and proportion of these components greatly influence the physical properties of soil including its texture, structure, and porosity, which is the fraction of pore space in a soil. In turn, these properties influence the movement of air and water in the soil, and thus help the soil to function better to aid plant growth.

4.1.1 Soil Texture and Porosity

Soil texture has profound effect on water retention and is considered the most important among the physical properties. The term texture is used to express the percentage of the three constituents of soils, viz, sand, silt and clay. These particles are distinguished mainly by size, and make up the mineral fraction. Particles over 2mm in diameter are not considered in texture, though in certain cases, they may affect water retention and other properties. The relevant amount of various particle sizes in a soil defines its texture, i.e., whether it is a clay, loam, sandy loam or some other textural category.

Porosity is the ratio of the volume of voids to the total volume of the soil which can be calculated from the relative density of the soil. Relative density is the ratio of the difference between the void ratio of a cohesionless soil in the loosest state and any given void ratio, to the difference between its void ratios in the loosest and densest states. Unlike texture, porosity and structure are not constant and can be altered by management, water and chemical processes. Long term cultivation tends to lower total porosity because of a decrease in organic matter. Surface crusting and compaction decrease the porosity and inhibit water entry into the soil, possibly increasing surface run off and erosion. Calcareous and salt affected soils can also
alter porosity and structure. In general, increasing organic matter levels, reducing the extent of soil disturbance, and minimizing compaction and erosion will increase soil porosity and improve its structure.

Due to the geometry of the pore spaces between the soil particles and the nature of the surface, soil has the capacity to hold the water. This property enables the soil to retain precipitation or irrigation water in the root zone in the form of a reservoir of water to be used by plants over time. The amount of water held depends upon the porosity and pore size distribution and the capillary pressure of water in the soil. This relationship between the amount of water held by the soil (soil water content expressed on weight or volume basis) and the force by which it is held (capillary pressure or suction or tension referred to as soil matric potential/tension expressed in bars or kPa/MPa) is depicted in the form of a curve commonly referred to as the soil water characteristics or soil moisture release curve or soil moisture retention curve or simply the pF curve. Some typical soil water release curves were shown in chapter 2. Two regions of this curve are of particular interest to agriculturists and irrigation engineers i.e. the field capacity and the permanent wilting point as they represent the upper and lower limit of water availability to the plants.

4.1.2. Field Capacity and Permanent Wilting Point

Field capacity (FC) is the term used to describe the maximum amount of water that an initially saturated soil will retain after the gravitational water has drained out. It does not generally correspond to a fixed soil water suction (or water potential) which varies from 1/10 bar (10 kPa) for coarse textured soils to 1/3 bar (33 kPa) for fine textured soils. Since FC values are dependent on the structure, they are best estimated in the field. Even undisturbed cores are not truly representative of the field values.

Permanent wilting point (PWP) is the soil water content at or below which plants will wilt and all growth processes will cease. It is assumed to correspond to 15 bar soil water tension or suction. In the absence of equipment necessary to determine this, the permanent wilting point is determined by growing sunflower or some other
indicator plants that have an extensive rooting system and show clear wilting symptoms.

4.1.3 Factors Affecting water Holding Capacity of Soils

The retention and movement of water in soils, its uptake and translocation in plants, and its loss to the atmosphere are all energy related phenomena. Vapour losses of water from the soils occur by evaporation at the soil surface and by transpiration from the leaf surface. The combined loss resulting from these two processes, termed evapotranspiration is responsible for most of the water removal from the soil during a crop growing period. A number of factors determine the relative losses from the soil surface and from transpiration:

(a) plant cover in relation to the soil surface,
(b) efficiency of water use by different plants;
(c) proportion of time the crop is on the land and
(d) climatic conditions.

Loss by evaporation from the soil is generally proportionately higher in drier regions than in humid areas. Such vapour loss is at least 60% of the total rainfall for dryland areas and losses by transpiration for about 35%, leaving about 5% for runoff.

Hydraulic conductivity and cation exchange capacity also have effect on the water holding capacity of the soils. The flow of water under saturated condition is determined by two major factors, the hydraulic force driving the water through the soil and the hydraulic conductivity, or the ease with which soil pores permit water movement. Cation exchange capacity depends on the capacity of the soil to hold positively charged cations. The larger the number of the Cation exchange capacity the more nutrients and water the soil can hold.

4.2 TEXTURAL CLASSIFICATION OF SOILS

Texture is the result of weathering, the physical and chemical breakdown of rocks and minerals. Because of differences in composition and structure, materials will weather at different rates, affecting a soil’s texture. The textural classification of soil incorporates only particle size. According to the triangular classification system followed by the agricultural scientists and modified triangular classification system
(developed by The Mississippi River Commission, USA) used by geotechnologists, the soils used in the study were classified as shown in Table 4.1 by conducting wet sieve analysis and hydrometer analysis.

