CODESRIA

Dissertation By

OSAKWE, Nduli Chijioke

DEPARTMENT OF GEOGRAPHY AND PLANNING
FACULTY OF THE ENVIRONMENTAL SCIENCES
UNIVERSITY OF JOS
JOS - NIGERIA

Irrigation water use in a farm on the Delimi Floodplain, near Jos plateau State

JANUARY, 1992

IRRIGATION WATER USE IN A FARM ON THE DELIMI FLOODPLAIN, NEAR JOS PLATEAU STATE

BY

NDUDI CHIJIOKE OSAKWE, B.Sc (Hons) Ibadan
PGES/UJ/5570/90

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE (M.Sc) DEGREE IN ENVIRONMENTAL AND RESOURCES PLANNING IN THE

DEPARTMENT OF GEOGRAPHY AND PLANNING
FACULTY OF THE ENVIRONMENTAL SCIENCES
UNIVERSITY OF JOS
JOS - NIGERIA

JANUARY, 1992

CERTIFICATION

I certify that the study presented in this dissertation was carried out under my supervision by OSAKWE C. NDUDI in the Department of Geography and Planning, University of Jos, Nigeria.

Dr. J. L. Nyagba, B.Sc (ABU) Ph.D
Supervisor

Date: 10th Jan 1992

DEDICATION

This work is dedicated to my mother Mrs. M. M. Osakwe for her insistence.

ACKNOWLEDGEMENT

With gratitude to God, I wish to express my appreciation to various people that helped in one way or the other in the completion of this study.

First, I am greatly indebted to my supervisor, Dr. J. L. Nyagba for the guidance and constructive criticism throughout the period of this work. My sincere thanks also go to the senior academic staff of the Department of Geography, particularly, Professors G.C. Okechukwu, K.S. Schonoeich, Mr. A.C. Eziashi and the University of Durham Fellows - Drs. Philips-Howard Kevin and Kidd Andrew.

I would also like to specially thank Wulha for making my stay in the University a worthwhile experience. Special thanks should also go to my sisters - Mrs Ifeanyi Atenaga-Osakwe and Mrs. Ebele Osakwe-Taiwo for their love which have remained unflinching. I would not forget in a hurry the encouragement and support provided by Appollonia Ugbomeh, Faith Owete, Alhaji Habibu and Onyenike Peter. I am equally grateful to Messrs Olowolafe and Abangwu of the Soil Conservation School, Kuru, Jos for allowing me access to their personal libraries.

I would also express my gratitude to my colleagues for providing the warmth and comfort of a good family.

Few names that readily come to mind are Ogunrinde A., Wuyep N., Mabur J., Usman D., Jankasa, Igben Jomata, Bolarinwa Bolaji, Jasper Dung, Abdullahi Muhammed and Kerenku T. Other persons that deserve mention are my 'secretaries' - Joy, Celina and Chinyere for helping in various tasks.

Lastly, special thanks should go to CODESRIA (Council for the Development of Social and Economic Research in Africa) for sponsoring this research work.

NDUDI C. OSAKWE

TABLE OF CONTENTS

TABLE OF CONTENTS CONTD.

TABLE OF CONTENTS (CONTD)

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

The spread in irrigated agriculture, particularly with the introduction of the mechanical pumps informed the need for the study on irrigation water use on the Delimi Floodplain.

An attempt was made to provide answers to the questions of when irrigation was necessary for the different crops cultivated within a farm area and the volume of water required for this purpose throughout the dry season.

To achieve this, data was collected on soil samples over a three-day irrigation interval, while water application was directly observed over a thirty-day period to ascertain irrigation time, discharge and the volume of water used in the various crop fields.

Results obtained from the study showed that the total volume of water required for all the crops during the dry season, given a total farm area of $2384m^2$ was 3.097×10^6 m^3. The result also revealed that the various crops were closely associated with certain soil types, with Lettuce and Tomatoes thriving on a wider range. The variation in the characteristics of these soils reflected on the different refilling points for the

various crops over a three-day irrigation interval, indicating some differences in the 'wilting threshold' for the crops. Water use and irrigation frequency were observed to vary based on the computed available water capacity. However, this relationship between irrigation frequency and water use for the different crops were found to be statistically insignificant.

Given the yield, water was construed to have a significant input in agricultural production.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Water is one of the most vital resources available to man. Its importance is revealed by its various demands, including domestic, industrial and agricultural (Camp and Lawler, 1969).

In agriculture, which is man's chief activity for producing both food and cash crops, water is a major structural component, constituting an appreciable fraction of crop vegetative biomass (Hillel, 1987). Water plays a central role in the metabolism of plants, and serves as raw material for photosynthesis. Furthermore, it dissolves and transports nutrients from the soil into the bodies of plants. Infact, the importance of water in the growth of plants cannot be over-emphasized.

On the Jos Plateau, agriculture is the dominant economic activity of the people (Ajaegbu 1986). Unfortunately, there is not enough water to meet the optimum requirement of crops. The reason is not far to seek. Jos Plateau, like other areas under the tropical climate is characterised by contrasting wet and dry seasons (Oguntoyinbo, 1982). The implication is that there is not enough rain during one half of the year, while the other sources of water viz, the rivers and streams dry up during the dry season and the amount of ground water supply equally diminishes. Agricultural practice on the Jos Plateau is therefore dominantly rain fed. According to Ajaegbu (1986), the reliance on a particular season for crop production was not a problem because the population was scanty. The mining of tin on the Jos Plateau marked a sharp increase in the demand for food by the labour migrants attracted to the region. To this end, the reliance on rain-fall as a major source of water became unsatisfactory. Flood plains (fadamas) were, therefore, cultivated to augment food supplies. Also the cultivation of the fadamas was intensified due to the decline in tin-mining activity. It was the only ready alternative to the ex-miners (Adepetu 1984). The flood-lains were considered no longer enough for the large number of persons engaged in agriculture, particularly, during the dry season. In order to achieve a high standard of year-round agriculture, irrespective of rain-fall availability, the system of irrigation was inevitable.

Irrigation is one of the means of improving the total volume or reliability of agricultural production by managing water for the crop (Worthington, 1977). According to Rydzevski (1968), irrigation, apart from being the application of water to soil for the purpose of supplying the moisture essential for plant growth, is a special case of intensive agriculture, in which technology intervenes to provide control for the soil moisture required in the crop root zone. In this regard, water control is of importance to other management efforts such as the use of fertilizers, hybrid seeds and mechanization.

Irrigation in many countries is an art as old as civilization (Israelsen and Hansen, 1962). From its early and primitive antecedents in the River valleys of the Middle East some million years ago, the practice of irrigation has evolved gradually in the direction of increasing the farmer's control over crop, soil and even weather variables. Unfortunately, the long history of irrigated agriculture has not always recorded success (Worthington, 1977). Despite these failures, the pressure of survival and the need for additional food supplies have given a new focus to the science of irrigation throughout the world. According to Hillel (1987:2),

> "the increasing demand for agricultural products, the search for new knowledge of how to improve the efficiency of irrigation, and the imperative to disseminate and apply the knowledge gained to date, have made the expansion of irrigated agriculture more urgent than ever."

At a seminar organised by the United Nations Food and Agricultural Organization (F.A.O.) in the Phillipines in 1970, a communique was issued on the need to encourage small scale irrigation to improve productivity in small units and on a manageable scale. This became imperative considering the fact that large scale irrigation projects require more systematic, industrialized organization of work, and strict schedules. Again, at the World Congress of the FAO in 1975, the International Commission for Irrigation and Drainage appointed a committee on 'assembling irrigation efficiency data' with a view to making recommendations for improving efficiency at all levels including field efficiencies, particularly in small scale irrigated agriculture (Stern, 1987). In their view, irrigation development is a necessary approach to food production required in the future. In the opinion of Hillel (1987), irrigation development involves good soil and water management, and a proper understanding of the soil-plant-water relations. The emphasis on water management becomes pertinent, considering the increasing demand of water for other uses.

In Nigeria, attempts at increasing agricultural production witnessed the setting up of several departments and the adoption of agricultural policies, including the River Basin Development Authorities (1977), Operation Feed the Nation 1978 and lately the Directorate of Food, Roads and Rural Infrastructure, 1987. On the Jos Plateau, the need to augment food supplies and increase agricultural productivity is more urgent, considering the fact that tin-mining activity in the region has left an acute shortage of land for agriculture (Okechukwu, 1983). Several efforts have been made towards improving crop production on the Plateau. The Plateau Agricultural Development Board, for instance, has been assisting farmers through the procurement of seeds and fertilizers. On the part of the farmers, the introduction of mechanical pumps and the use of artificial fertilizers have introduced some tremendous changes in the system of irrigated agriculture (Phillips-Howard, et al 1991). These developments have brought about an increase in farm sizes, and an expansion of farms into more elevated land, hitherto considered unirrigable. Generally, the increasing demand for agricultural products, particularly the vegetables, including tomatoes, cabbages and carrots among others in the urban centres and, barley and wheat for industries have brought about the intensification of land and water use. In the face of increased demand for farmland and variable rainfall, a slight improvement in thewater economy may spell the difference between marginal subsistence and profitable production. To the extent that food problems are to be met by enlarged production, the enhancement of irrigation is important.

It is against this background that the study would look at a primary requirement to an enhanced irrigation management - determining the soil-plant-water relations.

1.2 STUDY PROBLEM

Irrigated agriculture is becoming more popular on the Jos Plateau. Certain innovations have been introduced to make the system work. These include the introduction of the mechanical pumps as a replacement to the shadouf, the introduction of a great variety of high-yielding crops and the use of artificial fertilizers. The diffusion of the innovations have been enhanced because more young and educated people have been attracted toward irrigated agriculture (Phillips-Howard and Schonoeich, 1991). These 'new farmers' have the aptitude and education to radically transform agriculture on the Jos Plateau.

However, successful irrigation must start by trying to decide how much is needed by various crops, and then supplying that need (Hudson, 1983). This becomes necessary because to grow crops successfully, crops must achieve a water economy such that the demand made upon it by the climate in the process of evapotranspiration is balanced by the supply available to it at the root zone.

1.3 AIMS

This study is aimed at answering pertinent questions in irrigation management viz:

a) when to irrigate various types of crops (irrigation frequency)

b) how much water to be applied per irrigation session

1.4 HYPOTHESES

1. Ho: There is no significant difference in moisture contentover the irrigation internal for the different crops at depths of 0 - 10 and 10 - 30cm.

   H_1: There is a significant difference in moisture content over the irrigation interval for the different crops at depths of 0 - 10, 10 - 30cm.

2. Ho: There is no significant difference in the water use of the different crops.

   H_1: There is a significant difference in the water use of the different crops.

1.5 THEORETICAL/CONCEPTUAL FRAMEWORK

Irrigated agriculture on the Jos Plateau is spreading fast. According to Phillips-Howard and Schonoeich (1991), if the trend continues, the practice would expand to areas where it was previously not feasible such as elevated land, interfluves and other areas farther away from the flood plains and ponds. The implication is that some more technical and sophisticated means to deliver water to crop root zone would be introduced. Recent innovations in irrigation system being adopted include relay pumping, the use of pumps and hoses to convey water to areas which previously could not be reached by traditional irrigation methods. These innovations have changed the face of irrigated agriculture on the Jos plateau from the traditional system to a modern one, which requires a scientific basis.

According to Hillel (1987), 'any attempt to control the supply of water to crops must be based on a thorough understanding of the variable state of water in the soil, and of its cyclic movement into, within and out of root zone'. This is important because the water requirement for crops vary within an area, and for a specific crop, it varies with localities, depending on environmental conditions.

Irrigation practice on the Jos Plateau is based on mixed cropping, defined by Igbozuruike (1981), as the conscious and deliberate cultivation of more than one crop on one piece of land at the same time. The irrigator's concern, then, is to develop an overall irrigation schedule which optimizes the allocation of water throughout the season, and ensures an adequate supply during the peak period for irrigation water use. This may mean that more crops may not receive water at their optimal schedule. In view of the fact that some crops require more water than others at certain critical periods, and less at other periods, it is necessary to place the crop mix on the farm so as to balance the demand and the supply. This may not be achieved without a knowledge of the water requirement of the various crops.

According to Hillel (1987), there are several methods that can be used to determine the timing and quantity of water application. These include monitoring the soil, the crop and/or the micro climate. Though, several methods can be 'safely' used in the measurement and estimation of crop water requirements (see Methodology), most of these methods require special skill to use.

1.6 SCOPE OF STUDY

This study looked at irrigation water use as defined by Jensen (1969) as the amount of water actually being used for irrigation. To determine the actual water use, the soil monitoring method using the gravimetric technique was employed. The reason was that the soil is the recipient of all water applied to the field, so would provide better clue on when irrigation is required and how much to apply.

The study also considered an estimate of the total volume of water used in the farm.

For a pilot study of this nature, a field or farm plot irrigated as a single unit was required to provide reliable data.

1.7 STUDY AREA

1.7.1 Location

The study area is a portion of the Delimi River flood plain on the North Western part of Jos Town in Plateau State. It lies between lat. 9°58'N and Lat. 10° 00'N and Long. 8°53'E and Long. 8°54'E and located in an area locally referred to as Langalanga (Swinging bridge). It is situated between the Senior Staff Quarters of the University of Jos and the Students' Village (See Fig 1.1a and b).

1.7.2 Relief

The study area is characterised by level to gently sloping land flood plain of the river Delimi. The land surface slopes at varying gradients toward the river channel, a product of an uplift and denudational processes some millions of years ago (Ajaegbu et al 1986). The river valley is broad and marked on either side by well defined bluff lines.

1.7.3 Geology

The study area is located where sedimentary materials are produced due to periodic eluviation (which involves the movement of soil colloids, suspension and

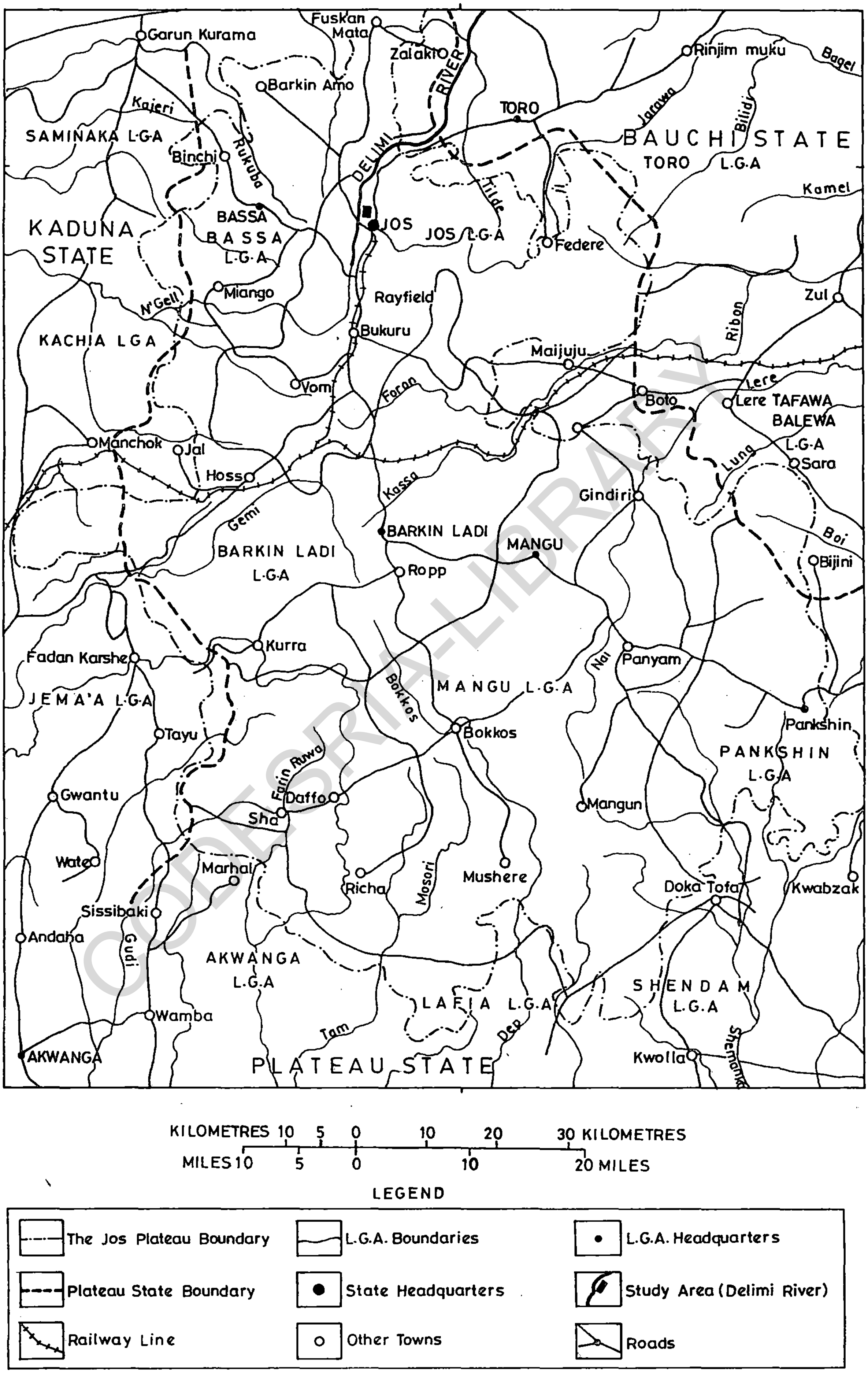


FIG 1.1a The Jos Plateau Area showing the Study Area.

