IRRIGATION EFFECT ON THE PHYSICAL PROPERTIES OF SOILS AT KADAWA IRRIGATION PROJECT KANO STATE

BY

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DECLARATION

I hereby declare that this thesis has been written by me and it is a record of my own research work. It has never been presented before in any previous publications for a higher degree.

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CERTIFICATION

This thesis entitled "Irrigation effect on the Physical Properties of soils at Kadawa Irrigation Project, Kano State" by Mr. Ibrahim Okai, meets the regulations governing the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

To my father Okai Abutu, my mother Salamatu Okai Abutu and those in my heart whose love, concern and exemplary life is a challenge to me.

ABSTRACT

A study was conducted to determine changes and relationships among physical, chemical and hydraulic properties of three major soil units at Kadawa. These soil units are representative of the upland plain soil groups of the Kano River Project Area. Sampling of the soils was done in such a way to include land areas left in fallow (virgin); areas for rain fed and areas for irrigation and rainfed agriculture.

Laboratory measurements of physical and chemical parameters and in-situ infiltration measurement were carried out. These properties were determined by depths.

The particle size analyses indicate that the clay and silt contents increase with depth while the sand fraction reduced. The soil reaction varied considerably among soils, with organic carbon, EC, ESP and CEC decreasing down the soil depth. The regression coefficient (r) for the Ks and particle size fraction for the bulked soil units shows that the soil with management condition of irrigation and rainfed agriculture was statistically significant at $P < 0.05$ ($r = 0.843^*$). Between the soils, variation of infiltration rates at measured points was high (CV = 102.6%); however, steady state infiltration rate was not reached even at 5.67 hours. The variation in soil particle size fraction and organic matter content prevalent in the area account for most of the differences in soil moisture retention at different suctions.

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CHAPTER 1

INTRODUCTION

Increased population, demand for food and fibre, the scarcity of water for year round rain-fed agriculture in many regions make it imperative to extend the cropping season by irrigation. Irrigation is the artificial application of water to soil for the purpose of crop production. Water is supplied to supplement that available from rain fall and the contribution of soil moisture from ground water. Development of water resources for irrigation also provides a control for floods which annually inundate fertile lands along the river courses.

In the Sudano-Sahelian regions of Nigeria, there is abundant expanse of land that is potentially good for agriculture. Rain-fed agriculture in the region is, however, limited by low total precipitation, erratic distribution of rainfall and high evapotranspiration rate. Irrigation therefore becomes an important complement to rainfall for raising agricultural productivity.

As a consequence of the importance of irrigation in the food programme of Nigeria, large scale irrigation projects were developed in the Sudano-Sahelian areas beginning in 1976. These are the Kano River Irrigation Project (KRIP), Bakolori Irrigation Project (BIP) and South-Chad Irrigation Project (SCIP). These projects have the potential for putting 101,600 ha of land under irrigated agriculture (Maurya and Sachan, 1984).

Kano River Irrigation Project (KRIP) which is under the Kano - Hadejia River Basin and Rural Development Authority has 62,000 ha

of irrigable land. Presently, only 16,600 ha of this irrigable land area is under surface irrigation. The source of water is the Tiga Dam.

Regardless of its source, irrigation water tends to contain impurities in the form of dissolved or sometimes suspended materials. The amount and nature of these materials under given environmental conditions have effect on the soil characteristics over time. Poor water management also creates problems on irrigated lands of Nigeria (Maurya, 1982; Nwa, 1982; Maurya and Sachan 1988). Waterlogging and concomittant salinization of soils are understandably the first indicators of problems. It is therefore, important to continuously monitor the hydraulic properties of the soil in order to irrigate efficiently and anticipate any pending problem in the project as a whole.

Other than the feasibility studies ahead of project commissioning, studies of the hydraulic properties of Nigerian soils under irrigation have been few, skeletal and far between. This study is therefore, designed to provide information on the present status of the Kadawa project soils and lay the basis for management of the physical characteristics of the other soils of the Hadejia - Jama'are River Basin.

Irrigation of soils with impermeable subsoil layers under arid and semi-arid climates may cause water-logging, build-up of salinity and sodicity, and nutritional disorder for crops. An impermeable sub-soil may be due to excessive traffic on the land and it is symptomized by changes in soil physical properties or the

ability of the soil to transmit water. Drilling through the resultant hardpan is feasible but expensive at the present economic condition. Any method to forestall a build-up of salt and undesired rise in water table must rely on a full knowledge and understanding of the hydraulic properties of the different soil series, and how they respond to irrigation over time. This study compares the status of the soils within and outside irrigation areas and allows deductions to be made on how this might affect long-term crop production. This study can be used as a basis for recommending appropriate soil water management practices.

1.2 Objectives

The objectives of the study are to:-

1. assess the status of soil physical properties under continous irrigation and intensive agriculture at the KRIP.
2. assess the rate of degradation due to intensive agriculture; and
3. recommend suitable irrigation method based on the existing physical condition of soil for sustainable agriculture at KRIP.

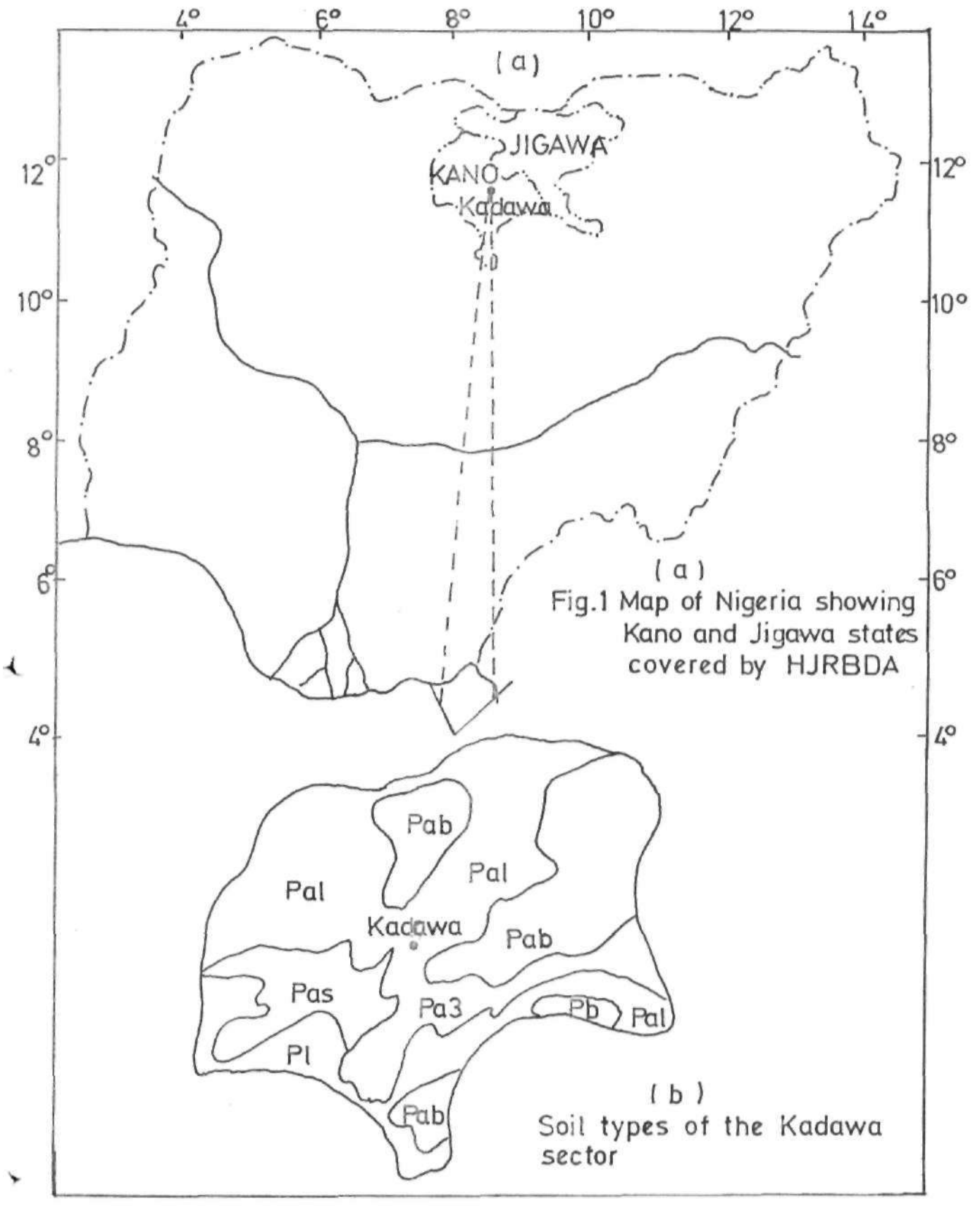
CHAPTER TWO

2. LITERATURE REVIEW

2.1 The soil

Soil is a complex system made up of four main components. These are the mineral particles and non-living organic matter which form the solid matrix, the soil solution, the soil air and the living organisms which occupy the pore space. The mineral particles are the chief components of most soils on a volumetric basis. They consist of rock particles developed in-situ by weathering or deposited in bulk by wind or water.

The most conspicuous property of the solid matrix is its particulate nature. In contrast, the pore space forms a continuous but geometrically complex system which usually constitute between 30 and 60 percent of the total volume (Kramer, 1969). It may be entirely filled with water, as in saturated soils, or largely filled with air as in dry soils. The water transmission capacity of any soil depends on the physical characteristics of the soil and how well it is managed. The physical characteristics are, themselves dependent on the texture or size distribution of mineral particles; on the structure or the manner in which these particles are arranged; on the kinds of clay minerals present and the kind and amount of exchangeable ions adsorbed upon them; and on the amount of organic matter incorporated with the mineral matter. The characteristics of the soil are measured by various concepts including bulk density, aggregate stability, Porosity, hydraulic conductivity, infiltration rate, salinity test among others.



(a)
Fig.1 Map of Nigeria showing Kano and Jigawa states covered by HJRBDA

(b)
Soil types of the Kadawa sector

2.1.1 The Kadawa Project Soils

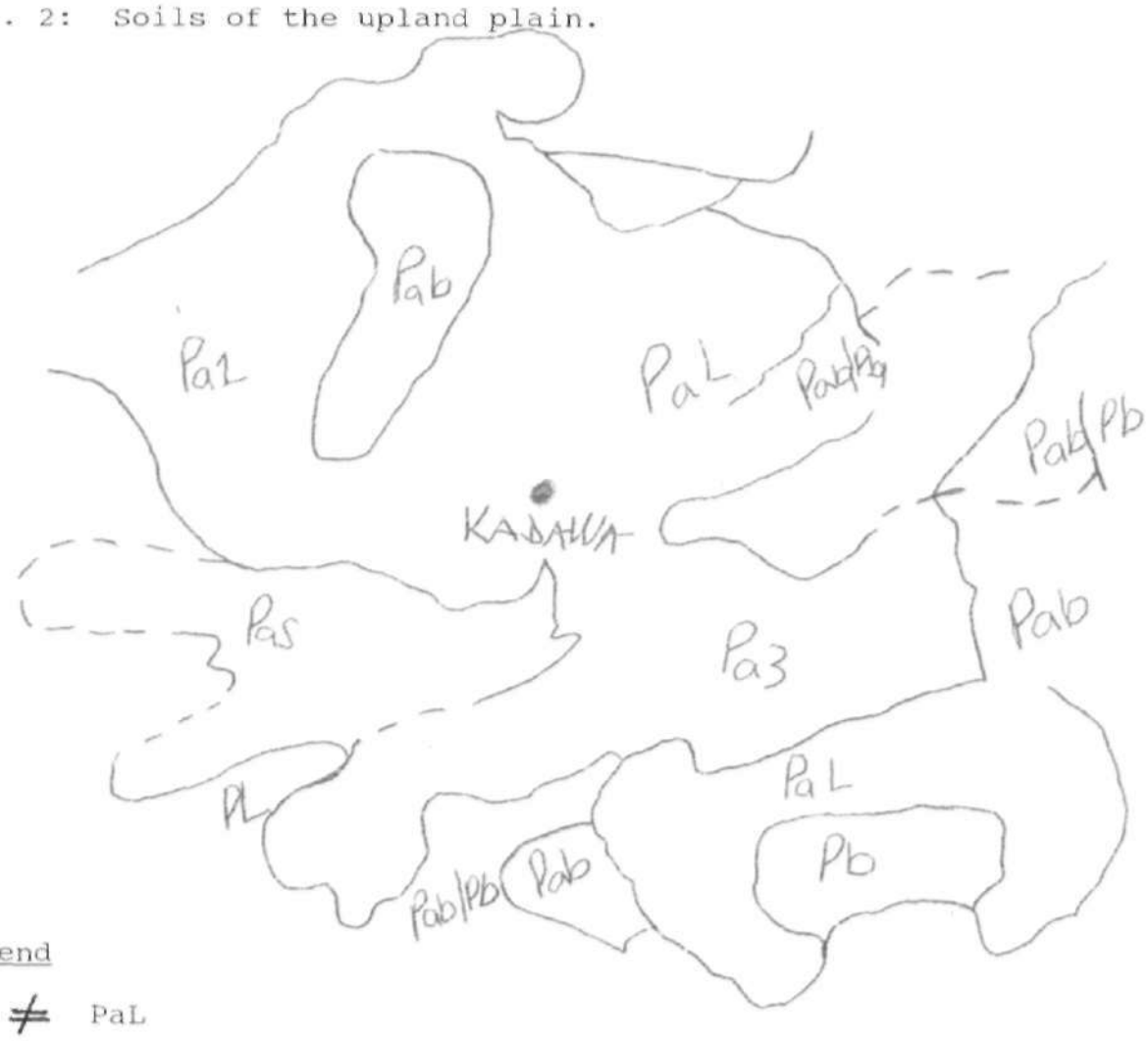
The Kano River Project soils have been divided according to their physiography into three classes: soils of the upland plain, soils of the higher terrace and soils of the lower terrace.

The Kadawa Project area is within the upland plain and is made up of four main soil series. Soil series Pa2 are deep soils having loamy sand over sandy clay loam. The Pa1 are moderately deep soils underlain by iron-pan, with loamy sand over sandy (clay) loam. The Pab are deep soils, having loamy sand layer over sandy clay loam while the Pb are deep soils with homogenious sandy clay loam texture. The soil descriptions were made according to the feasibility report (NEDECO, 1974).

2.1.2 Soil Profile Descriptions and Properties of Kadawa Project Area

NEDECO (1974) Pa2 soils are deep soils (more than 152.4cm) with a sandy top soil over a subsoil of relatively impermeable sandy clay loam, starting between 19.44 and 152.4cm deep. The upper 0-91cm or more consists of permeable, yellow-brown loamy sand and sandy loam. The topsoil is well aerated and no mottling occurs. This part of the profile is of aeolic origin.

Fig. 2: Soils of the upland plain.



Legend

Pa1 ≠ PaL

Pa1: deep soils, loamy sand over sandy clay loam

Pas: deep soils, undifferentiated textures, sloping topography

Pa1: moderately, deep soils underlain by iron pan, loamy sand over sandy clay loam

Pl: moderately, deep soils underlain by iron-pan, loamy sand

Pab: deep soils, loamy sand over sandy clay loam

Pb: deep soils, sand clay loam

Pab/Pb: complex of Pa and Pb soils.

Below a clear boundary, finer textured, grey mottled material of alluvial/colluvial origin is found. The mottled subsoil is not impervious in an absolute sense but there is a sudden decrease in permeability which influences the water movement through the profile. Residual strongly weathered material is found in the deeper surface at an average depth of (152.4 - 304.6cm). Often this material is separated from the upper reworked layers by a simple stone line or a layer of gravelly concretions.

Chemically, the mottled clay loam is too deeply buried in the profile to have much influence on the soil fertility. However, the base saturation of the top layers is 80-100% and increases with depth. The soil reaction is neutral (pH 6.6 - 7.3) to mildly alkaline (pH 7.4 - 7.8) for the subsoils. The CEC ranges from 5me/100g soil in the plough layer to 14me/100g soil in the surface. Available potassium and total phosphorous are always low to very low while the total amount of potassium is medium with values of about 300ppm.

The physical characteristics of the topsoils are good, but the percolation rates of the subsoil are definitely lower. The available moisture in these soils range between 15-20%.

Pal soils are (91.4 to 152.4cm) deep, and underlain by a lateritic iron-pan. Usually, they show profile development of clay and iron in the horizons above the lateritic hardpan. The textures vary from loamy sand to sandy clay loam. Most of these soils increase in texture with depth. Permeability decreases with depth. Hydraulic conductivities were measured by USBR, and range from

1.85 to 23.13 $cmhr^{-1}$). It is very unlikely, however that these figures represent the vertical permeability. The laterite consists of pores and cavities which are often blind and sometimes open-ended. Perhaps, the high values found by the USBR were in fact lateral conductivities.

The infiltration rates of the topsoils ranged from 10.16 to 15.24cm for the first hour. The available moisture content (pF 2.0 and 4.2) lies between 15 and 20%, which is rather high for a sandy soil.

The cation exchange capacity (CEC) was found to be from 30-40me/100g clay (3me/100g soil) which is relatively high suggesting the presence of clay minerals of both Kaolinitic and illitic type. The base saturation percentage (BSP) was very high and ranged from 80 to 90%. The pH (H_2O) varied between 6.8 and 7.3. Whereas the total K_2O was between 28 and 50ppm.

Pab are soils characterized by the presence of a relatively impermeable layer starting between 25.4 and 91.4cm depth. Often there is a sudden change in texture with increasing depth. The topsoils are composed of loamy sand while the compacted subsoils mainly consist of impermeable sandy clay loam.

The water storage capacity is very low. The available moisture content of the sandy top soil is limited.

The cation exchange capacity (CEC) averaged 5me/100g soil for topsoils and 11-12me/100g soil for the subsoils. The pH of paste varied from 6.0 - 7.5 for the non-alkaline soils to 7.5 - 8.5 for some of the alkaline subsoils.

Physically, the porosity of the layers is low with values below 40%. Infiltration tests on this soil type showed an intake rate of 3.81 - 6.35cmhr^{-1}) for the top layer.

