EVALUATION OF AERATION STATUS IN VERTISOL

By

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AFFECTIONATELY DEDICATED

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Shri Dhanraj Wamanrao Kendre has satisfactorily prosecuted his course of research for a period of not less than two years (four semesters) and that the dissertation entitled "EVALUATION OF AERATION STATUS IN VERTISOL" submitted by him is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the dissertation or part thereof has not been previously submitted by him for a degree of any university.

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Date: 26 May 1980

CERTIFICATE II

This is to certify that the dissertation entitled "EVALUATION OF AERATION STATUS IN VERTISOL" submitted by Dhanraj Wamanrao Kendre to the Marathwada Agricultural University in partial fulfilment of the requirements for the degree of Master of Science (Agriculture) in the subject of Soil Science and Agricultural Chemistry has been approved by the student's advisory committee after oral examination in collaboration with the external examiner.

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I hereby declare that the dissertation or part thereof has not been previously submitted by me for a degree of any University.

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CONTENTS

CHAPTER 1

INTRODUCTION

Chapter 1 INTRODUCTION

Plants experience difficulty in meeting its oxygen requirement under certain soil conditions. Lack of oxygen may be created due to either higher bulk density or excess water. Wiresum (1960) found that a very high water table limited availability of oxygen and lack of oxygen is the basic cause of poor nutrient uptake.

Soil air is one of the five major components of soil mass viz. soil air, soil water, organic matter, mineral matter and living phase of soil. Fifty per cent soil mass is occupied by air of which half is filled with liquid phase of soil. Thus the O_2 present into the soil air is taken up by the plants. Adequate aeration in soil is also important for living phase in soil to carry out their functions in a better way. Plants take CO_2 in day and evolved O_2 and reverse is the process at night. Plants also take O_2 from soil. Evolved CO_2 is important in respiration and photosynthesis in plant and in this way oxygen balance is maintained in nature. Exchange of CO_2 and O_2 between living organisms, soil and aerial atmosphere is called "soil aeration.

Now it is essential to measure and characterize aeration status of soil. Plants grow well in adequately aerated soils (Russel, 1961). Artificial aeration of plants growing in soil may be beneficial even though analysis indicates minor differences in the composition of atmospheres around aerated and non-aerated roots (Boicourt and Allen, 1964). Artificial aeration may depress plant growth (Anderson and Kemper, 1964). Moreover, results of several field experiments have failed to show that critical O_2 levels exist at any time in the soil when compared to critical levels established in controlled studies (Stolzy et al. 1961).

In other words, soil aeration is only one of several important facets in the study of plant behaviour; only one link in the chain of cause and effect. Plants cannot move to a more favourable climate and hence they are totally dependent on their environment for rapid flux of energy and matter through a highly permeable epidermis.

The air-filled pores in soils are the channels for mass transfer of water and gases. The amount of pore space directly control the movement of air and water in soil which in turn directly affects other soil physical properties and plant growth. The amount of percolations and therefore of leaching and erosion is related to the porosity of the soil so it is essential to measure the effective pore space as well as the total pore space.

Bulk density which is one of the most commonly used indices for the evaluation of soil physical conditions for any given soils, can be correlated with water transmission characteristics and also with the strength (Pearson 1965, Rao *et al*. 1973). A knowledge of bulk density and pore size distribution is important for judging the effect of soil compaction on the aeration porosity and the amount of water stored in the soil.

The deficiency of oxygen in soil air slows down the rate of microbial activity. Decomposition of organic matter is related and nitrification arrested. It also changes the type of microorganisms functioning in the soil. Aerobic organisms gain the upper hand when the oxygen supply is low and thus alter the nature of decomposition of both nitrogenous and non-nitrogenous substances leading to putrefactive and other undesirable fermentations.

The accumulation of carbon dioxide in the soil air is also injurious to plant growth as it exerts a toxic action. Excess of CO_2 also retards the germination of seeds. Hence, it is essential to remove the gas as soon as it is formed or at least not to allow it to accumulate beyond dangerous proportions. Soil aeration thus helps to replenish the supplies of oxygen lost from the soil air and to facilitate the escape of carbon dioxide from the soil pores. Scientists suggested that potato, cotton, tomato, tobacco, linseed, tea and legumes require specially high soil aeration. Grain crops are intermediate in oxygen requirement, while aquatic and semi-aquatic plants like rice are able to tolerate lack of soil oxygen to a greater extent.

Insufficient aeration of the soil also leads to the development of plant diseases. Wilt a very common fungal disease of plants, is attributed to defective aeration brought about by the water-logging of surface soils. Dieback of fruit trees (citrus and peach) is also a result of insufficient aeration in some cases, especially in heavy soils. Poor aeration also results in the development of toxins and other injurious substances such as dihydroxysteoric acid, reduced forms of iron and manganese etc. in the soil. It also leads to the accumulation of organic acids such as butyric, lactic, acetic etc. in toxic quantities. Hence proper aeration of the soil is very essential for successful crop production.

Another important aspect of soil aeration is the ease and rapidly with which the exchange of gases takes place. The exchange is quite rapid in sandy soils having large pores, while it is slow and sluggish in clayey and other fine textured soils whose soil pores, even the non-capillary pores, are few in number and small in size. In such soils, although the total air space may be adequate, it may not allow rapid exchange of gases between the soil air and atmosphere. The maintenance of poorer crumb structure having large aggregates is of very great importance in these soils so that it not only possesses a larger volume of non-capillary pore-space, but also facilitates the rapid movement of gases into and out of the soil pores. Texture and structure thus control the air content of the soil as well as the rapidity with which it is renewed.

With the above observation it is essential to find answers to the "problem of soil aeration".

Present investigation is undertaken to meet the following objectives:

1) To study the relation between porosity, bulk density (texture), and water content.

2) To know the percolation rate of water by judging the drainable porosity.

3) Retention of water by judging the capillary capacity of soil.

4) To determine pore size distribution, pore size density and effective saturation.

CHAPTER 2

REVIEW OF LITERATURE

Chapter 2 REVIEW OF LITERATURE

Many investigators attempted to find the relationship between bulk density, porosity, oxygen diffusion rate, capillary and non-capillary capacity of soil, water retentivity of soil viewed from time to time. Various methods of computing these physical parameters of soil have been suggested. Pertinent literature has been surveyed and presented under the following heads:

2.1 Capillary and aeration porosity.
2.2 Porosity in relation to bulk density and water retention.
2.3 Oxygen diffusion and porosity.

2.1 Capillary and aeration porosity:

Leather (1915) reported that the soil mass contains 50 per cent pore space and 50 per cent solid particles. The pore space is occupied by water and air. The quantity of each of these two components varies considerably, not only from soil to soil but also according to soil conditions. He mentioned that, the air content of the soil decreases as moisture content increases. Moisture held is found to be more in capillary pores.

Leamer and Lutz (1940) measured pore size distribution in the soil by applying tension equal to the capillary tension forces developed in the soil and concluded that there is no relationship between the total porosity and the effective pore space. There is a direct relationship between effective pore space and permeability.

Russel (1949) concluded that the air pycnometer is suitable for use in the rapid determination of soil moisture in the field. When it is realized that the bulk density, moisture content and percentage air filled pores can all be determined in the field at the rate that is largely determined by the time required to take the one sample, the potentialities of air pycnometer as an aid to the field evaluation of soil physical properties became evident.

Rao and Ramacharlu (1955) studied the changes in porosity of soil upon heating by employing the tensiometer technique and the tension water and pF-relations were further studied. From the tension relations water curves, the pore-size distribution in the different soils was obtained.

Black (1957) reported that decrease in porosity due to equivalent decrease in water suction depended on the particle and aggregate sizes. They reported that air porosity may be even less in fine than in coarse textured soils at equal suction water contents. Greater decrease in air porosity of soil with small aggregates than in soil with large aggregates as soil water increased.

Epstein and Kohnke (1957) showed that O_2 and CO_2 changed when porosity of Sidell silt loam was reduced by moisture or compaction. High moisture content, compaction and application of organic matter depressed O_2 levels and elevated CO_2 levels at the 8-inch depth. Leo (1963) reported that soils vary considerably in air porosity from disturbed to undisturbed soil sample.

Brooks and Corey (1964) used soil water desorption criteria in their analysis of the hydraulic properties important for drainage, but they attempted to separate pore-size distribution and water desorption characteristics. Two soil properties appear to be of particular importance. The first is the bubbling pressure of suction at which air begins to enter soils. Fine textured soils usually have high bubbling pressures and therefore comparatively low air and water permeabilities. Drainage of these soils is often slow. The second important hydraulic property is pore size distribution. At low suctions, soils with a wide range of pore size distribution may contain more water than soils with uniform pore size. At the extreme, soil with a few large pores will still be essentially saturated at relatively high suctions or heights above the static water tables.

Grable (1964) studied with undisturbed soil sample and showed that increase in clay content increases porosity of soil.

Aljibury and Evans (1965) showed that air permeability at 100 cm suction and water permeability were equal in a number of disturbed and undisturbed soil samples. Air porosity in the various soils ranged from 6 to 30 per cent at 100 cm suction. At higher suctions, air permeability increased greatly in fine textured soils but not at all in coarse-textured soils.

Vomocil and Flocker (1965) indicated that one of the principal deterimental effects of compaction of Yolow loam was reduced aggregate water stability due to decreased aggregate stability and it also resulted in greater tensile strength porosity.

Varade and Ghildyal (1967) reported that soil compaction occurs at the cost of macropore decrease.

Currie (1966) measured the air porosity of crumb by using simple apparatus by liquid displacement. Soil crumb porosity is measured by saturating 3 to 4 g samples of crumb with kerosene, measuring the weight of kerosene retained internally, then measuring their volume by displacement. Crumb porosity is proposed as a measure structural status for soils because it assesses the degree to which soil management has succeeded in holding the constituent primary particles apart from the positions of inherent closest packing that they would ultimately assume in an unstable soil.