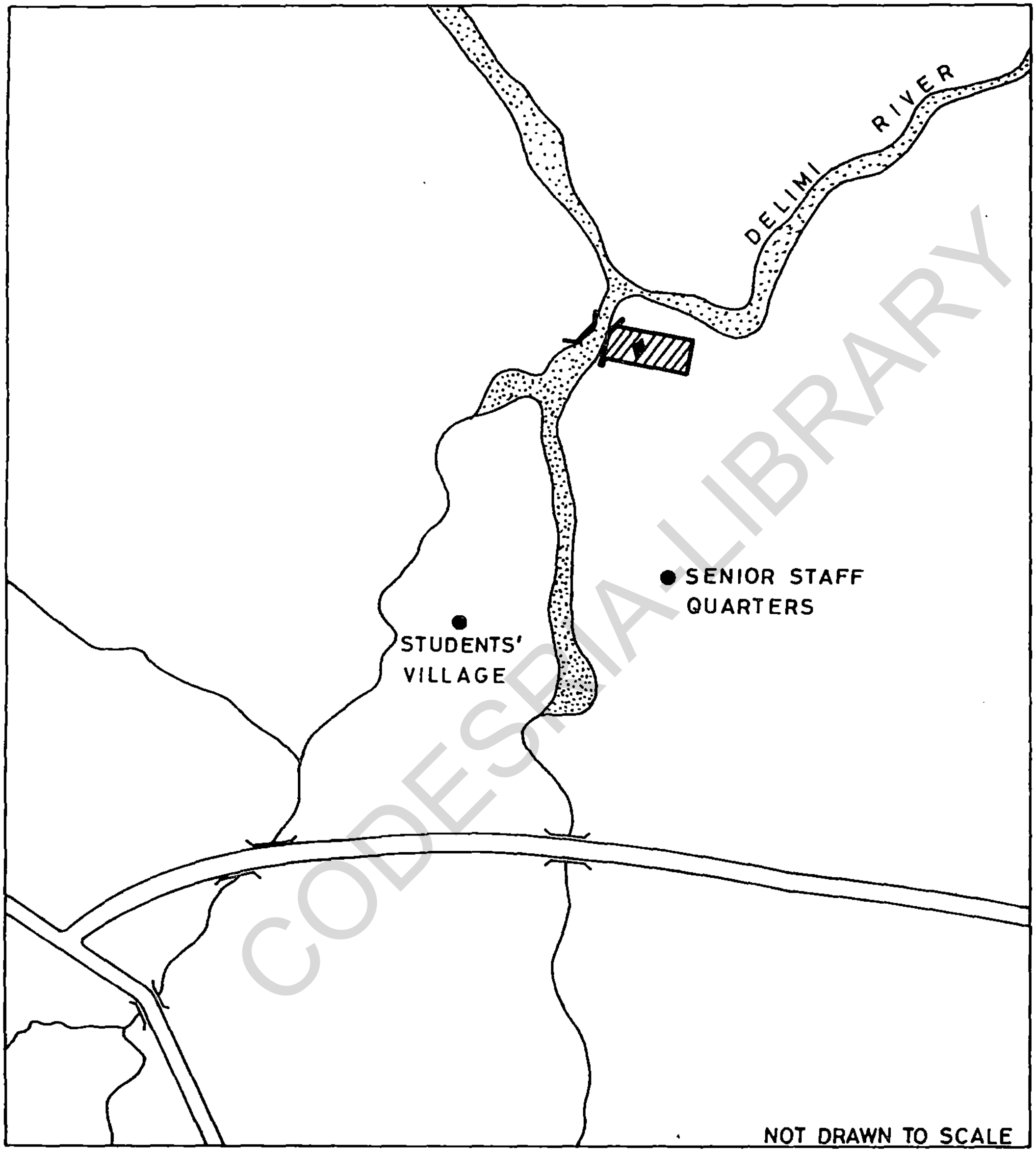
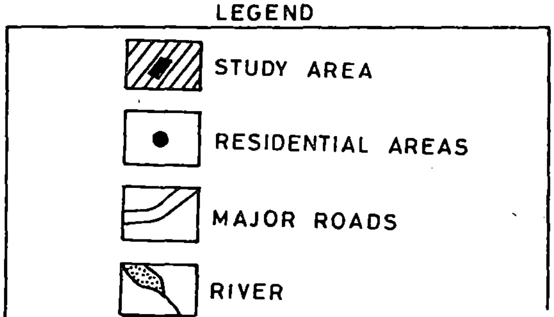


FIG.1.1b MAP OF THE DELIMI FLOODPLAIN SHOWING THE STUDY AREA.

LEGEND



fine particles on the river channel, particularly, during the peak of the rainy season) and continuous colluvial activity from the sides generated by a dual process of rain splash erosion and the removal of detached materials by unchannelled runoff on the adjacent plains. The detached materials are products of metamorphic rocks, principal of which are the migmatites and the granite - gneiss found on the gentle rolling areas.

1.7.4 Climate

The climatic conditions of the study area (which is part of the Jos Plateau) are influenced by its high elevation above mean sea level. The altitude brings about a reduction in the mean temperature of the region. Generally, the temperature as recorded at the University of Jos Weather Observatory is generally low with the average minimum of 16.6^{o}C and an average maximum of 29.4^{o}C. Low temperatures are recorded during the harmattan (December to February), and during the rains in summer, high temperatures are experienced during the months of March and April. The areas position relative to the Inter-Tropical Discontinuity (ITD) determine the sequence of the seasons. Generally, the weather is controlled by moist Tropical Maritime airmass during the rainy season, and the Tropical Continental airmass during the dry season. The South Westerly Winds are responsible for much of the rains occuring between April and October, while the North East trades are responsible for the dry season, lasting from November to March. The mean annual rainfall is 1170mm and about 175-180 rainy days are recorded per annum. The relative humidity is high (47.0% to 66.5%) during the rainy months between April and October, but is low (35.3% to 29%) during the dry months between November and March (See Fig 2.1). Evaporation levels are high during the dry season. The annual mean values is 5.0mm, using the class A pan.

1.7.5 Drainage

The study area is drained by the Delimi River. This river takes its course in the Jirgir and Barkin Ladi-Sabuwa area of the Jos Plateau. From its source, it flows eastward into Delimi biotite granite from where it flows north eastward through Jos to the Plateau edge and beyond.

During the dry season, the volume of water is reduced. Artificial impoundments are created during the

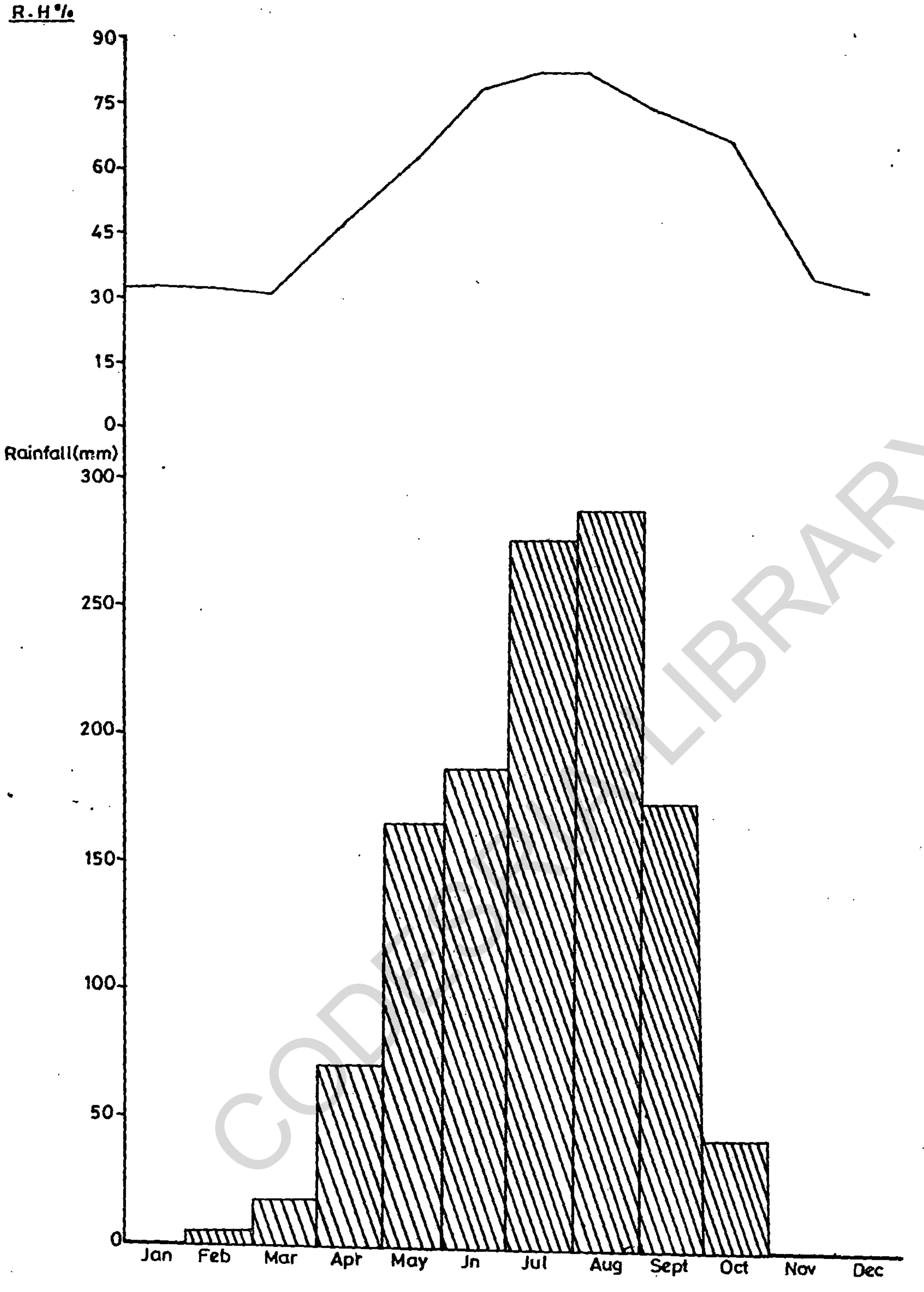


FIG. 1.2 MEAN MONTHLY RAINFALL AND RELATIVE HUMIDITY (1980-90) FOR THE STUDY AREA

Source: WEATHER OBSERVATORY, UNIVERSITY OF JOS.

dry season to hold water primarily to augment supply (fed by base flow) for irrigated agriculture in the area.

1.7.6 Soils and Vegetation

The spatial pattern of soils is determined by slope and relief which in particular, are responsible for differences in soil depth, texture, moisture regime and colour (Areola, 1982).

The soils in the study area are hydromorphic, developed on sandy alluvium and colluvium. Along the river valley, sand and some silt are deposited due to the transportation activity of the Delimi River, particularly during floods at the peak of the rains. The flood plains are equally recipients of sandy slope wash colluvial sediments from the adjacent plains. Though, the soil is deep, clay deposits are few, restricted to backswamps. This leaves the area imperfectly drained during the rains accentuated by a high water table condition.

Up the slope, colluvial soils formed out of migmatites and granite-gneiss are found. These rock types generally give rise to coarse skeletal soils. The depth of these soils become shallower, farther away from the valley side with depth not exceeding 30cm. These types of soils otherwise, referred to as lithosols are highly ferruginized. Most of them are characterised by weak differentiation of genetic horizon.

With respect to vegetation, the study area have almost been completely cleared of its natural vegetation as a result of cultivation, firewood collection and intensive cattle grazing. However, on sites unsuitable for cultivation, clans of trees and water loving tasselly grasses can be found. Economic trees, including mango, guava, cashew and eucalyptus trees are also found in pockets in the area.

1.7.7 AGRICULTURAL PRACTICE IN THE AREA

Agriculture is the main stay of the people in the study area. To ensure an all-year agricultural production, irrigated agriculture is practised. Prior to the introduction of the mechanical pumps, shadoofs were used in the lifting of water for the production of several temperate crops including tomatoes, lettuce, cabbage, leek onions, carrots, cellery, garden eggs, green beans among others. Land along the flood plain were put into use, though this technique of water lifting meant that small plots of land were cultivated.

Irrigation exercise in the area commences at the beginning of the dry season (October) with the clearing of the plots of farms. The plots are later tilled and then prepared into beds of varying sizes. Drainage channels and canals are laid down, taking into cognizance the topography of the land. Seeds are then put in nurseries for several weeks before they are ready for transplanting into the various basins. Different types of cropping patterns are practised. Most crops including cabbage, carrots, tomatoes, beetroot are monocropped. Where mixed cropping is practised, the intention is to maximise the use of space and revenue derivation. In this respect, sequential cropping pattern is practised, whereby crops of varying growing periods are farmed in the same basin. Water for this purpose is obtained from the Delimi River which during the dry season is fed by base flow. Though a small river, the nature of the underlying topography has made it free flowing most part of the year. However, during the dry season, impoundments are erected to augment flow.

As earlier mentioned, the river flows through metropolitan Jos, thereby rendering the quality of water poor. Though, not much work has been carried out in recent times on the quality of the water, it should be noted that a river flowing from an urban area would be polluted by different types of waste, including oil, detergents and metals. These various waste affect the quality of the crops produced on the Delimi floodplain.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The importance of water as an essence of life on which man depends not only for his direct consumptive need, but also for producing his food and fibre have made its management and control a crucial one. The management of water becomes more incumbent, as an important input into agricultural production required to feed the entire population. Unfortunately, its availability principally in the form of rain is variable over space and time. In order to maintain a continuous agricultural production, irrigation has become an inevitable venture. Irrigation as already defined can be seen as any process other than natural precipitation by which water is applied to field crops, orchards, forage grasses, legumes and other cultivable plants (Stern 1987).

2.2 HISTORY OF IRRIGATION

As already identified in Chapter One, irrigation activity has been practised for several thousands of years, particularly on the plains of Rivers Tigris, Euphrates and Nile.

In Nigeria, according to Nwa and Martins (1982), irrigation development could be traced back to the early 1900's when Colonel Collins, a military engineer, undertook work in the Sokoto River and Zamfara Valley Systems. These valleys came under the extreme north of Nigeria where rainfall amount is not sufficient for agricultural production. On the Jos Plateau, said Grove (1961), irrigated agriculture in the form of fadama farming was probably introduced by Hausas from densely populated areas of the North. In the opinion of Olaniyan (1986), this traditional skill and knowledge associated with fadama farming was introduced by labour migrants into the Tin mining region. However, this agricultural system was to remain at the 'fadama level' until the early 1980s when growing demand for agricultural products, particularly, vegetables stimulated its development farther away from the fadamas. Ever since, a lot of technological developments in the form of irrigation techniques have taken place, to deliver water to the crop root zone. According to Adepetu, 1984, three methods are commonly used including the shadoof, diesel operated pump and channel irrigation.

The shadoof, a device used in the lifting of water consists of a long crossbar pivoted between two upright posts. The shorter part of the crossbar carries a weight - a stone, ball or clay - and the longer part carries a rope or a long stick to which a bucket is attached. The shadoof is set up beside a pool, well or a water course and the farmer pulls the longer run of the crossbar down until the bucket dips into the water. Then assisted by the weight on the shorter end, he lifts the full bucket and pours the water into a ditch that carries it onto the land to be irrigated. The system was very popular until the early 1980's (Phillips Howard, 1991) when the mechanical pumps held sway as a better alternative in the technology of water lifting in small scale irrigated agriculture on the Jos Plateau. One of its shortcomings was that it was slow, laborious and energy sapping. The increase in the demand for agricultural products required that a better system, that can efficiently make water available farther away from the flood plains was needed. The introduction of the mechanical pumps have made this possible. Several innovations have taken place in the use of mechanical pumps such as the use of relay sequencing, whereby several pumps are linked together by hoses to reach the upland (Phillip-Howard and Schonoeich, 1991). In the opinion of Nwa (1984), it would make crop rotation possible, a factor considered to be important in the control of wilt and nematodes common in vegetable crops. The channel system of water use involves allowing water to flow under gravity in canals or channels made of earth (doki in Hausa) from the water source.