Pb soils have a relatively impermeable layer at or near the surface, starting between 0-2.54cm depth. There was often a thin top layer of whitish or light-grey loamy sand over the very hard; light or dark-grey coloured sandy clay loam subsoil. Downward water percolation and deep rooting is strongly inhibited by the layer. The area covered by Pb soils is rather small as compared to that covered by the complex of Pab and Pb soils.

Chemically, the Pb soils are low in fertility, whereas physically they have typical characteristics of a temporarily waterlogged soil, with a low porosity, a very low permeability and a low air content at field capacity. Pab/Pb complex soils are soils that have a combination of Pab and Pb characteristics. The soil conditions may vary considerably over short distances. The underlying rocks of the Basement complex largely influence the soil composition, because of the presence at a relatively shallow depth of these rocks and the presence of the protecting lateritic hardpan.

The permeability of the soils varies from almost impermeable to moderately permeable.

A summary of the physical and chemical characteristics of the soil series at the Kadawa Project areas as at project inception is provided in the Table (Source NEDECO, 1974).

LIBRARY

Table 1: Physical and chemical properties of some selected soil series at IAR station area

Soil Unit	Pa	3Pal	Pal (Expt. farm)	Pab (Expt farm)	Pab	Pb
Textural class	SL	SL	Vfs	Lvfs	SL	LS
Organic matter (org. C)	0.2	0.5	0.27	0.369	-	0.2
pH (water)	6.3	6.8	6.7	8.1	6.4	6.6
EC (mm hoscm^{-1})	0.03	0.05	0.09	0.19	0.03	0.03
CEC (me/100g)	14.6	4.8	3.80	8.92	5.38	3.9
Exchangeable cation (meq/100g)						
Ca	10.2	3.0	2.38	28.17	4.63	2.0
Mg	2.1	0.6	2.38	28.17	-	0.4
K	0.34	0.3	0.20	0.15	0.31	0.04
Na	0.09	0.1	0.30	0.80	0.38	0.2
ESP (%)	0.6	2.0	-	7.0	-	5.0
BSP (%)	-	83.0	76.00	100.0	100.0	65.0
Bulk density (gcm^{-3})	-	1.31	-	-	-	-
Porosity (%)	-	51.0	-	-	-	41.0
Available moisture	-	18.1	-	-	-	21.9

2.2 Hydraulic properties

The ability of a soil to retain or transmit water is referred to as its hydraulic property. Knowledge of the hydraulic property of soils is of major importance in modern agriculture since these properties influence soil aeration, soil temperature, drainage, irrigability, trafficability and eventual plant growth (Puckett et

al, 1985). Adeoye (1983) stated that the knowledge of water movement in tropical field soils is important with respect to transport of plant nutrients, other solutes and biocides. The hydraulic properties of a soil can indicate the potential for salt build-up in areas planned for irrigation.

The application of the theories of soil physics to the description and/or prediction of actual processes in the field depends upon knowledge of these pertinent hydraulic characteristics of the soil.

2.2.1 Hydraulic conductivity

Hydraulic conductivity is a measure of the relative ease of water flow through a system (Klute, 1972). The theory of movement of liquid water is based on a generalised form of Darcy's law which states that the volume of water (Q) flowing per unit time is directly proportional to the cross sectional area A of the column and to the difference in hydraulic head (Δh) measured by the level of water in manometers, causing the flow and inversely proportional to the length L of the column; thus

$$Q = \frac{KA\ \Delta h}{L}$$ where the

proportionally constant K with units of velocity is known as the hydraulic conductivity of the porous material (Young, 1991).

Hydraulic conductivity is of two types depending on the moisture condition of the soil at the time of assessment. Thus, saturated hydraulic conductivity is determined when a soil is completely saturated with water whereas unsaturated hydraulic

conductivity is measured when drainage proceeds and larger pores are emptied of water.

2.2.2 Saturated hydraulic conductivity

The saturated hydraulic conductivity measurement on samples in the laboratory usually repeats Darcy's experiment using a constant head to produce flow or making measurements of flow with a falling head. Another modification of the falling head permeameter is the oscillating permeameter requiring a small volume of water, which is useful for surface-active materials. In the absence of a water table, measurement of the hydraulic conductivity of saturated soils rely on the interpretation of infiltration theory (Young, 1991). Maurya (1982) and Nwa (1982) worked on the hydraulic conductivity of some soils in the Kadawa sector of the KRP. They found that the laboratory determined hydraulic conductivities (Ks) for Pal and Pab/Pb complex were 0.88 and 0.93 $cmhr^{-1}$ respectively. A decade after, a group of researchers worked on the same soil units. Expectedly, Mu'azu and Nwadukwe (1992) found in-situ saturated hydraulic conductivity for Pal and Pab/Pb complex soil units to range between 0.44 and 3.14 $mday^{-1}$.

In all the soil units, they reported decreasing hydraulic conductivity with depth. The variations were attributed to changes in soil texture, structure and possible effect of soil tillage.

2.2.3 Unsaturated hydraulic conductivity

Unsaturated zone plays an important role in the hydraulic

cycle. It forms the link between surface water and ground water and has a dominant influence on the partition of water between them. Much had been published on the determination and/or measurement of the unsaturated hydraulic conductivity (Van Genuchten and Nielsen, 1985; Mualem, 1986). There is no single method that is suitable for all soils and circumstances. Methods that require taking "unsaturated" samples are not well suited for soils with many stones or with a highly developed loose structure (Mualem, 1986). An in-situ method is better for such soils. Young (1991) reported that hydraulic conductivity for relatively dry conditions cannot be measured in-situ when the soil in its natural situation is always wet. Under such a condition, it is necessary to take the samples and dry them first. The latter process presents problems if the soil shrinks excessively on drying.

Apparatus for determining unsaturated hydraulic conductivity is not usually commercially available. However, many of the methods involve the measurement of water content, hydraulic head and/or soil water characteristic (Hillel, 1980). Young (1991), commented on working conditions in the laboratory as compared to field methods. He found that laboratory measurements have many advantages over field measurements. In the laboratory, he reported, all the usual facilities (electricity, water, vacuum) are available, and temperature variation is usually modest and can be controlled if necessary. Expensive and delicate equipment often cannot be used in the field because of weather conditions, theft and vandalisation.

Mu'azu (1992) used the internal drainage method to determine in-situ field unsaturated hydraulic conductivity in soils of KRP but the experiment failed because of the shallow water table condition in these areas. Other methods of determining field unsaturated hydraulic conductivity have been impossible because of dearth of equipment and difficulty in measurements (Maurya, 1992).

2.3.0 INFILTRATION

Careful water management is essential for a stable and efficient agriculture. Thus, efforts by a number of agricultural agencies are directed towards water management and conservation activities such as irrigation, drainage, flood prevention and erosion control. The realistic planning of these water management and conservation activities requires accurate information on the rate at which different soils will take in water under different conditions (Parr and Bertrand, 1960).

The time rate at which water will percolate into the soil through its soil-atmosphere inter-face is known as infiltration. Quantitatively, infiltration rate is the volume of water entering into the soil per unit area and unit time. In Hydrology, the term infiltration capacity is frequently used and is defined as the maximum rate at which rain can be absorbed by a soil in a given condition. Generally, under continued ponded conditions, infiltration has a high rate at the beginning, decreases rapidly and then moves slowly until it approaches a constant rate. As water moves deeper into the soil filling the pores, the hydraulic

gradient decreases and hence, the infiltration rate.

Field infiltration data do not necessarily agree with theoretical calculations, as soil profiles are seldom uniform with depth nor is the water content distribution uniform at the initiation of infiltration (Baver, et al, 1972). This inherent heterogeneity in properties makes field soils exhibit variation in properties both in time and space. Many workers (Nielsen, et al, 1981; Folorunso and Olorunju, 1986; Imrou and Babalola, 1986) have reported spatial variations in field measured soil properties. A common feature of spatial variability of infiltration is that it does not show a simple pattern of variation. It is expected that measurements close together in the field give values of approximately same magnitude, while points further apart differ by a greater degree of magnitude (Warrizk and Nelsen, 1980). For any measurement of soil properties, therefore it becomes necessary to study variations in space and time for a particular field.

2.3.1 Infiltration Processes

The infiltration process is of great importance and it affects many aspects of hydrology. It influences runoff and determines the water content of the soil. When moisture distribution in a uniform profile is studied during infiltration, a saturated zone is revealed at the soil surface to a depth of a few centimeters. Below this zone is a transmission zone through which water is being passed from saturated to the wetting zone at the bottom. In the wetting zone, the moisture content decreases with depth till it

merges with a wetting front which forms a sharp boundary between the wet and dry soil (Ghildyal and Tripatti, 1987). Early attempts at modelling the infiltration process used empirically derived constant to link infiltration rate (I) with sorptivity, S (Green and Ampt, 1911). Phillip (1957a, b) provided comprehensive mathematical solutions for idealized infiltration. At large values of time (t), cummulative infiltration (i), was described in terms of a power series of coefficients derived from unsaturated hydraulic conductivity and diffusivity.

Philip equation can be approximated by

$$I = St^{1}/_{2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

The sorptivity "S" is the slope of cummulative infiltration against t. This provides us with a convenient parameter of absorption rate of soils in units of length per square unit of time (Hamblin, 1985).

Cylinder infiltrometers are metal rings or compartments driven into the soil to depths ranging from a few to several centimeters so that the lateral or divergent flow of water from the ring could be held to a minimum. The methods of adding water to these cylinders include either the principles of constant heads, falling heads and sprinkling application.

In earlier studies only single ring were employed and many data indicate a high degree of variability which could be due in part to the uncontrolled lateral movement of water from the ring (Parr and Bertrand, 1960). Later studies have evolved the use of double rings or multi ring devices to minimize this divergent flow.

Little or no attempt has been made to continuously monitor the infiltration capacity and/or rate of intake of water in soils of Kano River Basin. Mu'azu and Nwadukwe's (1992) work on hydraulic properties of Kano River Project was silent on infiltration. Many factors affect the infiltration rate of the soil and these include texture, structure, hardpan formation, pore size distribution, swelling and shrinking and the nature of clay. Factors that affect water quality, also affect infiltration. Contamination of water by suspended materials and salts, temperature, viscosity, and rainfall characteristics can influence infiltration rate.

2.4.0 SOIL STRUCTURAL STABILITY

Good structure for crop growth depends on the presence of aggregates of soil particles 1 to 10mm diameter which remain stable when wetted. Such water stable aggregates should be porous (Pores > 75μm diameter) so that they remain aerobic and yet possess sufficient numbers of pores (3.0 - 0.2 μm diameter) to retain water for growth of plants (Tisdall and Oades, 1982). In nature, soil continually undergoes wetting by rainfall, diffusive flow, wind influence and drying by solar radiation. These cycles of wetting and drying have been related to the formation of soil aggregates in non-aggregate soils (Utomo and Dexter, 1982).

An agriculturist's interest in soil structural stability is very much associated with tilth which is a general term that signifies the ability of the granules or aggregates to withstand destruction by the impact of implements, rain-drop or running

water.

When an unstable air-dry aggregate is wetted rapidly it slake into smaller sub-units which may also be aggregated (Emerson, 1977). Slaking is common and occurs in a wide range of soils where the aggregates are not strong enough to withstand the pressure due to swelling in the field. Slaking of aggregates occurs mainly in surface layers since those below the surface are protected from air-drying and from rapid wetting. The capacity of aggregates to resist the slaking and dispersive action of water is an important soil property in relation to maintenance of a porous soil structure (Haynes and Swift, 1990).

2.4.1 Evaluation of Soil Structural Stability

The main method for determining the stability of soil structure is based on measuring the size distribution of the crumbs that small dry clods breakdown into on wetting. The size distribution can be determined by such methods as separation of the crumbs on a bank of sieves under water. This is a commonly used method. Size distribtution of the pores between the crumbs can also be measured by determining the moisture content suction curve for a shallow column of the soil crumbs after repeatedly drying and rewetting the column. The slope of this curve gives the pore size distribution between the crumbs (Russell and Russell, 1977). Toogood (1978) explained that stability of aggregate can be determined through the use of dry aggregates. In his method, air dried samples of aggregates of 1 to 2mm in diameter should be

vigorously sieved on 1mm sieve for one minute, weighed and sieved for a further five minute period. The weight of aggregates remaining after five minutes, expressed as a percentage of the weight remaining after 1 minute indicates the stability of the dry aggregates. This method is similar to the Mean Weight Diameter (MWD), method of Van Bavel, (1949). Though MWD does not give the value or degree of stability of two or more soils.

Studies to determine or evaluate the structural stability of soils of Kano River Project are yet to be carried out.

2.5.0 SALT PROBLEMS IN SOILS

It is generally accepted that water soluble salts particularly the sodium salts are responsible for the low fertility of salt affected soils. Saline or alkali soils are soils whose content of salts (or their ions) interferes with the growth of the majority of crops. Szabolcs (1974) recognised two classes of salt affected soils.

i. a class dominated by chlorides and sulphates which he named saline and;

ii. a class dominated by exchangeable sodium and/or sodium bicarbonate and sodium carbonate which he called alkali.

Salt problems commonly occur in regions with arid and semi-arid climates; and lower the productivity of extensive areas of agricultural land throughout the world. The origin of most of these problems is linked to the high evapotranspiration rates

characteristic of arid and semi-arid climates which tend to decrease the limited amount of water available for leaching and transporting salts out of root zones. Salts may also get into the soil via irrigation water, this is because all irrigation water irrespective of the source contain certain quantities of soluble salts. Inadequate natural drainage is intimately associated with, and contribute to the severity of saline and alkali conditions.

2.5.1 Saline Soils

These soils contain enough soluble salts so distributed in the soil profile that they decrease the growth of most plants (Reeve and Fireman, 1967). A soil is saline when the electrical conductivity (EC) of its saturation extract is at least 4 dsm^{-1} at 25°C and the exchangeable sodium percentage (ESP) is less than 15. Ordinarily, these soils are only slightly alkaline in reaction (pH $\geq$ 8.5). Saline soils are often recognised by the presence of white surface crusts and damp oily-looking surfaces devoid of vegetation.

2.5.2 Alkali (or Sodic) Soil

These are soils that contain sufficient exchangeable (or adsorbed) sodium to interfere with the growth of most crop plants. A soil is said to be sodic if its electrical conductivity is less than 4 dsm^{-1} of saturated extract at 25°C, exchangeable sodium percentage greater than 15 and its reaction is highly alkaline (pH 8.5 - 10.0).

Maurya, (1982) and Nwa (1982) have carried out extensive salinity survey of soils of Kano River Project (KRP). The soils were reported to be saline and there was a potential for continuous build up of the salinity.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site Description

The experiments were carried out at the Kadawa farm of the Irrigation Research Station (IRS), Institute for Agricultural Research in the Kano River Project of Hadejia-Jama'are River Basin Development Authority. The sites lie within Longitudes 8° 31′ to 9° 40′E and Latitudes 11° 30′ to 12° 03′N in the Sudan Savanna ecological zone.

The sites were located on the IAR farm, the Sasakawa Global 2000 Project farm and within the Hadejia-Jama'are farm and plantation. The soil units selected for study based on the sites are presented in Table 2. The Kadawa soils are representatives of the 'loess plain soil unit.

The study areas were chosen keeping in view the objective of monitoring the changes in soil properties due to irrigation. As such, the main soil groups of the upland plain were first identified as the Pal, Pab and Pab/Pb complex (figure 2). Sampling points were then made on the irrigated, rainfed and virgin lands within each of the three soil units. In all a total of nine soil profile were dug comprising three each of Pal, Pab and Pab/Pb complex in the order irrigated, rainfed and virgin. These soil units are classified based on the findings during the feasibility study by NEDECO (1974). The irrigated land refers to the area used for both rainfed and irrigated agriculture, (designated C) the

rainfed land refers to the area used only during the rainy-season (designed R) and the virgin land refers to the area where no arable farming is carried out at all (designed V).

Table 2: Location of sample points for all units

Soil Unit designation	Pal location	Pab location	Pab/Pb location
C	within Block 3.5	within Sasakawa Global 2000 F 2.9	within Block 3.3
R	Adjacent Block 3.7	Mr. X farm F 2A.1	Near main route F 2C.1
V	Within HJRBDA F 2.13	HJRBDA plantation F 2A.2	HJRBDA Plantation F 2C.4

Sampling was carried out during the dry (Harmattan) season period. During soil sampling, it was noticed that the groundwater table was at the points indicated:

C Pal - Encountered at 65 depth

C Pab - Encountered at 60cm depth

C Pab/Pb - Encountered at 45cm depth

R Pal - Encountered at 84cm depth

R Pab - Encountered at 84cm depth

R Pab/Pb - Not encountered even at 100cm depth

V Pal - Encountered at 65cm depth

V Pab - Encountered at 68cm depth

V Pab/Pb - Not encountered even at 100cm depth

3.2 Soil Sampling

Soil samples, both disturbed and undisturbed were collected from the surface to sixty centimetre depth in the range 0 - 15cm, 15-30cm, 30-45cm and 45-60cm. These depths were arbitrarily selected and bear no relationship to natural horizons. The samples were collected from pits dug on the different treatments of Pal, Pab and Pab/Pb complex units.

3.3 Laboratory Measurements

Laboratory determination for both physical and chemical properties were carried out. These comprise water content, bulk density, total porosity, particle size analysis, aggregate stability, soil moisture characteristics, saturated hydraulic conductivity, pH, electrical conductivity, percentage organic carbon, exchangeable bases and cation exchange capacity. Exchangeable sodium percentage was calculated from the values of cation exchange capacity.

3.3.1 Water Content

The water content was determined directly using gravimetric method (oven drying at 105°C for 24 hours). The water content (θw) was obtained by dividing the difference between wet and dry masses (w) by the mass of the dry sample (S). The ratio of the mass of water to the mass of the dry soil in percentage gives the water content on a dry-mass basis. This was converted to water content on volume basis (θv) by multiplying by the bulk density at the

depth and dividing by the density of water ($1gcm^{-3}$). The water content determination by gravimetric method was described by Gardner (1982).

3.3.2 Bulk density (Pb)

Soil bulk density is the ratio of the mass to the bulk or macroscopic volume of soil particles plus spaces in a sample. The mass was determined after drying to constant weight at 105°C and the volume was that of the sample as taken in the field. The determination consists of drying and weighing a soil sample, the volume of which is known, this is the core method described by Blake and Hartge, (1982).