According to both classification systems, the percentages of sand (size 0.05 to 2.0mm), silt (size 0.002 to 0.05mm) and clay (size less than 0.002mm) are plotted along the three sides of an equilateral triangle. The equilateral triangle is divided into 10 zones; each zone indicates a particular type of soil.

**Table 4.1 Textural Classification of Soils**

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>Grain Size Distribution</th>
<th>Textural Classification (Used by Agricultural Scientists)</th>
<th>Modified Triangular Classification (Used by Agricultural Engineers)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
<td>Silt (%)</td>
<td>Clay (%)</td>
</tr>
<tr>
<td>S1</td>
<td>70</td>
<td>19</td>
<td>11</td>
</tr>
<tr>
<td>S2</td>
<td>28</td>
<td>52</td>
<td>20</td>
</tr>
<tr>
<td>S3</td>
<td>94</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>S4</td>
<td>52</td>
<td>21</td>
<td>27</td>
</tr>
<tr>
<td>S5</td>
<td>77</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>S6</td>
<td>73</td>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>S7</td>
<td>56</td>
<td>16</td>
<td>28</td>
</tr>
</tbody>
</table>

From table 4.1, where all the seven soils are classified, the soils fall into four categories – sandy loam (soils S1, S5 and S6), silty clay loam (S2) S and (S3) and sandy clay loam (soils S4 and S7). Wherever detailed investigations were taken up, one from each category was chosen – soil S1 from sandy loam, soil S2 from sandy clay loam, and S3 for sand and S4 from sandy clay loam.

In order to determine the effect of porosity / relative density on water holding capacity laboratory experiments were carried out on all the seven soils as described below.

All the soil samples were prepared in different relative densities of 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7 in the cylindrical containers as discussed earlier in article 3.3.1. All the samples were allowed to get saturated initially and get drained till the gravitational drainage was negligible as indicated by the weight of the sample and the water content of sample was measured. This water content was a measure of the field capacity of the
corresponding soil samples. A graph is plotted between relative density (0.2, 0.3, 0.4, 0.5, 0.6 and 0.7) and this water content (field capacity) in Fig. 4.1.

![Graph showing variation of field capacity with relative density](image)

**Fig. 4.1 Variation of Field Capacity with Relative Density**

It can be seen from the figure that the field capacity does not vary much with variation in relative density. For all the seven soils the variation in field capacity is just around 3% even for a significant change in relative density from 0.2 to 0.7 (which is 350%) which indicates that bulk density of soil has little influence in water retention capability of soil. In almost all the soils the fall is marginal for relative densities of 0.2 to 0.4 and higher from 0.4 to 0.7. The loosest state 0.2 gives the highest field capacity but it may not be maintainable in field. The normal relative density in field which is available or maintainable for all the soils, with wide variation in soil texture, is around 0.4 which was selected for further investigations.

In comparison to the change in relative density, the field capacity is more sensitive to the percentages of fines. Soil S2 with a fines content of 72% has a field capacity of 40.97%, which is followed by S4 and S7 which have fines contents of 48% and 44% and field capacities of 29.85% and 24.9% respectively.

The porosity corresponding to each relative density was determined for all the samples and are tabulated together with the corresponding field capacity values in Table 4.2.
Table 4.2 Relation between Relative Density, Porosity and Field capacity

<table>
<thead>
<tr>
<th>R.D (%)</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>S7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>F.C (%)</td>
<td>n</td>
<td>F.C (%)</td>
<td>n</td>
<td>F.C (%)</td>
<td>n</td>
</tr>
<tr>
<td>0.2</td>
<td>0.4</td>
<td>20.95</td>
<td>0.55</td>
<td>40.97</td>
<td>0.45</td>
<td>22.11</td>
<td>0.47</td>
</tr>
<tr>
<td>0.3</td>
<td>0.39</td>
<td>20.50</td>
<td>0.54</td>
<td>40.00</td>
<td>0.44</td>
<td>21.51</td>
<td>0.46</td>
</tr>
<tr>
<td>0.4</td>
<td>0.38</td>
<td>20.30</td>
<td>0.53</td>
<td>39.91</td>
<td>0.43</td>
<td>20.82</td>
<td>0.45</td>
</tr>
<tr>
<td>0.5</td>
<td>0.38</td>
<td>19.98</td>
<td>0.53</td>
<td>39.10</td>
<td>0.42</td>
<td>20.13</td>
<td>0.44</td>
</tr>
<tr>
<td>0.6</td>
<td>0.37</td>
<td>19.00</td>
<td>0.52</td>
<td>38.43</td>
<td>0.41</td>
<td>19.68</td>
<td>0.43</td>
</tr>
<tr>
<td>0.7</td>
<td>0.36</td>
<td>18.66</td>
<td>0.51</td>
<td>37.23</td>
<td>0.4</td>
<td>19.11</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Note: R.D = Relative Density, n = Porosity, F.C = Field Capacity
As the porosity increases, field capacity also increases and it was seen that the porosity has not much effect on field capacity. Also, only for silty clay loam field capacity was found to be high at a higher porosity.