Once irrigation water is transported to a field, it is generally distributed using several techniques identified by Stern (1987) as basin, border, furrow, corrugation, wild flooding, spate and trickle irrigation. On the Jos Plateau according to Adepetu (1984) the watering of crops is commonly done by allowing water into the basins through a network of feeder canals until they are completely submerged. Submergence, however, depend on the size of the basin and strength of the flow through the canal to enhance crop-water relations.

2.3 CROPS AND WATER RELATIONS

Water is an essential component of all plant tissue and fulfils three primary functions, including keeping plants erect by filling the cells which make up its tissue; acting as a cooling agent in evaporating from the leaves preventing overheating under hot conditions and finally, carrying nutrients in solution from the soil into the plants through their leaves (Stern, 1987). Its importance was summarized by Graben (1979), "that plant evolve in an aqueous medium and are adapted to primarily maintaining a watery environment ...." The complexity of the relationship between water and growth parameters in plants have been given several foci (Turner, 1978). Hsiao (1973) identified the effects of water deficit on expansive growth, photosynthesis, and pollination and fruit setting as the critical effects.

2.3.1 Soil-Water-Crop Relations

Soil has been defined as the material in which plants grow (Stern, 1987). The structure of the soil consist of a framework of solid materials enclosing a complex system of pores and channels which provide space within the soil for air and water. When all these spaces are filled with water, the soil is said to be saturated. Any attempt, therefore, to control its supply to crops must be based on a thorough understanding of the variable state of water in the soil and of its cyclic movement into, within, and out of the root zone (Hillel, 1987).

The cycle of water in the field consists of a series of sequential dynamic processes beginning with the entry of water into the soil, continuing with its redistribution and downward drainage within the soil and culminating in its uptake by crops, According to Withers and Vipond (1980), three types of soil moisture can be recognised, including, gravity, capillary and hygroscopic water. Gravity water, as the name implies, drains out under gravity. It remains in the soil which is above a water table for a short time. Capillary water occurs as thin films on the soil particles or as droplets or thin threads within the pore structure, while hygroscopic water consists of a thin film held firmly on the soil particles. Of the three, only capillary water is the principal source of water to plants.

The amount of water made available to plant for its growth is traditionally defined to be the difference between the field capacity of the soil and the wilting capacity. According to the Soil Science Society of America, field capacity can be defined as the moisture content of a deep permeable, well drained soil several days after a thorough wetting. It is normally taken as the upper limit of the water available to plants (Hudson, 1983). On the other hand, the wilting point is defined as the moisture content at which the leaves of a plant growing in the soil fail to regain turgidity in a saturated atmosphere. However, for practical purposes, the permanent wilting point, defined as the moisture content at which plants become permanently wilted is accepted (Hillel, 1987, Hudson 1983; Israelsen and Hansen, 1962; Withers and Vipond, 1980).

The amount of available water to crop root zone is governed by the rate at which the water is applied to the surface. However, the rate at which the water would infiltrate into the soil depends on the structure and texture of the soil. Infiltrability is low in a compacted soil. Sand, by virtue of its relatively large pores cannot exert sufficient force to prevent gravity draining a large amount of the water held at saturation. In other words, its water holding capacity is low. With respect to clay, the water holding capacity is high because of its small pores (Withers and Vipond, 1980). To maintain water economy, therefore, some plants have developed certain physiological response. One of these responses is the development of dense and extensive root systems. Root patterns developed depend much on local soil conditions and water availability. According to Stern (1987), different plants have different rooting depths, and young plants have much shallower root systems than mature plants. He provided a guide to root patterns of crops in a fertile soil under unrestricted conditions:

TABLE 2.1 TYPICAL ROOT-ZONE DEPTHS (METRES) AT FULL GROWTH

SHALLOW	MEDIUM	DEEP
Beans 0.5 - 0.7	Barley 1.0 - 1.5	Alfalfa 1.0-2.0
Cabbage 0.4-0.5	Carrots 0.5-1.0	Cotton 1.0-1.7
Cauliflower 0.3-0.6	Peas 0.6 - 1.0	Maize 1.0 - 2.0
Lettuce 0.3 - 0.5	Peppers 0.5 - 1.0	Sugar cane 1.0 - 2.0
Onions 0.3 - 0.5	Tomatoes 0.7-1.5	
Spinach 0.3 - 0.5	Wheat 0.9 - 1.5	

According to Stern (1987), most of the water used by plants is taken from the upper half of the root zone. This implies that about half of the available water is actually used. In the opinion of Hillel (1987), available water capacity is of the order of 150mm to 200mm per metre-depthof the soil for clayey soils, 100 to 150 mm for loamy soils, 50 to 100mm for sandy soils.

2.3.2 Climate-Water-Crop Relations

The joint processes of evaporation and transpiration are important in the determination of the amount available to plants for the preparation of its food and growth. Evaporation is a process by which water in the form of water vapour enters the atmosphere from open water surfaces, including rivers and ponds etc. As a corollary, transpiration is the evaporation which takes place at the surfaces of plants leaves. The rate of these joint processes, otherwise referred to as evapotranspiration varies with climate, including relative humidity, wind velocity, temperature among other climatic elements. When the climate is hot and dry, the rate of evapotranspiration is high, and low when it is cool (Stern, 1987). In regions where there are marked seasonal changes in climate, there will be corresponding changes in the rate of evapotranspiration. Under natural conditions without irrigation, the actual evapotranspiration at the end of a hot dry season will be low, because the soil is dry, and there is no available moisture. However, where there is rainfall or irrigation, the rate of evaporation is high from bare surfaces. This is particularly enhanced where the water table is near the surface. Soil moisture in these 'regions' is moved by capillary rise amounting in most cases, to the deposition of salt at the soil surface. Where crops are cultivated, transpiration rather than evaporation becomes predominant. According to Thorne and Thorne (1979), much of the 80% of water making up the living cells and tissues of plants are lost in the process of transpiration than is available for metabolism, particularly in dry environments.

Water loss from plants occur through the stomates in their leaves, which incidentally are entry points for carbon dioxide in the process of photosynthesis. The implication is that if the evaporative demand of the atmosphere is high, plants would experience stress. In order to avoid dehydration, the rate of transpiration is reduced.

2.4 QUALITY OF IRRIGATION WATER

The quality of water is an important determinant in crop growth. It is determined by the content of living organisms and its content of mineral and organic matter which may be present in suspension, colloidal dispersion or in solution (Camp and Lawler, 1969). Practically, all the foreign matter in water are collected as it flows over the surface of the ground or through the soil and rocks. Surface waters including rivers and streams exhibit higher deterioration in quality than ground water as greater use is made of them. The quality is worse for rivers that flows through the urban areas where different types of domestic waste including detergents, kitchen oil, effluent and solid waste are discharged into them. According to Patterson (1986), the presence of these dissolved solids can cause problems of high salinity, as it causes plasmolysis of plant cells.

Shainberg and Oster (1978), identified certain criteria that can be used in determining the quality of water for irrigation purposes. These qualities include total salinity, that is, the total concentration of all salts in the water supply, sodicity, which is the concentration of sodium relative to the cations; anion composition of sodium solution, especially the concentration of bicarbonate and carbonate anions and the concentration of toxic elements. Generally, the principal solutes present in irrigation waters are the cations including calcium, magnessium, sodium and potassium, along with anions such as chloride, sulphate, nitrate and bicarbonate. In addition to these, some trace elements such as boron, lithium, selenium and several heavy metals, including lead, may be present and would have inhibitory effect on plant growth and human pathology.

However, investigation by Nwankwo (1987) on surface streams in Jos city on the presence on heavy metals including lead, cadmium, zinc, iron, copper, manganese among others revealed that their levels are much below the international averages for drinking water. This implied an insignificant delecterious effect on the consumption of agricultural products watered from these streams.

2.5 IRRIGATION SCHEDULING

The aim of irrigation practice is to ensure that the plant has an adequate supply of water in its root zone. This process otherwise referred to as irrigation scheduling has been used to describe the procedure by which an irrigator determines the timing and quantity of water applied to the crop root zone (James 1988). In other words, it provides a guide on when to apply water and how much to apply. Its importance was highlighted by the International Management Committee of the American Society of Agricultural Engineers when in 1979, a conference was held to establish the state of the art in irrigation scheduling for water and energy conservation.

According to Reginato and Howe (1985) irrigation scheduling is composed of many inter-related activities. In their opinion, it includes considering the capacity of the irrigation system, estimating when the next irrigation should start, the amount to be applied, the field size and time required to complete an irrigation, the advance time required to order water, the need to co-ordinate irrigations with other cultural operations and the probable crop-response to be expected. Little wonder, Hudson (1983), had it that successful irrigation effort must start by scheduling an irrigation program. According to him, it makes for a co-ordinated delivery of water, reduction of labour cost and ensures overall efficiency. Irrigation scheduling therefore, is a sine-qua-non in overall irrigation planning, including crop mixes and the use of irrigation tools and techniques. A knowledge of the rate of water use by crops and the water retention characteristics of soils is fundamental in the design of the water supply systems. It determines the canal, pipeline, storage and pumping capacities of the system (Withers and Vipond, 1980).

To determine when to apply water and the quantity to apply, several methods have been identified. Broadly, Hillel (1987) categorised these methods into three: plant indicators, microclimate and/or soil moisture studies.

2.5.1 Crop Indicators

The crop can be monitored to determine the water status of plants. According to Reginato and Howe (1985), to determine when to irrigate a crop, there is no substitute for interrogating the plant itself. According to them, neither the soil water status nor the atmospheric demand accurately represents the plant water status for the plant integrates its total environment - both soil and atmosphere. In other words, only by measuring plant parameters can a plant's general health be evaluated. Using the information, decisions on when to irrigate can be carried out.

Numerous techniques have been proposed over the years to monitor the physiological state of water in the plant. Among these are the techniques to estimate the xylem pressure potential (Bielorai and Hopmans, 1975 Blum 1967; Meyer and Green, 1980), or leaf diffusion resistance (Ehrler and Van Bavel 1967; Sumayao and Kanemasu, 1979) or the water status of various plant parts (Kassam and Elston, 1974). Others include psychometric measurements of leaf water potentials, found to be a good indicator of stress (Ehrler, 1973). The use of infrared thermometry, as a reliable surrogate for certain physiological - based water stress measurements have been emphasized. The major advantage of this method, according to Pinter and Reginato (1981) is the ease and rapidity at which plant temperature measurements can be made. Ehrler et al (1978) while utilizing the technique showed an inverse relationship between the stress degree day parametre and the xyleon pressure potential of wheat. Later, Idso *et al* (1981) refined the stress degree day parameter by taking the evaporative demand into account. The transformed stress parameter which is termed the crop water stress index was well correlated with the xylem pressure potential in alfalfa plants subjected to varying degrees of water stress. An obvious shortcoming of most of the studies is that most of them were made on individual plant parts. However, several studies have been carried out, by utilizing canopy temperature rather than individual leaves, prone to errors. Tanner (1963) was able to monitor crop canopy temperature, using the infrared thermometry to explore the moisture stress difficulties between plants under different water regimes.

Generally, the most common way to monitor the crop is by visual inspection. Some aspects of plant behaviour can be found to indicate water stress directly. Some of the indicators as identified by Vipond and Withers (1979), include growth measurement, plant colour, leaf movement, growth and size which may vary with turgor pressure. According to them, young leaves are the most sensitive, so when they begin to curl or become flaccid, an irrigation is overdue.

2.5.2 Monitoring the Weather

The irrigation needs of a crop are stochastic in nature because they are affected by climatological parameters. Considering all other factors - soil, topography, quality of water, irrigation practice and methods, irrigation need is a function of the stochastic variation of the local weather, that is evapotranspiration (Gupta and Chanhan, 1986). The idea of weather monitoring is to follow the meteorologically imposed evapotranspirational demand as it varies over time and to set the quantity of irrigation accordingly. Evapotranspiration is influenced by many factors including, temperature, wind velocity, humidity and the amount of sunshine. Other factors include water supplies to the leaves, which depend on soil condition and weather conditions on previous days and weeks and plant food supply to the roots.

Several methods have been developed to estimate evapotranspiration.

Penman (1948) determined the amount of water required by crops based on the estimation of potential evapotranspiration, defined as the amount of water transpired in a unit time by a short green crop completely shading the ground of uniform height and never short of water. In his analysis, several climatic variables including, temperature, humidity, wind velocity, vapour pressure and solar radiation were included. However, while it is of great interest, and indeed practical in irrigation scheduling, the Penman method is generally too difficult to apply in the context of small scale farming. Furthermore, most of the required variables for its computation are not available in weather stations. For these reasons, several modifications have been made to make the formular workable in all situations. According to Wright (1982), crop coefficients can be used to estimate actual water use for a particular crop from estimates or measurements of a potential or reference evapotranspiration. This is possible by using Penman combination equation. According to him, the empirical reference crop-coefficient are generally derived from daily weather data, and relatively simple data on crops and soil situation. Doorembos and Pruitt (1977), presented detailed procedures for estimating daily reference evapotranspiration for grass, which they defined as the rate of evapotranspiration from an extensive surface of 8 - 15cm tall green grass cover of uniform height, actively growing, completely shading the ground, and not short of water. Several crop-coefficients have been suggested for irrigation scheduling (Jensen et al 1971; Wright 1981, Wright and Jensen, 1972). Equally, it has been applied in the Agriculture Research Service of the United States Department of Agriculture (Jensen et al, 1971). The crop coefficients were developed from soil sampling data collected at various research locations for 5 - 15 day intervals.

Another method equally used in the determination of crop water requirement was developed by Blaney and Criddle (1950). The use of this method was provoked by the inavailability of sufficient data as required by the Penman

Formula. Furthermore, estimates of consumptive use are required for areas other than those where solar radiation, wind speed and air vapour pressure deficits are measured. The lack of weather data therefore in many areas and during many historical periods necessitates the use of this approach to incorporate the effects of temperature and day length only.

The Blaney Criddle method, however, may not be suitable for humid areas since it was designed to suit the needs of arid environment. For this reason, there have been several modifications including, the Soil Conservation Service (SCS) modification in 1970 and the Food and Agricultural Organization (FAO) modification in 1977. The FAO's was unique because it included a correction factor which helps to adjust for local weather or climatic conditions not provided for in the original Blaney-Criddle formula (Hawley , 1982). This equation was expressed thus:

$$E_{to} = \left\{ a + b \left[P \, (0.46T + 8.13) \right] \right\} \left[1 + 0.1 \left(\frac{Elev.}{1000} \right) \right]$$

where

E_{to} = estimated evapotranspiration from a grass reference crop in mon/day for the period considered.

T - means daily temperature in degree (celsius) over the period considered.

P - mean daily temperature of total annual daytime hours for a given time period and latitude.

a&b - correction factors which adjust with the ET estimate based upon measured or estimated mean daily minimum relative humidity.

Various agroclimatological methods have equally been developed to monitor the weather directly. These include the pan evaporimeter and lysimetry among others. Evaporation pans provide a direct estimation of the aggregated effects of radiation, wind, temperature and humidity on evaporation from a desired open water surface. Thus, measurement of evaporation can give individual applicators an indication of plant water use on the field and assist in determining when to irrigate and how much to apply (Westesen and Hansen, 1981). According to Hillel (1987), the evaporation pans appear to be the most practical of the various microclimatological methods, particularly if related with a calibrated crop coefficient. In his opinion, farmers can schedule their irrigation program without resorting to esoteric formulas. In the Townsend, Helena and Chinook areas of Montana, Westesen and Hansen (1981) in their study on evaporation pans and scheduling, indicated an increased yield and correct irrigation schedules. Among the various pans used are the United States Weather Bureau, Class A Pan, the piche evaporimeter, Sunken Colorade pan and the atmometers (Israelsen and Hansen, 1981).

Evaporative demand have also been measured using Lysimeters. According to Tanner (1967), proper evaluation of the water resources and more scientific management of water requires the development of tools that will provide satisfactory measures of crop water uses. The tool frequently used, according to him, is the lysimeter. The Lysimeter is the only hydrologic method in which the experimeter can obtain accurate and continuous measurement of evapotranspiration. It has been used to calibrate other agrometeorological methods. In a study conducted by Reicosky (1981) he observed that the lysimeter presents a good measure of water use on different treatments. When properly installed, operated and instrumented lysimeters provide the most accurate measurement of evapotranspiration. Though, several types can be recognised, including weighing and non-weighing types, the weighing lysimeters have been successfully used in determining water requirements of crops in short time periods (Israelsen and Hansen, 1962). In a study conducted by Lawson and Lal (1981) on crop water use in the humid/subhumid zones of West Africa, the lysimeter was used to obtain the mean maximum water requirements for cereals (4.4 mon/day) and the grain legumes about 3.8mm/day to meet their evaporative demand. It was equally utilized by Owonubi (1981) in his study on cowpeas water use in Samaru, Zaria.