3.3.3 Porosity (f)

The total porosity was calculated from the values of bulk density and particle density of the soil, as:

$$f = 1 - \frac{Pb}{Pp}$$

where Pp is particle density for which the typical value for mineral soils (Kowal, 1970a) $2.65gcm^{-3}$ was assumed. Macrosporosity (Sa) was calculated from the following relationship used by Mbagwu et al (1983).

$$Sa = S_t - \theta v(0.1)$$

where S_t = total porosity and θ_v (0.1) = percentage volume of water held at 0.1 bar suction (field capacity).

3.3.4 Particle size analysis

The major features of particle size analysis are the destruction or dispersion of soil aggregates into discrete units by chemical or mechanical means and the separation of particles according to size limits by sieving and sedimentation. The soils used were bulked together. The Hydrometer method of analysis (Day, 1965) was employed thereafter. At the end of a reading, the percentages of clay, silt and sand were calculated as follows:

$$\text{Clay} = \frac{C-R^*}{50} 100 = X$$

$$\text{Silt} = \frac{C-R^*}{50} 100 - X = Y$$

$$\text{Sand} = 100-(X+Y)$$

where C = corrected hydrometer reading, obtained as C = H + (0.36 $\triangle$T) with $\triangle$ T = T°C - 20°C and H - the Hydrometer reading. R* = Reading for Blank, T = Temperature.

3.3.5 Aggregate Stability

An aggregate is a group of primary particles that cohere to each other more strongly than to other surrounding soil particles. Disintegration of the soil mass into aggregates requires imposition of a disrupting force. Stability of aggregates is a function of whether the cohesive forces between particles withstand the applied disruptive force. The rotary apparatus developed by Chepil (1962) and Van Bavel (1949) was used. The method of mean weight diameter was employed to estimate the aggregate stability. The mean weight Diameter (MWD) which is equal to the sum of products of the mean

diameter (Xi) of each size fraction and the proportion of the total sample weight (Wi), occuring in the corresponding size fraction carried out over all n size fractions including the one that passed through the finest sieve. It follows that:

$$MWD = \sum_{i=I}^{n} XiWi$$

3.4 FIELD MEASUREMENT:

Infiltration was measured on the field at all locations.

3.4.1 Infiltration

The method of cylinder infiltration described by Bouwer (1982) was used for the infiltration measurement. A set of double ring infiltrometer consisting of a large outer ring of diameter 55cm, and a smaller inner ring of diameter 30cm (Eijel Kamp Agrisearch Equipment No. 07.04) was used. The set includes an adjustable measuring bridge and float with measuring rod. Other accessories include a withdrawal clamp, impact absorbing hammer, a driving plate, a stop watch, hoes, and bucket. In addition to the set, a thin polythene sheet of negligible thickness was used to pond water in the inner ring before cylinder was used to measure exact volumes of water required to maintain the pre-determined head in the inner ring. The water used for the infiltration test was obtained from the irrigation canal at the site. At each site, observations of the surface was done to determine the condition of the surface before the start of the infiltration test.

The inner ring was placed on the ground with the cutting edge on the surface. The driving plate was attached by means of adjustable screws. The ring was pushed at right angles into the soil to a marked depth of 10cm using the impact absorbing hammer. The outer ring was installed in a similar way, all along taking care not to disturb the soil within the inner ring. The soil-ring interface was packed with soil to minimise perimeter flow. Pre-determined 4.95 litres of water was measured into the inner ring on top of the polythene sheet, to maintain a head of 7cm initialy. This head was chosen to simulate field heads usually encountered during irrigation. With the float and measuring rod mounted over the inner ring (using the adjustable measuring bridge), the initial level position of the measuring rod was recorded against the time reference (t = O). Readings were made at 2 minutes interval and later at 4 minutes and much later at 6 minutes interval. The variations between the time was a result of fast water entering into some of the soils.

3.4.2 Soil Moisture Characteristic

Soil moisture characteristic was determined using the tension table (sand box) and pressure plate extractor with ceramic plates. (Eijkel Kamp Agrisearch Equipment No. 08.01) at different suctions.

In the sand box, samples were subjected to IKPa and 10KPa suctions. Suction was imposed and left for 24 hours during which time all water held at this tension was extracted. The samples were weighed in each case to determine loss in weight.

The duration of samples in the pressure extractors depended on when all water at the suctions were removed (2-3) days for the 1bar and 3-7 days for the 15bar as a result of some leakages in the pipes). The loss in weight at the various suctions was determined by weighing. The samples were left in the oven at 110°C for 24 hours, after which they were removed and weighed. The moisture characteristic is expressed graphically by a plot of water content (θv) against matric suction (Y) at different depths.

Available water holding capacity was determined at 0.1 bar as the upper limit and 0.15 bar as the lower limit. The available water holding capacity was calculated and illustrated using the approach by Mbagwu et al (1983).

3.4.3 Saturated Hydraulic conductivity

The method of measuring saturated hydraulic conductivity in the laboratory was described by Klute and Dirksen (1982). In this method, the equipment used for the measurement included soil core sampler, plastic caps, pieces of cloth, rubber bands, core sampler box and permeameter. Hydraulic conductivity was determined by the constant head method using the ICW laboratory permeameter (Eijel Kamp Agrisearch Equipment No. 09.02). Two core samples were taken horizontally at depths (0-15cm), (15-30cm), (30-45cm) and (45-60cm). The core measured 5.1cm in height and 5.0cm in diameter. The samples were retained fresh inside brass sampling rings whose open ends were protected with plastic caps, carefully sealed and transported in the cushioned sample box. Before measurement was

started, a piece of cloth was placed under the lower end of each sample and secured with a rubber band. An empty brass ring was connected to the upper end of the sample and secured firmly with adhessive tape. The samples were soaked in tap water over-night with the lower end in water. They were then transferred into the permeameter which operates on the principle that a pressure difference created on both sides of a well saturated soil sample causes water to flow through the sample. The flow rates, the pressure difference and sample dimensions form the essential data for the conductivity calculation from the equation:

$$K = \frac{(Q)}{At}\ \frac{(L)}{H} cm\ min^{1} \quad \ldots\ldots\ldots\ldots 1$$

where K = saturated hydraulic conductivity, cm/min

Q = volume of water collected, cm^3

t = time, min.

A = Cross sectional area of the sample, cm^2

L = length of the sample, cm

H = Hydraulic head difference, cm.

Length of sample, cross-sectional area, hydraulic head difference and time were all constant for each sample.

3.5.0 CHEMICAL ANALYSIS OF SOIL

For the purpose of chemical analysis, soil samples were taken before the commencement of irrigation from the three soil types at depths of 0-15cm, 15-30cm, 30-45cm and 45-60cm. The soil samples were air-dried in the field, crushed in a mortar and pestle to pass

through a 2mm mesh. Samples weighing 50g were taken, carefully bagged in transparent polythene bags and labelled. Laboratory analysis conducted on each of the samples are described below.

3.5.1 Soil pH

The level of acidity in water and 0.01m $CaCl_2$ solution at 1:2 soil to electrolyte ratio was determined using a pH meter with glass electrode (Juc, 1978).

3.5.2 Electrical Conductivity (EC)

The EC (1:2.5) soil to water ratio extract was determined using a direct electrical conductivity meter (Bridge type M.C 3) at room temperature. Results expressed in micromhos cm^{-1} and thereafter converted to decisiemens per meter (dsm^{-1}) were adjusted to that of 25°C using the appropriate factors (US Salinity Lab. Staff, 1954).

3.5.3 Exchangeable Bases

Soils were analysed for Calcium, Magnesium, Potassium and Sodium following extraction with IN NH_4 OAC (pH 7) using 1:10 soil to solution ratio. Sodium (Na+) in filtered extracts was determined with a Gallen Kamp Flame Analyzer while Ca^{2+}, Mg^{2+} and K^{+} were determined with a Palkin-Elmer Model 290 B atomic absorption spectrophotometer (Chapman, 1965).

3.5.4 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) usually expressed in milliequivalents per 100g of soil is a measure of the quantity of readily exchangeable cations neutralizing negative charge in the soil. The CEC values were measured using 1N ammonium acetate at pH 7.0 as described by Rhoades (1982).

3.5.5 Organic Carbon

The Walkley-Black method as described by Allison (1965) was used for the determination of organic carbon. A sub-sample of 0.3gm was taken from each sieved sample. Organic carbon was reduced with 1 normal potassium dichromate solution assisted by the heat generated from the addition of concentrated sulphuric acid. The unused dichromate was titrated against 1 normal ferrous sulphate solution.

3.5.6 Exchangeable Sodium Percentage (ESP)

Exchangeable cations are those that can be exchanged by a cation of an added salt solution. The exchangeable cations Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} often called the exchangeable bases commonly occur in soils in the order listed. These were determined using the Ammonium acetate method as described by Thomas (1982).

The ESP was calculated using the values obtained from the exchangeable bases and cation exchange capacity. The Gapon equation for ESP was used.

$$ESP = \frac{\text{Exchangeable Sodium content}}{\text{CEC}} * 100$$

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1.1 Particle size analysis data is presented in Table 3. The average values of percentage clay, silt and sand reveals a sandy loam/sandy clay loam texture in all the profiles investigated with the clay content increasing with increase in depth. Highest percentage clay was found at the 45-60cm depth of the Pab/Pb unit C soil. The textural classes were mainly sandy loam on the surface and sandy clay loam in the subsoils which agrees with the findings of Nwa and Ogunase (1983).

Generally, the difference observed is that over a decade the percentage sand has reduced and percentage silt increased. The increase in clay fraction with depth in the soils may be due to the process of elluviation from the surface whilst the increase in percentage silt could be due to effect of tractor disturbance and grazing animals which led to the reduction of sand and action of erosion from time to time.

Table 3: Particle Size Value (mm) for the soils

	depth (cm)	Pab soils				Pab soils				Pab/Pb soils			
		<------%-------->			Textural	<------%-------->			Textural	<------%-------->			Textural
		Clay	Silt	Sand	Class	Clay	Silt	Sand	Class	Clay	Silt	Sand	Class
C Soils	0-15	13	26	61	Sandy loam	8	26	66	Sandy loam	8	22	70	Sandy loam
	15-30	19	18	63	Sandy loam	12	26	62	Sandy loam	26	20	64	Sandy c.loam
	30-45	23	24	53	Sandy C. loam	20	22	58	Sandy C. loam	32	20	48	Sandy c.loam
	45-60	23	20	57	sandy c. loam	22	22	56	Sandy c. loam	32	22	46	Sandy c.loam
R Soils	0-15	8	28	64	Sandy loam	13	20	67	Sandy loam	10	28	62	Sandy loam
	15-30	14	22	64	Sandy loam	13	24	63	Sandy loam	12	22	62	Sandy loam
	30-45	14	24	62	Sandy loam	17	22	61	Sandy c. loam	12	22	66	Sandy loam
	45-60	12	26	62	Sandy loam	21	18	61	Sandy c. loam	12	24	66	Sandy loam
V Soils	0-15	11	22	67	Sandy loam	10	26	64	Sandy loam	10	28	62	Sandy loam
	15-30	13	22	65	sandy loam	12	24	58	Sandy loam	12	24	64	Sandy loam
	30-45	13	24	63	Sandy c. loam	12	30	56	Sandy loam	10	26	64	Sandy loam
	45-60	15	20	65	Sandy c. loam	18	26	62	Sandy loam	12	26	62	Sandy loam

4.1.2 Soil Reaction (pH) of the Three Soil Units Under Different Management Conditions

Soil reaction (pH) data is presented in Table 4.

Table 4: Reaction (pH) of the three soil units

Management condition	Soil depth (cm)	Soil units		
		Pal	Pab	Pab/Pb
C	0-15	7.5	6.3	6.2
	15-30	7.4	6.3	5.8
	30-44	7.4	6.1	6.0
	45-60	7.1	6.0	5.9
R	0-15	8.2	7.7	5.6
	15-30	8.5	7.5	5.8
	30-45	7.6	7.3	6.3
	45-60	4.8	7.5	6.4
V	0-15	6.7	9.2	6.6
	15-30	6.7	9.2	5.8
	30-45	7.3	9.1	6.6
	45-60	6.8	8.8	6.6

The soil reaction vary considerably among soils. The Pal unit has the lowest pH value of 4.8 at the 45-60cm depth. Its highest pH value of 8.5 at the 15-30cm depth of the R soil is exceeded only by the virgin soils of the Pab. The lowest value of 4.8 recorded could be due to hydrated oxides of iron or presence of soluble salts; and/or leaching of the soil. Overall, the Pal C soil can be considered to be almost neutral throughout its depth with pH ranging from 7.1 at 45-60cm to 7.5 at 0-15cm depth. The Pal V soil has slightly acidic reaction.

The Pab unit soils has reaction ranging from 6.0 to 9.2 with the highest recorded at the area with management condition V. The

Pab C soils is slightly acidic with pH 6.2 on average, which could be a result of leaching whereas the Pab R soil is almost neutral. A highest pH value ranging from 8.8 to 9.2 recorded on the Pab V soil makes it's reaction alkaline, which could have arisen as a result of the exchangeable Na^{+} hydrolysing from NaOH in the soil solution. This also can be said to account for the low Ca^{2+} and Mg^{2+} observed, since the Ca^{2+} and Mg^{2+} ions are precipated as carbonates because of the presence of HCO_3^{2-} ions (Jurinak, 1978). The groundwater quality shows that the HCO_3^{2-} was 6.0 ppm, a value higher than 0.48 ppm obtained by NEDECO (1974). The large increase in pH over two decades is enoumous that if not checked, the land can not be used for agricultural production in few years to come. However, with effective soil and water management put in place, the high pH can be reduced to acceptable level for crop production.

The Pab/Pb unit has pH range from 5.6 to 6.6. The soils, irrespective of use, are slightly acidic. This is not unconnected with the action of concretions which was observed near the surface. From the result obtained, there is no remarkable change from what was obtained during the feasibility study of the area, as such, the practice of irrigation on these soils have not affected remarkably the activity ratio.

4.1.3 Organic Carbon and Electrical Conducitivity of the Three Soil Series

Results of Organic carbon (gKg^{-1}) and Electrical conductivity (EC) measurements are presented in Table 5.

Table 5: Percentage Organic Carbon and Electrical Conductivity of the three Soil Units

Management Condition	Soil Depth (cm)	Soil Units: Pal Org. C (gKg-1)	Pal EC (dsm-1)	Pab Org. C (gkg-1)	Pab EC (dsm-1)	Pab/Pb Org. C (gkg-1)	Pab/Pb EC (dsm-1)
C	0-15	.24	.28	.92	.40	.56	.14
	15-30	.10	.13	.30	.13	.14	.15
	30-45	.06	.12	.28	.07	.40	.06
	45-60	.04	.65	.32	.66	.28	.40
R	0-15	.20	.39	.14	.12	.28	.06
	15-30	.26	.35	.12	.10	.24	.06
	30-45	.20	.18	.08	.10	.28	.05
	45-60	.18	1.11	.04	.44	.16	.23
V	0-15	.20	.06	.20	1.15	.54	.21
	15-30	.10	.06	.14	.95	.24	.18
	30-45	.04	.05	.24	.79	.20	.15
	45-60	.02	.23	.26	3.59	.30	.70

Organic carbon which is a measure of the soil organic matter decreases down the profile for all the units investigated. However, the Pab C soil exhibited higher content of organic carbon than others followed by the Pab/Pb unit soils. The high levels of organic carbon noticed could be attributed to mulch farming and incorporation of crops residues, since it is much engaged on these soils unlike the cultivation of rice that was prevalent on the Pal unit soils. It was noted that more farming activities take place on the Pal C and R soils than the other locations. The low organic carbon content recorded on the Pal V soil can be attributed to less activities of soil micro-organisms because of the presence of thorny grasses in the area. It is worth noting that generally, the

soils had low organic carbon from the beginning.

Electrical conductivity which has been recognised as giving a fair indication of total salinity of a soil (Agawal and Yadev, 1956) decreases down the profile for all the soils. This trend is so because of movement of water upward accompanied by soluble salts which are left behind after evaporation at the top soil.

The Pab V soil has the highest electrical conductivity of 1.15 dsm^{-1} at the 0-15cm depth. In the Pal soil type with management R and Pab/Pb, V soil values of EC in the profile are equally high compared with others suggesting high soluble salt concentration beneath the location resulting from the productions of weathering which are localised because rainfall other than irrigation is not sufficient to provide the leaching and transport of salt from the areas. If these areas are continously cultivated, the tendency of quick salinization could be high, and high EC value indicate that the osmotic pressure of the soil solution will increase which will affect plant yield by decreasing the water uptake.

On the average, the soils where all year agriculture is practised is developing salt build up with values for Pal, Pab and Pab/Pb complex been 0.06, 0.66 and 0.40 dsm^{-1} respectively. When these values are compared with the EC values of 0.05, 0.19 and 0.03 dsm^{-1} respectively for the same soils obtained during feasibility study of the areas, the increases in EC could have resulted from contributions from the ground-water and the irrigation water without proper management to control salt accumulation, because for every 100 mg/L of salt existing in a given irrigation water, 1

metric ton of salt is added to the soil per hectare of applied water (Bresler, 1981). In the areas where no irrigation is practised but with high EC recorded arises from contributions from basically the salt base minerals of the underlying parent material, since the ultimate source of soluble salt found in soil comes from the weathering of primary minerals in the rocks forming the continent (UNESCO/FAO, 1973). If these areas are cultivated, the tendency of the soils becoming sodic early is very high. On the other hand, in the Pal V soil where there were deep ramifications and penetration roots of palm trees, little or zero fertilization and minimum soil disturbance, EC value was lowest and not quite different from the values obtained by NEDECO. Invariably, it is an indication that irrigation has altered the physical properties of these soils.

4.1.4 Exchangeable cations, Cation Exchange Capacity and Exchangeable Sodium Percentage

The data for exchangeable cations, cation exchange capacity and exchangeable sodium percentage is presented in Table 6.