Tripathi and Ghildyal (1975) evaluated pore size distribution by different methods to calculate the hydraulic conductivity of soil. A comparison of measured and calculated hydraulic conductivity of Phoolbagh clay loam, Beni silt clay loam and Haldi loam soils of Pantnagar farm is presented. The calculated conductivities by the predictive methods agreed closely with the measured values in the tensiometer range, while at higher suctions the pore size distribution methods underestimate the hydraulic conductivity of the soil. The modified procedure of Marshall (1958), Millington and Qurick (1959) method suggested by Green and Corey (1971) conforms closely with the experimental values and was found to be superior to others. The computational scheme of Marshall with matching factors also resulted into better agreement with measured values of hydraulic conductivity as compared to Millington and Quirk, method with matching factor and its modified form by Kunze _et al_. (1968). For routine work the computational scheme of Green and Corey (1971) can be used safely, especially for light textured soils.

2.2 _Porosity in relation to bulk density and water retention_:

Sudds and Browning (1941) studied the relationship between bulk density and air porosity and concluded that porosity and bulk density are closely related with each other and opined that increase in bulk density decreases porosity.

Perrier _et al_. (1959) reported that bulk density and porosity of some soils must be corrected for soil moisture content.

White (1962) found that the bulk density and porosity of Pierre clays depend on the volume of soil samples. Porosity of clods was less than that of the profile as a whole because of desiccation voids formed between structural units. The larger the structural units in soils, the larger soil samples must be for accurate measurement of porosity. Thus the type of sample used can greatly influence measured values of porosity in some soils.

Fox (1964) examined the relation of bulk density and soil water in a swelling soil. Bulk densities and associated moisture contents were measured from 0 to 3 inch and 6 to 9 inch depths for a range of moisture contents for the years 1956-1960 inclusive.

Mathematical models of swelling soils were devised for defined moisture ranges, based on the assumptions, that swelling was either undimensional, that is in vertical direction only, or was three dimensional and equi-dimensional, that air did not enter horizontal voids, and that swelling was normal, that is change in soil volume equaled the change in soil moisture volume.

Ghildyal and Satyanarayana (1965) stated that the physical properties of soil, like hydraulic conductivity, non-capillary pore space and void ratio change, as the solid is compressed. The magnitude of the change varies considerably with the texture of the soil. Usually fine, well-aggregated soils, with low bulk densities, undergo greater compactions than coarse, poorly aggregated soils, with high bulk densities. They showed the relationship between hydraulic conductivity, capillary and non-capillary pores and void ratios at different bulk densities for some textural soil types of India. and concluded that non-capillary pores are more susceptible to compaction. A close relationship exists among the optimum moisture content for obtaining the maximum bulk density, the maximum bulk density achieved and the clay content. An increase in the clay content was associated with lowering of the maximum bulk density and an increase in the optimum moisture content. They reported that for soil containing 47.70 per cent clay the maximum bulk density was 1.47 g/cc at 20.80 per cent moisture, whereas soils having 9.70 per cent clay 1.60 g/cc bulk density was attained at 7.6 per cent moisture content. Lastly they showed that increase in bulk density corresponds to decrease in the void ratio and vice versa.

Rao _et al_. (1973) reported that more moisture was retained in sandy clay loam soil than in sandy loam soil at any combination of pF and bulk density. Similar results were obtained by Rao and Ramacharalu (1959) and Misono (1963). With an increase in bulk density, the moisture content at all pF values increased. However, in sandy loam soil moisture retained decreased with an increase in the bulk density from 1.7 to 1.8 g/cc at all the pF values. This may be attributed to the relatively less increase in fine pore space than the decrease in total pore space and also stated that air filled porosity at pF 2.5 indicates that aeration may become limiting at the bulk density of 1.7 g/cc in sandy clay loam soil.

Gupta and Bhatia (1975) studied the relationship between air permeability, moisture content and bulk density of black soil. The behaviour of air permeability at various combinations of moisture content and bulk density was attributed to reduction in air filled porosity with increase in moisture content coupled with swelling of solid phase at the expense of void space, maximum swelling effects in the moisture content range of 22 to 36 per cent by volume at relatively low bulk densities and change in pore size distribution on compaction of the soil.

Sharma and Rao (1976) opined that change in bulk density according to pore size distribution in sandy loam soil. The bulk density of surface soil ranged from 1.42 to 1.75 g/cc and between these limits, pore greater than 30 micron decreased by 17.5 per cent where as, pores less than 10 micron increased by 7.2 per cent. It can be deduced from the regression equation that the quantity of pores of size less than 30 micron will be zero at a bulk density of 1.79 g/cc (total porosity 30.5 per cent) or top soil and at 1.8 g/cc (total porosity 30.25 per cent) from subsoil. It is also seen that any increase in bulk density drastically decreases the per cent pores greater than 30 micron whereas per cent pores less than 10 micron increases with the increase in bulk density and vice versa.

Gupta and Gupta (1978) concluded that the bulk density associated moisture content of clods collected from 0-10, 50-60, 100-110 and 150-160 cm layers of a wet clay soil profile were determined and statistically correlated in the 0.05-0.25 g/g moisture content range. The bulk density at all depths decreased linearly with increase in moisture content, increased with depths through 100 cm profile at a particular moisture content. Analysis of the moisture content volume change data revealed a significant effect on over-burden on soil moisture potential and suggested estimation of over-burden potential for inferring metric potential from in situ measurements of soil moisture potential in the wet range. The matric potential at respective moisture contents thus inferred should be used rather than in situ measured moisture retention curve to characterize field profile of a predominantly swelling clay.

In general the bulk density decreased linearly with increase in moisture content in the 0.05-0.25 g/g moisture content range.

Rao _et al_. (1978) suggested that the bulk density changes with change in moisture content of soil. In studies concerning the effect of tillage, compaction and amendments on bulk density of soils, density changes are generally attributed to direct effect of treatments. But in swelling soils considerable changes in bulk density occur due to changes in soil moisture content. These studies with black soils have shown that for precise compression between treatments, bulk density must be corrected to a chosen reference water content.

Sur et al. (1979) worked on relationships on density and porosity of aggregates of alluvial soils and reported that aggregate density decreased asymptotically with increase in aggregate size to a minimum constant value, which was characteristic of a given soil. This constant value decreased with the fineness of soil texture in general. Density of aggregates especially of bigger size fraction depended more on organic carbon ($r = -0.88$) and clay contents ($r = -0.85$). A high correlation ($r = 0.92$) was observed between the aggregate density of neighbouring size fractions, which diminished as the sizes departed from each other. In a given size range, the aggregate density was highly correlated ($r = 0.99$) with the bulk density. The inter-aggregate porosity was independent of the size of fraction of aggregate and its average volume was 42.3 per cent and it lay between the limits set by theoretical models of cubic and cubic-tetrahedral packing of spheres. Intra-aggregate and total porosity however increased with decrease in size of aggregates. Maximum intra-aggregate porosity was recorded in the aggregate size range about 1.5 mm, which signifies the importance of these aggregates in providing better soil-air-water relationships in alluvial soils of Punjab.

2.3 Oxygen diffusion and porosity:

Hannen (1892) first reported that the sum of the cross section of areas of the effective pore volume was the most important factor affecting the diffusion of the CO_2 in soils.

Buckingham (1904) observed that the diffusion rate increased with the sequence of the free pore space that is the rate of diffusion is reduced one-fourth as the free pore space is reduced one half.

Penman (1940) observed that the diffusion rate increased with the square of the free pore space, that is the rate of diffusion is reduced one-half.

Blake and Page (1948) made direct measurement of gaseous diffusion in soils, using carbon bisulfide. For 22 samples of Paulding clay, they found that D/DO was equal to 0.6185, for 15 samples of Brookenston clay, this value was 0.7988.

Evans (1949) reported that the permeability of some Iowa soils under different cropping systems and treatments has been measured. Highly significant results were obtained between the air permeabilities of well managed plots and check plots.

Luthin and Kirkham (1949) measured soil permeability of soil in situ below a water table of using piezometer. Pipes were driven into the soil below a water table, the soil is augered out of the pipe, and the rate of rise of the water in the pipes was measured. The soil permeability was calculated from this rate of rise by means of an appropriate formula.

Raney (1949) suggested one of the earliest methods used to determine the oxygen concentration in the soil pore space given by him. This method consisted of allowing the free diffusion of oxygen into a diffusion chamber that was inserted into the soil. Analyses of the gas were made at 10 minutes intervals. The calculated partial pressure of O_2 in the chamber was used to evaluate the diffusion rate.

Taylor (1949) concluded that oxygen diffusion through the porous media as a measure of soil aeration may be used. A new soil parameter λ was proposed which is a relative measure of the rate of diffusion of gases through the soil. It was found that λ became smaller as porosity increased. At first the decline was rapid but it gradually became slower.

Lemon and Erickson (1952) introduced the platinum electrode to measure the O.D.R. in soils. Its use is predicted upon the concept that the limiting factor in the oxygen supply to plant roots is the rate of diffusion of O_2 through the moisture film around the root. The O.D.R. therefore characterizes the soil O_2 conditions.

Van Bavel (1952) developed a theoryo of soil aeration in which he took into account not only the partial pressure of the vapours and the rate of diffusion but also the rate at which gases were liberated or consumed in the dynamic process of respiration occurring in soils.

Baver (1956) showed how the percolation rate of water increases with the porosity factor. The porosity factor is the ratio of air porosity to the log of the moisture suction at which capillary pores begin to drain (flex point). The soil water content at the flex point is approximately equal to the water content at 40 per cent air porosity. The porosity factor depends on both pore size distribution (water desorption characteristics), and the amount of pores.