2.5.3 Soil Indicators

Soil based irrigation scheduling is the traditional method of determining when and how much to apply. According to Campbell and Campbell (1985), the fact that irrigators still trust the 'feel' and colour of a shovelful of soil in preference to many other irrigation scheduling procedures indicates that scheduling by soil moisture is still the most popular of all methods. In their opinion, since the soil is the primary recipient of the irrigation water, it seems reasonable that the answers to the questions - when should the water be turned on and how much to apply should come from monitoring the soil.

The idea of soil monitoring is to observe the moisture reserve of the root zone as it gradually dimishes following each irrigation, so as to know when that reserve has been depleted to some level predetermined to serve as the minimum allowable level (James, 1988). At that point, the irrigator is to apply the volume of water calculated to replenish the soil reservoir of the root zone to its full level. A precondition to effective management of root zone soil moisture is to establish the rooting depth. of the specific crop as it varies during the growing season (Hillel, 1987). The volume of soil included within the rooting zone of a plant is the first determinant of the size of the soil moisture reservoir potentially available to it. That volume can be assessed by considering the areal extent and density of the crop stand and the depth of crop penetration. According to Haise and Hagan (1967), measurements of soil water should be made as frequently as possible, and should be at the depth of maximum activity. This is generally between 15 and 30cm for irrigated crops. These measurements are plotted as functions of time on a graph similar to the simulated records of field moisture depletion between irrigations as described by Gear et al (1977).

Irrigation should be scheduled so that the soil water content stays between the refill and full values. If it goes above the full point, leaching will occur, if it goes below the refill point, production will be reduced. However, for best results in determining when to water, Carver (1986), provided some clues including, having knowledge of soil types, their water holding and field capacities. On the basis of these, the computation of the amount of irrigation water can be made.

There are several approaches to the determination of soil moisture. These include the in situ or point measurement, computers and the booking methods.

2.5.3.1 Insitu Methods

Gravimetric Technique

Among the insitu methods is the gravimetric technique. It involves the oven drying of a representative soil sample at 105°C until a constant weight is achieved. Usually, this weight is obtained within 12 hours (Schmugge et al, 1980). Though, for large samples, the drying time may increase. Usually, the weight of the soil sample is taken before overdrying. The amount of water in the soil can be determined, and the moisture calculated and expressed as a percentage of the dry soil weight.

$$w = \frac{Ww - Wd}{Wd - Wc} \times \frac{100}{1}$$

where

w - Moisture content of the soil on a dry weight basis expressed in percentage

Ww - wet weight (g)

Wd - dry weight (g) - after oven drying

Wc - weight of container (g)

When rate of use is plotted against time, a curve can be drawn from which the seasonal use can be obtained. To obtain the volumetric content, the gravimetric value is multiplied by the bulk density of the soil. It is expressed this:-

$$\Theta_v = \frac{WW\ yd}{Wd\ yw} 100$$

where:-

Θ_V - volumetric water content, %

W_w - weight of water (g)

Wd - dry weight of soil (g)

yd - Oven dry bulk density (g/cm^3)

yw - density of water (g/cm^3)

Though, the use of the gravimetric technique has a lot of advantages, including the ease at which samples can be taken using an auger or tube sampler and the ease in the calculation of soil moisture content, it has some disadvantages such as the problem of obtaining representative soil samples. For the fact that several samples are required, it is laborious and time consuming.

However, despite these shortcomings, the gravimetric method is probably the most widely used technique of all insitu methods for measuring soil moisture (Schmugge et al, 1980). In a study of the effects of varying levels and frequencies of irrigation on growth, yield, nutrient uptake and water use efficiency of maize and cowpea by Mbagwu and Osuigwe (1985), the result using the gravimetric technique revealed that the growth of maize was best when irrigating with water equivalent to 75% field capacity at daily interval. Furthermore, the optimum yields and nutrient uptake of both crops (maize and cowpea) were obtained by irrigating with water equivalent to 100% field capacity at daily or 2-day interval. The technique has equally been used to assess the spatial variability within farm plots and in comparing the variability shown by tensiometers and gypsum blocks. Cary (1981) in his study on perspective on irrigation dates was able to achieve the comparison by taking gravimetric samples at depths of 15, 30 and 45cm from two cores taken 2m apart, twice weekly at random locations in the rows near the blocks and tensiometers.

NEUTRON MOISURE METER

It is also an insitu method. The instrument includes a probe (with a source of fast neutrons and a detector of slow neutron) lowered from a shield containing hydrogenous material into the soil through an access tube. It senses volumetric wetness with minimum disturbance, while measurement can be made repeatedly in the same locations and the results made available immediately on the field. (Gear et al 1977). On the basis of this, the amount of water present in the soil profile can be easily calculated, and once the water holding capacity of the soil is determined, an irrigation schedule can be established. It was used to provide an on-farm scheduling for farmers in the Lethbridge region of Alberta, USA (Mckenzie and Chanaysk, 1981). Twenty seven fields ranging in size from 20ha to 64ha were irrigated for crops including sugar beets, soft wheat, barley and alfalfa. Soil textures were clay loam or sandy clay loam and all fields were sprinkle irrigated. Using the neutron probe, irrigation was recommended when the soil water reached 50% of capacity. On the basis of the information obtained from each of the fields, soil moisture depletion curves for the surface zone of the irrigated field were charted as scheduled for the farmers use. The experiement revealed that the scheduling information was beneficial in terms of planning irrigation for each field, planning overall farm operations and making farm decisions. Its use is limited by high cost, radiation hazards and maintenance problems.

TENSIOMETERS: Were first defined by Richards and Gardner (1936) as an unambiguous reference to the porous cup and vacuum gange combination for measuring capillary tension or the energy in which water is held. In addition to moisture tension, it measures moisture content. After an irrigation, as soil moisture is depleted by evaporation and root extraction, the tensiometers register an increase in tension and if properly interpreted can provide a forecast of when plants might begin to suffer stress. In an evaluation study conducted on four methods of irrigation scheduling at Florence, South Carolina, data from tensiometers indicate that soil water potentials maintained above 0.2 bars in the upper 60cm produced maximum yields (Lambert et al 1981). According to them, tensiometers provide an easy way to properly maintain soil water potentials within the desired limits for optimum crop growth. An example was given for corn where a few stressed days can result in substantially reduced yields.

2.5.3.3 Computer Scheduling

An irrigation scheduling program for large digital computers was developed by Jensen (1969) for the United States Department of Agriculture. It is currently being used on about 400,000 ha in the United States using meteorological data to calculate water use and water budget. The computers also forecast the timing and amount of irrigation water necessary for optimum crop production. Computer procedures may provide a clearer estimate of when to irrigate and how much water to apply at a lower total cost than conventional field procedures. An important step in the development of computer irrigation scheduling procedures is to improve the reliability of field data acquisition and data entry. In Colorado, it was possible to schedule field crop irrigation for an entire season without adjustment to the computer adjusted soil moisture depletions (Harrington and Heermann, 1981). Its use are limited by several reasons including, the difficulty in obtaining accurate feedback of dates and amount of irrigation. There is also the problem of delay in the production of schedule as compared with an on-the-spot-personalized field estimate.

A major limitation to its use is that they measure potential only in the immediate vicinity of the unit so that several tensiometers are needed to give a reliable spatial coverage.

2.5.3.2 CHECK BOOK METHOD

It was developed as a relatively simple method of on-farm scheduling, using maximum air temperature, long term average radiation and crop growth stages. According to Lundstrom and stegman (1976), it was developed in the mid 1970s for the determination of irrigation time in Northern Dakota, USA. The first step in its preparation is the development of a set of potential evapotranspiration data calibrated from Jensen et al (1971) scheduling model. Based on evapotranspiration and soil moisture data, irrigation scheduling may start in any week during the irrigation season. However, its use is location specific as its accuracy depends on similar condition of latitude elevation and summer climate as in North Dakota.

2.6 IRRIGATION WATER USE EFFICIENCY

The term "efficiency" is generally understood to be a measure of the output obtainable from a given input. Though, several types of irrigation efficiency as explained by Israelsen and Hansen (1962) can be identified, including conveyance, application and distribution efficiencies among others, the efficiency considered in this work is the water use efficiency. According to Yaron (1966) irrigation water can and should be treated just like other productive factor which takes part in the production process and contributes its share to the total output.

Over time, researches aimed at illuminating the relationship between crop yield and water use have been guided by various notions of what constitutes a desirable level of water use. According to Vaux and Pruitt (1983), some of the researches involve those directed at the goal of establishing the level of water input necessary to achieve maximum yield per acre. This maximum yield was defined by Hillel (1987) as the amount of dry matter produced per unit volume of water taken up by the plant from the soil. As most of the water taken up by the plant in the field is transpired, plant water use is in effect the reciprocal of the transpiration ratio; defined as the quotient of the amount of water transpired during growth, and the dry weight of plants at the time of harvest. De Wit (1958), in an investigation of the determinants of transpiration and yield revealed that their relationship was linear.

Stewart and Hagan (1973), however, have argued that although evapotranspiration is the field level parameter associated most directly with yield, the depth of irrigation water applied is of most concern to Planners and Irrigators. This argument provided a lending support to the proposal advanced by Yaron (1966), that the basic variables of water quantity, irrigation frequency (timing) and irrigation depth are desirable in performing economic analysis of water use efficiency. In his opinion, under conditions at one and the same location, the marginal yield of a crop is a function only of the quantity of water (other irrigation variables being equal).

2.7 SUMMARY AND CONCLUSION OF THE REVIEW

From the foregoing review, the relationship between the soil, crop and atmosphere was revealed. Furthermore, the importance of water (and its quality) as a major complement in crop growth and production was highlighted particularly in areas of variable rainfall. The theoretical basis on the need for irrigation scheduling was equally mentioned. Two pertinent questions were identified as being crucial to any irrigation effort - when to apply water and how much water is applied. To answer these questions, several approaches were identified. Reasons were provided by various authors on the choice of approach.

In Nigeria and on the Jos Plateau, few literature are available on irrigation scheduling (water use). Those that were available included works by Mbagwu and Osuigwe (1985), Lawson and Lal (1981) and Owonubi (1981). However, based on the theoretical background provided, the gravimetric technique was used in the investigation of irrigation water use. Though it requires less skill and sophistication, the results obtained are comparable to those obtained using other techniques. Furthermore, the proposal advanced by Yaron (1966) shall be utilized in the determination of volume of irrigation water.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

In order to achieve the desired aims of the study, the work was carried out in stages.

3.2 INDOOR PREPARATION

The choice of study area was considered based on several factors including cost, intensity of irrigation activity, proximity and time available. Maps of the study area, weather data were obtained and review of available literature was made. Principal among the sources of literature were the International Institute for Tropical Agriculture (IITA), Jos Environmental Resource Development Programme, the Universities of Jos and Ahmadu Bello, relevant theses and textbooks.

3.3 FIELD RECONNAISANCE

A reconnaisance survey was conducted to familiarize myself with the study area. This was quickly followed up with a pilot survey (October, 1991) to locate farms that were being prepared for cultivation. Thirty two farms were identified. The irrigation practice adopted size of farms, crops and the cropping patterns, and a quick survey of the soil characteristics were noted. The farms were found to have the same types of crops, similar cropping pattern and use of mechanical pumps. Though, there was variability in the soil types, a relationship was found between the degree of variability and the size of farms.

3.4 DATA COLLECTION

On the basis of the findings during the reconnaisance, six farms that met the requirement of $50m^2$ as recommended by Hawley *et al* (1982), for soil study were selected. The farms were assigned numbers 1 - 6. The choice of the representative farm was determined by the throwing of a dice whereby each farm had a chance of being selected. This was in consonance with the method described by Campbell and Campbell (1981) that 'in order to schedule irrigation using soil moisture measurements, one must select a site (irrigated as a single field) for monitoring soil moisture'. According to them, set full and refill points for the particular soil being monitored andestablish some kind of record keeping scheme which will show when irrigation is necessary.

The farm eventually selected measured 2384m^2 and was used for the purpose of direct measurement of soil samples and the monitoring of water application. All fields - lettuce, tomatoes, leek onion and carrots - were numbered prior to the first sampling event, retaining the identification throughout the study period. A systematic sampling pattern was adopted in order to efficiently cover the entire fields. Profiles were made to reach the required depths (0 - 10, 10 - 30cm) for the respective sampling points. On the whole, 18 sampling points were taken(see fig3.3)

The gravimetric method was used to measure the moisture content in the various crop fields.

To compute the percentage water content on a dry weight basis, the following equation was given thus:

$$\theta w = \frac{Ww - Wd}{Wd} \times \frac{100}{1} \qquad \text{Eq. 1}$$

(after James L.G. (1988).

where:

θw = Soil water content on a dry basis (%)

Ww = Wet Weight (g)

Wd = dry weight (g)

IRRIGATION WATER USE

CROP TYPE, AREA AND DIRECTION OF WATER APPLIED

SCALE: 1:800

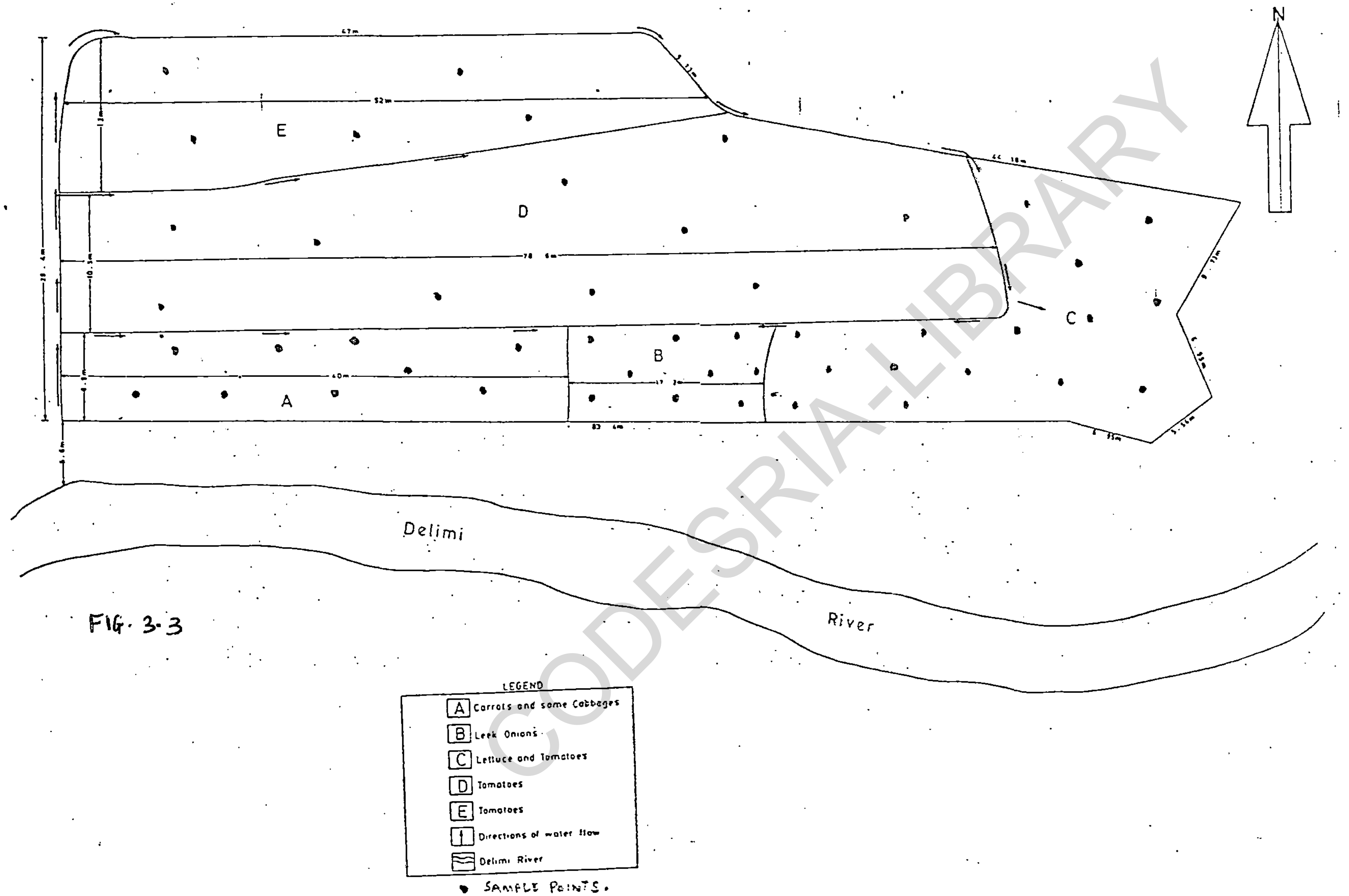


FIG. 3.3

This was converted to volumetric content in order to determine the amount of water (mm) per unit depth (m) using the equation:

$$\theta v = \frac{\theta w \; Wd}{V_T} \quad OR \quad v = \frac{Vw}{V_T} \; 100 \qquad \text{Eq. 2}$$

(after James L G, 1988)

where

θv = Soil water content on a volume basis (%)

V_T = Total volume of soil and voids (g/cm^3)

= density of water (g/cm^3)

Vw = Total volume of water

The volume of water was determined on the field as described by Israelsen and Hansen (1962) while the bulk density was determined separately to convert the moisture content to volumetric content.