The Exchangeable cations determined were the Ca^{2+}, Mg^{2+} and Na^{+}. Overall, the exchangeable cations decreases down the profile with high percentage of the cations found in the areas where all year agriculture is practised, and the least percentage in the irrigation areas. The high percentage with the management option C may not be unconnected with the use of fertilziers during each of the planting season. This finding agrees with the general fact that calcium and magnesium are the principal cations found in a

Table 6: Values of Exchangeable, cations, cation Exchange capacity and Exchangeable sodium percentage of the three soil units

Management Condition	Soil Depth	Soil Units: Pal Extrable cations Meq/100g					Pab Extractable cations Meq/100g					Pab/Pb Extractable cations				
		Ca	Mg	Na	CEC Meq/.1kg	ESP %	Ca	Mg	Na	CEC Meq/.1kg	ESP %	Ca	Mg	Na	CEC Meq/.kg	ESP %
C	0-15	3.25	.71	.63	7.6	8.5	5.59	1.48	.69	10.6	6.51	4.11	.72	.23	6.4	3.59
	15-30	4.38	.77	.20	9.2	2.2	5.39	1.22	.33	9.2	3.59	5.59	1.35	.18	9.4	1.91
	30-45	4.53	.75	.22	13.1	1.7	5.99	1.35	.24	9.7	2.47	6.69	1.58	.19	10.4	1.83
	45-60	4.75	.75	.23	12.9	1.8	6.79	1.51	.21	10.2	2.06	6.19	1.45	.17	10.1	1.68
R	0-15	4.99	.69	3.64	10.2	35.69	4.13	.93	.26	8.2	3.2	3.79	.69	.14	5.2	2.69
	15-30	4.99	.89	2.33	9.5	24.53	3.63	.85	.13	8.9	1.5	4.07	.95	.12	6.4	1.88
	30-45	5.39	.92	1.03	8.2	13.56	4.00	1.01	.18	11.4	1.6	4.03	.86	.16	6.1	2.62
	45-60	5.19	.89	.75	8.0	9.38	5.38	1.58	.28	15.8	1.8	4.19	.86	.37	6.8	5.44
V	0-15	2.25	.78	.28	7.9	3.5	3.59	.63	5.72	13.1	43.66	4.19	.68	.23	6.8	3.38
	15-30	2.25	.75	.25	11.2	2.2	2.99	.63	5.72	12.6	45.4	5.19	.91	.16	7.6	2.11
	30-45	2.25	.56	.23	13.6	1.7	3.19	.76	5.81	14.0	41.5	4.07	.71	.12	6.1	1.97
	45-60	2.50	.75	.21	14.9	1.4	4.79	1.09	6.33	14.2	44.58	4.87	.72	.17	6.8	2.50

soil and on the exchange complex of the irrigation soils from arid and semi-arid regions (Shainberg, 1973). In view of this, and the fact that the irrigation water quality was low, accounts for why there is gradual build up of sodium, since an excess of soluble salts acumulates and sodium becomes the dominant cation in the soil solution because under such conditions, part of the calcium and magnesium originally adsorbed is replaced by sodium.

Exchangeable sodium percentage (ESP) measures the degree of sodicity of the soil. The ESP data provided show the dangerously high level in PaL R soil with ESP of 35.69% and Pab V soil with 43.66% at 0-15cm depth. The high ESP manifests itself in the deterioration of the physical condition of the soil. This breakdown in the physical structure of the soil could be the result of swelling and eventual dispersion of the clay fraction or due to the salt base minerals of the underlying parent material. It can be accepted that the effect of the swelling and dispersion which effectively blocks the conducting - pore system of the soil matrix accounts for the reduced hydraulic conductivity that was found to be very low, as was observed in the Pab V soi, while on the other hand, the case of the Pal R can be taken to be that the ESP in the study areas decreases down the profile depth with the exception of Pab V soil where it recorded overall highest value 45.40%. The values of ESP of the area was found to be high throughout the depth. The Pab V soil can be classified to be sodic when it's high electrical conductivity value is combined with the content of exchangeable sodium at the pH value (> 8.4), which have a high

potential of interfering with the growth of crop plants. There is high tendency of the cultivated soils becoming saline as a result of intensive agriculture going on from year to year. This is due to contribution of soluble salts from the groundwater, high use of inorganic fertilizers, development of soil reflecting to a large extent the properties of the parent material and the antecedent problem of irrigated agriculture in the zone. This assertion is based on the wide disparity noticed between the present result and the findings by NEDECO (1974) that the ESP of Pal and Pab soils were 2.0% and 7.0% respectively. The other soils can not be said to be sodic since their ESP values fell below the 15% level of sodicity. Hence, irrigation is a factor affecting the deterioration of the soil.

Cation Exchange Capacity (CEC) ranged from 5.20 meq/0.1Kg soil in the Pab/Pb unit R soil to 14.90% meq/0.1Kg soil in the Pal unit V soil. Generally, the CEC decreases down the profile depth. The values in all cases show that the soil has a medium to high CEC potential. Although CEC in the Pal unit soils is appreciably increasing over the years, the gains in the Pabunit is not substantial while there was no record to compare for the Pab/Pb unit. The increase in CEC is more remarkable in the C and R soils of all the units because of increasing content of exchangeable calcium and other cations resulting from cultivation and use of amendments. Calcium is moderate in the soils while exchangeable magnesium and sodium are from moderate to high.

Table 7: Soil Physical properties

Management Cond.	Soil depth (cm)	Pal unit: Bulk density gcm-3	Pal unit: Porosity (%)	Pal unit: Sat. hyd. cond. (mday-1)	Pal unit: Moisture content (cm3cm-3)	Pab unit: Bulk density gcm	Pab unit: Porosity (%)	Pab unit: Sat. hyd. cond. (mday-1)	Pab unit: Moisture content (cm3cm-3)	Pab/Pb unit: Bulk density gcm-3	Pab/Pb unit: Porosity (%)	Pab/Pb unit: Sat.hyd cond. (mday-1)	Pab/Pb unit: Moisture content (cm3cm-3)
C	0-15	1.64	44	16.37	.27	1.41	48	2.40	.27	1.61	39	3.87	.13
	15-30	1.58	40	10.11	.33	1.45	45	1.12	.30	1.49	44	2.13	.35
	30-45	1.54	42	9.92	.37	1.58	40	0.45	.34	1.24	53	0.22	.36
	45-60	1.63	38	6.25	.41	1.58	40	0.11	.38	1.50	43	0.005	.35
R	0-15	1.65	38	10.62	1.51	1.77	39	.54	.17	1.33	50	$1.91x10^{-4}$	.03
	15-30	1.58	40	7.90	.30	1.68	37	.44	.19	1.42	46	$1.79x10^{-4}$	.03
	30-45	1.68	37	4.91	.35	1.72	35	.37	.25	1.20	55	$3.67x10^{-5}$	.04
	45-60	1.68	37	2.53	.37	1.69	36	.07	.32	1.61	39	$3.97x10^{-7}$	.10
V	0-15	1.56	41	8.62	.08	1.50	43	.21	.13	1.50	43	$5.93x10^{-5}$	.10
	15-30	1.60	40	6.40	.11	1.53	42	.16	.18	1.60	40	$6.96x10^{-7}$	.34
	30-45	1.49	44	4.91	.14	1.42	46	.13	.21	1.41	47	$4.56x10^{-7}$	.31
	45-60	1.53	42	2.53	.20	1.40	47	.12	.37	1.48	44	$2.40x10^{-7}$	.38

4.2 HYDRAULIC PROPERTIES

Hydraulic properties are the properties of the soil mass which enable the soil to retain and transmit water when all soil conditions are favourable.

4.2.1 Bulk Density

Bulk Density (Pb) is a measure of the compactness of a soil. The bulk density values as presented in Table 7 ranged from 1.20 (Pab/Pb R soil, 30-45cm depth) to 1.77 (Pab R soil, 0-15cm depth) gcm^{-3}. The bulk density values generally are high which could be due to heavy traffic on the soils. A decade ago, the bulk densities of some of the soils (cultivated fields only) were found to average 1.64, 1.53 and 1.65 gcm^{-3} respectively (Nwa and Ogunase, 1983). This average is rather too high for effective root growth. When these averages are compared with the averages of values obtained in this study for the soils, it was found to be 1.60, 1.51 and 1.45 gcm^{-3} respectively. This is showing that there was reduction in bulk densities over the years. However, generally, the bulk density decreases down the profile up to the 45-60cm depth where an increase is noticeable. This may be connected with compaction due to continous cultivation using heavy implements. It has been shown in most work that soils under mechanized continous cultivation develop compaction at depths below 30cm (Adeoye, 1983).

Generally, high bulk density signifies a high soil compaction as this property restricts root growth and development which consequently affects crop yield. Adeoye, (1983) found that bulk

density > 1.62 gcm^{-3} was high enough to affect root growth in the Northern Guinea savannah.

4.2.2 Percentage Porosity:

Percentage Porosity is a measure of the volume of voids in the soil i.e those parts of the soil volume not occupied by solid but either by air or/and water. On the average, percentage porosity for Pal, Pab and Pab/Pb units were found to be 40%, 42% and 45% respectively. The high percent porosity recorded in the Pab/Pb soils is due to the high content of coarse materials in the soils whereas the increase in percentage porosity in the V soils of all the units is possible due to the activities of micro-organisms which open the top soil through to the lower layers of the profiles. The activities of these micro-organisms would be enhanced by the effect of root ramification in the lower layers. There is a serious reduction in percentage porosity of these soils when the result is compared with the values obtained two decades ago. NEDECO (1974) found that the percentage porosity of the Pal unit was 51 while in this study the average was 40% for the same Pal unit. The reduction has again confirmed the long term disadvantage of mechanised continous cultivation as soils are compacted under heavy traffic. Compaction was found to reduce porosity of a sandy loam soil in the North Eastern part of Nigeria by Ohu et al, (1989). These reductions in porosity will create unfavourable aeration condition and poor drainage in the soils, accounting for the high waterlogging problem prevalent in the

locations during the rains and irrigation periods.

Low porosity is not uncommon in tropical soils. For example, low porosity of the surface soil of some northern Nigeria soils was reported by Kowal (1968). Similarly Lal (1979b) reported some studies in Nigeria and elsewhere in the tropics which indicate that tropical soils are easily compacted, and subsequently, decreasing the saturated hydraulic conductivities of these soils. Ohu et al (1989) showed that the Ks of a sandy loam and a loamy sandy soil decreased with increases in compaction and bulk density. A similar result was obtained on a coarse sandy soil in Niamey (Hoogmoed and Klaij, 1990).

4.2.3 Water content

Water content (θv) is the result of assessments of volumetric water content (θv) is presented on Table 7. Generally, in all the soils, volumetric water content increases down the profile, a trend which corresponds with increasing clay content. However, a rather low volumetric water content was recorded at the Pab/Pb R soil (0.03 $cm3cm^{-3}$ at 0-15 cm and 0.10$cm3cm^{-3}$ at 45-60cm depth). This occurence was surprising though the groundwater was not reached at depth 100cm, since at the other locations, groundwater were at some points which would had contributed through capillary rise. Inspite of the total dryness of the location, the infiltration and saturated hydraulic conductivity values has not indicated high degree of macropores which would have aided permeability and good drainage, yet the clay content was not unusual. On the other hand,

the high water content registered at the other locations was due to reduced tillage practices that aid storage.

4.2.4 Aggregate stability

Percentage distribution of aggregates as indicated by MWD are shown on Table 8.

Table 8: Percentage distribution of aggregates of the three soil units

Soil Unit	Pal	Pab	Pab/Pb
C	17.32	17.20	44.93
R	49.89	42.80	46.15
V	75.84	47.30	63.86

From the values, the Pal unit soil has higher stability than others before commencement of farming activities on these soils. It can be inferred that when the soils were brought under cultivation, its structure deteriorated with time. Such a deterioration is associated with a reduction in aggregate stability, size and the air porosity (Dixon, 1966).

Generally, the Pab unit had the weakest structure soil in the beginning under all management options studied.

4.2.5 Saturated hydraulic conductivity (Ks)

The saturated hydraulic conductivity Ks values are presented in table 6. The saturated hydraulic conductivity Ks, varied considerably among the soil units. It ranged from 2.4 x 10^{-1} to

16.37 $mday^{-1}$ among the soil units. The values of saturated hydraulic conductivity, in all the soils studied revealed Ks decreasing with increasing profile depth. The decrease might be due to the increased bulk density, which agreed with the finding of Ohu et al (1989) where they showed that the saturated hydraulic conductivity of a sandy loam and a loamy sandy soil decreases with increase in compaction and bulk density. Since bulk density is an index in predicting Ks (Puckett et al, 1985) the high bulk density other than the exchangeable sodium obtained in the study can account for the low conductivity of these soils. The exchangeable cations data has shown that the high value of exchangeable sodium which swells on wetting and disperses effectively block the conducting-pore system of the soil matrix, reducing its hydraulic conductivity. Adeoye et al (1988) work on the vertisols of lake chad basin showed that calcium and magnesium on the other hand floculate the particles thus increases the porosity as well as saturated hydraulic conductivity.

Generally, the Pal soils are better conducting than the Pab or Pab/Pb unit soils. A positive correlation exists between the saturated hydraulic conductivity and particle size distribution values of the soils after they were bulked. The regression coefficient, r was found to be 0.843, 0.675 and 0.629 for the C, R and V bulked soils respectively. These r values were not statistically significant at $P < 0.01$. However, the r value of the C bulked soil was statistically significant at $P < 0.05$ ($r = 0.843^*$). The higher the sand fraction in the soil, the higher is

the saturated hydraulic conductivity rate while as clay increases (which was the case with these soils with increasing depth) the clay particles clog conducting pores and decrease the saturated hydraulic conductivity. The high Ks values obtained in the Pal unit soils was due to cultivation which encourage the activity of micro-organisms on the one hand and the natural structure of the soils. The highest Ks value of 17.20 $mday^{-1}$ recorded in the Pal V soil was probably caused by root of Palm trees which created pores and cracks in the soil.

The other groups could be attributed to the weak, structural stability of the soils resulting from bad management practices. The values of saturated hydraulic conductivity obtained appear to be very low when compared with those of NEDECO, (1974); Nwa and Ogunase, (1983).

In view of these differences, it can be inferred that the management practices carried out on these soils are not favourable. The saturated hydraulic conductivities exhibited extreme variability among the three units within two decades. If this trend continues, then irrigation is not a blessing, rather new practise that will take into consideration the nature of the soils so as to reduce its negative effect and reduce deterioration, and enhance productivity is encouraged.

Table 9: Infiltration data at the nine locations

Management Condition	Soil units			
		Pal	Pab	Pab/Pb
	Time(min)	Cun.Inf(cm)	Cum.Inf(cm)	Cum.Inf(cm)
C	20.0	0.055	0.035	0.007
	40.0	0.083	0.053	0.014
	60.0	0.102	0.066	0.021
	80.0	0.117	0.079	0.034
	100.0	0.125	0.085	0.047
	120.0	0.135	0.090	0.054
	140.0	0.147	0.095	0.067
	160.0	0.159	0.100	0.080
	180.0	0.162	0.103	0.093
	200.0	0.168	0.106	0.106
	220.0	0.173	0.109	0.119
	240.0	0.177	0.112	0.132
	260.0	0.181	0.115	0.145
	280.0	0.185	0.117	0.155
	300.0	0.188	0.119	0.165
	320.0	0.191	0.120	0.178
	340.0	0.194	0.121	0.188
R	20.0	0.076	0.016	0.002
	40.0	0.152	0.025	0.007
	60.0	0.228	0.031	0.010
	80.0	0.379	0.036	0.013
	100.0	0.455	0.040	0.016
	120.0	0.531	0.044	0.018
	140.0	0.607	0.047	0.021
	160.0	0.758	0.050	0.023
	180.0	0.834	0.052	0.025
	200.0	0.872	0.054	0.026
	220.0	0.910	0.056	0.027
	240.0	0.986	0.058	0.029
	260.0	1.062	0.060	0.031
	280.0	1.138	0.062	0.032
	300.0	1.176	0.064	0.033
	320.0	1.252	0.065	0.034
	340.0	1.290	0.066	0.035

Table 9 Contd: Infiltration data at the nine locations

Management Condition	Soil units			
		Pal	Pab	Pab/Pb
	Time(min)	(un.Inf(cm)	Cum.Inf(cm)	Cum.Inf(cm)
V	20.0	0.12	0.026	0.030
	40.0	0.21	0.039	0.040
	60.0	0.27	0.052	0.045
	80.0	0.32	0.065	0.050
	100.0	0.36	0.078	0.055
	120.0	0.39	0.081	0.060
	140.0	0.42	0.084	0.063
	160.0	0.45	0.087	0.066
	180.0	0.47	0.090	0.069
	200.0	0.49	0.092	0.071
	220.0	0.51	0.094	0.073
	240.0	0.53	0.096	0.074
	260.0	0.55	0.098	0.075
	280.0	0.56	0.100	0.076
	300.0	0.57	0.102	0.077
	320.0	0.58	0.118	0.078
	340.0	0.59	0.134	0.079

4.3.1 Infiltration Rate

Infiltration was carried out on the locations. The surfaces of C soil, of Pal, Pab and Pab/Pb units were rough from ploughing. The surfaces contained few grasses which were carefully removed. There was no surface wetness from previous irrigation. At the R soils of the units surface crust was noticeable along with some dried grasses. In the V soils where no farming takes place, there were little cracks grasses and heavy root ramification.

Data on accumulated infiltration for 340 minutes and depth of wetting are given on table in appendix. However, table 7 contain the data for the cummulative infiltration for the three soil units.

