EFFECT OP DIFFERENT CULTIVATION TECHNIQUES ON INFILTRATION

BY

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ABSTRACT

The literature on infiltration and factors affecting it was reviewed. Special emphasis was given to the effects of different cultivation techniques. As infiltration is one of the key factors affecting soil erosion by water the literature review opened with a brief survey of erosion problems in Nigeria.

The effects of different cultivation techniques on soil physical properties were assessed by measuring infiltration with double ring infiltrometers. The cultivation techniquee included a manual system, a bullock-powered system, a system of zero tillage and a variety of tractor-powered systems. An aggregate stability test was also carried out for selected treatments.

The infiltration measurements were carried out on four occasions spaced over the growing season. Each infiltration run lasted four hours and the differences in cumulative infiltration between the third and the fourth hours were taken as the equilibrium infiltration rates.

Infiltration was also measured in a 6-year old zero tillage experiment in which zero tillage was contrasted with

continuous cultivation. In another experiment, infiltration in a field under grass fallow was compared with that in a 30 year old continuously cultivated field.

The results of infiltration measurements showed that infiltration and cultivation technique were closely related. Cumulative infiltration under the manual system was superior to either the zero tillage or the bullock-powered system and greatly superior to the mechanised system. Statistical analysis of equilibrium infiltration rates confirmed this. The manual system was significantly superior to the bullock-powered and tractor-powered systems at 5% level of significance. The statistical analysis also showed that zero tillage was significantly superior to all the mechanised treatments while there was no significant difference among the mechanised treatments. The grass fallow was greatly superior to the continuously cultivated soil. The lowest infiltration rates were obtained in the mid-season when rainfall was at its peak suggesting that infiltration and initial soil moisture content were related.

The aggregate stability test showed that the surface soil under zero tillage was much more stable than surface soil under any other treatment; the significance level was 0.1%. At the same level of significance, surface soil under manual and bullock-powered systems were more stable than surface soil under any of the mechanised treatments.

In view of the importance of infiltration rate with respect to surface runoff and soil erosion, the conclusions about the effect of different cultivation techniques on infiltration should be tested for all the major soil types in Nigeria. In addition, further studies are needed to find **out** the exact causes of reduced infiltration in particular cases.

TABLE OF CONTENTS

LISTS OF TABLES

LIST OF FIGURES

Page

CHAPTER I

INTRODUCTION

The ability of the soil to absorb rainfall is one of the most important characteristics determining the severity of soil erosion. Water only runs off the soil surface when the rate of water application exceeds the infiltration rate. Hence every factor that reduces the permeability of the soil increases the likelihood of surface runoff and erosion.

The ease with which water moves into and through the soil is greatly influenced by the relative volume of soil pores. This is not all, size and continuity of these pores are also very important. The larger and the more conductive the pores are, the greater the rate of water entry. In other words during infiltration, the large (or coarse) transmission pores are by far the most important because increased infiltration rates largely depend on them. Large pores are also responsible for free movement of air and root penetration.

The pore sizes depend on the agents which create porosity. Some of these agents include soil organisms, drying and soil cultivations. As the roots elongate and grow bigger through the existing pores, they expand them and when they die and decompose, they leave behind long continuous and fairly stable channels.

Soil organisms like ants, earthworms, termites and crickets, burrow through the soil and produce channels. Soil cultivations help to increase the pore space. Drying and frost action (in temperate lands) often cause soils to crack. The cracks produced form channels through which water passes.

For efficient water transmission, the pores created by these agents must remain fairly stable and conductive. Agents responsible for their stabilisation include soil organic matter, root exudates, clay fraction and larger soil organisms. Humus possesses many large molecules shaped like ropes or nets which help to attach primary soil particles together. In freshly decomposing organic matter, polysaccharide gums produced by bacteria and fungal hyphae are also very effective in stabilising the pores. Living roots also produce high molecular weight material called mucigel, which can help to stabilise the soil pore space.

As for the clay size particles, they possess both positive and negative charges. These enable them to cling to one another and to the larger primary particles by electrostatic attraction. This helps to stabilise the larger aggregates and pores in and between them. Earthworms on their part exude mucus as they burrow through the soil which also helps to produce stable soil crumbs as well as stable pores.