Each sampling day was analysed independently to maintain some consistency, at least, with respect to the antecedent meteorological and moisture conditions.

The samples were weighed, using the Dial-O-Gram balance and oven dried at 105°C for 24 hours.

For water application, measurement was taken between 20 November to 18th December, 1991. The pilot survey and other visits revealed that irrigation was done on Saturdays and Wednesdays. Using a stop watch, the amount of water applied on the different crop fields were recorded. The area of the crop fields were measured using a tape. Furthermore, a bucket of known volume was used to determine the amount of water made available to the farm, using the mechanical pump at full capacity. On the basis of these measurements, the total volume of water applied was determined, while a map of 1:500 was prepared.

Direct interview was conducted with the farmer about the crops cultivated (identified during the pilot survey - See Plate 3.1a-d- their growing periods, methods of cultivation and yield.

Plate 3.1a: Showing the carrot field
Source: Author's field Survey 1991

Plate 3.1b: Showing the leek onions
Source: Author's Field Survey 1991

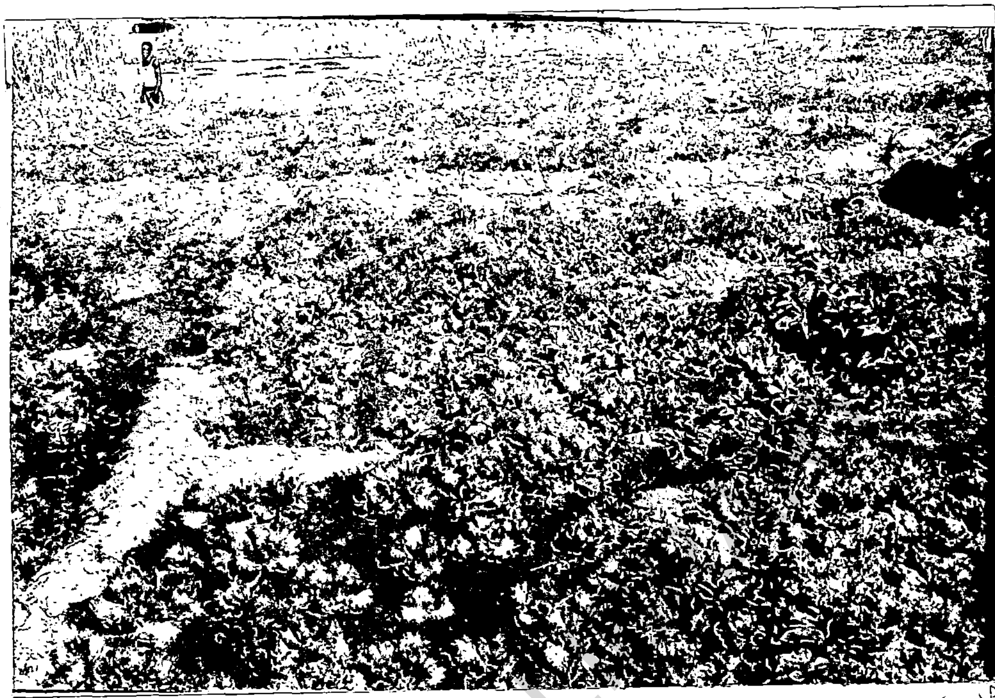


Plate 3.1c: Showing a part of the lettuce field
Source: Author's Field Survey 1991

Plate 3:1d: Showing a part of the tomato field.
Source: Author's Field Survey 1991.

3.5 DATA ANALYSIS

Data was summarized using several methods including mean as a measure of central tendency, tables and graphs such as the line, bar and pie charts.

The hypotheses were tested using student t and Analysis of Variance (ANOVA).

3.6 DATA PRESENTATION

The data collected were presented under three headings namely:

a) Field observation,

b) Total volume of water used,

c) The soil as a recipient of irrigation water.

CHAPTER FOUR

DATA PRESENTATION ON WATER AND SOIL INVESTIGATIONS

4.1 INTRODUCTION

This chapter is aimed at analysing the data collected in the process of determining irrigation water use in the study site. Data was presented under three headings:

a. Field observation

b. Total volume of water used

c. The soil as a recipient of irrigation water.

4.2 FIELD OBSERVATION

Farmer's response to questions on the growing periods of the crops is presented in Table 4.2:

TABLE 4.2 CROPS AND THEIR GROWING PERIODS

Crop	Germination (Days)	Harvest (Days)
Carrot	7 - 10	90
Leek Onion	7	60 - 120
Lettuce	3 - 4	50 - 60
Tomatoes	4	120 - 150
Celery	10	60 - 90
Cabbage	10	90

On his output last year, 1991 for the various crops, yield was measured in baskets, bags and dozens - the standard measures for the farmers as in Table 4.3:

TABLE 4.3: YIELD OF THE VARIOUS CROPS (1991)

Crop	Yield	Land Area (m^2)
Carrot	250 baskets	276
Leek Onion	110 dozen	127.3
Lettuce	3200 baskets	531.6
Tomatoes	750 "	1449.3
Celery	50 "	403.3
Cabbage	10 bags	N.A.

A basket is equivalent to 40kg
and the bag 60kg

4.3 TOTAL VOLUME OF WATER USED

To determine the volume of water used for irrigation, the area of the different crop fields were measured using a tape. On the basis of this, a map of 1:800 was prepared for the study area, showing the size of the different crop fields (fig. 4.4). The process of water application was also illustrated on the map (see fig. 4.4).

CROP TYPE, AREA AND DIRECTION OF WATER APPLIED

SCALE: ~~[illegible]~~ 1:800

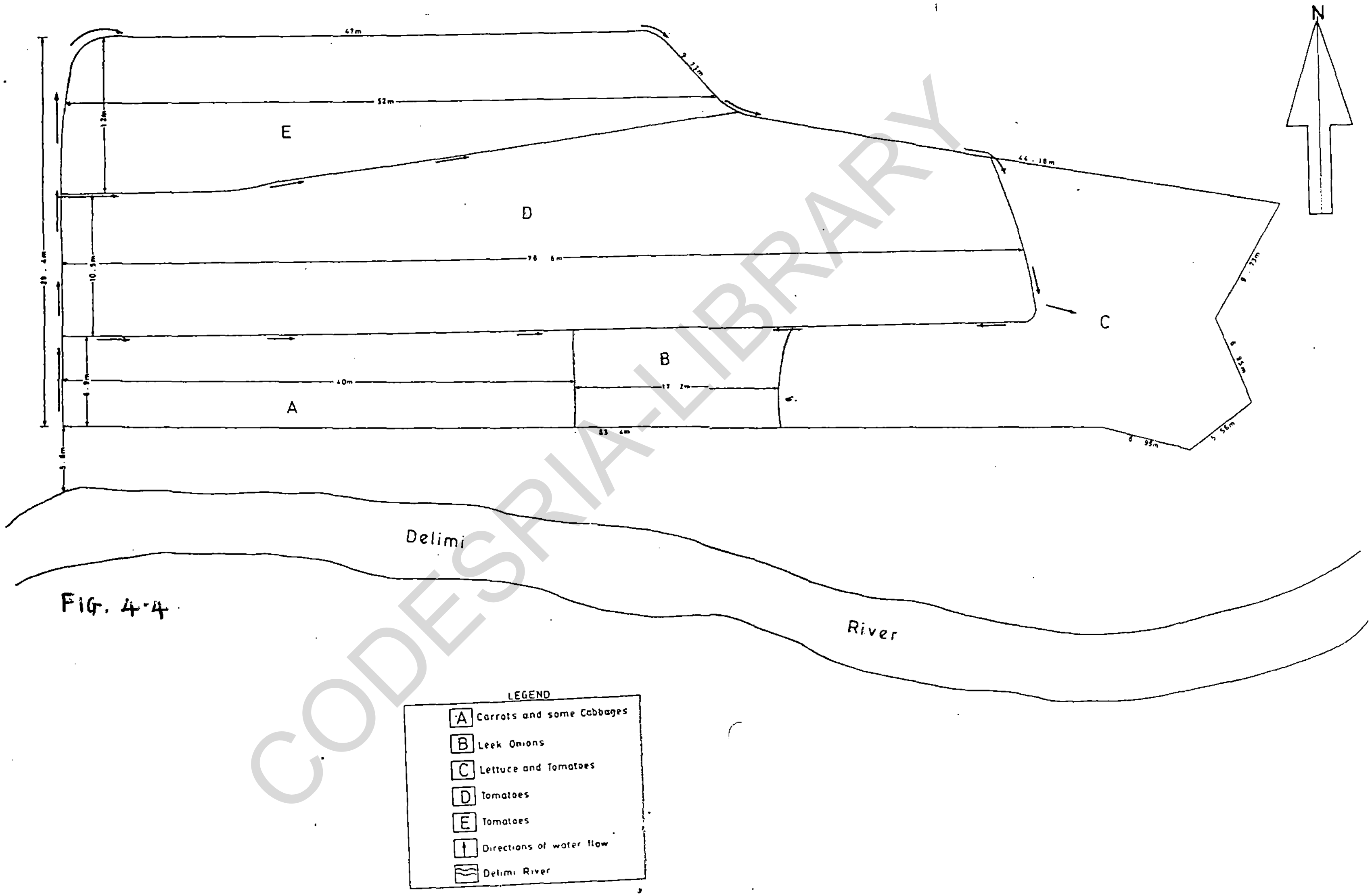


FIG. 4-4

At an average velocity of 2.6 litres per second (see Appendix I), the mean irrigation time for the various crops over the study period (20th November, 1991 to 18th December, 1991) is presented as in Table 4,4 (See Appendix 2 for details).

TABLE 4.4 CONTACT TIME FOR THE VARIOUS CROP AREAS

Crop Type	Size of Farm (m^2)	Contact Time (mins)
Carrot	276	77
Leek Onion	127.3	71
Lettuce	531.6	132
Tomatoes	1449.3	145

The relationships between the crop areas and irrigation time are illustrated in Fig. 4.5a and 4.5b.

To calculate the volume of water used in the various crop fields, the following procedure was taken:

* Unit area - defined as the area of the crop field.
* Irrigation time - Given as the contact time (irrigation duration) multiplied by irrigation

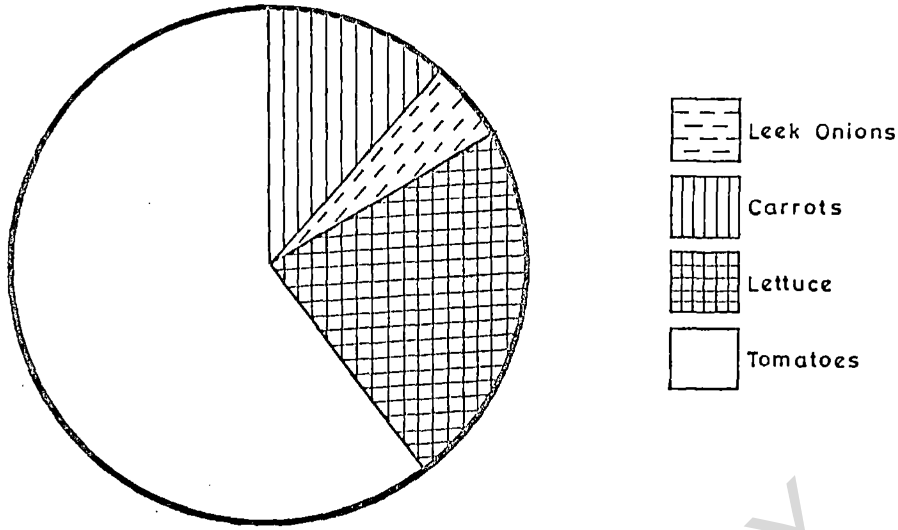
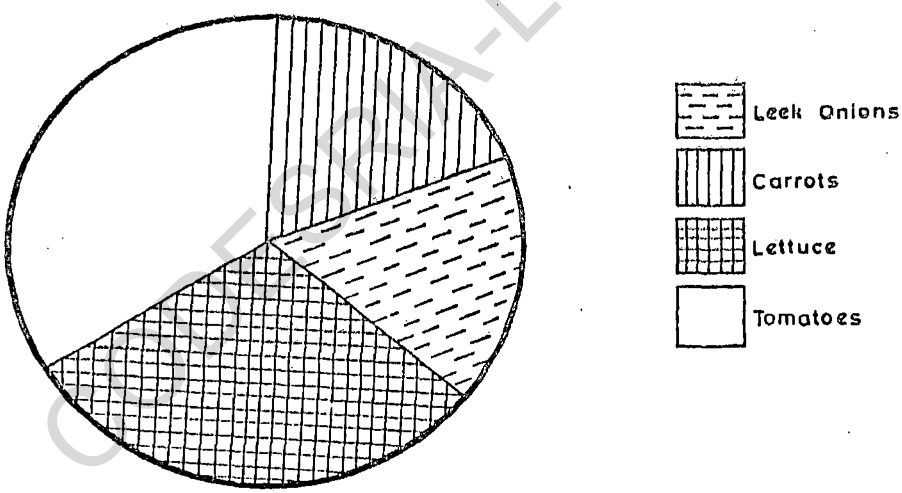


FIG. 4.5a. PIE CHART SHOWING AREAS OF IRRIGATED FIELDS.



4.5b PIE CHART SHOWING THE CONTACT TIME FOR THE VARIOUS CROPS.

interval x the number of irrigations throughout the crop's growing period (as in Table 4.2). For irrigation interval, the following values were used based on the field work - since the plots were irrigated twice a week (Wednesdays and Saturdays), it followed that in a month (30 days), eight irrigation exercises were taken et cetera.

Discharge - The amount of water pumped at full capacity. Measured on the field to be 2.6 litres per second.

On this basis, the total volume of water used for the various crops are thus presented in Table 4.5

TABLE 4.5 VOLUME OF WATER USED DURING CROPS GROWING PERIOD

Crop Type	Unit Area (m^2) A	IRRIGATION TIME (MINS) Growing Period B	Contact Time	Dis-charge C(L/S)	Volume of Water(m^3) AXBXC
Carrot	276	90	77	2.6	$0.079x10^6m^3$
Leek Onion	127.3	90	71	2.6	$0.033x10^6m^3$
Lettuce	531.6	55	132	2.6	$0.164x10^6m^3$
Tomatoes	1449.3	135	145	2.6	$1.18x10^6m^3$

Most of these crops including the carrots, leek onions and lettuce were harvested before the end of the field exercise. In their stead, new crops such as celery was introduced on the farm. The crop areas and water use are represented in Table 4.6:

TABLE 4.6: VOLUME OF WATER USED FOR IRRIGATION (PHASE II)

CROPS TYPE	UNIT AREA (M^2) A	IRRIGATION TIME (mins) Growing Period B	Contact Time	DIS-CHARGE C L/S	VOLUME OF WATER (M^3) A X B X C
Celery	403.3	90	74	2.6	$0.111 \times 10^6 m^3$
Tomatoes	1980.9	135	138	2.6	$1.53 \times 10^6 m^3$

The total volume of water utilized for irrigation, therefore between October, 1990 and March, 1991 was estimated to be the sum total of water used in the cultivation of all the identified crops within the period as shown in Table 4.7.

TABLE 4.7: ESTIMATION OF THE TOTAL VOLUME OF IRRIGATION WATER USE BETWEEN OCTOBER AND MARCH

Crops	Irrigation Water Use (x $10^6 m^3$)
Carrots	0.079
Leek Onions	0.033
Lettuce	0.164
Tomatoes	2.71
Celery	0.111
Total Vol. of Water Used	3.097 x $10^6 m^3$

4.4 THE SOIL AS A RECIPIENT OF IRRIGATION WATER

The soils in the crop fields were investigated using field techniques to determine the textural classes of the soils in which the crops were cultivated. Field technique for textural examination involves the making of shapes with soil samples until a given shape is obtained, beyond which no other shape can be achieved. The result of the field exercise is summarised in Table 4.8.

TABLE 4.8 CROPS AND SOIL TYPES

CROPS	SOIL TYPES
Carrot	Sandy loam
Leek onion	Loam
Lettuce	Sand/Loamy Sand/Clay Loam
Tomatoes	Sand/Loamy Sand

Soil samples were collected from the crop fields at various points to obtain a representative sample of soil character horizontally (spatially) and vertically (depths at 0 - 10cm and 10 - 30cm) identified as the effective rooting zone. Samples were collected for a three day period in order to determine the full point and the refilling point for each of the crops. The mean field moisture values for the various crops are presented in Table 4.9 a - d. Detailed information is available in Appendix 3.