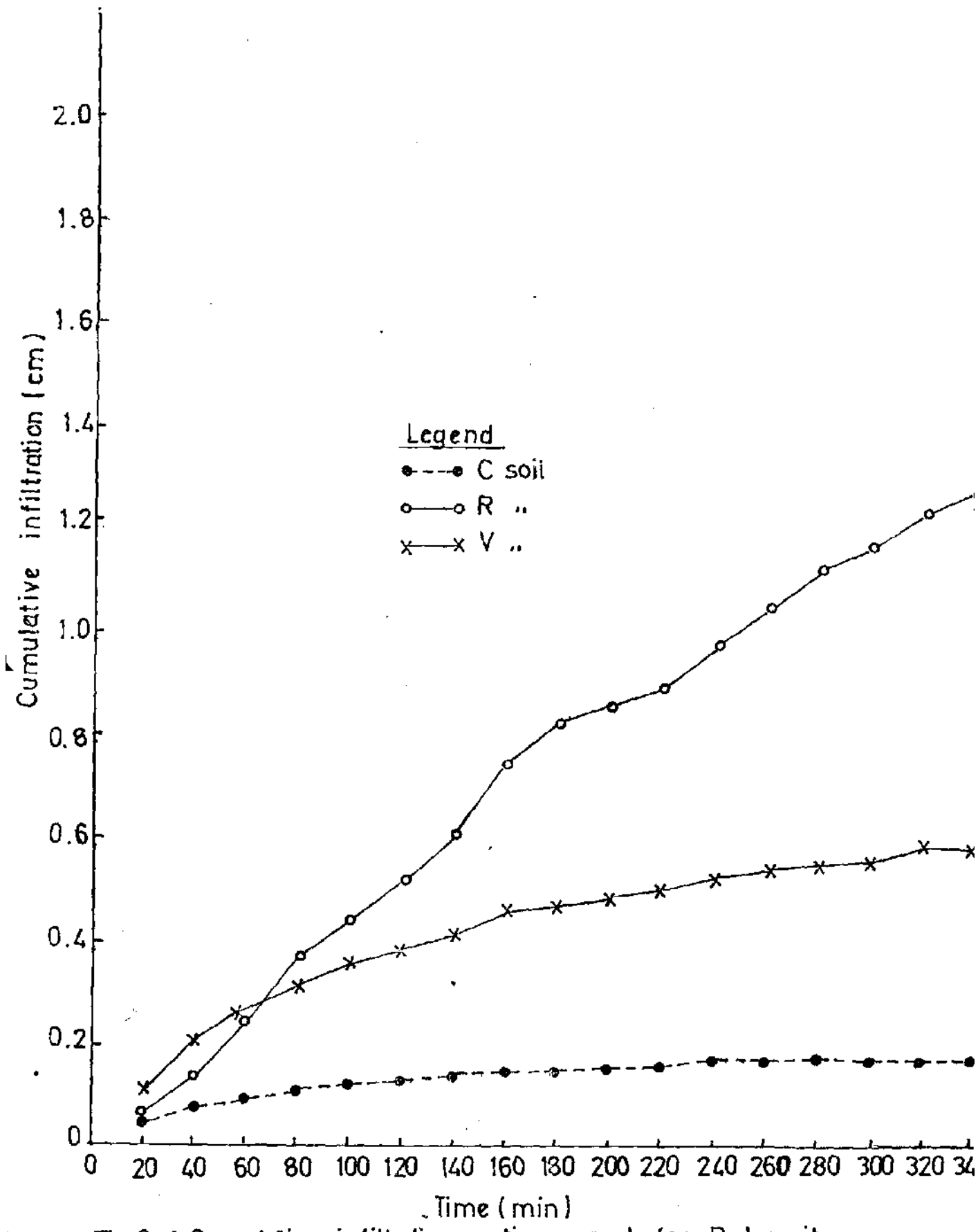
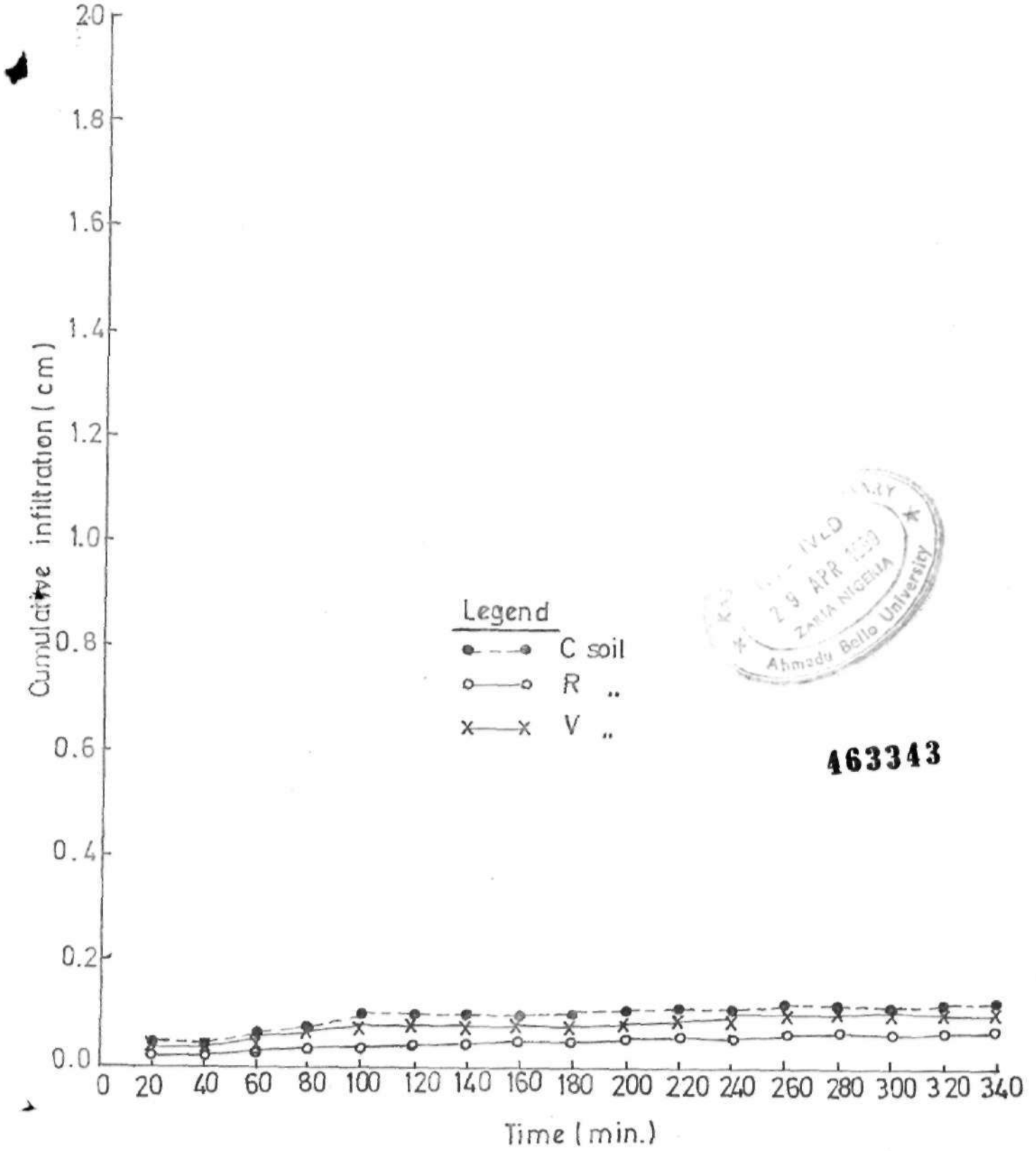


Fig.3a: Cumulative infiltration vs time graph for PaL unit



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Fig.3b: Cumulative infiltration vs time graph for Pab unit

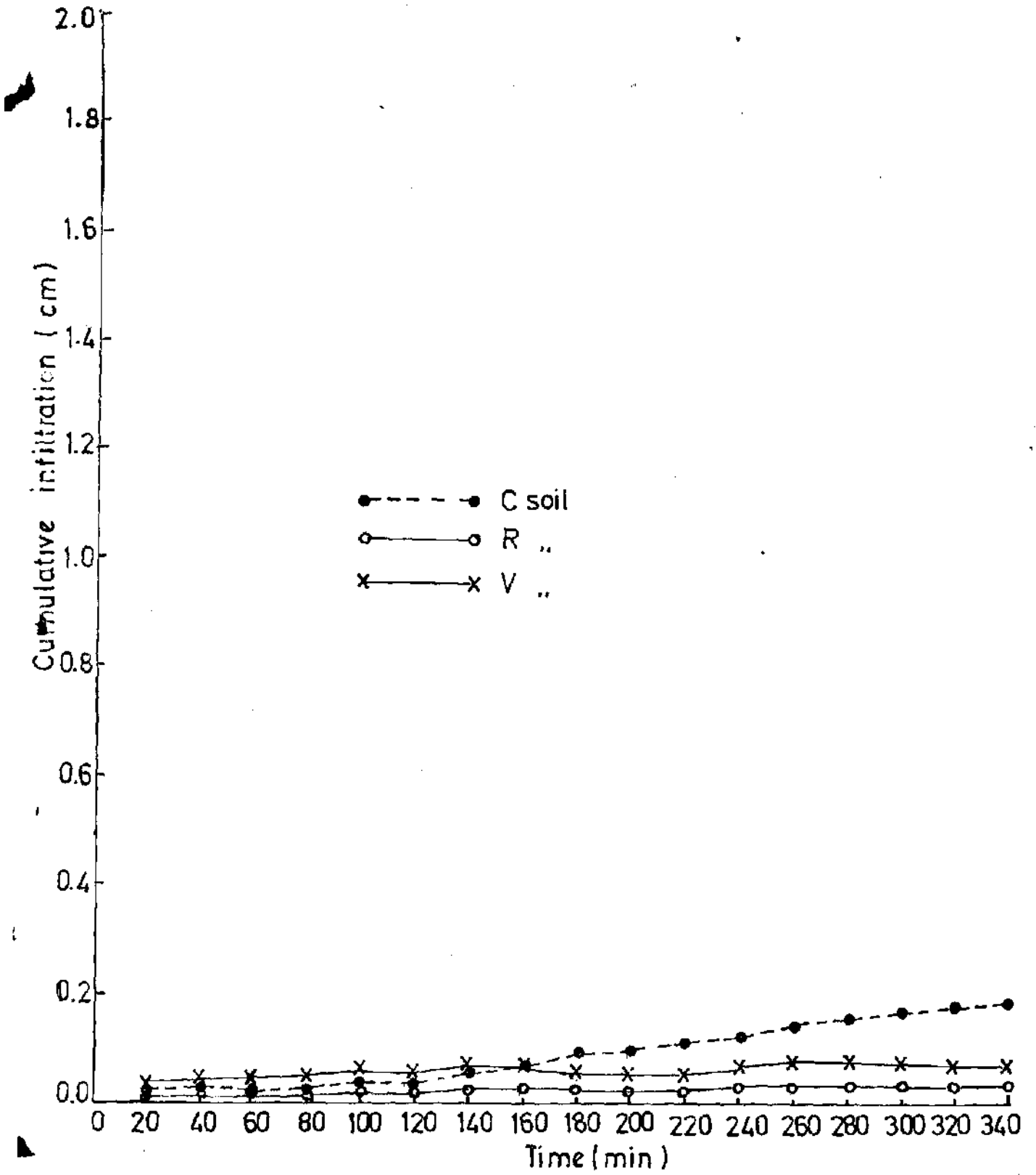


Fig.3c. Cumulative infiltration vs time graph for Pab/Pb unit

The graphs of the infiltration are presented in figures 3a, 3b and 3c. The pattern of the graphs shows variability in infiltration rate among the soils. The infiltration rate at the Pab and Pab/Pb sites is low. Though the C and R soils of these units should have shown a better infiltration rate as a result of cultivation, this finding is in contrast with the finding by Ahmed and Maurya (1989) where they reported that under conventional tillage in Kadawa, Kano State, infiltration rate decreases as the texture gets finer. Yet the values of particle size distribution shows that, generally, the sand content decreases with depth. The low infiltration rate could be due to soil surface crusting, dispersion resulting from sodium concentration, thereby clogging conducting pores; whereas on the other hand tillage and crop residues management practices, improved the infiltration rates, all these alter soil physical properties and these properties in turn affected the infiltration rate.

Highest infiltration was recorded on the Pal unit with the R soil being more porous, followed by V and C. This could be due to the presence of crevices or different saturated conductivities near the surface. The unsteady pattern of the R soil could be as a result of slaking which results with spontaneous ponding of water on the surface (Kowal, 1970) a feature apparent in the rainfed areas cultivated and inherent soil heterogeneities of field soils (Hillel, 1980). Variation of infiltration rates between all measured points was high (CV = 102.6%). This variability is higher than that reported by Imorou and Babalola (1986) and Folorunso and Olorunju (1986).

In all cases, steady state infiltration was not attained 340 minutes (5.67 hours) after the start of infiltration. These results differ widely with the 3½ and 4 hours respectively reported for the attainment of steady state infiltration in tropical soils by Ahmed (1982) and Adeoye (1986). Hence the high coefficient of variation reported. Finally, the irrigation method practiced in the area is Border which is not suitable to soils having a very low infiltration rate. Wheat and rice are mostly grown on these soils because of this condition. Evidently, the soils absorb water slowly, therefore to reduce soil degradation, puddling and crusting, a wide relatively shallow furrow method gives more area for the water to infiltrate.

Table 10: Moisture content (Θv) at different suction (Kpa)

Depth (cm)	<------Pal unit------>				<----- Pab unit------->				<---Pab/Pb unit---->			
C Soils	10	100	1000	1500	10	100	1000	1500	10	100	1000	1500
0-15	.18	.13	.07	.07	.24	.12	.10	.08	.20	.12	.08	.07
15-30	.28	.17	.11	.08	.21	.11	.09	.07	.38	.18	.17	.16
30-45	.37	.22	.14	.11	.36	.20	.15	.12	.36	.20	.17	.17
45-60	.41	.24	.16	.11	.37	.17	.15	.13	.45	.24	.21	.21
Soils												
0-15	.40	.18	.15	.11	.21	.14	.09	.05	.18	.09	.06	.05
15-30	.39	.22	.13	.11	.20	.13	.08	.07	.16	.09	.07	.06
30-45	.42	.19	.04	.05	.28	.17	.12	.09	.16	.08	.06	.05
45-60	.43	.18	.10	.04	.34	.22	.15	.10	.27	.14	.11	.09
V Soils												
0-15	.19	.11	.06	.05	.39	.19	.16	.15	.48	.12	.08	.08
15-30	.21	.13	.08	.05	.43	.18	.16	.11	.46	.10	.08	.03
30-45	.21	.12	.07	.05	.42	.23	.12	.12	.40	.07	.06	.02
45-60	.21	.14	.09	.06	.47	.25	.17	.17	.44	.10	.09	.03