Table 4.3 shows the in situ dry density of all the seven soils and the chosen dry density values obtained for relative density test. It can be seen from the table that five of the in situ dry densities are chosen to the values corresponding to R.D = 0.4 and the remaining two are for R.D = 0.3. This clearly show that the normal relative density for a farm soil will be around 0.4. This value can be taken when soil specimens are prepared for various tests.

**Table 4.3 In situ and Dry Unit Weights of Different Soils**

<table>
<thead>
<tr>
<th>Soils</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>S7</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_d$ in- situ (kN/m$^3$)</td>
<td>15.90</td>
<td>11.00</td>
<td>14.40</td>
<td>13.70</td>
<td>14.50</td>
<td>14.40</td>
<td>14.00</td>
</tr>
<tr>
<td>$\gamma_d$ from tests (kN/m$^3$)</td>
<td>15.90</td>
<td>11.00</td>
<td>14.40</td>
<td>13.40</td>
<td>14.30</td>
<td>13.30</td>
<td>14.40</td>
</tr>
<tr>
<td>R.D</td>
<td>0.4</td>
<td>0.4</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.40</td>
<td>0.53</td>
<td>0.44</td>
<td>0.45</td>
<td>0.44</td>
<td>0.42</td>
<td>0.47</td>
</tr>
<tr>
<td>% Fines</td>
<td>30</td>
<td>72</td>
<td>6</td>
<td>48</td>
<td>23</td>
<td>27</td>
<td>44</td>
</tr>
</tbody>
</table>

Fig. 4.2 shows the relation between insitu porosity with percentage of fines of soil. It can be seen that there is only a marginal increase in porosity with the increase of percentage of fines ie. silt and clay.
A relation between in situ porosity and fines content has been obtained from the results presented in Fig. 4.2 as:

\[ n = 0.001F + 0.41 \]

with a correlation coefficient \( R = 0.91 \)

where \( n \) is the in situ porosity and \( F \) is the percentage of fines.

### 4.3. EVAPORATION LOSSES AND WATER HOLDING CAPACITY

More than half of the precipitation in dry land areas is usually returned to the atmosphere by evaporation directly from the soil surface. Evaporation losses are also high in arid regions irrigated agriculture. Even in humid regions, rained areas evaporation losses are of significance in hot rainless periods. Such losses rob the plants of much of their crop production potential.

#### 4.3.1 Factors affecting evaporation losses

Solar radiant energy provides the calories (540) necessary to evaporate each gram of water whether it is from the soil (E) or from the leaf surface (T). On a cloudy day, the solar radiations striking the soil and plant surface are reduced, and evaporation potential is not as great.
Evaporation occurs when the atmospheric vapour pressure is low compared to the vapour pressure at plant and soil surfaces. Evaporation is high from irrigated soils in arid climates and much lower in humid regions at comparable temperatures. A rise in temperature increases the vapour pressure at the leaf and soil surfaces but has much less effect on vapour pressure of the atmosphere. As a result on hot days, there is sharp difference in vapour pressure between soil surface and the atmosphere, and evaporation proceeds rapidly. This temperature difference definitely enhances the rate of evaporation. A dry wind will continually sweep away moisture vapour from a wet surface and hence intensify evaporation from soils.

Laboratory experiments were conducted, as per the methods described in chapter three, during a period January – May to study the drying process operating in agricultural soils of different textures collected from Trivandrum District. This period was selected for investigation as Kerala has dry spell from January to May while the remaining months comprises of the two monsoons. During that period, the temperature varies from 28 to 33°C inside the room and 33 to 39°C outside.

4.3.2. Investigations on Evaporation Losses

Studies on evaporation losses from the soil were carried out on all samples which were allowed to get saturated initially and get drained later till the water content reaches field capacity. The weights of the samples were to determined every day for a period of 4 to 5 weeks from which the water content and evaporation losses could be calculated for all the seven soils. Loss of water content from soil with plant life takes place due to two reasons, mainly water absorbed by plant life and water lost due to evaporation. In order to study the loss due to the latter, samples saturated were exposed to room temperature and to direct sun light and the evaporation loss was determined from the weight of the samples taken on each day.