Domby and Kohnke (1956) measured O.D.R. with the help of carbon disulfide. In order to determine the ability of a soil sample to permit gaseous diffusion, it can be fitted into a special box containing carbon disulfide in its lower parts, while the soil rests on a fine screen above it. The soil is sealed into this chamber in such a way that the carbon disulfide can escape only in vapour form through the soil. Assuming that the soil was air dry at the beginning, any loss in weight of the system is due entirely to the evaporation of carbon disulfide that has diffused through the soil.

Bertrand and Kohnke (1957) obtained a good correlation between the O.D.R. values measured at 8 inch depths with the platinum electrode and D/DO determined at the same depth with an oxygen analyser. However, the correlation was not as good as at the 16 inches depth.

Robinson (1957) investigated more direct method of measuring the O.D.R. It consists of a small chamber with a closable opening at the lower side is burried in the soil. Two tubes lead from it to the surface. With the bottom valve closed, the chamber is flushed with nitrogen, the tubes are closed, and the valve opened again. After a given time the contents of the chamber are analysed for oxygen.

Lemon and Erickson (1960) suggested that the decrease in O.D.R. as the soil suction increased or moisture content decreased was due to a build-up of OH^- concentration formed by the reaction because of slow diffusion away from the electrode.

Wiersum (1960) found that visual observations of depth of root penetration correlated very well with measurements by the platinum electrode. Since the boundry conditions at the platinum electrode are quite similar to those around the root in the soil, and since individual reading can be made quickly using simple equipment, this technique offers, possibilities for wider usage for evaluating the aeration status of soils. One must exercise condition in its use and make sure that the conditions previously refers to are taken into consideration.

Willey and Tanner (1963) determined the O_2 concentration in soil air with a membrane covered polarographic electrode. The probe is enclosed in a plastic membrane that is permeable to O_2. When a small voltage is applied between the polarographic cathode and the non-polarizable anode, almost all the O_2 which diffuses to the cathode is reduced and the concentration of O_2 at the electrode surface is very close to zero. The resulting current is proportional to the rate of reduction of O_2, which in turn is limited by the rate of diffusion of O_2 to the electrode. The measurements is applicable to measurements in situ.

Brikle *et al.* (1964) studied factors influencing oxygen diffusion rates in soil as measured by the platinum microelectrode. On aspect studied was how soil moisture affected O.D.R. measurements. In their studies, a ceramic double-walled pot was used to maintain different soil suction levels and moisture contents in sands. Oxygen diffusion measurement with 22- and 25- gauge electrodes showed that at high moisture contents similar O.D.R. were measured with both electrodes. As the moisture content decreased, the O.D.R. measured by the larger electrode (22 - gauge) dropped off first and at the higher moisture content than the 25- gauge. This information provides that the decrease in O.D.R. with increasing soil moisture is caused by incomplete electrode wetting.

Letey and Stolzy (1964) stated that the method given by Lemon and Erickson fails in relatively dry soils since the electrode must be wetted so that the whole electrode surface is covered by a moisture film. The rupturing of moisture films at higher moisture tensions makes the technique more applicable to fine textured soils over a wider range of soil moisture tensions than to coarse textured soils. The O.D.R. decreased as the moisture content increases because of a diminishion in volume of air filled pores, and lengthening of the diffusion path to the electrode.

Stolzy and Letey (1964) found that O.D.R. decreases with depth. The extent of this decrease depends upon the O_2 concentration at the soil surface. The O.D.R. at a single depth does not represent the aeration status for the whole soil volume.

Stolzy and Letey (1964) studied the relationship between soil suction and O.D.R. in a loamy sand and krilium treated silt loam and concluded that the loamy sand had very low O.D.R. from 0-20 millibars of suction. As the soil suction was increased from 20-80 millibars, rapidly decreased. O.D.R. in the silt loam rapidly increased with increasing soil suction between 0-20 millibars suction.

Ghildyal _et al_. (1967) used three methods to characterize aeration status of rice soils, viz. 1) Bulk density,

2) Oxygen diffusion rate (O.D.R.) and 3) Redox potentials (Eh). By changing the non-capillary pore space, which are mainly responsible for conducting air in the soil, the aeration capacity of the soil was investigated. Various levels of soil bulk densities were achieved through compaction. Using platinum micro-electrode, O.D.R. in soils were studied. Redox potentials were measured by potentiometer. The results of soil bulk density, O.D.R. and Eh correlated with the aeration status of rice soils.

Kar et al. (1979) studied the growth responses of a rice root system to particle and pore size distributions were assessed in eight soil mixtures artificially synthesized from separated clay, silt, and sand-sized quartz powders, under a controlled optimum, submerged (3 ± 1 centimeters) soil temperature regime of 37-25°C. Moisture retention characteristics were utilized for calculating the average macropore size and effective pore size densities of the soils.

The pore frequencies were maximum at 15-19 microns in finer soils - clay, silt clay, silt, silty clay loam, and clay loam - and at 19-24 microns in coarser soils - loam, sandy loam, and sand. With the decrease in clay and a corresponding increase in sand or silt content, the average macropore size of the soils appreciably increased. The highest rice root growth was recorded in silty clay loam, followed closely by that in sandy loam. Larger radii for maximum pore frequencies and of average macropore in sandy soils and greater mobility of particles in silty soils as compared with that in clayey soils contributed to higher root and shoot growth. In clay, silty clay, and clay loam soils, rice root growth was highly restricted, and the roots could penetrate only to an average soil depth of 14 centimeters.

CHAPTER 3

MATERIALS AND METHODS

Chapter 3 MATERIALS AND METHODS

Materials used and methods employed in the present investigation are presented.

3.1 Climatic condition of Parbhani:

Parbhani is situated at 17° 16' N latitude and 76° 47' E longitude and at an altitude of 409 m. The average rainfall is 830 mm with a wide variation from year to year. The maximum and minimum temperature ranges between 41.6° C and 11.0° C respectively. The climatic type is classified as semi-arid by Rao *et al.* (1979). The water deficits are 26.85 and 261.0 per cent during kharif and rabi seasons respectively.

3.2 Soil sampling:

For the present investigation the soil samples were collected in the month of December, 1979 from Agricultural College farm, Marathwada Agricultural University, Parbhani. The pits of 3' x 3' x 4' size were exposed of at 3 locations to a depth of 120 cm. Undisturbed cores from each soil profile for eight depths i.e. 0-15 cm, 15-30 cm upto 105-120 cm depths were taken by core sampler, which were 5 cm in height and 4 cm in diameter and made up of iron. From each layer of 15 cm three cores were obtained. These samples were placed in a tray and labelled for. All possible care was taken to avoid any physical disturbances of soil cores during the transportation and storage in the laboratory.

3.3 Preparing soil samples:

The core samples were tied with a muscline cloth at lower end with the rubber band. These were placed in water for 10-12 hours for saturation with capillary rise. The cores were submerged up to half so that full saturation and the air removal is satisfactory. On saturation the cores were taken, external moisture was wiped out and weights at saturation were recorded.

3.4 Tension table:

Tension table (Leamer and Shaw, 1941) was constructed which is of 60 cm x 60 cm in size and 150 cm in height, as shown in figure 1. Above the tension table glass was kept having hole at the centre, on which a wire gauge of size 12 cm x 9 cm was placed on which the ordinary filter paper was used. In the hole a plastic tube was fitted tightly. Sufficient water was added on the filter paper for better operation of system. The tube used was flexible having diameter 3 mm and which was transparent to make air bubbles visible.

After having subjected cores to 50 cm suction for 8 hours cores were reweighed. Same samples were kept by maintaining 100 cm and 150 cm of tensions, and placed in oven at 105° c to calculate bulk density.

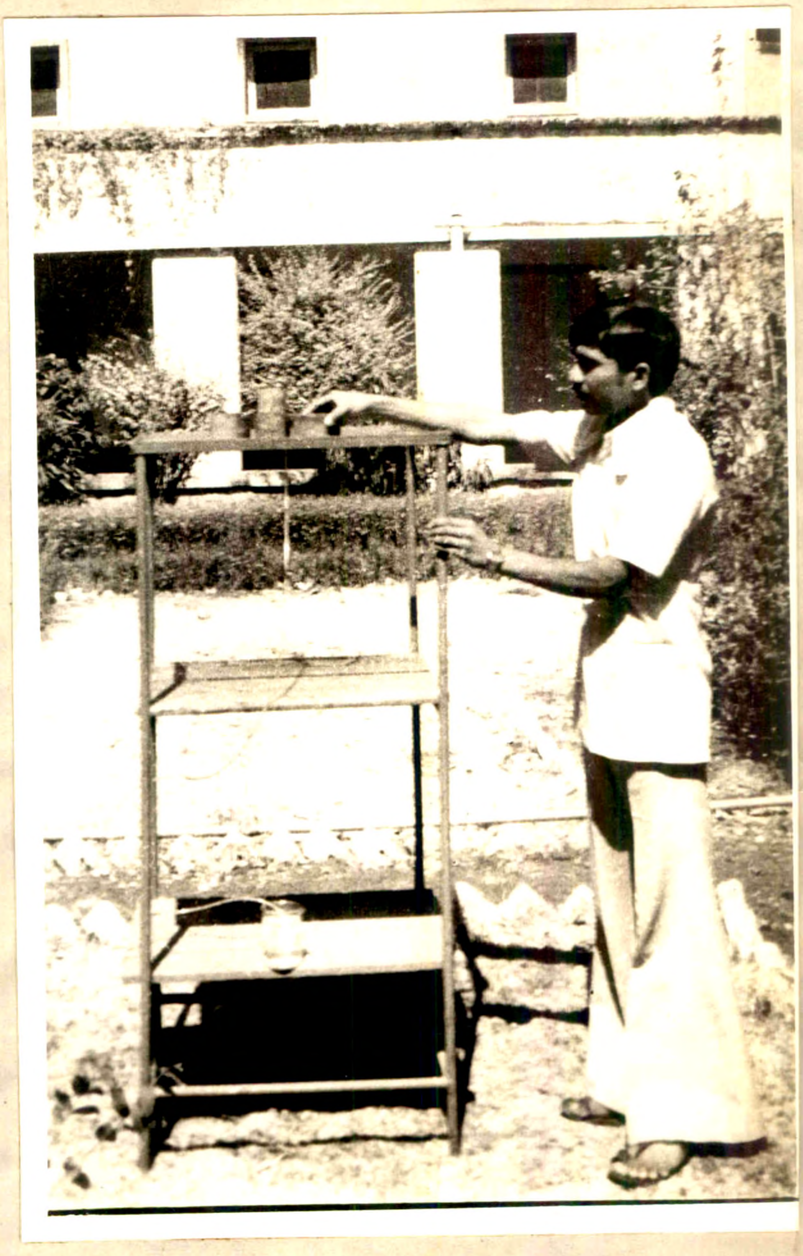

FIG. 1 - TENSION TABLE

Saturated core samples were weighed and placed on the tension table on filter paper. Care was taken so that the surface area of bottom of cores must be connected with the paper. Polythene sheet was used to cover the samples on the tension table to check the evaporation so that water loss due to evaporation is eliminated and system should function well.