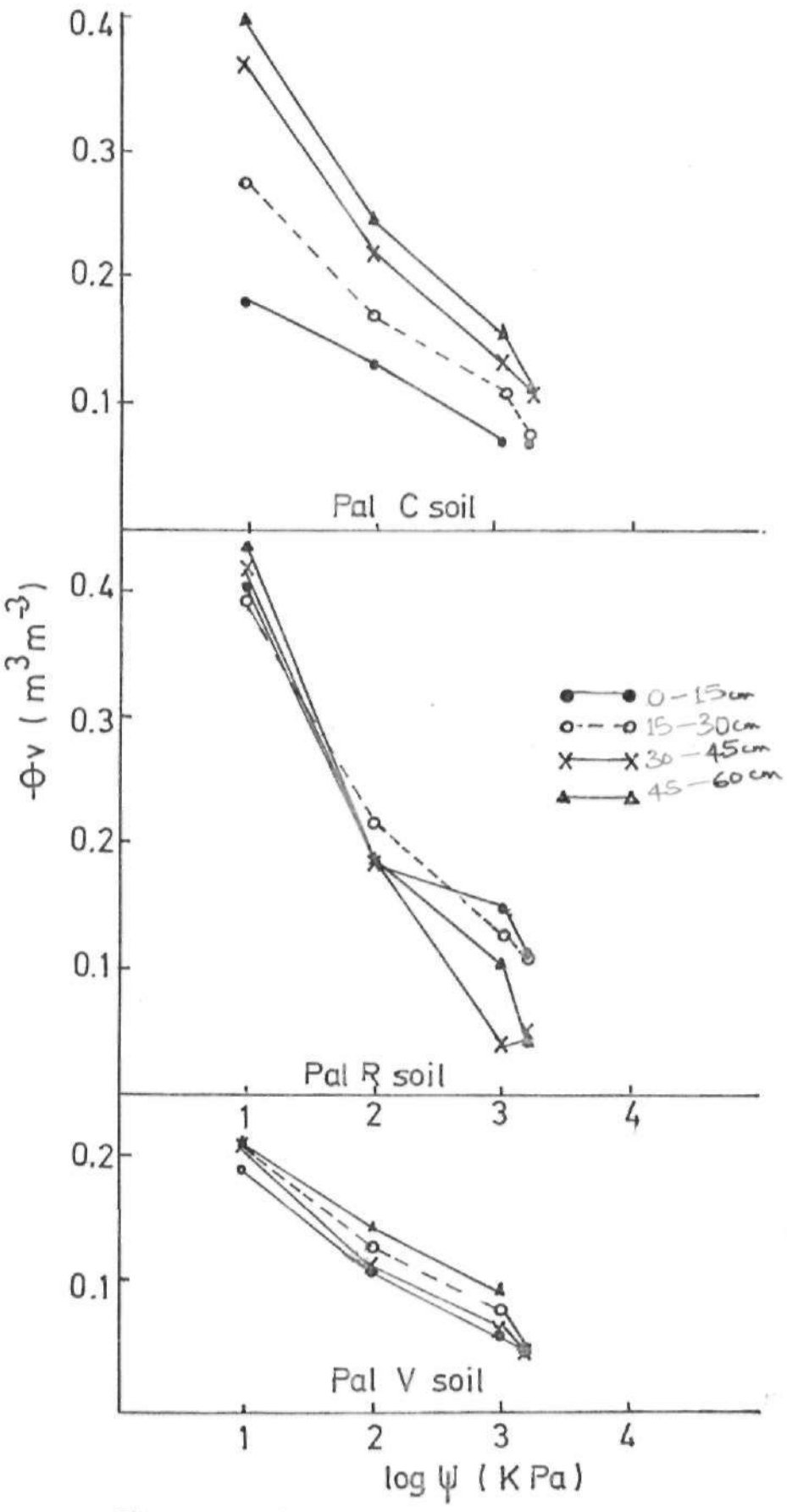


Fig. 4a Moisture content against matric potential for Pal unit soils

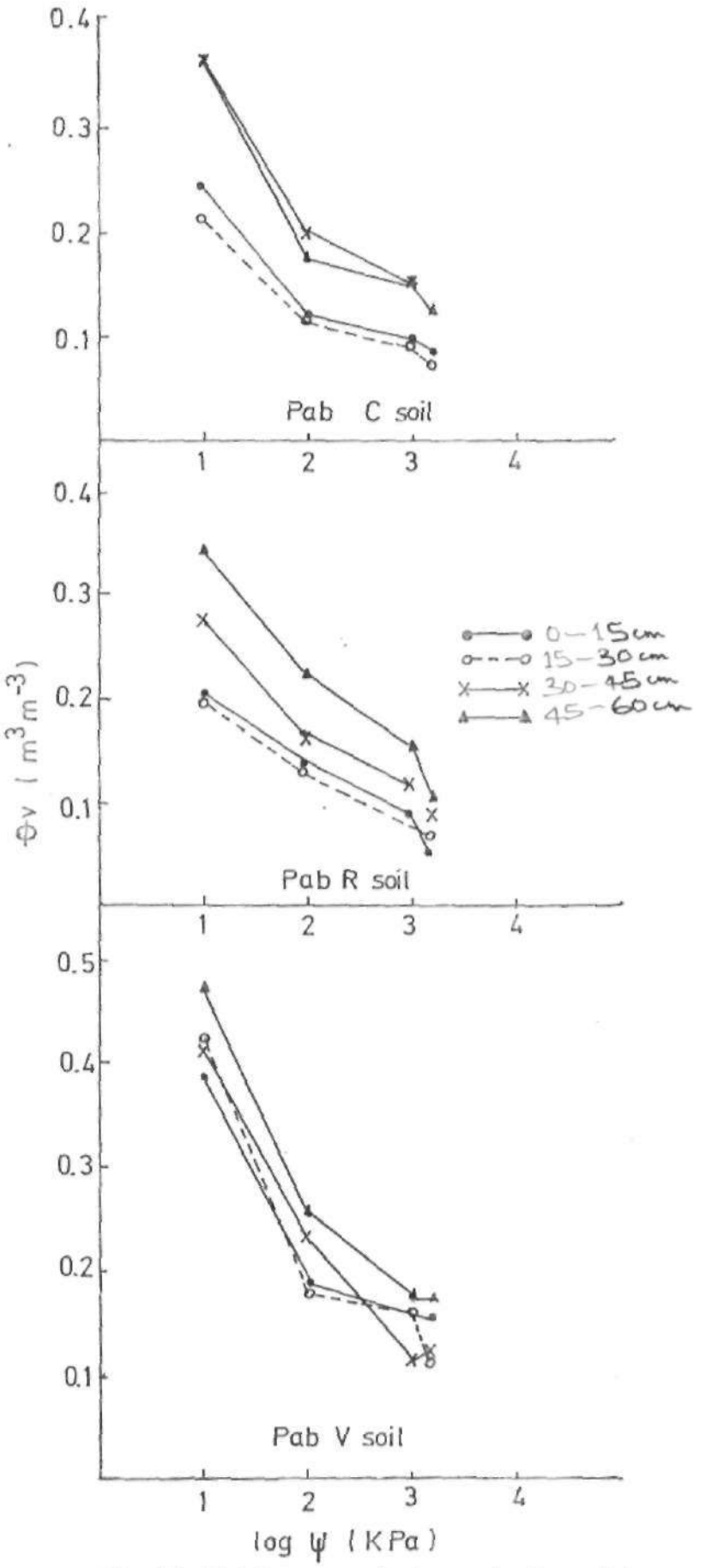


Fig. 4b. Moisture content against metric potential for Pab unit soils

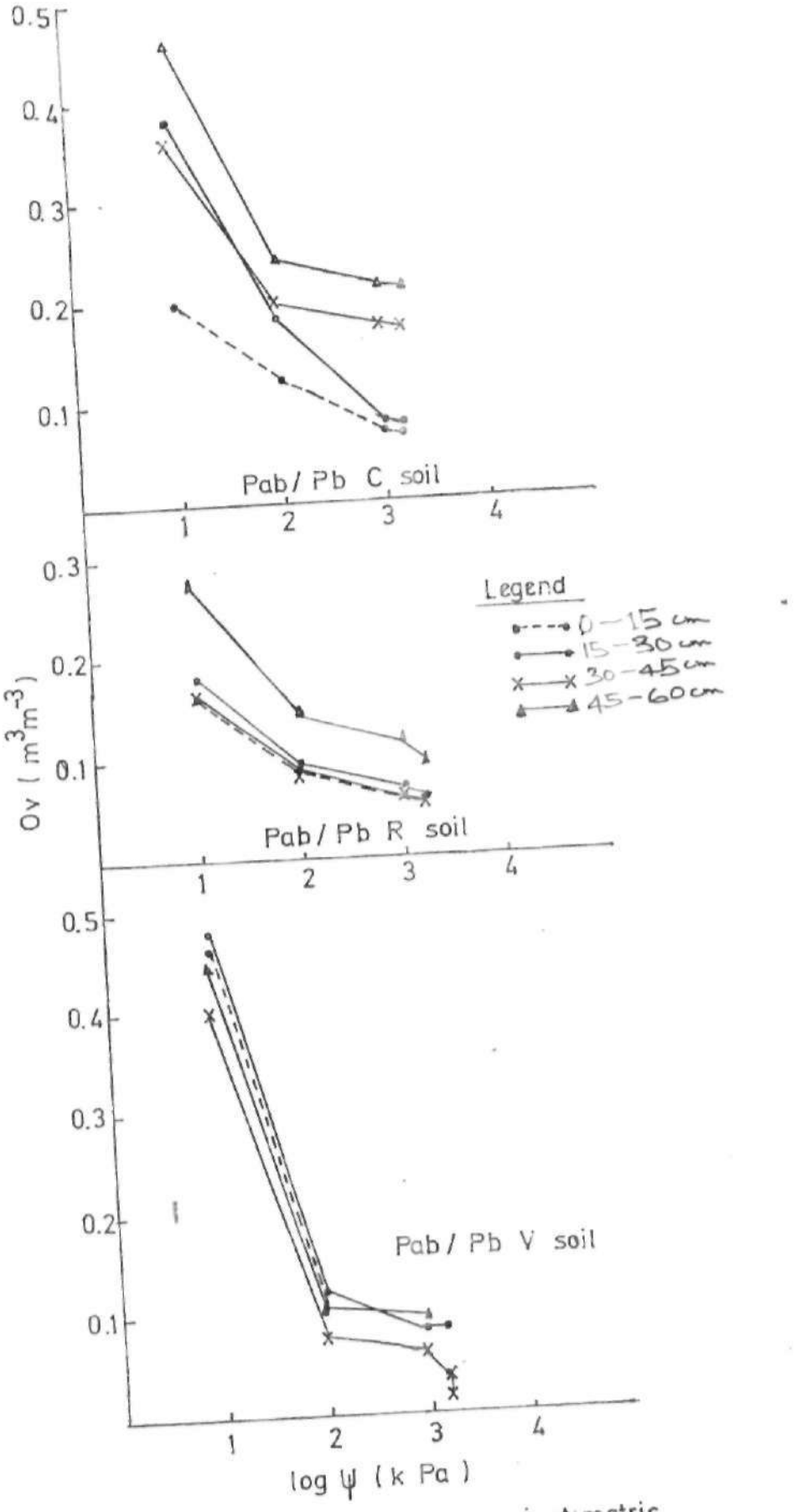


Fig. 4c Moisture content against matric potentail for Pab/Pb unit soils

4.4 COMPARISM OF SOIL PHYSICAL PROPERTIES

4.4.1 Soil Moisture Retention and Available Water Capacity

The moisture Retention characteristics of soils are important because they determine the amount of moisture that is available for extraction by plants. The ranges of moisture level at saturation and 15-bar suction are shown in figures 4a, b and c for the three unit soils. The moisture retained at 0.1 bar, 1 bar and 15-bar are different for all the soils. The differences are also reflected in the available water-holding capacity of these soils.

Generally, the moisture contents at the different suctions increased with depth in the C, R and V soils Pal unit and the C and R soils of the Pab/Pb unit. The others show fluctuations in moisture content retained at different depth. Although in the whole at the 45-60cm depth, all the units exhibit highest moisture retained at all suctions. This could be as a result of elluviation of fine particles to this depth. The available water holding capacity of the Pab/Pb unit is the lowest of the three soil units. The soils tend to exhibit high degree of tenacity to water at suctions lower than $^{1}/_{3}$ bar. The soils can only sustain crops that have less demand for moisture, though, it was noted that there is serious waterlogging problem in these soils.

The integrated available water holding capacity for all the soils are shown in figures 5a, 5b and 5c. Within the whole profile (60cm depth), the Pal C and Pab V soils had more available water (2.33 and 2.38cm respectively) than the remaining soils. Generally, the available water capacity of these soils is low.

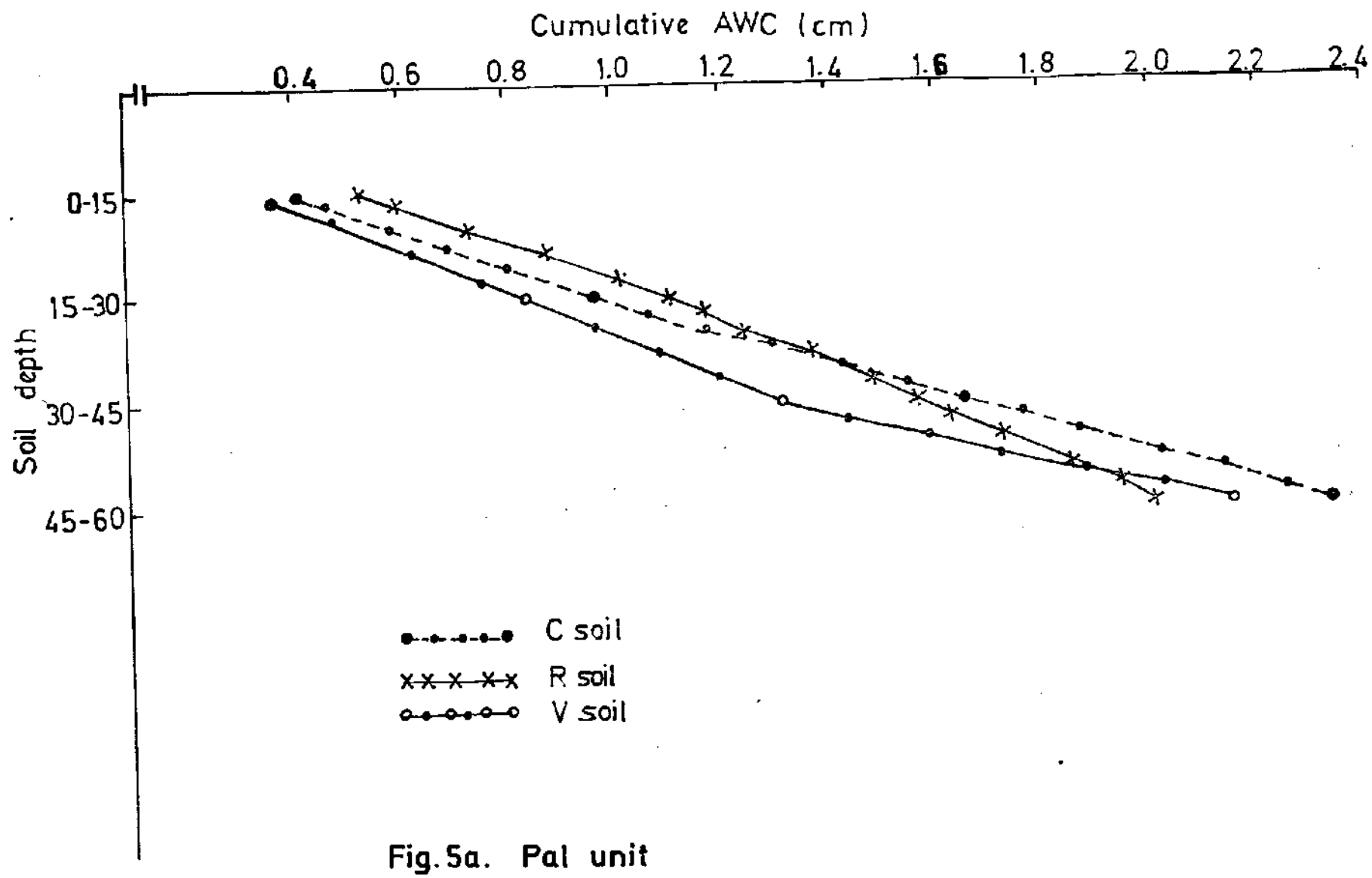


Fig. 5a. Pal unit

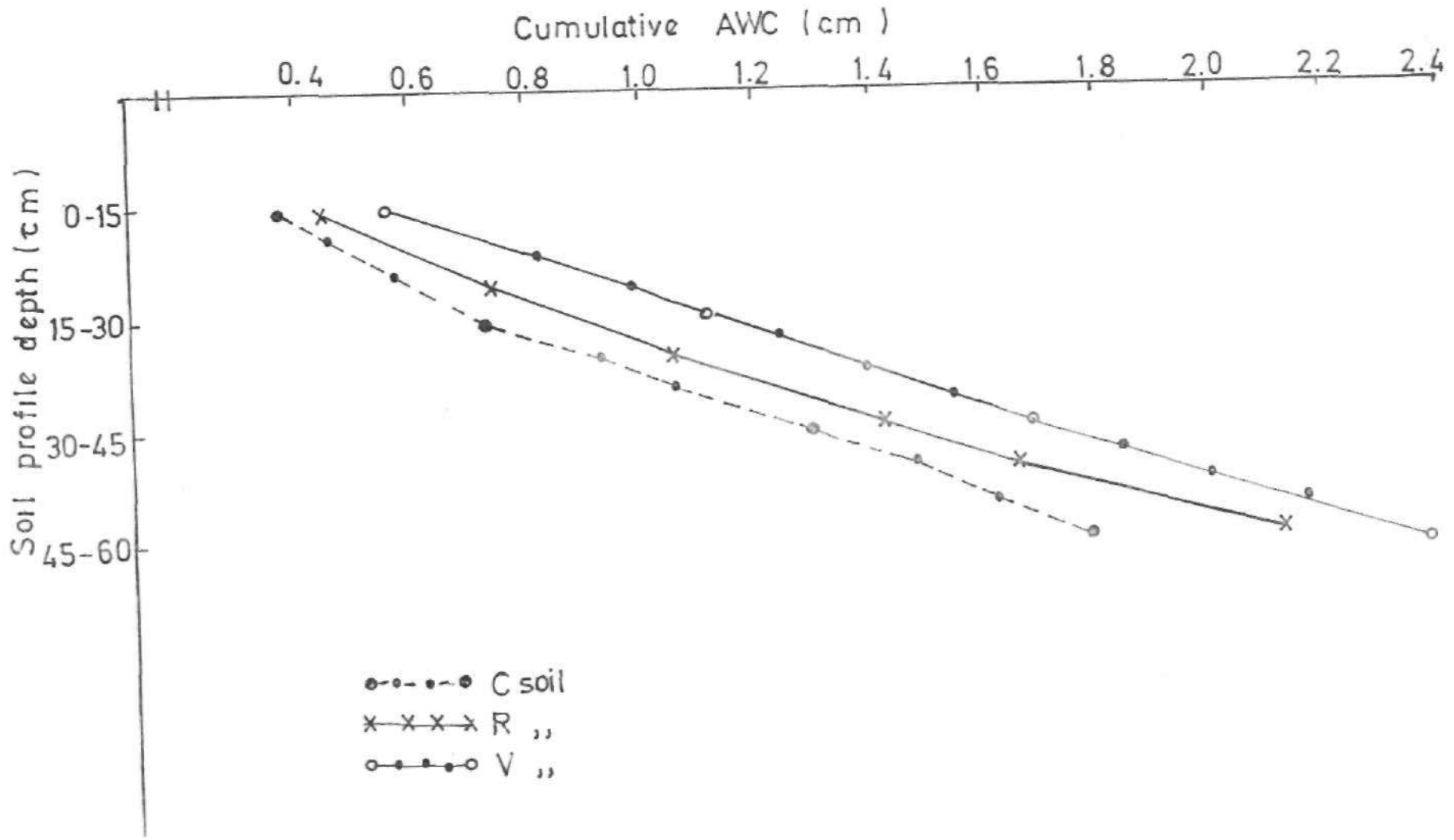


Fig.5b Pab unit

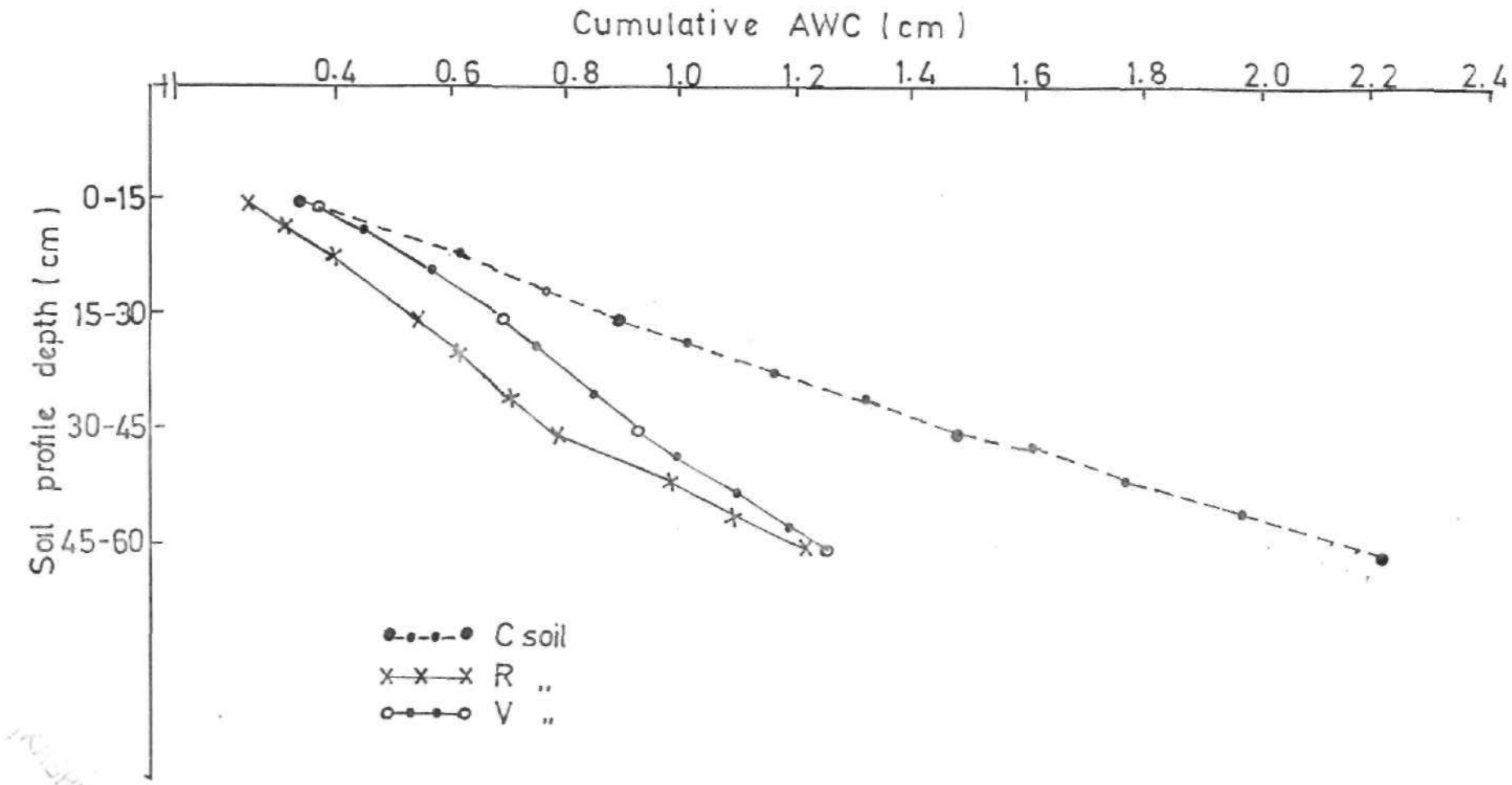


Fig. 5c Pab / Pb unit

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With this low available water capacity, irrigation application of the basin method will be appropriate since no run-off of soil or water takes place and wetting depth can be more uniform. It is best suited for soils of moderate to slow infiltration rates as was seen in the figures of infiltrability.