Out of the seven soils, soil S2, collected from Chuzhattukota Trivandrum has the main content of fines (Silt and clay) which is 72% and soil S3, collected from Kizhavoor Trivandrum has the least content of fines viz 6% which is a sandy soil are selected. The relation between evaporation loss and time, for these two soils are shown in figure 4.3 when the soils are exposed to direct sunlight and room temperature. Though the trend in evaporation is same for both soils, for soil S3, the evaporation is rapid and for soil S2, it is comparatively slow which can be attributed to the fine texture of the soils. Soil S3 (sand) has a coarse texture so that it is difficult to prevent evaporation.
Fig 4.3 Variation of Evaporation Loss with Time for S2 and S3 Kept at Sun Light and Room Temperature
From that curve, we can note three stages in evaporation. First phase, at higher water content, the evaporation is fast and the slope of the curve is steep at that phase. In the second phase, evaporation is comparatively slower and the slope of the curve is less steep and in the third phase, the rate of evaporation is very low and the curve is almost flat. When the evaporation is carried out on sun light, the third phase is reached approximately after 15 days and at room temperature, it takes 30 days. There are techniques by which direct sun light could be almost totally controlled or even avoided to bring down the evaporation losses.

The texture of the soil especially the fines content influences the water retention capacity of the soil considerably. Soil S2 with 72% fines retains more water than soil S3 with 6% fines. However the rate of evaporation loss is more or less same in either case whether the soil is exposed to direct sunlight or not, as indicated by the two pairs of curves which seen parallel to each other in Fig 4.3.

4.3.3. Control of Evaporation losses

Any material used at the surface of a soil primarily to reduce evaporation or to keep weeds down is designated as mulch. Examples are sawdust, manure, straw, leaves, crop residue etc. Mulches are highly effective in checking evaporation and are most practical for home garden use and for high valued crops. Intensive gardening justifies the use of these moisture saving materials. Mulches composed of crop residue are effective in reducing evaporation and in turn in conserving soil moisture.

Spreading plastic sheets on the soil surface around the trees or crops or incorporating stubbles or treated coir - pith in the soil will act as a mulch on the surface to reduce the evaporation losses. Mulching protects soil against beating action of rain drops. It also facilitates rain water absorption by soil. Surface mulching immediately after sowing is an effective means of controlling runoff and soil loss on cultivated sloping land. In order to minimize evaporations from soil surface, dry soil mulch is created simply by stirring the soil with the interculturing implements.

Specially prepared paper and plastics are also used as mulches. This cover is spread and fastened down either between the rows or over the rows. The plants in
the latter case grow through suitable slits or other openings. Paper and plastic mulches can be used only with crops planted in rows or in hills as long as the ground is covered, evaporation and weeds are checked and in some cases remarkable crop increase has been reported.

Direct evaporations from soil is often a major loss of available water as it does not contribute to biomass production. Reducing evaporation can help conserve soil moisture, save irrigation water and reduce salt accumulation in surface layer of soil. Even small reduction in evaporation loss can be of great value in critical situation like germination of seed under dry conditions. Application of mulches is known to be effective in reducing soil evaporations. It was reported that organic mulch and tree shelter treatments increased the survival of plants. Mulching has also been reported to be effective reducing leaching of nitrate fertilizer and thus reduce solution.

From Fig. 4.3, it can be seen that at the evaporation of the soils kept at room temperature is significantly less compared to that at sun light. This represents the effect of mulching/shading, i.e. evaporation loss can be significantly reduced by mulching/shading.

Graphs were plotted for evaporation loss for all the seven soils as shown in Fig. 4.4. Lowest cumulative evaporation was observed in silty clay loam, which had high water holding capacity, followed by sandy clay loam, sandy loam and sand. The most effective practices aimed at controlling evaporations are those that provide some cover to the soil. This cover can be provided by mulches and by selected conservation tillage practices and in some cases by green house farming.

From the graph plotted between evaporation loss and time for soils in Fig. 4.4. The time for 25 and 50% evaporation loss is determined for the samples kept at room temperature and exposed to sun light.
Fig 4.4 Variation of Evaporation Loss with Time for Soils Exposed to Direct Sunlight and Kept at Room Temperature
Fig. 4.5 shows the relation between percentage fines and the time for 25% and 50% evaporation obtained from the figure 4.4, from soils kept at room temperature and those exposed to sun light for soils S1, S2, S3 and S4. It was seen that the time required for evaporation increased with percentage finer.

![Graph showing time for evaporation vs percentage fines](image)

**Fig 4.5 Relation between the Time for Evaporation and Percentage Fines**

Fig. 4.6 shows the save in time due to mulching/shading with percentage fines for 25 and 50% evaporation from soils kept at room temperature and that exposed to sun light with percentage fines. It was seen that the mulching or shading rate increased with percentage fines.
Variations of water content with time for all the seven soils are shown in figure 4.7. It can be seen that S2 which has a fine content of 72% has the highest water holding capacity compared to that of other soils. From these graph we can get the water content at any time for the corresponding soils so that we can arrange the replenishment at the required time.

4.3.4 Studies on Water Holding Capacity

Fig 4.8 shows the variation of water content with texture for different types of soil with the increasing content of fines. From this figure the plant available water which is the difference between field capacity and permanent wilting point for soils ranging over sand, sandy loam, loam, silty loam, clayey loam and clay can be determined.
Fig. 4.7 Variation of Water Content of Soils with Time kept at Room Temperature
The field capacity and wilting point of all the seven soil samples were determined corresponding to their field densities using pressure plate apparatus by the method described in clause 3.3.1. Results of the tests are given in table 4.4 with the percentage of fines of soils and plant available water.