The physical properties and moisture retention characteristics of different soils were studied as per the methods given below.

3.5 Physical properties:

3.5.1 Soil colour: The colours of soils were compared with Munsell colour chart and designated accordingly (Munsell colour company Inc. Baltimore-2, Meryland).

3.5.2 Mechanical composition: Mechanical analysis of soil was carried out by International pipette method (Piper, 1966).

3.5.3 Moisture retention: Moisture retention studies were done at saturation and at various tensions i.e. 50 cm, 100 cm and 150 cm.

3.5.4 Bulk density: Bulk density of the soil was determined by using oven dry weight of sample.

$$\text{Bulk density} = \frac{\text{Oven dry weight of soil (g)}}{\text{Volume of core (cm}^3\text{)}}$$

3.5.5 Porosity: It was obtained from particle density (Dp) and bulk density (Db) by the relationship:

$$\text{Porosity} = \left(1 - \frac{Db}{Dp}\right) \times 100$$

The value of particle density was taken as 2.65 g/cc throughout the calculation (U.S.D.A. Handbook, 60). Capillary and non-capillary porosity was calculated at 100 cm tension of water column.

Firstly water desorbed from cores were recorded. That desorbed water at 100 cm tension was the volume occupied by macropores (non-capillary) and obtained by formula given below:

$$\text{Non-capillary porosity} = \frac{\text{Water desorbed (cm}^3\text{)}}{\text{Soil volume (cm}^3\text{)}} \times 100$$

Total porosity is the sum of capillary porosity and non-capillary porosity. Microporosity was obtained by deducting non-capillary porosity from total porosity.

$$\text{Capillary porosity} = \text{Total porosity} - \text{Non-capillary porosity}$$

3.5.6 Pore size distribution: The micropore radii (r, micron) for different values of suction (h, cm) were calculated by utilizing the capillary rise equation as described by Brutsaert (1966).

$$r = \frac{2T \cos \phi}{\rho g h}$$

where

r = micropore radius (micron)

T = surface tension of water, dynes cm^{-1} at 25° C

ϕ = contact angle, which was taken equal to 0

= density of water, g cm^{-3}

g = acceleration due to gravity cm sec^{-2}

h = suction, cm of water (50, 100, 150 cm of water column).

The average macropore size (R, micron) was calculated numerically from the equation

$$R = \frac{\sum_{n=0}^{N} Vn \; rN}{\sum_{n=0}^{N} Vn}$$

where

R = macropore radius (micron)

Vn = volume of water released at a suction for which the corresponding radius rN.

rN = pore radius corresponding to 50 cm suction.

3.5.7 Calculation of effective saturation: The effective saturation (Se) was calculated by introducing linear transformation.

$$Se = \frac{S - Sr}{1 - Sr}$$

where

Se = effective saturation

S = degree of saturation

Sr = irreducible saturation.

Irreducible saturation was taken as moisture held at field capacity i.e. 38 per cent throughout the calculation.

3.6 Statistical analysis:

Simple correlations between silt, silt + clay and clay with micropores, macropores and total porosity respectively were worked out by standard method (Snedecor and Cochran, 1967).

CHAPTER 4

RESULTS AND DISCUSSION

Chapter 4 RESULTS AND DISCUSSION

Three profiles from different locations at Parbhani were exposed and samples of soils from various depths were analysed for total porosity, capillary and non-capillary pores, bulk density, mechanical composition and water retention at very low suction values and pore volume proportion. The data on these properties are presented below.

4.1 Physical properties

4.2 Soil moisture retention

4.1 Physical properties:

4.1.1 Soil colour: Soil colour indicates the type of soil. It also indirectly throws light on some properties such as parent material, organic matter content and drainage etc. Dark or dark grey colour indicates the higher amount of organic matter, while red brown and yellow tinge are principally due to iron content. Red colour suggest well drained soils. The soil colours were compared with Munsell colour chart as shown in table 1. Soils from Agricultural College farm Parbhani near Radio tracer laboratory and Agronomy department were found dark grey whereas the soil from Sorghum Research Station dark greyish brown. But in general the surface soils were dark in colour as compared to sub-surface soils in most of the samples. The soil is hard when dry with moderately rapid permeability

Table 1: Soil colours

Sr. No.		Location	Soil colour		Textural class
1.	A	Agricultural College Farm, Parbhani	Dark grey	10 YR 4/1	Clay
2.	B	Agriculture College Farm, Parbhani	Dark grey	10 YR 4/1	Clay
3.	C	Agriculture College Farm, Parbhani	Dark greyish brown	10 YR 4/2	Clay

A = Agronomy farm

B = Near Radiotracer laboratory

C = Sorghum Research Station

4.1.2 Mechanical composition: The relative proportion of different soil separates i.e. coarse sand, fine sand, silt and clay is important as it affects different soil properties and crop production practices. Mechanical composition of different layers are presented in table 2. Among the soils studied all are clayey. The clay content in surface layers of three soils ranged from 40.35 to 54.90 per cent. Silt varies from 24.30 to 26.25 per cent and sand fraction is smaller. Since the soil at all three locations contained high amount of clay, the aeration porosity has to be determined at 100 cm soil moisture suction. Therefore, pore volume vacated at 100 cm suction when saturated samples subjected was determined. This information provided the basis for aeration porosity determination.

4.1.3 Bulk density: The bulk density of the soil was measured on oven dry soil in cores obtained from various depths and the data are presented in table 3. From the table it is observed that in general, higher the clay content, lower is the bulk density. It varied from 1.12 to 1.75 g/cc and it has been observed that there is corresponding increase in bulk density with increasing depth. It is interesting to note that the bulk density at all three locations increased as a function of depth. This has a significance in the porosity values and ultimately it must interfere with water flow. This increase in

Table 2: Mechanical composition (per cent) of three profiles

Sr. No.	Depth in cm	A				B				C			
		Coarse sand	Fine sand	Silt	Clay	Coarse sand	Fine sand	Silt	Clay	Coarse sand	Fine sand	Silt	Clay
1.	0-15	4.45	13.37	25.95	54.90	6.25	14.95	24.30	50.93	8.93	20.97	26.25	40.35
2.	15-30	4.20	12.25	23.37	57.30	7.10	15.10	35.95	40.55	9.00	21.10	25.00	40.80
3.	30-45	5.15	14.10	24.80	55.65	7.50	15.25	34.10	42.16	9.81	22.31	23.15	37.10
4.	45-60	3.90	12.10	24.89	56.95	8.50	16.25	35.15	42.00	10.00	22.00	21.95	31.68
5.	60-75	5.15	15.20	27.73	50.86	9.50	17.00	33.87	44.60	11.50	22.50	23.20	29.95
6.	75-90	6.25	16.35	30.25	46.68	10.50	17.50	32.19	44.15	12.00	23.00	25.28	29.19
7.	90-105	6.31	14.35	25.00	55.90	11.00	18.00	34.95	39.25	13.00	23.50	21.90	28.10
8.	105-120	5.25	13.29	28.35	49.15	11.50	19.00	20.19	26.16	14.00	24.00	20.25	32.35

Table 3: Relationship between clay content (per cent) and bulk density (g/cc)

Sr. No.	Depth in cm	Bulk density (g/cc)			Clay percentage		
		A	B	C	A	B	C
1.	0-15	1.12	1.20	1.40	54.90	50.93	40.35
2.	15-30	1.12	1.38	1.44	57.30	40.55	40.80
3.	30-45	1.35	1.37	1.53	55.65	42.16	37.10
4.	45-60	1.43	1.53	1.63	56.95	42.00	31.68
5.	60-75	1.37	1.45	1.64	50.80	44.60	29.95
6.	75-90	1.37	1.50	1.66	46.68	44.15	29.19
7.	90-105	1.44	1.58	1.65	55.90	39.25	28.10

bulk density as a function of depth may be ascribed to decrease in clay content as well as compaction of lower layers due to over burden pressure. The density is very high at lower depth which may interfere with the flow of water as well as root penetration (Gupta and Gupta, 1978; Rao et al., 1978).

4.1.4 Porosity: The results presented in table 4 indicate that the total porosity decreases as the bulk density increases. The porosity ranges from 42.33 to 58.00 per cent in A while in B and C it was 36.50 to 54.67 and 36.67 to 47.67 per cent respectively. It was found that porosity normally decreases with the depth. Higher the clay content of soil higher the porosity. Light soils contain less pore spaces and made up of mainly macropores while heavy soils contain larger pore spaces made up of mainly micropores. The micropores have great affinity to hold more moisture. As such heavy black soils having micropores are capable of retaining more moisture as compared to macropores containing light soils. In general the porosity has decreased as the bulk density increased. In most of the cases the bulk density increased with decrease in pore volume. Further, there was a corresponding decrease in non-capillary porosity with increase in bulk density. The critical evaluation of non-capillary porosity (table 4) reveals that the values are usually higher than 10 per cent except in at 15-30 cm and

0-45 cm depth in profile A and B. Therefore it is evident that these soils do not limit aeration base. Van Bavel (1952), Stolzy and Letey (1964) and Baney (1949) indicated that if the aeration porosity is 10 per cent or higher, the oxygen diffusion rates are not limiting since it can provide greater oxygen flux than 20.0 x 10^{-8} g cm^{-2} min^{-1}.