In all, it can be infered that the Pal and Pab soils can be improved if a better soil management techniques employed because from figure 4c, the Pab/Pbc soil which is under continous cultivation has shown an improvement in water holding capacity than the Pab/Pb R and V soils. Compaction, surface crusting and sealing is a prevalent problem in the soils which is adversely affecting water storage capacity.

4.4.2 Volume wetness - Matric suction

The volume wetness-matric suction data are presented on Table 10. Figures 6, 7 and 8 reveal the behaviour of the soil moisture as a result of varied suctions. As expected, moisture content decreases with increasing suction in all the soils under investigation. Additionally, the behaviour of soil moisture at different suction is influenced by the texture of the soil. Increasing clay content with depth increases the ability of the soil to hold water against the suction force, hence at 15-bar, water is still available to the plants but only at lower depths (i.e 60cm) because of the higher clay content in these depths. Most available water for plants at the top layer is between 0.1 and 1.0 bar. Given that the amount of moisture stored up to 60cm depth

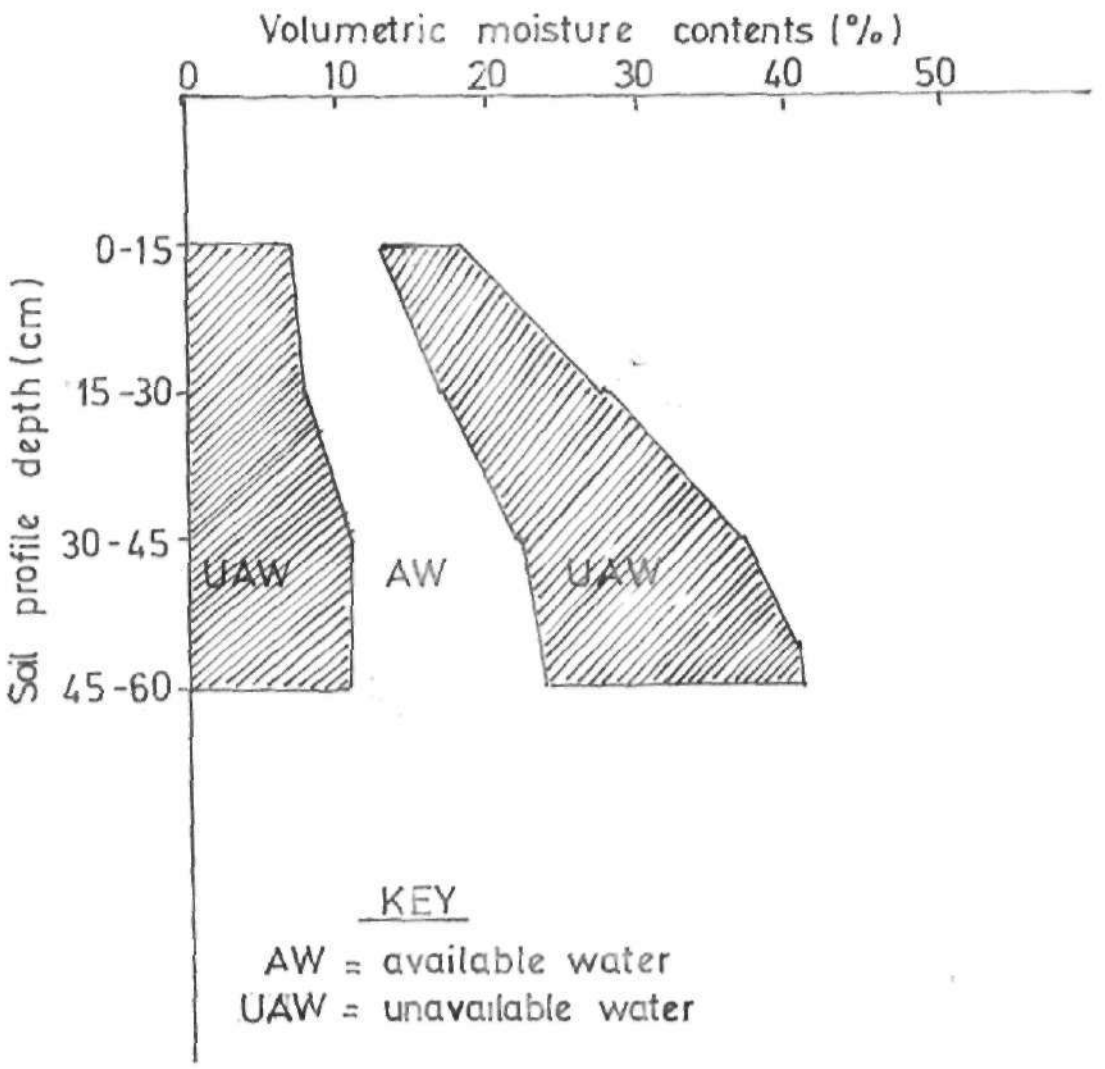


Fig. 6Q Pal C soil

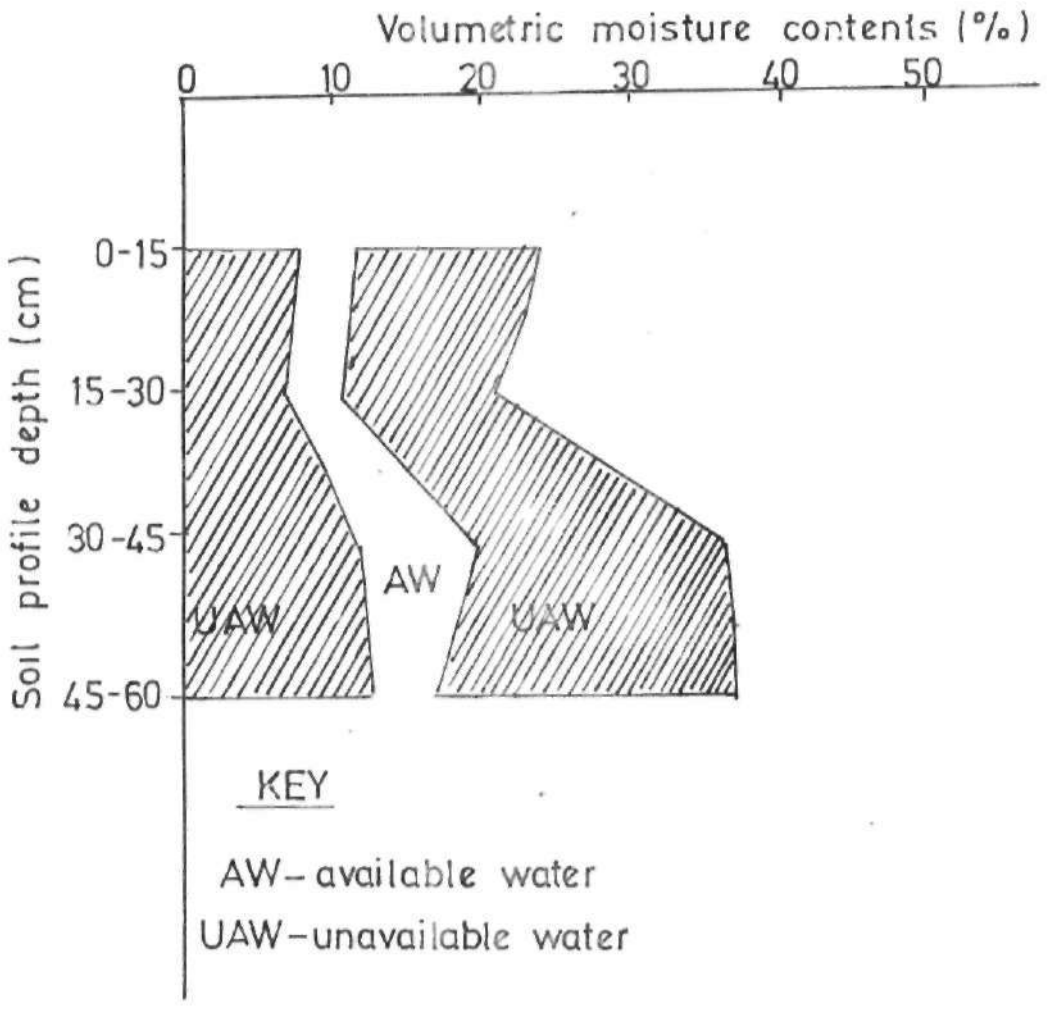


Fig. 7a Pab C soil

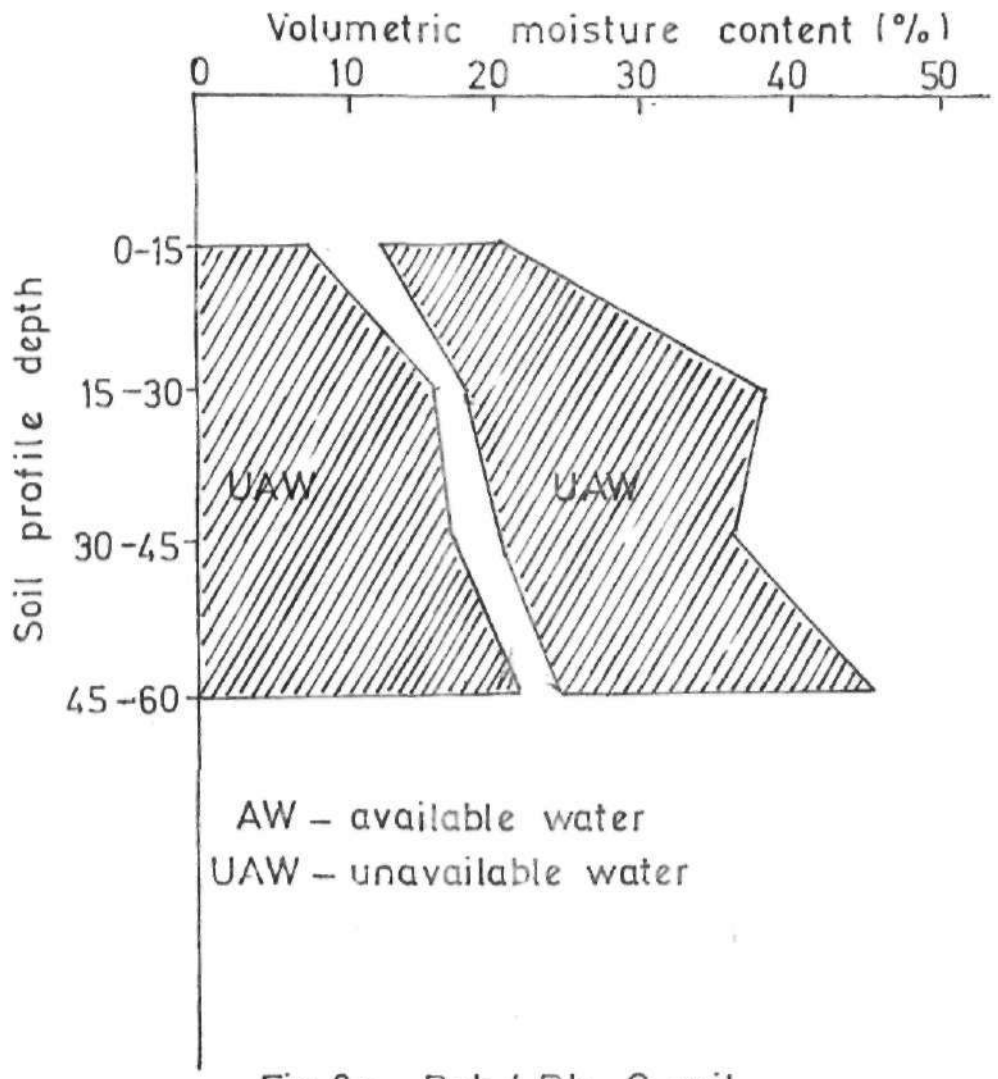


Fig. 8a. Pab / Pb C soil

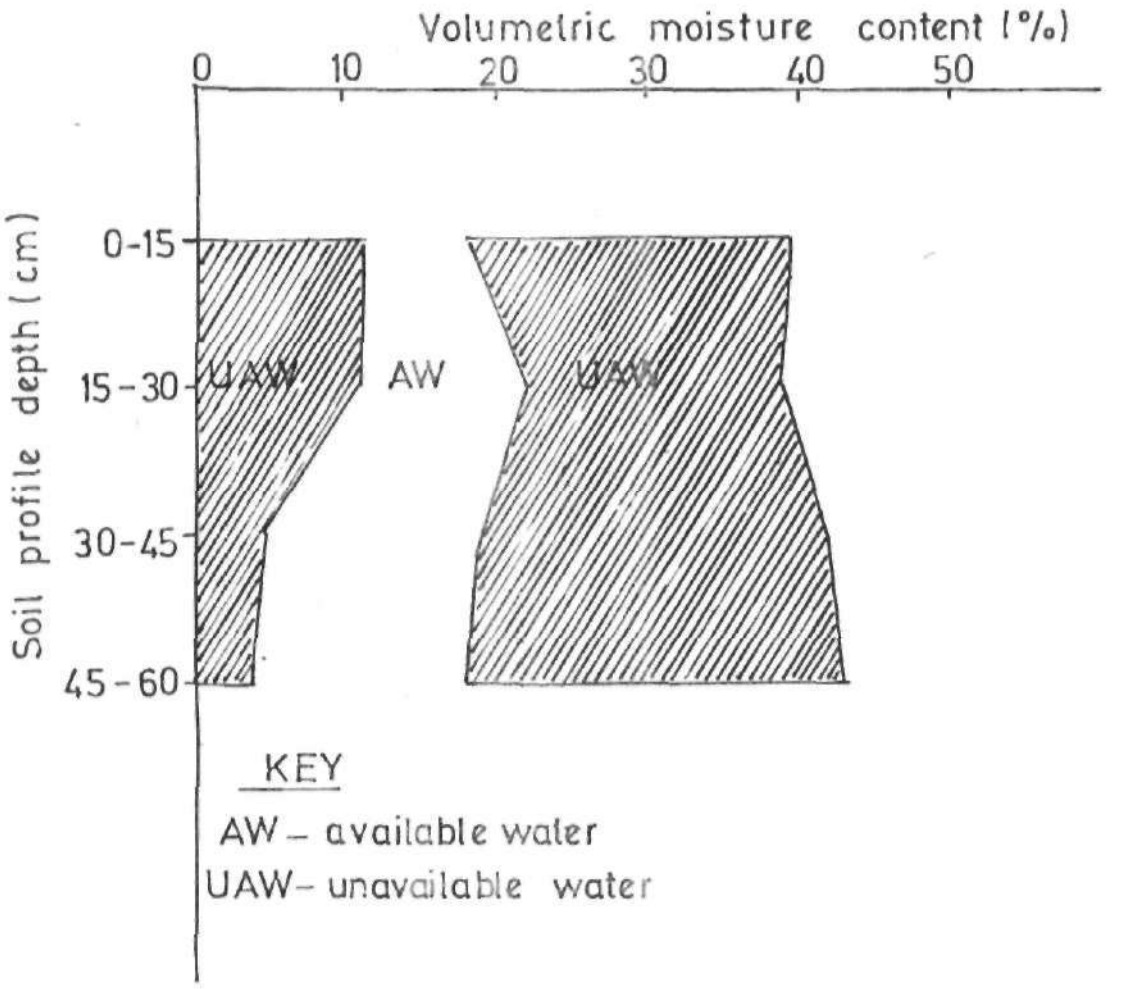


Fig. 6b Pal R soil

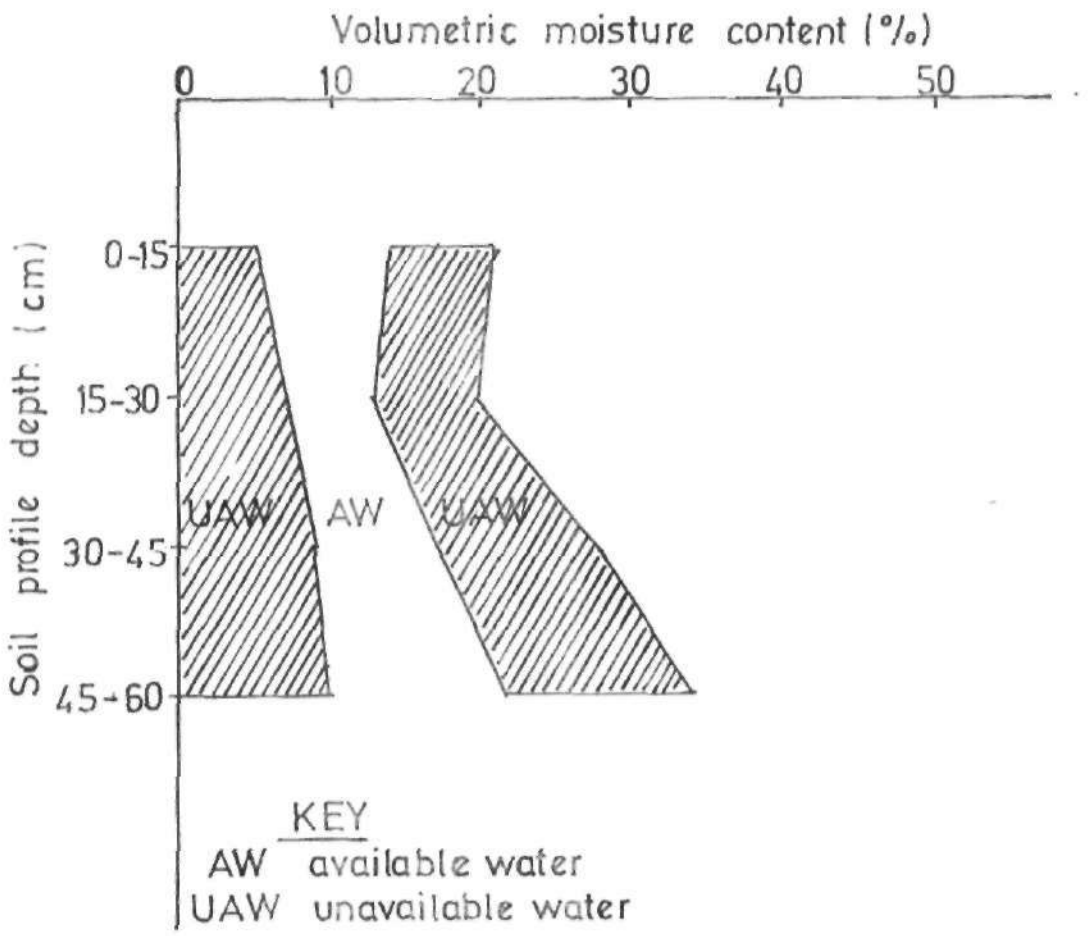


Fig. 7b Pab R soil

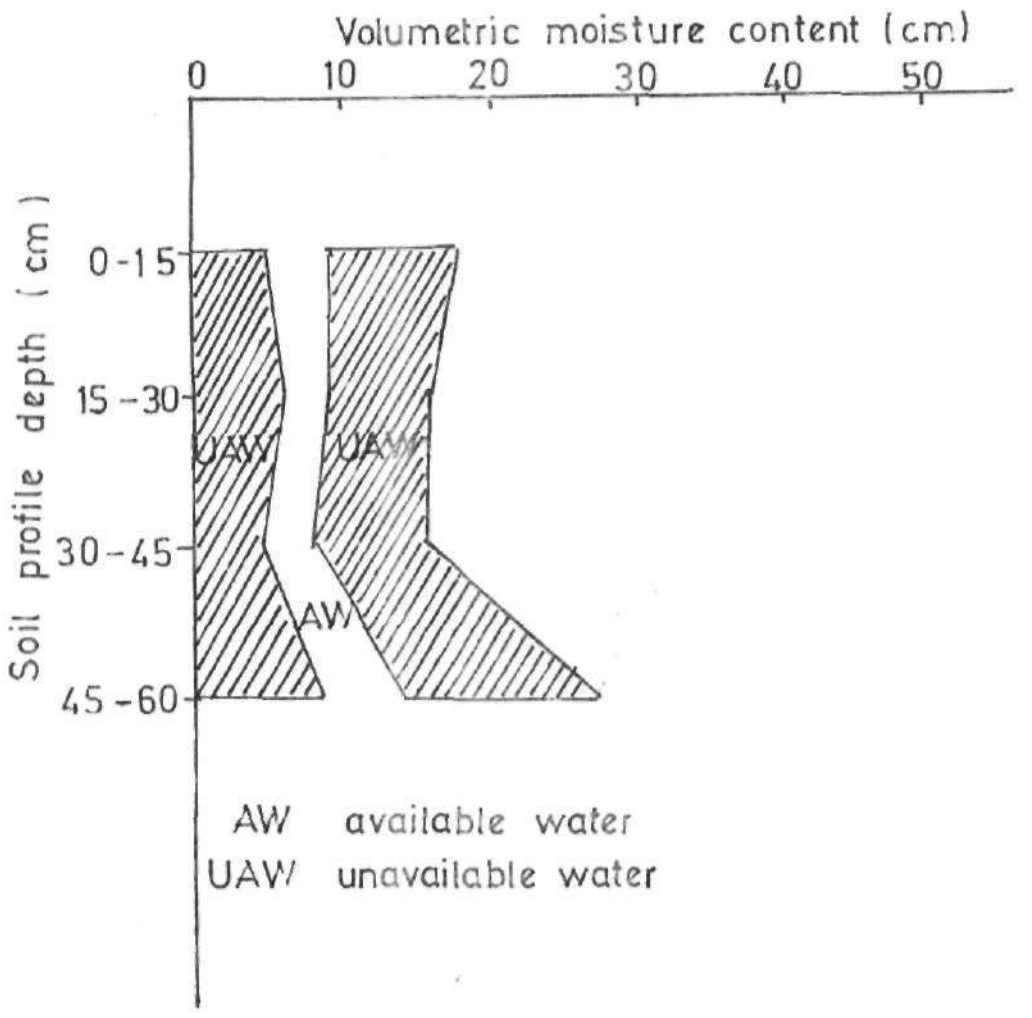


Fig. 8b Pab / Pb R soil

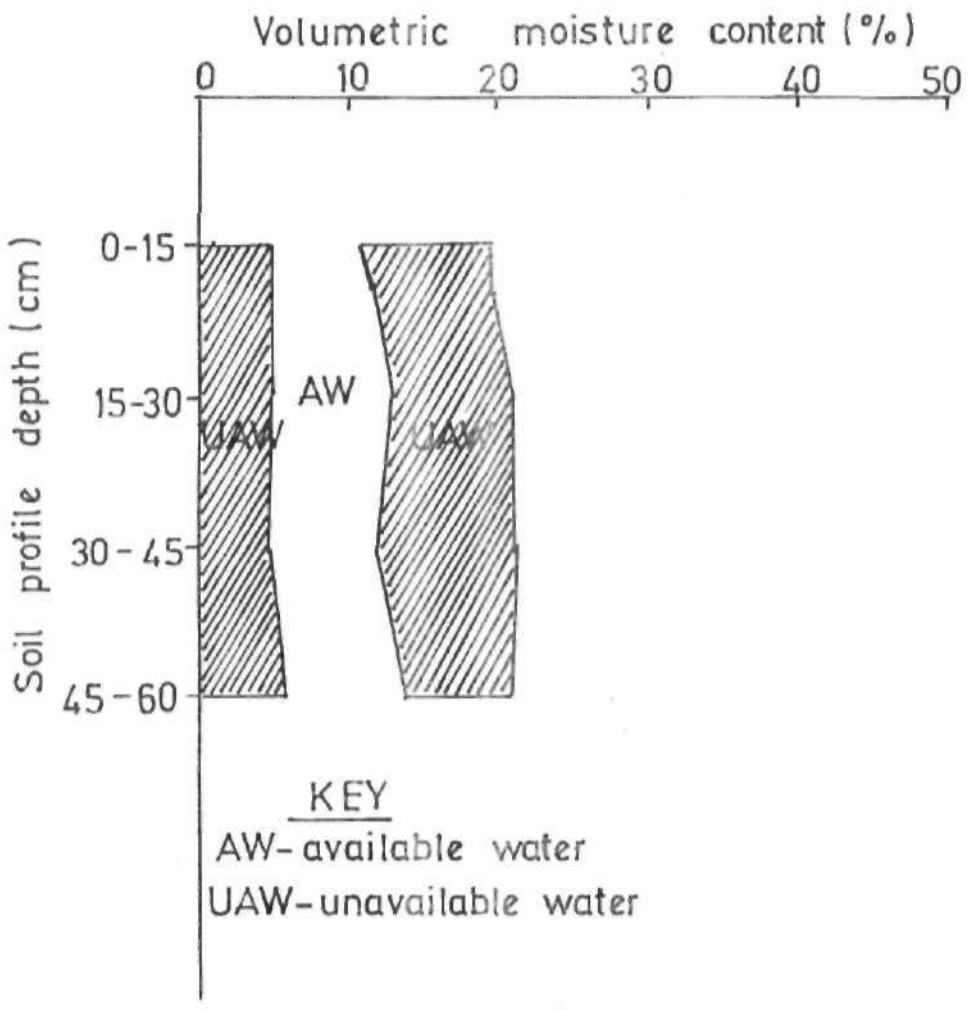


Fig. 6c Pal V soil

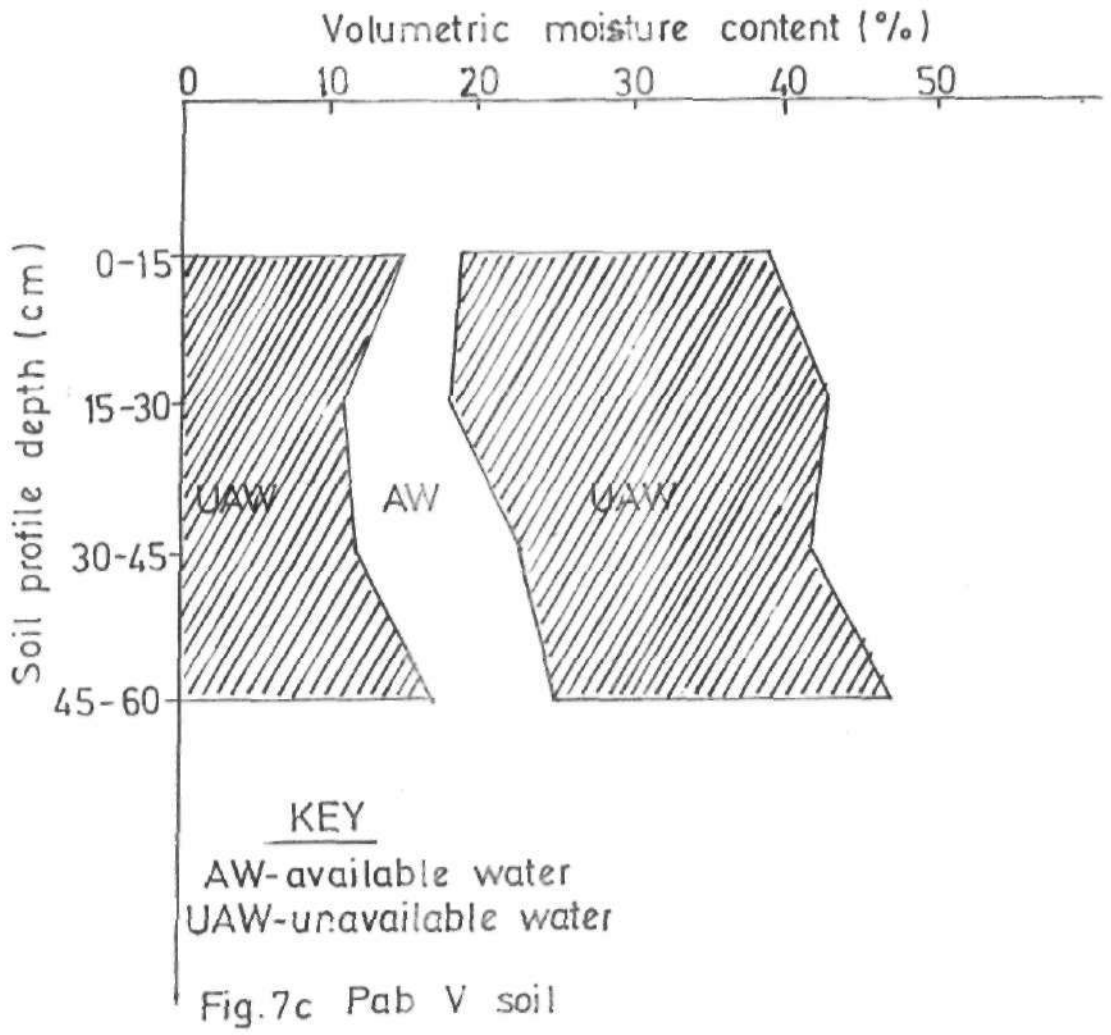


Fig.7c Pab V soil

between 0.1 and 15 bars on average for the Pal, Pab and Pab/Pb units are 2.14, 2.10 and 1.56 cm respectively and considering that the potential evaporation alone can be up to 60mm day^{-1} or more (Kowal and Knabe, 1972) the available soil moisture would be depleted within a period of 10 days without rain or irrigation.

Within the Pal unit, readily available water regardless of amount can still be available to plants at a little above the 1.0 bar in the cultivated C and R soils whereas less moisture is available and tightly held to the soil matrix in the V soils. This could be so as a result of presence of particles with small surface areas.

Within the Pal unit, readily available moisture is more pronounced at the upper layers (between 0-30cm depth) which seems to have more of finer particles. The opposite is the case here where the uncultivated soil (Pab V soil) has more moisture than the cultivated C and R soils respectively.

In the case of the Pab/Pb unit, there is more readily available moisture further down the profile in the R than C soils at the top 0-15cm depth; whereas more moisture will be available at lower suctions at the top soils than at the subsoils. In this soil, if cultivated of shallow rooted crops, will benefit more than deep rooted crops, only that more of the water will be lost through evaporation when the climate is very dry.

Generally, the moisture in the 30-60cm depth zone is more closely held by the soil matrix compared with the top soils. The soil layer between 10 and 30cm depth represent a transition in

hydraulic properties between the relatively coarse textured soils above and the fine textured materials below. This observation is in agreement with the generally accepted views and my findings that the moisture retention characteristics of a soil at low suctions is dominated more by structure than texture.

CHAPTER FIVE

5. SUMMARY AND CONCLUSIONS

Three soil units of the upland plain of the Kano River Project area were looked at to assess the hydraulic characteristics as affected by irrigation and whether the management practices in place should be continued. Between the three soils of the three units studied, the Pal unit soils has better characteristics for continous agriculture under good management practice. However, the Pab and Pab/Pb unit soils can be more productive for irrigated agricultutre under intensive management because of the weak structure and strong winds prevalent in the area.