![Graph showing field capacity and available water](image)

**Fig.4.8. Variation of Water Content with Fineness of Soil**

**Table 4.4 Results of Available Water**

<table>
<thead>
<tr>
<th>Soil type</th>
<th>% of fines</th>
<th>Field capacity (FC) (%)</th>
<th>Permanent wilting point (PWP) (%)</th>
<th>Available Water (%) = FC – PWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>30</td>
<td>20.25</td>
<td>9.15</td>
<td>11.10</td>
</tr>
<tr>
<td>S2</td>
<td>72</td>
<td>39.84</td>
<td>20.25</td>
<td>19.59</td>
</tr>
<tr>
<td>S3</td>
<td>6</td>
<td>21.42</td>
<td>9.78</td>
<td>11.64</td>
</tr>
<tr>
<td>S5</td>
<td>23</td>
<td>20.40</td>
<td>10.30</td>
<td>10.10</td>
</tr>
<tr>
<td>S6</td>
<td>28</td>
<td>21.20</td>
<td>11.09</td>
<td>10.91</td>
</tr>
<tr>
<td>S7</td>
<td>44</td>
<td>23.13</td>
<td>11.03</td>
<td>12.10</td>
</tr>
</tbody>
</table>
A graph was plotted with percentage of silt and clay versus field capacity and it was seen that as the percentage of fine grained soil increases the field capacity also increases (Fig. 4.9).

![Graph showing the relation between field capacity and percentage of silt and clay](image)

\[ y = 0.30x + 15.74 \]

\[ R = 0.92 \]

**Fig. 4.9 Relation between Field Capacity with Percentage of Fines**

An equation is obtained for field capacity in terms of percentage fines of soil i.e.

\[ F.C = 0.30F + 15.74 \]

with correlation coefficient \( R = 0.92 \)

where

- \( F.C \) is the field capacity and
- \( F \) is the percentage of fines

Fig 4.10 shows the relation between permanent wilting point and percentage fines of soil and it was found that the soil available water is more for soils with high percentage of silt and clay.
An equation is obtained for permanent wilting point in terms of percentage fines of soil as:

\[ \text{PWP} = 0.18F + 5.75 \]

with correlation coefficient \( R = 0.91 \) where

PWP is the percentage water content at permanent wilting point and F is the percentage of fines.

Fig 4.11 shows the relation between soil water content and percentage fines at field capacity and permanent wilting point and it was found that the difference between field capacity and permanent wilting point (available water) increases with percentage of silt and clay.
Fig. 4.11 Relation between Percentage of Soil Fines and Water Content

Fig. 4.12 shows the relation between plant available water and percentage fines of soil. It was also found that the plant available water is more for soils with higher percentage of silt and clay.

Fig. 4.12 Relation between Plant Available Water and Percentage Fines
An equation is obtained for available water in terms of percentage fines of soil as:

$$\text{PAW} = 0.12F + 7.89$$

with correlation coefficient $R = 0.91$

where

- $\text{PAW}$ is the percentage of plant available water and
- $F$ is the Percentage fines

We can see that the available moisture in soil S2 is nearly twice that of soils S1 and S3 and larger than other soils. So it can be inferred that soil S2 has higher water retention capacity when compared to that of other soils. In the case of sandy soils, there are more macropores due to which the soil loses considerable amount of water through gravitational drainage. Consequently, many pores are open for aeration and little water remains for plant use before PWP is reached. But in the case of soil S2, they have enough macropores to provide drainage and aeration during wet periods, but also have adequate amount of micropores to provide water to plants between irrigation events. Also the organic matter (4.06%) present in S2 helps in holding and retaining large quantities of water.

From the results and discussions presented so far, it is obvious that the water retention capabilities are most influenced by the percentage of fines (i.e. silt and clay) than any other physical property.

### 4.3.5. Water Use Efficiency and Irrigation Interval

Many irrigation projects were designed to supply water to each farm unit on a fixed and infrequent schedule rather than to make water continuously available on demand. The traditional mode of irrigation made good economic sense because many furrow, flood or portable sprinkler systems have a fixed cost associated with each application of water. With such systems, it is desirable to minimize the number of irrigations per season by increasing the interval of time between successive irrigations.

For high water use efficiency (WUE), maximum applied and stored water must be used as transpiration by crop and minimum amounts be lost by
percolation and direct evaporation from soil. The plant roots absorb water from soil and transport it into the leaves to be lost as transpiration to the atmosphere, while the green leaf area and atmospheric evaporativity govern the crop water demand, soil water status and water uptake capacity of roots determine the water supply to the crop. When the demand is fully met by supply, the plant performs to maximum capacity. But when supply falls short of demand, the plant shows wilting and its performance decline which reduces yield or quality. Irrigations are scheduled based on depletion of available water from effective root zone of the crops. Soil water tension, which is an energy index of soil water, has also been used as a criteria for scheduling irrigation to crops.