4.1.5 Proportion of solid to porosity: This was calculated to represent the physical model of the soil. It means that how much solid, water and air contained in particular soil. This proportion of solid, liquid and gas is represented in table 5 and figure 2. It was found that proportion of solid, liquid and gas in A, B and C was 50.83, 43.93, 15.06; 54.23, 42.54, 12.38 and 59.78, 29.55, 18.97 per cent cm^3 respectively. It was concluded that as increase in clay content there is decrease in solid volume and increase in porosity.

4.1.6 Correlation studies: The correlation coefficient between macropores, micropores and total porosity as related to silt, clay and silt + clay are presented in table 6. It is noteworthy that the high correlation value ($r = 0.77$) between clay and total porosity is indicative that volume occupied by pores in soil is a function of clay content. As the amount of clay content increases total porosity also increases. However, as far as pore size distribution is concerned macropore volume decreases as the clay content increases since the r-values are

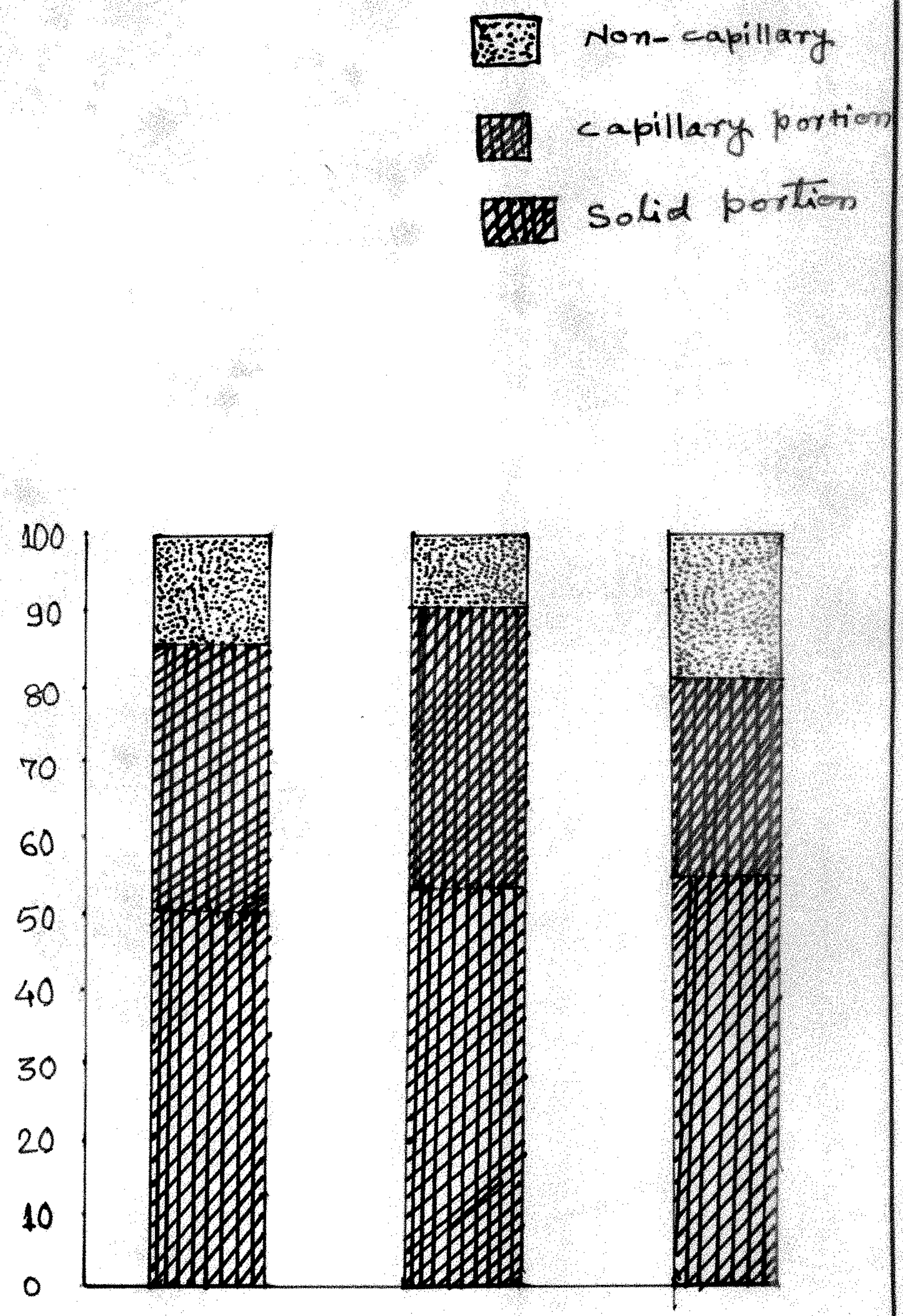

FIG. 2. PROPORTION OF SOLID TO POROSITY

negative. It is also evident that micropores in B profile have increased very much due to increase in clay content. This clearly indicates that the effective aeration porosity decreases rapidly with the corresponding increase in clay. This further signifies that at low values of soil moisture suction crops sensitive to aeration may experience oxygen deficiency in the capillary fringe of water table condition exists. This situation is developing on command areas. It is therefore essential to drain water to increase aeration efficiency in heavy swelling types of soils.

4.1.7 Pore size distribution: The micropore and macropore radii were calculated at various suctions by the formula as described in materials and methods. It was found that an increase in suction decreased the macropore size and these were calculated at 50 cm, 100 cm and 150 cm of water suctions and recorded 29.35 micron, 14.67 micron and 9.78 micron respectively. Average of radii of pores is presented in table 7. It is interesting to note that the average macropore size ranged between 23.10 to 25.03 micron, there being no appreciable variation. This is ascribed to high clay content in the whole profile. It is also clear that as the clay content varied from 46.68 to 57.30 per cent there was corresponding decrease in average macropore radii from 25.03 to 23.10 micron. Similar results were obtained in various synthesized soils by Kar et al. (1979).

Table 4: Relationship between bulk density (g/cc) and porosity (per cent).

Sr. No.	Depth in cm	A				B				C			
		a	b	c	d	a	b	c	d	a	b	c	d
1.	0-15	1.12	58.00	49.15	8.85	1.20	54.67	46.45	8.21	1.47	45.00	23.46	21.54
2.	15-30	1.12	58.00	49.15	8.85	1.38	48.33	41.56	6.70	1.44	45.67	31.63	14.03
3.	30-45	1.35	49.33	41.28	8.05	1.37	48.67	41.08	7.58	1.53	42.33	23.81	18.52
4.	45-60	1.43	46.67	32.98	13.68	1.53	42.87	26.39	16.47	1.63	38.67	20.78	17.89
5.	60-75	1.17	56.00	42.58	13.41	1.45	45.33	32.50	12.73	1.64	38.00	26.94	11.06
6.	75-90	1.37	49.33	36.15	13.18	1.50	43.33	29.79	13.55	1.66	37.73	26.76	10.57
7.	90-105	1.44	45.00	31.29	13.71	1.58	41.00	28.93	12.06	1.65	37.67	28.87	8.79
8.	105-120	1.53	42.33	25.51	16.82	1.75	36.50	27.52	8.97	1.68	36.67	14.75	22.04

a = Bulk density, b = Total porosity, c = Capillary porosity and d = Non-capillary porosity.

Table 5: Proportion of solid to porosity (per cent cm^3).

Sr. No.	Depth in cm	A				B				C			
		a	b	c	d	a	b	c	d	a	b	c	d
1.	0-15	5.08	1.92	7.00	53.33	6.97	1.23	8.20	45.33	3.52	3.23	6.75	55.00
2.	15-30	7.37	1.33	8.70	42.00	6.23	1.02	7.25	51.67	4.75	2.10	6.85	54.33
3.	30-45	6.19	1.21	7.40	50.67	6.16	1.14	7.30	51.33	3.57	2.77	6.34	57.67
4.	45-60	4.95	2.03	6.98	53.33	3.96	2.47	6.43	57.13	3.12	2.68	5.80	61.33
5.	60-75	6.39	2.01	8.40	44.00	4.88	1.91	6.79	54.67	4.04	1.66	5.70	62.00
6.	75-90	5.42	1.98	7.40	50.67	5.87	1.45	7.32	51.23	4.01	3.24	7.25	62.27
7.	90-105	4.70	2.06	6.76	55.00	4.34	1.81	6.15	59.00	4.33	1.31	5.64	62.33
8.	[illegible]05-120	3.83	2.52	6.35	57.67	4.13	1.35	5.48	63.50	2.21	2.00	4.21	63.33

Table 6: Correlation studies.

Sr. No.	Mechanical fraction	Porosity	r-values		
			A	B	C
1.	Silt	Micropore	-0.30	-0.04	0.53
2.	Clay	Micropore	0.27	0.96	0.05
3.	Silt + Clay	Micropore	0.24	0.36	0.22
4.	Silt	Macropore	0.38	0.27	0.22
5.	Clay	Macropore	-0.34	-0.15	-0.62
6.	Silt + Clay	Macropore	-0.63	0.22	0.39
7.	Silt	Total porosity	-0.17	0.18	0.64
8.	Clay	Total porosity	0.17	0.30	0.77
9.	Silt + Clay	Total porosity	0.07	0.57	0.71

Table 7: Average of radii of pores.