TABLE 4.9(b): MEAN MOISTURE VALUES FOR CARROT

DEPTH	DAY 1		DAY 2		DAY 3	
CM	Θw	Θv	Θw	Θv	Θw	Θv
0 - 10	16.55	39.15	11.87	29.11	8.20	20.35
10-30	17.82	20.7	14.57	17.30	11.97	14.34

TABLE 4.9(b): MEAN MOISTURE VALUES FOR LEEK ONIONS

DEPTH CM	DAY I		DAY 2		DAY 3	
	θw	θv	θw	θv	θw	θv
0 - 10	22.54	51.09	19.88	45.45	16.47	38.87
10 - 30	18.52	21.51	17.19	20.22	15.44	18.45

TABLE 4.9(c): MEAN MOISTURE VALUES FOR LETTUCE

DEPTH CM	DAY I		DAY 2		DAY 3	
	θw	θv	θw	θv	θw	θv
0 - 10	15.31	36.64	10.39	25.97	6.67	17.20
10 - 30	16.87	19.70	12.19	14.96	7.81	9.98

TABLE 4.9(d): MEAN MOISTURE VALUES FOR TOMATOES

DEPTH CM	DAY I		DAY 2		DAY 3	
	θw	θv	θw	θv	θw	θv
0 - 10	15.07	35.07	8.45	21.59	5.05	13.31
10 - 30	6.66	8.32	4.46	5.74	2.96	3.88

The moisture content on the crop fields were found to deplete over time as shown on Table 4.9 A - D. This relationship is further illustrated in fig. 4.6a-d, using trend curves to show variation in moisture content over the days and at the two depths (0 - 10cm and 10 - 30 cm).

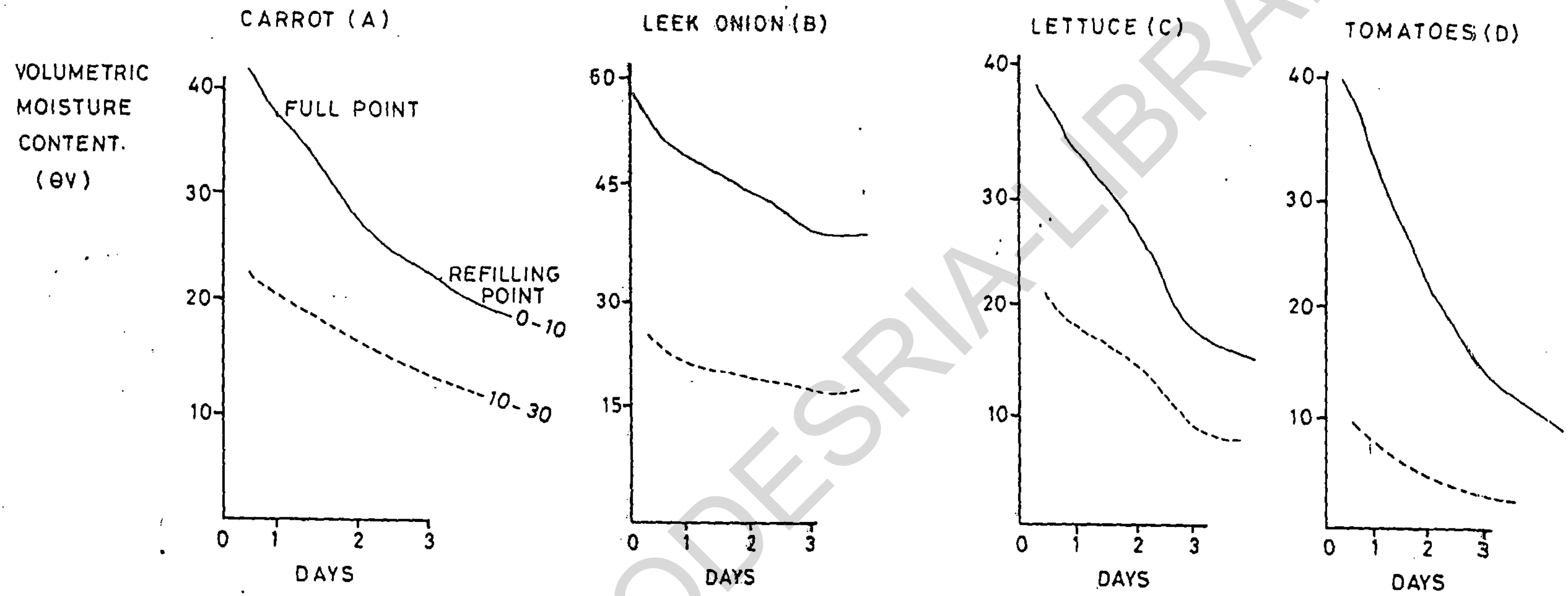


FIG. 4.6 A-D: MOISTURE DEPLETION CURVES FOR THE VARIOUS CROPS.

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 INTRODUCTION

This chapter discusses the results of the research findings and attempts an evaluation of the key issues identified in the course of the research.

5.2 INTERVIEW WITH THE FARMER

An oral interview conducted with the farmer revealed that he started cultivating the irrigated farm at the beginning of the dry season (October 16, 1991) and that he hoped to stop watering the farm by March when the rains commence. Though, actual irrigation exercise commence by October, crops are put in nurseries in September, as the amount of rainfall decreases. Depending on the type of crop and its growth pattern, as identified in Table 4.2, transplanting is done in three phases September, November/December, and January/February. The farmer went further to explain that crops are intercropped in such a way that those with short growing period are mixed with those with long harvest time, otherwise, referred to as the major crop. The area of land put into cultivation for these major crops and number of transplants are testimonies of their importance, for instance, tomatoes. In the study site, the area devoted to tomato cultivation was $1449.3m^2$ as in Table 4.4 and was to expand into other areas as the crops cultivated in them were harvested as Table 4.6 illuminates. The reason given by the farmer for the inter/mixed cropping practice was that the secondary crops provide the initial revenue,as the major crop matures to offset farming expenses. On the use of ash, the farmer explained that it gave cohesion to the soil, therefore tend to enhance the water holding capacity of the soils; while enriching the soil with organic matters.

Though, the farm was watered every Wednesday and Saturday while high labour cost was incurred on farm labour, the harvest as recorded from last year's (1991) as in Table 4.3 indicated a satisfactory benefit-cost ratio.

5.3 CONSIDERATION ON TOTAL VOLUME OF WATER USE

The application of water starts with the pumping of water into a major canal - about 30 cm wide - upslope - then allowed to flow into the secondary canals by gravity (See Plate 5.2). The water is made available on the farm using mechanical pump as shown in Plate 5.3. With the aid of the pump, it was possible to lift water farther away from the floodplain (Fig. 4.4), thus providing extensive land area for irrigated agriculture and an increase in water use as typified by Table 4.5, 4.6 and 4.7. For the period under study, the total volume of water used to produce the various crops as in Table 4.3 was $3.097 \times 10^6 m^3$ (See Table 4.7). Table 4.7 also estimated the amount of water actually used for each crop field.

5.4 <u>THE SOIL AS A MOISTURE MEDIUM</u>

The results obtained in the field work revealed that the soil types for the various crop fields differed as in Table 4.8 hence their varying capacities to retain water as exemplified in Table 4.9 A - D and Fig. 4.6 A-D. However, the result of the T-test aimed at determining the difference in the moisture content over the irrigation interval for the different crops with depths was significant at 0.01% and 0.05% levels for the Leek Onion, Lettuce and Tomatoes fields (See Appendix 4 A-D). The result of the test for carrot field was not

Plate 5.2: Showing the advance of water to the Farm.
Source: Author's Field Survey 1991.

Plate 5.3: Showing a mechanical pump lifting water into the Farm.
Source: Author's Field Survey 1991.

significant suggesting that there was no significant difference in the moisture content over the irrigation interval with depths. The results for the various crops are confirmations of the inferences drawn in Fig. 4.6 A - D. Having the test result as a back-up, the 'no difference' in the moisture content at depth for carrot reflects the texture of the soil type - sandy loam - found on the field. It is coarse textured and allows water to infiltrate by gravity. Enhanced by its good structure, the gravitational force continues through the sub soil. The depletion curve (F.g 4.6a) suggests that the soil is deep while drainage is rapid. For root crops such as carrot, it creates allowance for root development.

The significant differences in the moisture content with depth for the other crops including leek, lettuce and tomatoes shall be explained accordingly. For the leek onion, the basic soil type was loam which is medium textured, while the underlying subsoil at 30cm depth was loamy clay. Though, a deep soil, the clay content of the soil disallowed free passage of water, hence much was lost by capillary attraction.

The lettuce field contained find sand, therefore, a high infiltration rate, while at the subsurface depth, the sandy content gave way to clay loam. Similarly, the tomatoes field exhibited a high infiltration rate because of the presence of sand, and loamy sand on the top soil, while the sub-soil was underlain by boulders and plutonic rock surfaces, hence characterised by shallow soils. This is in agreement with fig. 5a and 5b whereby the contact time during water application was relatively small. Its drainage characteristic was enhanced by slope conditions accelerated by the underlying impervious rock surfaces.

Generally, the moisture content in the various crop fields was influenced by management practices, whereby ash used in the farm increased the organic matter content of the top soil, hence played a major role in the soil structure as well as water retention. However, climatic factors including evapotranspiration and wind velocity had some effect on the moisture retained on the top soil.

Nevertheless, the available water for the different crop fields was calculated as the difference between moisture content (volumetric percent) of the full point and the refilling point, determined on mean value basis for the entire effective rooting zone (0 - 30cm) as in Table 5.10.

TABLE 5.10: AVAILABLE WATER AT FULL POINT FOR THE CROPS

CROP	FULL POINT	REFILLING POINT	AVAILABLE WATER MM/M
Carrot	29.92	17.34	12.58
Leek Onion	36.30	28.66	7.64
Lettuce	28.17	13.59	14.58
Tomatoes	22.01	8.59	13.42

The relationship in the available water capacity of the different crop fields was illustrated in Fig. 5.7.

When compared with Fig. 4.5a and b and Fig. 4.6 A - D, the relationship in the available water capacity is illuminated, suggesting that the different crops have different water capacity, therefore, different water use. Several reasons account for this relationship including soil texture, depth, slope, climatic factors and management practice. However, the ANOVA test on the difference in the water use of the crops was not significant at both 0.01 and 0.05% levels (see appendix 5). The result can be explained by the management practice of the farmer perfected over time, whereby the respective fields were watered on the same day, irrespective of the varying factors earlier identified.

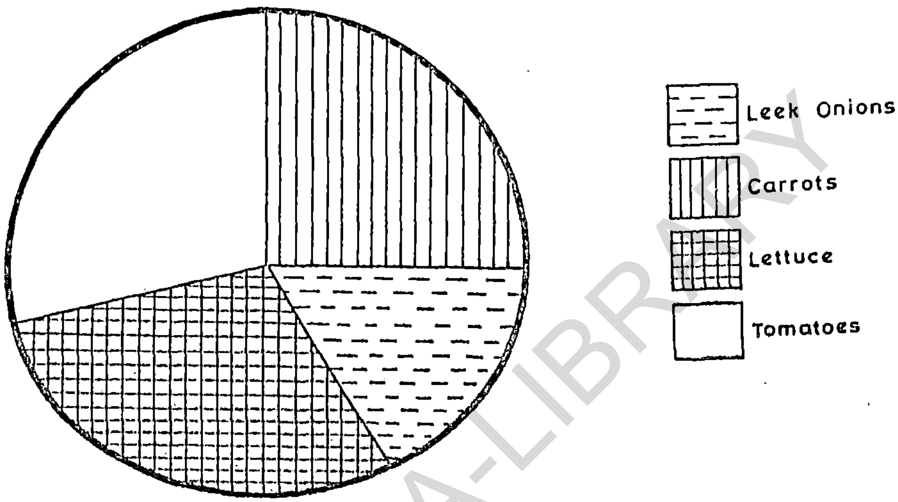


FIG 5·7 PIE CHART SHOWING THE AVAILABLE WATER CAPACITY OF THE CROPS.

CHAPTER SIX

SUMMARY AND CONCLUSION

6.1 OVERVIEW OF THE STUDY

Irrigated agriculture is radically being transformed on the Delimi floodplain. Among the various innovations made, there is a general shift in the method of water lifting and application from the traditional shadoof system to the use of mechanical pumps which bring more areas farther away from the floodplain under cultivation. These developments demand an understanding of water use for irrigation, which should begin by trying to decide how much water is needed by the various crops and then supplying that need.

This study, therefore, sought to provide answers to two questions in irrigation management, namely;

a) when to irrigate the various crops

b) how much water was applied to the various crop fields.

To achieve the desired aims of the study, data was collected from both primary and secondary sources. In collecting primary data, a farm site was chosen. Data was consequently collected on soil samples over a three-day irrigation interval. The total volume of water applied was equally measured over a thirty-day period to ascertain the irrigation time, discharge and area of the different crop fields. Secondary sources of data were also consulted, including an insight into the environmental conditions which constitute necessary inputs in the study of irrigation water use in the area.

The bulk of the data collected were summarized using several methods including percentages, tables, and graphs. To test the first hypothesis on whether there was any significant differences in the moisture content over the irrigation interval for the different crops at depths, the student 't' was employed, while on the second hypothesis testing the difference in the water use of the different crops, the Analysis of Variance (ANOVA) was used.

6.2 SUMMARY OF THE RESULTS

The results of the present investigations have revealed that:

1. The volume of water made available to the crop fields, varied. Carrot with an area of $276m^2$ representing 11.6% of the total farm area was

applied 0.079 x 10^6 m^3 of water, while Leek Onion with an area of 127.3^{m2} (5.3%) had 0.033 x 10^6 m^3 of water. Also, the Lettuce field which made up $531.6m^2$ representing 22.3% of the total crop area had 0.164 x 10^6 m^3 of water made available to it. Tomatoes with an area of $1449.3m^2$ being 60.8% of the total cropped area in the farm was applied 1.18 x 10^6 m^3 of water. However, the volume of water applied to the Tomato field increased to 1.53 x 10^6 m^3 because of its introduction in the Lettuce field when it was harvested; bringing the total cropped area for Tomato to $1980.9m^2$. In the same vein, Celery, a 'new crop' was introduced in place of Carrot and Leek Onion harvested. The volume of water applied to this field ($403.3m^2$) was 0.1 x 10^6 m^3.calculated for the whole of the dry season.

2. Variations exist in the soil characteristics for the different crops. While carrot was cultivated in a sandy loam soil, Leek Onions was planted in loam. On the other hand, lettuce was cultivated in a wider range of soil types, including sand, loamy sand and some skeletal clay loam soils. Tomatoes were noted to be dominantly

cultivated in sand and loamy sand. These variations were reflected on the contact time in water application for each of the crops. Carrot with a medium textured soil type recorded a contact time of 77 minutes, while it took 71 minutes to irrigate the Leek onion. 132 minutes was taken to irrigate the Lettuce crop field and could be explained by the areal extent and depth of the soil in someparts of the field. On the other hand, the shallow depth of soil in the tomato field together with the high infiltrability of the soil types - sand and loamy sand - gave an irrigation timeof 145 minutes, despite its relatively large areal extent.

With the varying contact time for the different crops influenced principally by the soil characteristics and to a lesser degree, by the area of crop field, the moisture retention capacity of thesoils in the various fields were found to vary between irrigation. For the carrot, the amount of moisture depleted from 29.92mm on the first day to 17.34mm on the last day considered to be the 'wilting threshold' for carrot. On the other hand, the full and refilling points for the Leek onion was 36.30mm and 28.66mm respectively, while the value for lettuce on the first day after irrigation was 28.17mm. This amount depleted to a wilting threshold value of 13.59mm on the third day prior to irrigation. The difference in moisture content was most glaring in the tomato field, irrigated on the first day to 22.01 full point level. On the third day, much of the moisture had depleted to a low of 8.59mm. The implication is that the water use of the various crops differ hence should require different irrigation scheduling. This is reflected in the available water capacities for the various crops. Carrot requires 12.58mm/m volume of water to reach the full point while leek requires only 7.64 mm/m. Lettuce and Tomatoes need 14.58mm/m and 13.42mm/m of water to reach their respective full points.

3. Based on the 1991 harvest, the amount of yield for the various crops were given as follows:

*Carrot - 250 baskets *Leek Onions - 110 dozen

*Lettuce - 3200 baskets *Celery - 50 baskets

*Cabbages - 10 bags.