The classical questions involved in irrigation management are *when* to irrigate and *how much* water to apply at each irrigation. To the first question, this has been the traditional reply: Irrigate when the available moisture is nearly depleted. To the second question, the traditional reply was that apply sufficient water to bring up the moisture reserve of the soil root zone to field capacity, plus a “leaching fraction” of, say, 10 – 20% for salinity control.

![Fig: 4.13 Variation of Water Content with Time for S2 and S3 at Room Temperature](image-url)
To determine the irrigation interval, water content vs time graphs were plotted for the two typical soils S2 and S3 kept at room temperature and exposed to sun light as shown in Fig. 4.13 and 4.14.

Fig 4.14 Variation of Water Content with Time for S2 and S3
Kept at Sun Light

An equation is obtained from the best fit curve

For soil S2

\[ w = 0.084t^2 - 2.908t + 38.99 \]

with correlation coefficient \( R = 0.986 \) and

For soil S3

\[ w = 0.071t^2 - 2.304t + 21.6 \]

with correlation coefficient \( R = 0.987 \)

where

\( w \) is the water content and
\( t \) is the time in days

From these equations we can determine the time at which the corresponding soil would reach a particular water content.

The permanent wilting point for soil S2 and S3 are 20.25% and 9.78% respectively. Providing 50% allowance for transpiration and other losses, the
permanent wilting point may be reached earlier i.e. 1.5 times of the above PWP for S2 and S3 which are 30.38% and 14.67% respectively. The soil should be irrigated before reaching this water content for the healthy growth of plants and the time for irrigating the soil or the interval of irrigation is the time corresponding to the above value i.e. 3 days. Thus, knowing the evaporation loss, permanent wilting point and field capacity, one can fix the irrigation schedule for all types of soils.

4.4 Soil Moisture Tension

Soil moisture tension can be defined as the force per unit area that must be exerted to remove water from the soil. Therefore, it gives a measure of the tenacity with which water is retained in the soil. The higher the soil moisture content, lower is the tension and vice-versa. Certain soil moisture potential levels have particular significance in relation to the water holding capacity of the soil and to plant growth. The points of most practical importance are saturation, field capacity, moisture equivalent, wilting point, and oven dryness.

The field capacity is defined as the moisture content of the soil after downward movement of water has “materially decreased”. In mineral soils it may occur at widely varying tensions. For example, in sands at 100 cms, in loams at over 300 cms, and in clays at tensions of over 600 cms. The moisture equivalent is defined as the soil moisture content held against a force of 1000 times gravity in a specially designed centrifuge. This correlates closely with 1/3 atmosphere tension and is often taken as an approximation of the field capacity.

The wilting point may also vary widely depending on the suction head. While ranges between 7 and 32 atmospheres have been observed, 15 atmospheres is a satisfactory average. At this moisture level the potential of the plant root to absorb moisture is balanced by the moisture potential of the soil, and thus soil moisture is not available to the plant. Plants will be permanently wilted if the moisture in the root zone falls to the wilting point. Oven-dry soil has a moisture potential of 10000 atmospheres. The moisture content of the soil corresponding to a particular tension is influenced by soil texture, structure, soil solution and temperature. Therefore, soil moisture characteristic curves which give the relationship between the moisture content and the tension for different kinds of soils should be prepared for further use.
The SWRC (Soil Water Retention Curve) for the four soils at 0.33, 1, 3, 5 and 15 bar pressure is shown in Fig. 4.15.

Fig 4.15 shows that soil S2 has the higher water content at .33 bar and 15 bar pressure application followed by S4, S1 and S3 respectively. The higher water potentiality of S2 may be due to the higher percentage of fine content and organic content. Knowing the water content at permanent wilting point (PWP) and measuring the actual water content of soils in the field one can easily determine the time for irrigating this soil.

The soil moisture potential often is referred to as the capillary potential, because in the high moisture range, the forces involved are primarily capillary forces. At tensions of 1000 cm (pF value = 3) or more it is likely that the forces are primarily of molecular origin at the solid-liquid interfaces; at lower tensions, surface tension forces at the air-liquid interfaces are dominant. Fig. 4.16 shows the relationship between pF value and moisture content of four soils.
pF value is the logarithmic value of the water potential in cms. At saturated condition of the soil the pF value is zero and at over dried stage it is 5. The shape of the pF vs water content curve are similar for soils having similar texture.