Sr. No.	Depth cm	R (micron)
1.	0-15	24.20
2.	15-30	23.10
3.	30-45	23.56
4.	45-60	23.40
5.	60-75	24.05
6.	75-90	25.03
7.	90-105	23.80
8.	105-120	24.20

4.2 Soil moisture retention:

Soil moisture retention study was carried out by applying the different tensions and value of retained water was calculated. This is represented in table 8. It was found that as higher the clay content more moisture is held by the soils. It was observed that A soil profile retained more moisture than B and C. Water held at saturation was found to be more in A than B and C depending upon the clay content. The water holding capacity varies between 24.39 to 68.08 per cent.

4.2.1 Water retention at different tensions: The soil moisture retention at 50 cm, 100 cm and 150 cm is determined and presented in table 8. In A moisture retention was observed in the range of 39.88 to 52.52 per cent, 38.25 to 51.12 and 37.07 to 49.00 per cent at the tensions of 50 cm, 100 cm and 150 cm respectively.

In B profile the moisture retention ranges from 24.39 to 64.08, 20.69 to 58.38, 19.27 to 57.29 and 17.65 to 56.88 per cent at saturation, 50 cm, 100 cm and 150 cm of tensions respectively. In C profile this was recorded that 24.48 to 51.41, 19.92 to 42.94, 19.16 to 41.65 and 18.59 to 40.35 per cent at saturation, 50 cm, 100 cm and 150 cm of tensions respectively.