6.3 CONCLUSIONS

Based on the objectives of the study, the nature of data collected and analysis carried out, the following conclusions were reached:

1. Given the area for the different crops, irrigation frequency and growing periods of crops, the total volume of water used for irrigation during the dry season (October to March) for the farm site with a total area of $2384m^2$ was estimated to be $3.097 \times 10^6 m^3$.
2. Though the various crops have different refilling points, beyond which crops may wilt, the irrigation frequency was found to be insignificant. This finding is buttressed by the mixed cropping practice in the site where all the crops are watered the same day.
3. Given the yield, irrigation is construed to have a significant input in agricultural production, particularly with the availability of water in the Delimi river all year round that can sustain agricultural activity even in the face of a drought event.

6.4 SUGGESTIONS FOR FURTHER STUDIES

Though this study looked at irrigation water use, the conclusions reached may not be wholly representative due to lack of time. Furthermore, the methods used may not have given the desired results. For instance, it would have been possible to set up an experimental plot in order to actually identify the full capacity and the wilting point for the various crops. However, it is suggested that similar researches should be carried out elsewhere to confirm the results obtained and to improve on the study.

Nevertheless, several areas for further investigation have been suggested.

1. An urgent research need is required on Irrigation water quality, its effects on plants growth and human pathology. On my part, attempt was made to analyse some water samples to determine its goodness in the cultivation of vegetables. Unfortunately the result was not reliable due to lack of good equipment and staff to conduct the analysis. The importance of this research need is borne out of the

fact that the water used in the cultivation of the crops on the Delimi river flows through the Jos metropolis. A lot of waste including domestic (urine, kitchen oil, laundry, bath) greases from mechanics, petroleum products and solid waste are all components of the water. The implication is that when these crops watered with it are consumed, various toxic elements including lead, selenium etc could be injurious to health. As a matter of fact, the colour of the water is dark brown, turbid and sometimes exude pungent odour.

2. Another area of research that requires attention is irrigation water use during the various stages of crop's growth.

3. Of equal consideration is benefit-cost analysis and efficiencies of irrigation water use.

4. Lastly, the importance of water in agriculture can stimulate a research on irrigation water use and yield.

REFERENCES

1. Adepetu, A.A. (1985): Farmers and their farms on the four fadamas on the Jos Plateau. Jos Plateau Environmental Resource Development Program. Interim Report No.2

2. Ajaegbu, H.I. (1986)(Ed): Jos Plateau Environmental Resource Development Program. Final Report on the 1981 - 1986 training and research activities of the program. Department of Geography and Planning, University of Jos.

3. Areola, O.O. (1982): Soils and Vegetation in a Geophy of Nigerian Development (2nd Ed), Oguntoyinbo J.S., Areola O.O. and Filani M.O. (eds). Heinemann Boks Nigeria.

4. Bielorai, H. and Hopmans P.A. (1975): Recovery of Leaf Water Potential, Transpiration and Photosynthesis of Cotton during Irrigation Cycles, Agronomy Journal Vol.67(5): 629 - 632

5. Blaney H.F. and Criddle W.D. (1950): Determining Water Requirements in Irrigated areas from Climatological and Irrigation Data. United States Department of Agriculture. Soil Conservation Technical Bulletin 96.

6. Blum, A (1974): Leaf water potential and stomatal activity in sorghum as influenced by soil moisture stress. Israel Journal of Botany Vol. 23:14-17

7. Camp, T.R. and Lawler, J.C. (1969): Water supplies in Davis, C.V., and Sorenson, K.E. (Eds). Handbook of Applied Hydraulics, 3rd Ed. McGraw Hill Inc.

8. Campbell G.S. and Campbell, M.D. (1981): Irrigation Scheduling using soil moisture in Proc. Irrigation Scheduling for Water and Energy Conservation in the '80s ASAE

REFERENCES

9. Carver, K. (1986): Scheduling based on soil moisture and measurements in Irrigation and the Environment. Proc. Technical Conference San Anthonio, Texas.

10. Cary, J.W. (1981): Irrigation Scheduling with soil instruments. Error levels and micro processing design in Irrigation scheduling for Water and Energy Conservation in the '80s. Proc. of the American Society of Agricultural Engineers pp. 81-90.

11. De Wit C.T. (1958):'Transpiration and crop yield' Vers Landbouk Onderz no. 64 Wageningen, The Netherlands.

12 Doorembus J. and Pruitt W.D. (1977): Guidelines for predicting crop-water requirements, FAO Irrigation and Drainage paper 24 (rev.)

13. Ehrler, W.L., Idso, S.B., Jackson, R.D. and Reginato, R.J. (1978): Wheat canopy temperature: Relation to Plant water potential. Agronomy Journal 70:251-256

14. Ehrler, W.L. and van Bavel, C.H.M. (1967): Sorghum folial response to changes in soil water content. Agronomy Journal Vol. 59(3): 243-246

15. Gabel, M. (1979): Hoping: Food for Everyone. Strategies to eliminate hunger on spaceship Earth. Anchor Press - New York.

16. Gear, R.D., Dranfield, A.S., and Campbell, M.D. (1977): Irrigation Scheduling with neutron probe. Journal of Irrigation and Drainage ASCE 103 (1R3): 291 - 298

17. Grove, A.T. (1961): Population densities and Agriculture in Northern Nigeria in Barbour K.M. and Prothero R.M. (eds): Essays on African Population. Routledge and Kegat Paul, London

REFERENCES

18. Gupta, R.K., and Chanhan, H.S. (1986): Stochastic modelling of Irrigation requirements. Journal of Irrigation and Drainage, Vol. 112 No. 1

19. Hagan, R.E. and Wang, K.J., (1981): Irrigated rice production systems design procedures. Westview Tropical Agriculture Series No. 3

20. Haise, H.R. and Hagan, R.M. (1967): Soil, plant and evaporative measurements as criteria for scheduling irrigation. Agronomy Journal, 577 - 604.

21. Harrignton, G.J. and Heerman, D.F. (1981): State of the art in Irrigation scheduling computer program in Irrigation Scheduling for Water and Energy Conservation in the '80s. ASAE

22. Hawley, M.E., McCuen, R.H. and Jackson, T.J. (1986): Volume-Accuracy relationship in soil moisture sampling methodology. Journal of Irrigation and Drainage Vol. 108 IR1: 1 - 11

23. Hillel, D. (1987): Efficient use of water in Irrigation. Principles and Practices for improving Irrigation in Arid and Semi Arid regions. World Bank Technical Paper No. 64.

24. Hsiao, T.C. (1973): Plant responses to Water Stress. Annual Review of Plant Physiology 24:519 - 570.

25. Hudson, N.W. (1983): Field Engineering for Agricultural Development. Oxford University Press, N.Y.

REFERENCES

26. Idso, S.B., Jackson, R.D., Pinter, P.J. and Reginato, R.J. (1981): Normalizing the stress-degree-day-parameter for environmental variability. Agricultural Meteorology, 24: 45-55

27. Igbozuruike, M.U. (1981): Agriculture at a Cross-road. A comment on Agricultural Ecology. University of Ife Press, Ile-Ife, Nigeria.

28. Israelsen, D.W. and Hansen, V.E. (1962): Irrigation Principles and Practices. John Wiley & Sons, Inc.

29. James, L.G. (1988): Principles of Farm Irrigation System Design. John Wiley and Sons, London.

30. Jensen, M.E. (1969): Scheduling Irrigation using computers. Journal of Soil and Water Conservation 24(5): 193-195.

31. Kassam, A.H. and Elston J.F. (1974): Seasonal changes in the status of water and tissue characteristics of leaves of vicia faba L. Annals of Botany Vol. 38: 419-429.

32. Lambert, J.R., Doty, C.W. and Quisenberry V.L. (1981): Irrigation Scheduling in humid areas in Irrigation scheduling for Water and Energy Conservation for the '80s. ASAE pp. 132-143

33. Lawson, T.L. and Lal.R. (1981): Crop water requirements and water use efficiency in the humid and sub-humid zone of West Africa in Proc. 4th Afro-Asia Regional Conference on Irrigation and Drainage Vol. I.

REFERENCES

34. Lundstrom, D.R., Stegman, E.C. and Werner, H.D.(1976): Irrigation Schduling by the checkbook method. Extension Agricultural Engineering Department. North Dakota State University, Fargo.

35. Mackenzie, R.H. and Chamaysk; D.S. (1981): On-farm Irrigation Scheduling is Southern Alberta in Irrigation Scheduling for Water and Energy Conservation in the '80s. ASAE pp. 219 - 221

36. Mbagwu, J.B.C. and Osuigwe, J.D. (1985): Effects of varying levels and frequencies of irrigation on growth, yield, nutrient uptake and water use efficiency of maize and cowpeas on a sandy loam ultisol. Plant and Soil 84: 181-192.

37. Meyer, W.S. and Green, G.C. (1980): Water use by wheat and plant indicators of available soil water. Agronomy Journal, Vol. 57(1): 38-40.

38. Miller, T. (1982): Living in the Environment. Wadsworth Publishing Company, California.

39. Nwa, E.U. (1984): An evaluation of small pump and shadouf systems of irrigation in Northern Nigeria, Samaru 1(2): 191 - 201.

40. Nwa, E.U. and Martins, B. (1982): Irrigation Development in Nigeria in Proc. 4th Afro-Asia Regional Conference on Irrigation and Drainage Vol. 1:1-18

41. Oguntoyinbo, J.S. (1982). Climate in A Geography of Nigerian Development (2nd Ed.), Oguntoyinbo J.S., Areola, O.O. and Filani M.O. (eds). Heinemann Books Nigeria.

REFERENCES

42. Okechukwu, G.C. (1983): Effect of Tin Mining on the Hydrology and Water Resources of the Jos Plateau. Jos Plateau Environmental Resource Development Program. Interim report No. 3

43. Owonubi, J.J. (1981): Water use and energy balance of two cowpeas varieties in Samaru. Samaru Vol. 1 No.1

44. Patterson, G. (1986): Tin Mine Ponds of the Jos Plateau. Their nature and resource value. Interim Report No. 8 Jos Plateau Environmental Resource Development Program, Department of Geography, University of Durham.

45. Penman, H.L. (1948): Natural evaporation from open water, bare soil and grass. Proc. Royal Society London. A 193: 120-145.

46. Phillips Howard, K.D., Adepetu, A.A. and Kidd A.D.(1991): Aspects of change in fadama farming along the Delimi River (1982-1990). Jos Plateau Environmental Resource Development Project. Interim Report No. 18.

47. Phillips-Howard, K. and Schonoeich, K. (1991): The irrigation potential of water resources on the Jos Plateau. A preliminary analysis. A paper presented at the National Workshop on the Strategies for Agricultural Development and Management, Jos.

48. Pinter, A.J., and Reginato R.J. (1981): Thermal infra-red technology for assessing plant water stress in Irrigation Scheduling for Water and Energy Conservation in the '80s. ASAE pp 1 - 9.

REFERENCES

49. Reginato, R.J., and Howe, J. (1985): Irrigation Scheduling using crop indicators. Journal of Irrigation and Drainage. Vol. III (2): 125-133

50. Reicosky, D.C. (1981): A research tool for evapotranspiration measurements for model validation and irrigation scheduling in Irrigation Scheduling for Water and Energy Conservation in the '80s. ASAE

51 Rydzevski J.R. (ed) (1968): Irrigation Development Planning. Southampton University. K.K.

52. Schmugge, T.J., Jackson, T.J. and Mckin J.L., (1980): Survey of Methods for Soil moisture determination. Water Resources Research Vol. 16(2): 961-179.

53. Shainberg I. and Oster, J. (1978): Quality of Irrigation water. International Irrigation Information Centre. Bet Dagan, Israel.

54. Stern, P. (1987): Small Scale Irrigation. A Manual of low cost water technology, Russell Press Limited, Nottingham, Reprinted.

55. Stewart, J.I. and Hagan, R.M. (1973): Functions to predict effects of crop water deficits. Journal of Irrigation and Drainage. ASCE pp 421-439

56. Sumayao C.C. and Kanemasu E.T. (1979): Temperature and Stomatal resistance of soyabean leaves. Canadian Journal of Plant Science Vol. 59: 153-162

57. Tanner, C.B. (1963): Plant Temperatures. Agronomy Journal 55: 210-211.

REFERENCES

58. Thorne, D.W. and Thorne, M.D. (1979): Water Requirement of Crops in Soil Water and Crop Production. Avi Publishing Company Inc. Wesport, Connecticut.

59. Thornthwaite C.W. (1948): An approach towards a rational classification of climate. Geographical Review 38: 55-94.

60. Turner, N.C. (1978): Experimental approaches and techniques for the measurement of Plant Water Status. Plant and Soil 58

61. Vaux, H.J. and Pruitt, W.O. (1983): Crop-Water Production Functions in Advances in Irrigation. Vol. II (Hillel D., ed), Academic Press, Orlando Florida.

62. Westesen, G.L., and Hansen, T.L. (1981): Irrigation scheduling using wash tub evaporation pans in Irrigation Scheduling for Water and Envery Conservation in the '80. ASAE pp 144 - 149.

63. Withers, B. and Vipond S. (1980): Irrigation Design and Practice, 2nd Ed. B.T. Batford Ltd London.

64. Worthington, E.B. (Ed) (1977): Arid Land Irrigation in Developing Countries. Environmental Problem and Effects. Pergamon Press Inc. N.Y.

65. Wright, J.L. (1981): New Evapotranspiration Crop Co-efficients. Journal of Irrigation and Drainage Vol. 108(2) IR2 March

66. Wright, J.L. and Jensen, M.E. (1972): Peak Water requirements of crops in Southern Idaho. Journal of Irrigation and Drainage. Vol. 98 IR2: 193-201.

REFERENCES

67. Yaron, D. (1971): Estimation and use of water production functions in crops. Journal of Irrigation and Drainage, ASCE: 97:291-303.

APPENDIX 1.

RATE OF FLOW OF WATER INTO THE FARM AT FULL CAPACITY

To determine the amount of water made available per second in the farm, a bucket was used. The dimensions were as follows:

- Upper diameter = 28cm
- Upper radius (Ur) = 14cm
- Lower diameter = 17cm
- Lower radius (Lr) = 8.5cm
- Height = 25cm

$$\pi r^2 u = 3.14 \times 14^2 = 615 cm^2$$

$$\pi r^2_L = 3.14 \times 8.5 cm^2 = 226 cm^2$$

$$(615 + 226) cm^2 \div 2 = 420 cm^2$$

Total volume of the bucket ∴

$$420\ cm^2 \times H(25cm) = 1050\ cm^2$$

$$= 10.5 \text{ litres}$$

Rate of flow of water from the mechanical pump determined using a stop watch = 4 seconds.

$$\text{Discharge} = \frac{10.5}{4}$$

$$= \underline{2.6 \text{ litres/second}}$$

APPENDIX 2

AVERAGE IRRIGATION TIME FOR THE PLOTS

DATES	CROP TYPE	TIME OF IRRIGATION	DURATION	SIZE
20/11/91	Lettuce	9.05 - 11.19 a,m.	2.14 hours	531.6m^2
23/11/91	"	8.47 - 10.59 a.m.	2.12 hours	
30/11/91	"	9.45 - 12.00 a.m.	2.15 hours	
4/12/91	"	8.32 - 10.49 a.m.	2.17 hours	
7/12/91	"	9.20 - 11.30 a.m.	2.10 hours	
11/12/91	"	10.45 - 12.59 p.m.	2.14 hours	
14/12/91	"	8.00 - 10.08 a.m.	2.08 hours	
		$\bar{x}$ time (Irrigatn)	2.12 hours	
20/11/91	Leek Onions	11.20 - 12.34 p.m.	1.14 hours	127.3m^2
23/11/91	" "	11.16 - 12.19 p.m.	1.09 hours	
30/11/91	" "	9.57 - 11.07 a.m.	1.10 hours	
7/12/91	" "	1.50 - 3.00 p.m.	1.10 hours	
4/12/91	" "	10.50 - 12.03 pm	1.13 hours	
11/12/91	" "	2.56 - 3.29 p.m.	1.13 hours	
14/12/91	" "	10.09 - 11.18 a.m	1.09 hours	
18/12/91	" "	3.30 - 4.45 p.m.	1.15 hours	
		Mean Irrigation Time	1.11 hours	

APPENDIX 2 CONTD.