Generally, there had not been appreciable change in the texture of these soils though the tendency of developing clayey sub-soil is very high in future in the cultivated areas because of mechanised systems of cultivation.

The chemical properties of the soils are changing very fast, and at the rate, the fertility of the soils will be lost in a few years time. Initially, the soil fertility was low and has not improved with time instead it is continously being depleted. For good yield to be obtained, large quantity of soil amendments will be required. Sodicity, one of basic problem of irrigation will be developed in later years if the rise in ground water which is almost near surface at the climatic condition is not checked by improved drainage.

The physical properties of the soils have changed remarkably over the years. Increased bulk density resulting from compaction

due to mechanised system of cultivation was noticed though in the uncultivated area, that could be due to human and grazing animal traffic. Hence the low porosity resulting in overall low air content. The initial weak structure of some of the soils along with cultivation account for the deterioration in structure with time hence the gradual reduction in aggregate stability.

Generally, the hydraulic conductivities of the soils has decreased with time, and varied greatly among the soils. The porosity and Bulk density which are good indicators of conductivity showed poor relationship. Soil moisture characteristics revealed that most available water is released at a or below 100 KPa, which implies poor storage characteristics of the soils. The Pal unit soil has more available water than the other soils. In all, it is noticed that there is more available water in the areas where there are more fine particles.

Infiltration rates varied considerably among the soils, and very low in the Pab and Pab/Pb unit soils. This resistance to water transmission lies mainly with the mechanised system practiced and the contribution from surface crusting and compaction. Low infiltration rates are closely associated with low saturated hydraulic conductivity, low organic carbon, low aggregate and less toutursity.

With the present management practices, weak fragile nature of the soils and the threat of groundwater, the soils will be completely unproductive in a few years time.

From this study conducted, it can be inferred for all the units thus;

Pal:- The Pal unit has good, irrigable soils with favourable physical qualities but a low chemical fertility. This low fertility makes them susceptible to erosion. Continous irrigation may pose drainage problems in lower-lying areas.

Pab:- The Pab unit has irrigable soils with limitations in crop choice, cultivation and irrigation methods. The main problem is the presence of a dense sub-surface horizon with lower root zone which inhibits free drainage. This problem can be arrested by deep ripping and possibly dril through the horizon down the soil profile. Also, there is the need for proper soil and water management to reduce the soil reduction to an acceptable value in areas of high bicarbonate concentration.

Pab/Pb:- the Pab/Pb unit has marginal irrigable soils with limitations in crop choice. Especially, shallow rooting crops are preferable, and can not be advised for use throughout the year.

5.1 RECOMMENDATIONS

1. Concommittant rise in groundwater should be reduced by providing good drainage through drilling of the hardpan.

2. Mechanised system which leads to high intensity of soil disturbance should be reduced to the barest minimum possible and zero tillage encouraged.
3. Incorporation of crop residues should be encouraged so that more stable soil rich in organic matter is maintained.
4. Ridging is closely associated with the development of a dense surface crust in the furrows, which in turn limits water infiltration should be discouraged, instead a wide relatively shallow furrow and horizontal basin methods is encouraged.
5. Deep ripping of the sub-soil and cultivation of deep rooting crops to improve the surface structure and porosity of the soil should be common practice.

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