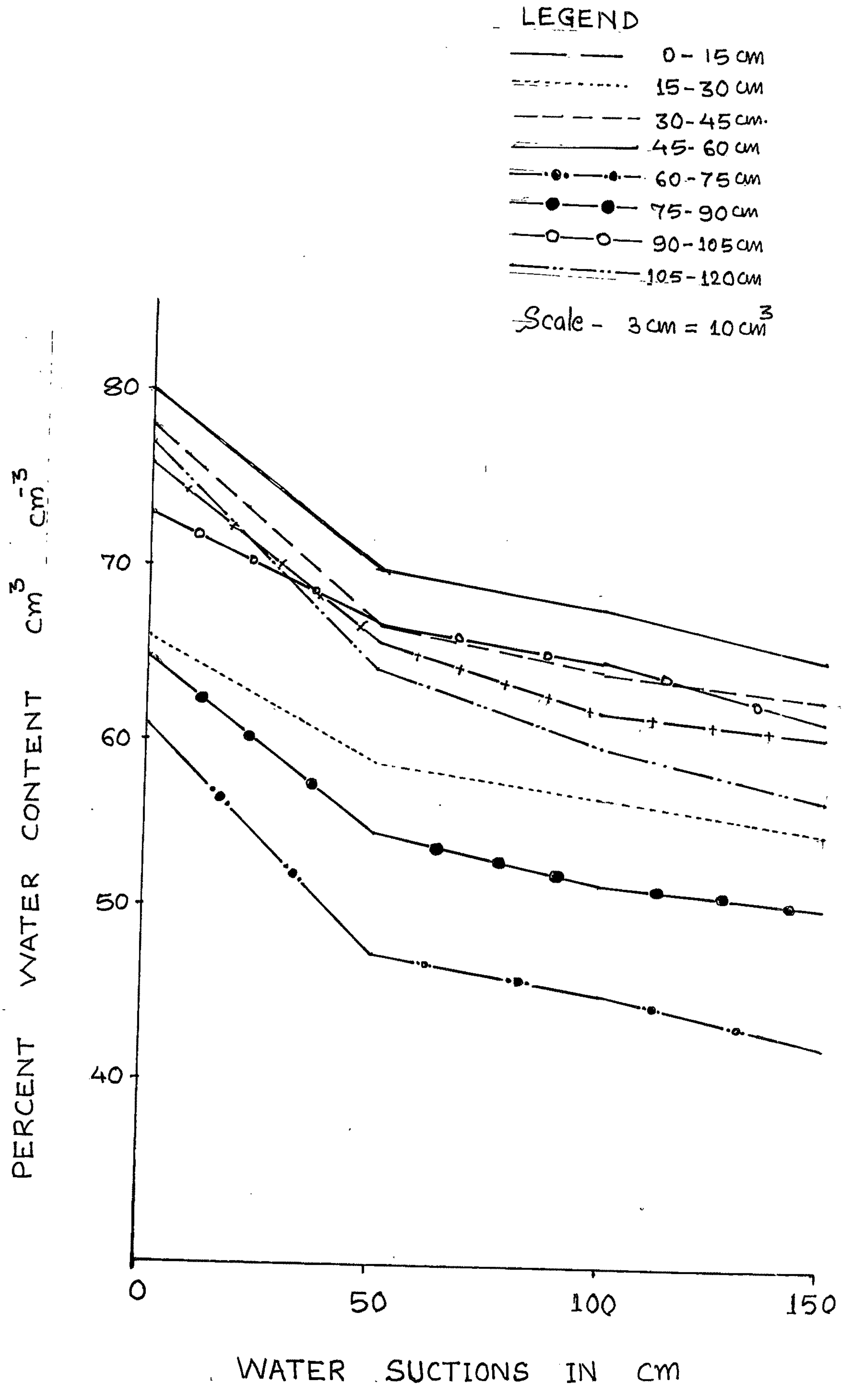

FIG.-3. WATER HELD AT DIFFERENT SUCTIONS

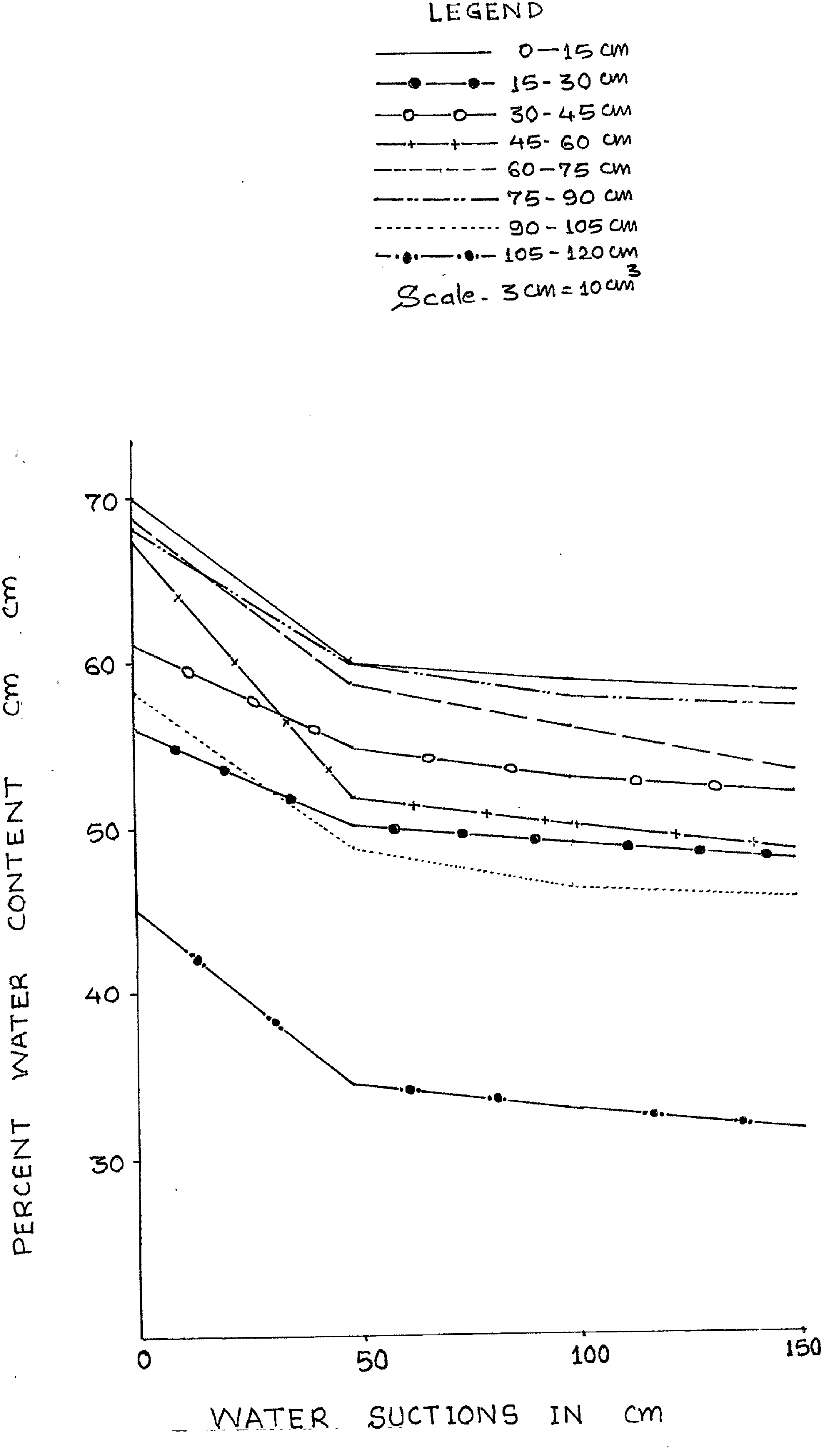

FIG.-4, WATER HELD AT DIFFERENT SUCTIONS

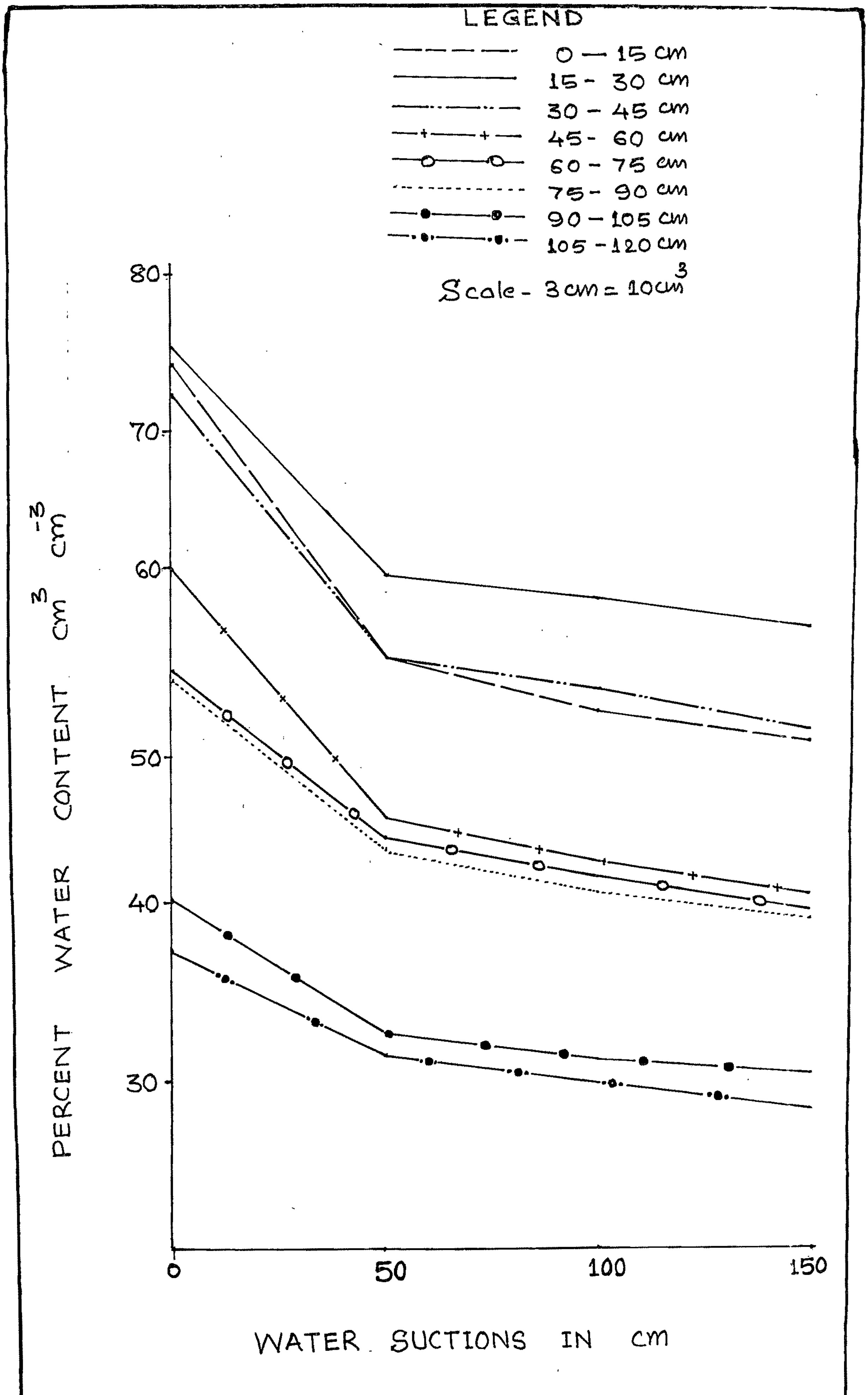

FIG. 5, WATER HELD AT DIFFERENT SUCTIONS

It was concluded that the soils varied over a wide range so far as the soil moisture retention is concerned. In general, the soil moisture retention was found to be related with texture of soil and some extent depth of profile. As the soil became finer and the depth increase, high moisture was held by the soils at given soil suction. The data on moisture retention were utilized for soil moisture retention curves and represented in figure 3, 4 and 5 for A, B and C respectively.

4.2.2 Effective saturation: Effective saturation was calculated at various tensions as a function of depth and concluded that increase in water suction occurred corresponding decrease in effective saturation was observed. It is represented in table 9. Effective saturation is closely related with the clay content. As there was increase in clay, the effective saturation also increased.

Table 8: Soil water retention at different tensions (per cent).

Sr. No.	Depth in cm	A				B				C			
		a	b	c	d	a	b	c	d	a	b	c	d
1.	0-15	53.53	46.50	44.53	43.31	64.08	58.38	57.29	56.88	50.50	38.15	35.88	34.53
2.	15-30	58.92	52.52	51.12	49.00	47.77	43.66	42.89	42.13	51.41	42.94	41.65	40.35
3.	30-45	54.10	49.31	48.13	46.88	51.67	47.26	46.29	45.32	47.26	36.77	35.15	33.09
4.	45-60	57.57	49.35	48.00	45.70	50.24	40.78	39.56	38.10	37.66	28.31	26.69	25.44
5.	60-75	51.76	41.04	39.57	36.55	53.97	47.47	45.41	43.62	33.31	27.59	26.61	25.82
6.	75-90	47.95	39.88	38.25	37.07	52.93	46.63	45.81	44.81	33.16	27.89	26.90	26.12
7.	90-105	54.18	46.59	44.77	42.95	43.59	37.53	35.93	35.28	24.48	19.92	19.16	18.59
8.	105-120	50.24	42.23	39.32	37.37	24.39	20.69	19.27	17.67	38.94	28.05	25.95	23.77

a = Per cent water held at saturation, b = Per cent water held at 50 cm suction,
c = Per cent water held at 100 cm suction, d = Per cent water held at 150 cm suction.

Table 9: Effective saturation.

Sr. No.	Depth in cm	0 cm			50 cm			100 cm			150 cm		
		S	Sr	Se	S	Sr	Se	S	Sr	Se	S	Sr	Se
1.	0-15	1	0.70	1	0.86	0.70	0.53	0.83	0.70	0.43	0.80	0.70	0.33
2.	15-30	1	0.64	1	0.89	0.64	0.69	0.86	0.64	0.61	0.83	0.64	0.52
3.	30-45	1	0.70	1	0.91	0.70	0.70	0.88	0.70	0.60	0.86	0.70	0.53
4.	45-60	1	0.67	1	0.87	0.67	0.60	0.84	0.67	0.51	0.80	0.67	0.39
5.	60-75	1	0.73	1	0.79	0.73	0.22	0.76	0.73	0.11	0.74	0.73	0.04
6.	75-90	1	0.79	1	0.83	0.79	0.19	0.81	0.79	0.09	0.80	0.79	0.04
7.	90-105	1	0.70	1	0.85	0.70	0.50	0.82	0.70	0.40	0.79	0.70	0.30
8.	105-120	1	0.75	1	0.84	0.75	0.36	0.78	0.75	0.12	0.76	0.75	0.04

S = degree of saturation, Sr = irreducible saturation and Se = effective saturation.

CHAPTER 5

SUMMARY

Chapter 5

SUMMARY

In the present investigation, three profile soil samples were collected from Agronomy farm, Radio-tracer laboratory and Sorghum Research Station, Marathwada Agricultural University, Parbhani. These samples were analysed for colour, mechanical composition, bulk density, total porosity, capillary and non-capillary capacity, pore size distribution, water retention at saturation and at various tensions i.e. 50 cm, 100 cm and 150 cm of water suctions and effective saturation.

Out of three profiles undertaken for study, two have shown dark grey and third one was dark greyish brown in colour. Mechanical composition showed that all soils contained more than 40 per cent clay and were placed under clayey soils. Clay percentage in all these three profiles ranged from 40.35 to 54.90 per cent in surface soils. It decreased as a function of depth.

The values for bulk density ranges from 1.12 to 1.40 g/cc in surface samples and decreased with depth due to over burden pressure. It can also be concluded that bulk density helps to give insight about physical properties of soil.

Total porosity ranges from 45.0 to 58.0 per cent and decreased with increase in bulk density. More porosity was observed where soils have high clay content. The porosity normally decreases with the depth. As soils having more clay content capillary porosity was found to be higher. It is concluded that clay soils are capable of holding more moisture. Non-capillary pores are drainable pores and was found in less amount. High correlation value ($r = 0.77$) was found between clay and total porosity is indicative that volume occupied by pores in soil is a function of clay content. Macropore volume decreases as the clay content increases since the r-values are negative.

Pore size distribution was found to increase as suction decreases. The average macropore size ranged between 23.10 to 25.03 micron. It was observed that higher the clay content lower the macropore radii.

The water holding capacity ranged from 74.25 to 76.90 per cent cm^3 in surface soils at saturation, again it is the function of clay content. It was found that as increased tension of water suction there is decrease in water retention.

Effective saturation decreased with the increase in water suction and it was found that 0.53, 0.43 and 0.33 at the tensions 50 cm, 100 cm and 150 cm of water suction in surface soils respectively. However it decreased with increase in depth and also observed that it increased with increase in clay content.

LITERATURE CITED

Abrol,, I.P. and Bhumbla, D.R. (1966) Moisture retention and storage characteristics of some Hissar soils. Proc. Symp. Water Management, Indian Soc. Agron. pp. 9-18.

Abrol, I.P.; Khosla, B.K. and Bhumbla, D.R. (1968) Relationship of texture to some important soil moisture constants. Geoderma 2: 33-39.

Ali, M.H.; Chatterjee, R.K. and Biswas, T.D. (1966) Soil moisture tension relationship of some Indian soils. J. Indian Soc. Soil Sci. 14: 51-62.

Aljibury, F.K. and Evans, D.D. (1965) Water permeability of saturated soils as related to air permeability at different moisture tensions. Soil Sci. Soc. Am. Proc. 29: 366-369.

Baver, L.D. (1938) Soil permeability relation to non-capillary porosity. Soil Sci. Soc. Am. Proc. 3: 52-56.

Baver, L.D. (1956) Soil physics. 3rd edition, Wiley, New York.

Betrand, A.R. and Kohnke, H. (1957) Sub-soil conditions and their effects on oxygen supply and the growth of corn roots. Soil Sci. Soc. Am.Proc. 21: 135-140.

Biswas, T.D. and Ali, M.H. (1969) Retention and availability of soil water as influenced by soil organic carbon. Indian J. Agric. Sci. 39: 618-626.

Black, C.A. (1957) Methods of soil analysis Part I and II No.9, American Society of Agronomy.