Most often, the geometry of these conducting pores is altered by the action of raindrops, agricultural implements, movement of men and animals, rapid swelling and air pressure associated with rapid wetting of previously dry soil. The walls of the coarser pores may also collapse slowly if the soil becomes waterlogged. This is because waterlogged conditions are conducive to the bacterial degradation of polysaccharide gums into smaller molecules which have no ability to bond soil particles together. The end result is disruption in the continuity of the conducting pores.

Cultivation has possibly the greatest effect on destruction of large pores. Baver (1965) refers to tillage as the different mechanical manipulations of the soil that are used to provide the necessary soil conditions favourable to the growth of crops. Russell (1973) describes the functions of tillage operations as follows:

(a) to obtain good seedbed

(b) to kill weeds

(c) to undo the damage done by previous traffic over the land or previous cultivations.

(d) to increase the permeability of the surface soil or subsoil to water which will allow better drainage and aeration in the soil and hence better root penetration.

Historically, tillage was necessary to eliminate weeds and loosen up the soil so that seeds could be planted. Essentially this is still the same today but power equipment and herbicides have greatly modified they way in which these goals are achieved.

Cultivation to a great extent has unique consequences on the soils physical condition. The method employed, the type of soil and its previous history as well as the weather during and after cultivation, all influence the outcome. During cultivation especially when the soil moisture content is high, tractor wheels often cause compaction and smearing. The end results of these are difficulty in root penetration, reduced infiltration and waterlogged condition with all its undesirable effects. Thus the purpose of cultivation itself is defeated.

In the Northern States of Nigeria, a wide range of cultivation techniques is used. The traditional tillage tool commonly used is the hoe. It varies in size and shape depending on the specific function it is to perform. Examples include the weeding hoe (*fartanya* in Hausa) and the ridging or mound hoe (*garma* in Hausa). Animal powered and tractor powered cultivations are also being practised but to a lesser extent, especially the latter.

This project compares some of the cultivation practices being employed in the Northern states. The treatments are a manual system, a bullock-powered system, six different tractor powered systems and a system of zero tillage with the use of herbicides. In another small experiment the effect of grass fallow on infiltration was also investigated.

The objectives of this thesis are to evaluate different cultivation systems in terms of their effects on infiltration and as far as possible to relate infiltration to other soil properties such as aggregate stability.

CHAPTER 2

LITERATURE REVIEW

Since infiltration has an important effect on soil erosion, the first part of the review is devoted to a survey of erosion problem areas in Nigeria. The survey covers water erosion and wind erosion, but as will be seen, water erosion is the dominant mechanism in most part of the country. The second and third parts of the review deal with infiltration and the factors affecting it. The last part of the review deals with methods of measuring infiltration.

2.1 Survey of Soil Erosion Problem Areas in Nigeria.

A distinction is sometimes made between natural erosion which is the result of geologic forces and that which is the result of man's efforts to obtain a living from the land. The latter is often referred to as accelerated erosion. Natural erosion is so slow in terms of human life as to pass generally unnoticed except by the geologist. In most places, it is relatively unimportant.

What takes nature hundreds or thousands of years to build, man can, and often does, destroy almost overnight by haphazard land use and improvident husbandary. Problems arise when land is exposed to erosion by cutting and ravaging of forest lands for timber, by overgrazing of range and pasture lands and also by cultivation of the soil for crop production.

Apart from all these, engineers who undertake construction work often care very little about some of the wider consequences of their activities. As Salbany (1960) pointed out, the engineer whose responsibility it is to maintain a road or a route-way takes only his project into consideration and is normally not interested in any problem that may arise as a result of his activities.

Some of the ill effects of soil erosion are:

(a) loss of soil

(b) poorer physical condition of the remaining soil and

(c) loss of soil fertility.

In Nigeria today, soil erosion has become so apparent in many parts that there is no longer any doubt about its damaging effects. In the forest region, the main causative agent of soil erosion is running water (Floyd, 1965; Ofomata, 1965). The extent to which this occurs is largely defined by climate, landscape, topography, inherent soil properties and land use patterns. Water erosion is also important in parts of the Northern states (Ologe, 1978).

Soil losses due to action of wind have also been reported in some parts of the Northern state, (Chalk, 1963 ; Jones and Wild, 1975; Ahmed, 1972; and Ologe, 1978).