DATE	CROP TYPE	TIME OR IRRIGATION	DURATION	SIZE
20/11/91	Carrot	12.34 - 1.53	1.19 hrs	$276m^2$
23/11/91	"	12.20 - 1.37	1.17 hrs	
30/11/91	"	11.07 - 12.20	1.13 hrs	
4/12/91	"	12.03 - 1.23	1.20 hrs	
7/12/91	"	3.00 - 4.15	1.15 hrs	
11/12/91	"	3.29 - 4.08	1.19 hrs	
14/12/91	"	11.18 - 12.33	1.15 hrs	
18/12/91	"	4.45 - 6.05 pm	1.20 hrs	
		$\bar{X}$	1.17 hrs	

(b) (a)

SIZE - $825.3m^2 + 624m^2 = 1449.3m^2$

20/11/91	Tomatoes	a) 1.53 - 2.58	1.05 hrs	
		b) 2.58 - 4.33	1.35 hrs	2.40 hrs
23/11/91	"	a) 1.40 - 2.30	0.50 hrs	
		b) 2.30 - 3.48	1.18 hrs	2.08 hrs
30/11/91	"	a) 2.09 - 3.01 hrs	0.52 hrs	
		b) 3.01 - 4.21 hrs	1.20 hrs	2.12 hrs
4/12/91	"	a) 2.01 - 3.01	1.00 hr	
		b) 3.05 - 4.44	1.39 hrs	2.39 hrs
7/12/91	"	a) 11.32 - 12.22	0.50 hrs	
		b) 12.22 - 1.42	1.20 hrs	2.10 hrs
11/12/91	"	a) 4.07 - 5.07	1.00 hr	
		b) 1.20 - 2.57	1.37 hrs	2.37 hrs
14/12/91	"	a) 1.08 - 2.01	0.53 hrs	
		b) 2.03 - 3.21	1.18 hrs	2.11 hrs
18/12/91	"	a) 12.00 - 1.03pm	1.03 hrs	
		b) 1.04 - 2.44	1.40 hrs	2.43 hrs
		$\bar{x}$	2.25 hrs	

APPENDIX 3

MOISTURE CONTENT VALUES

DAY ONE (FULL POINT)

CROP TYPE/DEPTH	Ww(g)	Wd(g)	θw(%)	θv %
A Carrot 1 0 - 10	100	90.0	11.11	27.77
10 - 30	"	90.0	11.11	13.88
2 0 - 10	"	83.0	20.48	47.21
10 - 30	"	80.0	25.0	27.77
3 0 - 10	"	84.7	18.06	42.49
10 - 30	"	85.2	17.37	20.55
B Le Onion 1 0 - 10	"	82.3	21.50	49.15
10 - 30	"	86.0	16.27	19.43
2 0 - 10	"	81.5	22.69	51.36
10 - 30	"	78.8	25.31	28.05
3 0 - 10	"	81.0	23.45	52.76
10 - 30	"	87.7	14.00	17.05
C Lettuce 1 0 - 10	"	84.0	19.04	44.42
10 - 30	"	80.0	25.0	27.77
2 0 - 10	"	90.0	11.11	27.75
10 - 30	"	82.0	21.95	24.99
3 0 - 10	"	90.0	11.11	27.75
10 - 30	"	85.0	17.60	20.77
4 0 - 10	"	84.0	19.04	44.42
10 - 30	"	90.0	11.11	13.88
5 0 - 10	"	86.0	16.27	38.86
10 - 30	"	92.0	8.69	11.10

APPENDIX 3 CONTD.

DAY ONE (FULL POINT)

CROP TYPE/DEPTH	Ww(g)	Wd(g)	Θw(%)	Θv %
D Tomatoes 1 0 - 10	100	83.0	20.48	47.21
10 - 30	"	90.0	11.11	13.88
2 0 - 10	"	93.7	6.72	17.49
10 - 30	"	90.0	11.11	13.88
3 0 - 10	"	81.0	23.45	52.76
10 - 30	"	90.0	11.11	13.88
4 0 - 10	"	90.0	11.11	27.77
10 - 30	"	0	0	0
5 0 - 10	"	88.0	13.63	33.31
10 - 30	"	0	0	0

DAY TWO

CROP TYPE/DEPTH	Ww(g)	Wd(g)	Θw %	Θv %
A Carrot 1 0 - 10	100	92.4	8.22	21.0
10 - 30	100	93.6	6.83	8.87
2 0 - 10	100	91.0	9.89	24.99
10 - 30	100	82.0	21.95	24.99
3 0 - 10	100	85.1	17.50	41.36
10 - 30	100	87.0	14.94	18.05

DAY TWO CONTD.

CROP TYPE/DEPTH	Ww(g)	Wd(g)	Θw %	Θv %
B. Leek Onion 1 0 - 10	100	82.5	21.21	48.60
10 - 30	"	86.5	15.60	18.74
2 0 - 10	"	82.1	21.80	49.71
10 - 30	"	81.4	22.85	25.83
3 0 - 10	"	86.3	15.87	38.04
10 - 30	"	88.4	13.12	16.10
C. Lettuce 1 0 - 10	"	88.0	13.63	33.31
10 - 30	"	85.8	16.55	19.72
2 0 - 10	"	94.6	5.70	14.97
10 - 30	"	89.0	12.35	15.26
3 0 - 10	"	89.9	11.23	28.04
10 - 30	"	86.5	15.60	18.74
4 0 - 10	"	88.7	12.73	31.36
10 - 30	"	91.8	8.93	11.38
5 0 - 10	"	92.0	8.69	22.20
10 - 30	"	93.0	7.52	9.71
D. Tomatoes 1 0 - 10	"	92.0	8.69	22.20
10 - 30	"	91.8	8.93	11.38
2 0 - 10	"	93.9	6.49	16.92
10 - 30	"	92.1	8.57	10.96
3 0 - 10,	"	90.0	11.11	27.77
10 - 30	"	95.4	4.82	6.38

APPENDIX 3 CONTD.

DAY TWO CONTD.

CROP TYPE/DEPTH	Ww(g)	Wd(g)	θw %	θv %
D. Tomatoes (contd)				
4 0 - 10	100	92.4	8.22	21.0
10 - 30	"	0	0	0
5 0 - 10	"	93.0	7.52	19.42
10 - 30	"	0	0	0

DAY THREE (REFILLING POINT)

CROP TYPE/DEPTH	Ww(g)	Wd(g)	θw %	θv %
Carrot 1 0 - 10	100	95	5.26	13.88
10 - 30	"	97	3.09	4.16
2 0 - 10	"	97	3.09	8.32
10 - 30	"	83	20.48	23.68
3 0 - 10	"	86	16.27	38.86
10 - 30	"	89	12.35	15.26
Leek Onion 1 0 - 10	"	83	20.48	47.21
10 - 30	"	88	13.50	16.50
2 0 - 10	"	84	19.04	44.42
10 - 30	"	83	20.48	23.60
3 0 - 10	"	91	9.89	24.99
10 - 30	"	89	12.35	15.26
Lettuce 1 0 - 10	"	92	8.69	22.20
10 - 30	"	92	8.69	11.10
2 0 - 10	"	97	3.09	8.32

APPENDIX 3 CONTD.

DAY THREE (REFILLING POINT) CONTD.

CROP TYPE/DEPTH	Ww(g)	Wd(g)	θw %	θv%
Lettuce (contd.)				
10 - 30	100	95	5.26	6.94
3 0 - 10	"	91	9.89	24.99
10 - 30	"	89	12.35	15.26
4 0 - 10	"	93	7.52	19.42
10 - 30	"	94	6.38	8.32
5 0 - 10	"	96	4.16	11.09
10 - 30	"	94	6.38	8.32
Tomatoes 1 0 - 10	"	97	3.09	8.32
10 - 30	"	93	7.52	9.71
2 0 - 10	"	94	6.38	16.65
10 - 30	"	95	5.26	6.94
3 0 - 10	"	96	4.16	11.09
10 - 30	"	98	2.04	2.77
4 0 - 10	"	95	5.26	13.88
10 - 30	"	0	0	0
5 0 - 10	"	94	6.38	16.65
10 - 30	"	0	0	0

APPENDIX 3 CONTD.

MEAN MOISTURE VALUES

DAY ONE (FULL POINT)

CROP TYPE/DEPTH		θw %	θv %
Carrot	0 - 10	16.55	39.15
	10 - 30	17.82	20.70
Leek	0 - 10	22.54	51.09
	10 - 30	18.52	21.51
Lettuce	0 - 10	15.31	36.64
	10 - 30	16.87	19.70
Tomatoes	0 - 10	15.07	35.70
	10 - 30	6.66	8.32

DAY TWO

CROP TYPE/DEPTH		θw %	θv %
Carrot	0 - 10	11.87	29.11
	10 - 30	14.57	17.30
Leek	0 - 10	19.88	45.45
	10 - 30	17.19	20.22
Lettuce	0 - 10	10.39	25.97
	10 - 30	12.19	14.96
Tomatoes	0 - 10	8.45	21.59
	10 - 30	4.46	5.74

APPENDIX 3 CONTD.

DAY THREE (REFILLING POINT)

CROP TYPE/DEPTH		θw %	θv %
Carrot	0 - 10	8.20	20.35
	10 - 30	11.97	14.34
Leek	0 - 10	16.47	38.87
	10 - 30	15.44	18.45
Lettuce	0 - 10	6.67	17.20
	10 - 30	7.81	9.98
Tomatoes	0 - 10	5.05	13.31
	10 - 30	2.96	3.88

APPENDIX 4.

HYPOTHESES TESTING

HYPOTHESIS ONE: There is no significant difference in moisture content over the irrigation interval for the different crops at depths of 0 - 10 and 10 - 30cm.

To determine the relationships, the student 't' test was employed as the statistical technique. The formula is given thus:

$$t = \frac{\bar{x}_a - \bar{x}_b}{\sqrt{\frac{\sigma_a^2}{n_a} + \frac{\sigma_b^2}{n_b}}}$$

where $\bar{x}a$ = values for 0 - 10 cm

$\bar{x}b$ = values for 10 - 30 cm.

A. FOR CARROT

	$\bar{x}a$	$\bar{x}b$
	27.77	13.88
	47.21	27.77
	42.49	20.55
	21.00	8.87
	24.99	24.99
	41.36	18.05
	13.88	4.16
	8.32	23.60
	38.86	15.26
Σ	265.88	157.13
$\bar{x}$	29.54	17.45
σ^2	187.34	59.86

APPENDIX 4 CONTD.

To calculate 't'

$$t = \frac{29.54 - 17.45}{\sqrt{\frac{187.34}{9} + \frac{59.86}{9}}}$$

$$= \frac{29.54 - 17.45}{\sqrt{20.8 + 6.65}} = \frac{12.09}{5.23}$$

$$t = 2.31$$

$$Df = n_{xa} + n_{xb} - 2 = 9 + 9 - 2 = 16$$

Critical Value of t at 0.01% = 2.58

0.05% = 2.92

Conclusion: Since the calculated t (2.31) is less than the critical values of t at 0.01 (2.58) and 0.05% (2.92), the null hypothesis which states that there is no significant relationship in the moisture content over the irrigation interval for carrots at depts of 0 - 10cm and 10 - 30 cm is accepted.

APPENDIX 4 CONTD.

B. FOR LEEK ONIONS

	$\bar{x}_a$	$\bar{x}_b$
	49.15	19.43
	51.36	28.05
	52.76	17.05
	48.60	18.74
	49.71	25.83
	38.04	16.10
	47.21	16.50
	44.42	23.60
	24.99	15.26
	406.24	180.56
$\bar{x}$	45.13	20.06
σ^2	75.86	21.53

$$t = \frac{45.13 - 20.06}{\sqrt{\frac{75.86}{9} + \frac{21.53}{9}}} = \frac{25.07}{3.28}$$

$$t = 7.64$$

$Df = n_{xa} + n_{xb} - 2 = 9 + 9 - 2 = 16$

Critical Value of t at 0.01% = 2.58

0.05% = 2.92

APPENDIX 4 CONTD.

Conclusion: Since the calculated t (7.64) is greater than the critical values of t at 0.01 (2.58) and 0.05 (2.92) the H_o which states that there is no significant difference in the moisture contentover the irrigation interval for leek onions at depths of 0 - 10 and 10 - 30cm is rejected. The alternative hypothesis indicating a significant relationship is accepted.

C. FOR LETTUCE:

	$\bar{x}_a$	$\bar{x}_b$
	44.42	27.77
	27.75	24.99
	27.75	20.77
	44.42	13.88
	38.86	11.10
	33.31	19.72
	14.97	15.26
	28.04	18.74
	31.36	11.38
	22.20	9.71
	22.20	11.10
	8.32	6.94
	24.99	15.26
	19.32	8.32
	11.09	8.32
Σ	399.00	223.26
$\bar{x}$	26.6	14.88
σ^2	118.72	39.95

APPENDIX 4 CONTD.

$$t = \frac{26.6 - 14.88}{\sqrt{\frac{118.72}{15} \quad \frac{39.95}{15}}} = \underline{11.72}$$

$$t = \underline{3.61}$$

$$Df = n_{xa} + n_{xb} - 2 \quad 15 + 15 - 2 = 28$$

Critical value of t at 0.01 = 2.46

0.05 = 2.76

Conclusion: Since the calculated t (3.61) is greater than the critical values at 0.01 (2.46) and 0.05 (2.76), then Ho which states that there is no significant relationship is the moisture content over the irrigation interval for lettuce is rejected. The H_1 which indicates a significant relationship is accepted.

FOR TOMATOES:

	$\bar{x}_a$	$\bar{x}_b$
	47.21	13.88
	17.49	13.88
	52.76	13.88
	27.77	0
	33.31	0
	22.20	11.38
	16.92	10.96
	27.77	6.38
	21.64	0
	19.42	0
	8.32	9.71
	16.65	6.94
	11.09	2.77
	13.88	0
	16.65	0
	353.08	89.78
$\bar{x}$	23.53	5.98
2	158.78	34.36

$$t = \frac{23.53 - 5.98}{\sqrt{\frac{158.78}{15} + \frac{34.36}{15}}} = \frac{17.55}{3.57}$$

$$t = 4.91$$

APPENDIX 4 CONTD.

$$Df = n_{x_a} + n_{x_b} - 2 = 15 + 15 - 2 = 28$$

Critical value of t at 0.01 = 2.46

0.05 = 2.76

Conclusion: Since the calculated t (4.91) is greater than the critical values at 0.01 (2.46) and 0.05% (2.76), the Ho which states that there is no significant relationship in the moisture content over the irrigation interval for tomatoes is rejected. The H_1 which indicates a significant relationship is accepted.

APPENDIX 5

HYPOTHESIS 2

Ho: There is no significant difference in the water use of the different crops.

The Analysis of Variance was used to determine the relationships.

CARROT		LEEK		LETTUCE		TOMATOES	
A	A^2	B	B^2	C	C^2	D	D^2
39.15	1532.75	51.09	2610.18	36.64	1342.48	35.70	1274.49
20.70	428.49	21.51	462.68	19.70	388.09	8.32	69.22
29.11	847.39	45.45	2065.70	25.97	674.44	21.59	466.12
17.30	299.29	20.22	408.84	14.96	223.80	5.74	32.94
20.35	414.12	38.87	1510.87	17.20	295.84	13.31	177.15
14.34	205.63	18.45	340.40	9.98	99.60	3.88	15.05
140.95	3727.67	195.59	7398.67	124.45	3024.25	88.54	2034.97

Total sum of Squares $= Ex^2 - \frac{(Ex)^2}{n}$

$$= 16185.59 - \frac{(549.53)^2}{24}$$

$$= 16185.59 - 12582.63$$

$$= 3602.96$$

Between sum of squares

$$= \sum \frac{(Ex)^2}{ng} - \frac{(Ex)^2}{n}$$

$$\left(\frac{140.95}{6}\right)^2 + \left(\frac{195.59}{6}\right)^2 + \left(\frac{124.45}{6}\right)^2 + \left(\frac{88.59}{6}\right)^2 - \frac{301983.22}{24}$$

$$= 3311.15 + 6375.90 + 2581.30 + 1308.03 - 12582.63$$

$$= 993.75$$

Within Sum of Samples = $Ex^2 - \frac{(Ex)^2}{n}$

x_a^2 = 3727.67 - 3311.15 = 416.52

x_b^2 = 7398.67 - 6375.90 = 1022.77

x_c^2 = 3024.25 - 2581.30 = 443.95

x_d^2 = 2034.97 - 1308.03 = 726.94

Wss = 416.52 + 1022.77 + 443.95 + 726.94

= 2610.18.

Degrees of Freedom

Df =	TSS	= N - 1	=	24 - 1 = 23
	BSS	= K - 1	=	4 - 1 = 3
	WSS	= N - K	=	23 - 3 = 20

Mean Squares

Between Mean Squares = $\frac{993.75}{3}$ = 331.25

Within Mean Squares = $\frac{2610.18}{20}$ = 130.5

Calculated F = $\frac{\text{Between Mean Squares}}{\text{Within Mean Squares}} = \frac{331.25}{130.5}$

Calculated F = 2.53

Total Value of F at 0.01% = 4.93

0.05% = 3.09

APPENDIX 5 CONTD.

Conclusion: Since the calculated F value (2.53) is less than the Table value at 0.01 (4.93) and 0.05 (3.09) levels, the Ho which states that there is no significant difference in the water use of the different crops is accepted.