Table 4.5 shows the values of water content at fully saturated condition and the field capacity for the seven soils. The difference between the two values fall in the range of 7.92% to 10.36%. This does not show any specific trend with the fines content, it may be more dependent on the arrangement of pores.
4.5. STUDY ON HYDRAULIC CONDUCTIVITY OF VARIOUS SOILS

The types of movement of water within the soil are recognized as saturated flow and unsaturated flow. Saturated flow takes place when the soil pores are completely filled with water. Unsaturated flow occurs when the pores in even the wettest soil zones are only partially filled with water. In each case, moisture flow is due to energy – soil relationship. The flow of water under saturated condition is determined by two major factors, the hydraulic force driving the water through the soil (commonly gravity) and the hydraulic conductivity or the ease with which soil pores permit water movement. The hydraulic conductivity of a uniform saturated soil is essentially constant and is dependant on the size and configuration of the soil pores. The average value of the saturated hydraulic conductivity of different soils using Rawe cell apparatus and odometer texts was shown in Table 4.6. As expected, the hydraulic conductivity of the soil S3 which is sandy in nature has the highest permeability and the soil S2 which has the highest fines content has the least permeability.

Table 4.6. Hydraulic Conductivity of Various Soils

<table>
<thead>
<tr>
<th>Soil type</th>
<th>% of fines</th>
<th>Permeability (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>30</td>
<td>$1.57 \times 10^{-4}$</td>
</tr>
<tr>
<td>S2</td>
<td>72</td>
<td>$1.55 \times 10^{-5}$</td>
</tr>
<tr>
<td>S3</td>
<td>6</td>
<td>$6.28 \times 10^{-4}$</td>
</tr>
<tr>
<td>S4</td>
<td>48</td>
<td>$2.89 \times 10^{-5}$</td>
</tr>
<tr>
<td>S5</td>
<td>23</td>
<td>$1.98 \times 10^{-4}$</td>
</tr>
<tr>
<td>S6</td>
<td>26</td>
<td>$1.75 \times 10^{-4}$</td>
</tr>
<tr>
<td>S7</td>
<td>44</td>
<td>$3.50 \times 10^{-5}$</td>
</tr>
</tbody>
</table>
The permeability values of all the soils are presented in Table 4.6 and they are plotted in Fig. 4.17 in log scale against percentage fines. A correlation has been obtained between the two as given below.

\[ k = 0.0008 e^{-0.058F} \]

where

- \( k \) = permeability of soil (cm/sec)
- \( F \) = percentage fines

With a correlation coefficient of 0.98

### 4.6. STUDY ON pH AND NUTRIENTS OF VARIOUS SOILS

Of the thirteen essential elements obtained from the soil by plants, six are used in relatively large quantities and consequently receive first attention. They are nitrogen, phosphorous, potassium, calcium, magnesium and sulphur. Because they are used by plants in relatively large amounts, they are designated for convenience as macronutrients. Plant growth may be retarded if these elements are actually lacking
in the soil, or they become available too slowly, or they are not adequately balanced by other nutrients. Nitrogen, phosphorous and potassium are commonly supplied to the soil as farm manure or as commercial fertilizers. Therefore they are often called fertilizer elements. The other nutrient elements viz iron, manganese, copper, zinc, boron, molybdenum and chlorine are also used by plants but in very small quantities.

The soil samples collected after experiments were analyzed to find the effect on pH value, organic carbon and nutrients such as available nitrogen, potassium, phosphorus and calcium. Analyses were carried out in the Laboratory of Central Tuber Crops Research Institute, Thiruvananthapuram and Laboratory of Environmental Engineering, College of Engineering, Trivandrum as per standard procedures.

The ranges of pH and different nutrient parameters of soil are shown in section 2 (Tables 2.4 &2.5). Values of pH ranges from 5.5 to 7.5. Values of pH and different nutrients such as organic matter, available nitrogen, potassium, phosphorus, calcium etc. for various soils are given in the table. Table 4.7 shows the comparison of different nutrient parameters before and after three months of watering for the four soils S1, S2, S3 and S4, selected for studies in detail.
Table 4.7. OC, pH, NPK, CA and EC Values of Soils on and after Three Months of Watering

<table>
<thead>
<tr>
<th>Soil type</th>
<th>OC%</th>
<th>Available N Kg/ha</th>
<th>Available P Kg/ha</th>
<th>Available K Kg/ha</th>
<th>Available Ca Kg/ha</th>
<th>pH</th>
<th>Cation Exchange Capacity cmol/kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>S1</td>
<td>0.3</td>
<td>0.29</td>
<td>46.38</td>
<td>46.30</td>
<td>44.38</td>
<td>44.38</td>
<td>53.76</td>
</tr>
<tr>
<td>S2</td>
<td>1.36</td>
<td>1.35</td>
<td>240.00</td>
<td>239.01</td>
<td>12.36</td>
<td>12.30</td>
<td>380.8</td>
</tr>
<tr>
<td>S3</td>
<td>0.14</td>
<td>0.14</td>
<td>126.00</td>
<td>125.8</td>
<td>8.24</td>
<td>8.23</td>
<td>188.16</td>
</tr>
<tr>
<td>S4</td>
<td>0.48</td>
<td>0.45</td>
<td>70.00</td>
<td>70.00</td>
<td>131.18</td>
<td>131.00</td>
<td>239.68</td>
</tr>
</tbody>
</table>

1 represents values of soil before watering.