A brief survey of areas where soil erosion has been documented is given below:

Anambra and Imo states

This part of the country is the worst hit in terms of soil erosion caused by running water due to the alarming dimensions of the gullies. Hectares of land have been destroyed which are usually referred to as badlands.

Floyd (1965) commenting on the severity of the problem wrote:

> "The Eastern Region of Nigeria has one unfortunate claim to fame which might be better left unpublished except that it relates to a problem of monumental proportions and of great interest and concern to geographers, pedologists, agriculturists, conservationists as well as other scientists the world over.
>
> Within the region, there occurs some of the most spectacular examples of soil erosion and "badland" topography to be seen in West Africa. Erosion

gullies attain a degree of severity and destructiveness seldomly experienced in other parts of Africa."

He attributed this to a particular combination of geological formations and landforms together with marked disturbance of the natural vegetation cover by man in the course of agricultural pursuits.

Ofomata (1965) on the other hand, observed that the role of man in creating the spectacular erosion features in this area has been, on the whole, grossly exaggerated.

Dramatic gully erosion could be seen in the plateau escarpment zone particularly along the scarp of Awka-Orlu Uplands, and the Nsukka - Okigwi escarpment to the east. Less pronounced though equally insidious sheet and gully erosion is widespread across the region extending from the plateaux in the north-west as far south as the coastal plains in the Ikot Ekpene - Itu - Uyo triangle and eastwards to the Cross River Basin (Floyd, 1965).

The most notorious area of the gully erosion in these states is near the villages of Agulu, Nanka and Oko. This area, in common with other areas around, has a very high annual rainfall. The rainy season is of 7-8 months duration. Regular and often intense precipitation occurs from May to October, falling on already exposed soil surface and causing serious damage.

Violent storms with short, yet torrential downpours, common in the beginning and at the end of the rainy season often cause more damage within the space of an hour or so than regular rains over a much longer period of time. Ten miles south of Awka, the head water of the subsequent N. Awdaw river, a tributary of the northward flowing Mamu (in the Imo clay-shale lowlands) have deep gullies and revines into the eastward - facing Nanka sandstone escarpment. Figure 1 shows the ecological zones and the most notorious erosion zones in Nigeria.

Benue and Plateau State

The grassy plains of the Jos Plateau and the absence of tse-tse fly favour a large population which eventually leads to overgrazing and consequently to soil erosion. The rich alluvial tin deposit lends itself to mining operations which often leave a scene of earth mounds dried out ponds, tin tailings and reservoirs rendering the land unproductive for agriculture, forestry or grazing without expensive rehabilitation programmes.

Around Shendam and Pankshin areas, gully erosion is a common feature (Grove, 1952). In some other areas of these two states, indiscriminate and uncontrolled burning by farmers for hunting purposes and by the Fulanis to get a quick flush of grass has also contributed immensely to the long term damage of the vegetation cover (private discussion with an Agricultural Officer in Jos, 1978). At the end of the dry season, there is often little or no land that has not been grazed over repeatedly.

The complete removal of crop residues and the repeated trampling of cultivated land cause soil campaction and loss of soil structure. These tend to decrease infiltration and the result is increased erosion hazard.

Kaduna State

Ologe (1978) in a survey of soil erosion problem areas of some parts of Northern States observed that gully erosion and sheet erosion are common features in Kaduna state. These he attributed to continuous cultivation and overgrazing.

Kaduna - Kafanchan- Kwoi areas are noted for widespread gullying though most of the gullies are no longer erosionally active. This is evident as most gullies are covered with dense vegetation. Ganawuri and Kagoro hills are also affected. Also around Zaria, valley side gullying is a common phenomenon (Ologe, 1971). Travelling along Kaduna-Zaria road, deep gullies probably resulting from construction work, can be seen on both side of the road (personal observation).

To the northern part of the State, around Katsina - Kaita, there is slight wind erosion while gullying is found along large rivers.

Kano State

The State can be divided into two:

(a) areas underlain by basement complex

(b) areas of sedimentary rocks.

In areas underlain by basement complex, gully, sheet and wind erosion occur but vary in intensity. Gullying is most severe within the basins of the Gari, Watari, Chalawa, Kano and Dudurum (Ologe, 1978).

Mortimore and Wilson (1965) noted that "Soil erosion is most serious along valley sides where the steepest slopes occur, gullies frequently working back from the river banks and cultivation furrows alligned at right angles to the banks."