Bodman, G.B. and Harradine, F.F. (1938) Mean effective pore size and clay migration during water percolation in soils. Soil Sci. Soc.Am. Proc. 3: 44-51.

Boynton, D. and Reuther, W. (1938) A way of sampling soil gases in dense subsoils, and some of its advantages and limitations. Soil Sci. Soc. Am. Proc. 3: 37-42.

* Brikle, D.E.; Letey, J.; Stolzy, L.H. and Szuszkiewicz, T.E. (1964) Hilgardia.

* Brooks, R.H. and Corey, A.T. (1964) Colorado State Univ. Hydrol. paper No.3.

Corey, A.T. (1957) Measurement of water and air permeability in unsaturated soil. Soil Sci. Soc. Am. Proc. 21: 7-10.

Currie, J.A. (1966) The volume and porosity of soil crumbs. J. Soil Sci. 17 (1): 24.

Dastane, N.G. (1972) A practical manual for water use research in Agriculture. Nawabharat Prakashan, Poona.

Domby, C.W. and Kohnke, H. (1956) The influence of soil crusts on gaseous diffusion. Soil Sci. Soc. Am. Proc. 20: 1-5.

Epstein, E. and Kohnke, H. (1957) Soil aeration as affected by organic matter application. Soil Sci. Soc. Am. Proc. 21: 585-587.

Evans, D.D. and Kirkham, D. (1949) Measurement of the air permeability of soil in situ. Soil Sci. Soc. Am. Proc. 14: 65-73.

Fox, W.E. (1974) A study of bulk density and water in a swelling soil. Soil Sci. 68: 307.

Ghildyal, B.N.P.; Satyanarayana and Varade, S.B. (1967) Aeration characterization of rice soils. J. Indian Soc. Soil Sci. 15 (3): 201.

Grable, A.R. (1966) Soil aeration and plant growth. Advan. Agron. 18: 57-101.

Gupta, R.K. and Gupta, U.S. (1978) Volume change in a swelling clay and its influence on soil moisture relations. J. Indian Soc. Soil Sci. 26 (4): 323-327.

Gupta, R.K. and Bhatia, S.C. (1975) Dependence of air permeability of black clay soil on moisture content and bulk density. J. Indian Soc. Soil Sci. 23 (3): 280-285.

Gupta, R.N. (1967) A simple technique for determination of permeability of multiple undisturbed soil cores. J. Indian Soc. Soil Sci. 15 (3): 201.

Jain, M.C. (1974) A simple O.D.R. apparatus for measuring soil aeration status. J. Indian Soc. Soil Sci. 22 (2): 109-112.

Jamal, S.D. (1970) The relation of particle size to available moisture in soils of Zubair. Annals of Arid Zone. 9 (3): 1971-1974.

Jamison, V.C. and Kroth, E.M. (1958) Available moisture storage capacity in relation to textural composition and organic matter content of several Mossouri soils. Soil Sci. Soc. Am. Proc. 22: 189-192.

Jamison, V.C. and Reed, I.F. (1949) Durable asbestos tension tables. Soil Sci. 63: 311-318.

Kanwar, J.S. and Raichaudhari, S.P. (1971) Review of soil research in India, I.C.A.R., New Delhi.

Kar, S.; Varade, S.B. and Ghildyal, B.P. (1979) Pore size distribution and root growth relations of rice in artificially synthesized soils. Soil Sci. 128 (6): 364-368.

Kolarkar, A.S. and Singh, N. (1971) Moisture storage capacities in relation to textural composition of western Rajasthan soils. Annals of Arid Zone. 10 (1): 29-32.

Kunze, R.J.; Uehara, G. and Graham, K. (1968) Factors important in the calculation of hydraulic conductivity. Soil Sci. Soc. Am. Proc. 32: 760-765.

Leamer, R.W. and Lutz, J.F. (1940) Determination of pore size distribution in soils. Soil Sci. 49: 347-360.

* Leather, J.W. (1915) Soil gases. Mem. Dept. Agric. Ind. Chem. Ser. 4: 85.

Lemon, E.R. and Erickson, A.E. (1952) The measurement of oxygen diffusion in the soil with a platinum electrode. Soil Sci. Soc. Am. Proc. 16: 160-163.

Lemon, E.R. and Erickson, A.E. (1955) Principle of platinum microelectrode as a method of characterizing soil aeration. Soil Sci. 79: 383-392.

Leo, M.W.M. (1963) Effect of freezing and thawing on some physical properties of soils as related to tomato and barley plants. Soil Sci. 96: 267-274.

Letey, J. and Stolzy, L.H. (1964) Measurement of oxygen diffusion rates with the platinum electrode. I. Theory and equipment. Hilgardia. 35: 545-554.

Luthin, J.N. and Kirkham, D. (1949) Piezometer method for measuring permeability of soil in situ below a water table. Soil Sci. 68 (5): 349-358.

Millington, R.J. and Qurik, J.P. (1959) Permeability of porous media. Nature. 183: 387-388.

Nielsen, D.R. (1958) Small fritted glass bead plates for determination of moisture retention. Soil Sci. Soc. Am. Proc. 22: 574-575.

Page, J.B. (1948) Advantages of the pressure pycnometer for measuring the pore space in soils. Soil Sci. Soc. Am. Proc. 12: 81-84.

Pal, D. and Varade, S.B. (1976) Capillary conductivity and soil water diffusivity as influenced by moisture content and texture. J. Indian Soc. Soil Sci. 24 (1): 1.

Panse, V.G. and Sukhatme, P.V. (1954) Statistic methods for Agricultural workers, I.C.A.R. Publication, New Delhi.

Paterson, G.W.; Cunningham, R.L. and Matelski, R.P. (1968) Moisture characteristics of Pennysylvania soils. Soil Sci. Soc. Am. Proc. 32: 271-275.

Paterson, G.W.; Cunningham, R.L. and Matelski, R.P. (1968) Moisture characteristics of Pennysilvania soils (b) Soil factors affecting moisture retention within a textural class silt, loam. Soil Sci. Soc. Am. Proc. 32: 866-870.

Rajagopal, A. (1967) The relationship of soil water with soil moisture constants. Madras Agric. J. 54: 470-475.

Raney, W.A. (1949) Field measurement of oxygen diffusion through soil. Soil Sci. Soc. Am. Proc. 14: 61-65.

Rao, K.B.; Ramavathram, N.; Prihar, S.S. and Quaser, M.A. (1978) Changes in bulk density of soils due to changes in moisture content. J. Indian Soc. Soil Sci. 26 (4): 320-322.

Rao, S.K. and Ramacharalu, P.T. (1955) Porosity changes and pF-water relation in heated soils. Soil Sci. 79: 393-405.

Richards, L.A. (1949) Methods of mounting porous plates used in soil moisture measurements. Agron. J. 41: 489-490.

Richards, S.J. (1938) Moisture content calculations from capillary tension records. Soil Sci. Soc. Am. Proc. 3: 57-64.

Russell, M.B. (1949) A simplified air-pycnometer for field use. Soil Sci. Soc. Am. Proc. 14: 73-76.

Salter, P.J. and Williams, J.B. (1965) The influence of texture on the moisture characteristics of soils (II) Available water capacity and moisture release characteristics. J. Soil Sci. 16: 310-317.

Sekhon, G.S. and Arora, H.S. (1967) Moisture retention characteristics of some Punjab soils and their relationship with their physico-chemical properties. J. Res. Ludhiana. 4: 330-337.

Smith, R.M. and Browning, D.R. (1947) Soil moisture tension and pore space relation for several soils in the range of the "field capacity". Soil Sci. Soc. Am. Proc. 12: 17-21.

Stolzy, L.H. and Letey, J. (1964) Characterizing soil oxygen conditions with a platinum microelectrode. Advan.Agron. 16: 249-279.

Sudds, R.H. and Browning, G.M. (1941) The effect of soil management methods on certain physical and chemical properties in relation to the infiltration rates in West Virginia orchards. Proc. Am. Soc. Hort. Sci. 39: 38-45.

Sundara Sarma, K.S. and Rao, Y.N. (1976) Relationship between bulk density and pore size distribution in a sandy loam soil. J. Indian Soc. Soil Sci. 24 (3): 314-316.

Sur, H.S.; Singh, C. and Singh, N.T. (1979) Density and porosity relationships of aggregates of alluvial soils. J. Indian Soc. Soil Sci. 27 (3): 236-241.

Taylor, S.A. (1949) Oxygen diffusion through porous media as a measure of soil aeration. Soil Sci. Soc. Am. Proc. 14: 55-61.

Tripathi, R.P. and Ghildyal, B.P. (1975) Evaluation of pore size distribution methods for calculating the hydraulic conductivity of soil. J. Indian Soc. Soil Sci. 23 (3): 273-279.

Van Bavel, C.M.H. (1952) A soil aeration theory based on diffusion. Soil Sci. 73-91.

Van Doren, D.M.; and Erickson, A.E. (1966) Factors affecting the platinum microelectrode methods for measuring the rate of oxygen diffusion through soil solution. Soil Sci. 102:

Varade, S.B. and Ghildyal, B.P. (1967) Mechanical impedence and growth of paddy in artificially compacted lateritic sandy loam soil. J. Indian Soc. Soil Sci. 15 (3): 157-162.

Velayutham, R.D. (1971) Inter-relationship between soil separates and properties of soils of Tamilnadu. J. Indian Soc. Soil Sci. 19 (4): 353-361.

Vomocil, J.A. and Flocker, W.J. (1968) Degradation of structure of Yolow loam by compaction. Soil Sci.Soc. Am. Proc. 29: 7-12.

White, E.M. (1962) Volume changes in some clay soils. Soil Sci. 94: 168-172.

* Wiersum, L.K. (1960) Neth. J. Agric. Sci. 8: 245-252.

Willey and Tanner, C.B. (1963) Membrane-covered electrode for measurement of oxygen concentration in soil. Soil Sci. Soc. Am. Proc. 27: 511-515.

* Original not seen.