2 represents the values of soil after three months of watering.
From the table we can see that there are no significant differences between the values OC, pH, NPK, CA and CEC of soils after three months of watering.

From Table 4.8 we can see that for all the soils S1, S2, S3 and S4 the pH value is less than 5.5 and it denotes that it is acidic in nature and it can be amended by suitable treatments with admixture or manures to achieve a neutral value. The organic content in S2 is higher than the normal value. It shows that soil S2 has a high fertiliser value in organic content and the fertiliser dosage of organic matter can be reduced. The available potassium for S2 is lower than the lower limit of N. It also can be improved by suitable fertilisers. The potassium content of S1 is lower than the lower limit of potassium and it can be improved by the proper treatment. The calcium content of S3 and S4 are lower than the lower limit for that and that also required treatment. The pattern of ion exchange capacity are lower for S1 and S3.

4.7. QUALITY OF WATER

Quality of water refers to its degree of suitability for a specific purpose and it largely depends on its physico-chemical composition. Quality of water for irrigation refers to the degree of suitability for crop growth and it depends on nature and amount of dissolved salts which contain relatively small but important amounts of dissolved salts originating from dissolution of weathering rocks and soil and dissolving of lime, gypsum and other salt sources, as water passes over or percolates through them.

The quality of water used in the experiment was subjected to physicochemical analysis. The properties of water used in the study such as pH, total dissolved solids, acidity, alkalinity etc were determined by using IS methods and summarized in Table 4.8. It also shows the comparison between the water used in the study and effluent water collected after 3 months.
## Table 4.8 Comparison between Water Used and Effluent Water

<table>
<thead>
<tr>
<th>Parameter that control Quality Characteristics</th>
<th>Parameter of Water Used</th>
<th>Range of parameter as per Standard</th>
<th>Parameter of Effluent Water after 3 Months for Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7</td>
<td>6.5 to 8.5</td>
<td>S1</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>130.0 ppm</td>
<td>500.0 – 2000.0 ppm</td>
<td>840</td>
</tr>
<tr>
<td>Total hardness (as CaCO₃)</td>
<td>60.0 ppm</td>
<td>300.0 – 600.0 ppm</td>
<td>120</td>
</tr>
<tr>
<td>Fluoride (as F)</td>
<td>Nil</td>
<td>1.0 – 1.5 ppm</td>
<td>Nil</td>
</tr>
<tr>
<td>Acidity</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>70.6 ppm</td>
<td>200 – 600 ppm</td>
<td>16.2</td>
</tr>
<tr>
<td>Iron (as Fe)</td>
<td>0.3 ppm</td>
<td>0.3 – 1.0 ppm</td>
<td>0.3</td>
</tr>
<tr>
<td>Chloride (as Cl)</td>
<td>33.75 ppm</td>
<td>250.0 – 1000.0 ppm</td>
<td>160</td>
</tr>
<tr>
<td>Sulphates (as SO₄)</td>
<td>Nil</td>
<td>200.0 – 400.0 ppm</td>
<td>20</td>
</tr>
<tr>
<td>Residual free Chlorine</td>
<td>Nil</td>
<td>0.2 ppm</td>
<td>Nil</td>
</tr>
<tr>
<td>Nitrate (as NO₃)</td>
<td>2 ppm</td>
<td>45.0 ppm</td>
<td>Trace</td>
</tr>
</tbody>
</table>

It can be seen from the table that the constituent properties of the water, when it seeps through the four soils register certain changes. The water turns slightly acidic as shown by the pH value and alkalinity. Both the total dissolved solids and total hardness increase. The iron content shows inconsistent changes. Chloride and sulphate get increased while nitrate gets reduced. Thus water when it seeps through this soils change their characteristics to some extent. This indicates that the water that is used for irrigation and water that reaches the root system of soil may have different characteristics.

The physical and chemical properties of the soil affect many processes in the soil that make it suitable for agricultural practices and other purposes. The texture, structure and porosity influence the movement and retention of water, air and solutes in the soil, which subsequently affect plant growth and organism activity. Most soil chemical properties are associated with the colloid fraction and
affect nutrient availability, growing conditions, and, in some cases, soil physical properties. Biological properties in the soil contribute to soil aggregation, structure and porosity, as well as decomposition of soil organic matter and mineralization. Organism activity is controlled by various soil conditions and may be altered by management practices. Since many soil properties are interrelated with one another, it is difficult to draw distinct lines of division where one type of property dominates the behaviour of the soil. Therefore, understanding and recognising the soil properties and their connection with one another is important for making sound decisions regarding soil use and management.