In areas underlain by sedimentary rock, sheet erosion is found mostly in poorly vegetated areas. Wind erosion is common in the northern part of the state during the dry season and in areas where vegetation cover has been removed. Furthermore sheet erosion occurs in areas devoid of vegetation due to overgrazing.

Niger State

As in Kaduna State, (Ologe, 1978) also observed that accelerated erosion was taking place or has taken place in the not-too-distant past in certain areas around the Federal Capital Territory. He noticed sheet erosion on dissected plains east of Bwari which he attributed to removal of vegetal cover through cultivation, overgrazing and annual burning.

Gully erosion was also found to be a common feature in most parts of the state; e.g. in the upper reaches of the rivers Ndawuse and Usuman, along Mokwa river and Kontagora area. Some of the gullies were reported to be as deep as 3 - 5 metres.

Ondo and Oyo States

As in other southern states, soil erosion in these states is caused mainly by running water due to heavy precipitation.

Lal (1976a) commented that soil erosion on Alfisols is a serious limiting factor when continuous cropping is introduced on these soils. Anxiety on this account is heightened by the fact that continuous farming will gradually replace shifting cultivation and bush fallow in this area.

Lal (1976b) also found out that relative nutrient concentrations in eroded soil indicate that most of the nutrient-loss in runoff water is associated with eroded sediments. In other studies he found that soil erosion increased the gravel content and decreased the silt and clay contents of the surface horizons. The moisture content capacity of the surface soil also decreased significantly. He also recorded a decrease in infiltration rate from 3.5 cm/minute in February 1972 to 0.2 cm/minute under bare fallow and 0.1 cm/minute under maize - maize (ploughed) in February 1974.

Travelling along Ife - Ondo and Ondo-Ore roads large gullies along the road sides and on nearby hills can be seen (personal observation).

Sokoto State.

Around Sokoto town itself and in places where permanent damage has been done, sheet erosion has been found to be very severe. Gully erosion is also common along river valleys.

However, in the northern parts of the state wherever vegetation cover has been completely or largely removed, wind erosion is found to be a serious problem. This often occurs during the long dry season and at the begining of the rainy season. Around Sokoto valley, the sedimentation pattern in the flood plains indicates that accelerated erosion started many hundreds of years ago (FAO, 1969).

Prothero (1962) reported that drifting sand has made it necessary to shift roads and often constitutes a menace to the farmer who may have to replant his crops several times as blown sand commonly overwhelms young plants and burries them.

Chalk (1963) wrote: "Where airphotos have been systematically appraised over large areas as at Sokoto along Sokoto - Rima, unofficial estimates indicate that from 20-50 percent of the upland is being affected by gully erosion.

Other States

The fact that documented evidence are not available for some areas as to the extent of erosion damage does not mean that soil erosion does not occur there. For instance one can infer from the situation in Sokoto State that similar thing may be expected in Borno State; though this is yet to be confirmed in a report. The underlying reasoning being similar rainfall.

Drilling of oil in Rivers and Bendel States has caused large expanses of land to lie waste either because of pollution or direct exposure to water erosion. The Daily Times of November 17, 1977 reported an incident whereby the Escravos communities in Bendel State petitioned the then military governor to save them from continuous oil pollution and erosion in the area.

From this background it appears that soil erosion is widespread in many parts of Nigeria. It is imperative therefore that conscious efforts be made to combat this serious problem or else the much talked about Operation Feed the Nation and industrial development would be meaningless. It is hoped that the present thesis will contribute to these efforts by focussing attention on the importance of soil management as a major factor affecting infiltration, surface run-off and soil erosion.

2.2 Infiltration

Infiltration is usually defined qualitatively as the downward entry of water into the soil. Horton (1933) described infiltration as the process whereby water soaks into or is absorbed by the soil. Harrold *et. al.* (1976) defined it as the entry of water into the soil surface.

Infiltration rate is defined as the quantity of water entering the soil surface per unit area per unit time. The dimensions are LT^{-1}; for example mm/hr, cm/hr or in/hr.

For stable and efficient agriculture sound and careful water management practices are essential. These include erosion control, improvement of infiltration and prevention of flood.

The realistic planning of these water management and conservation practices, requires accurate information on the

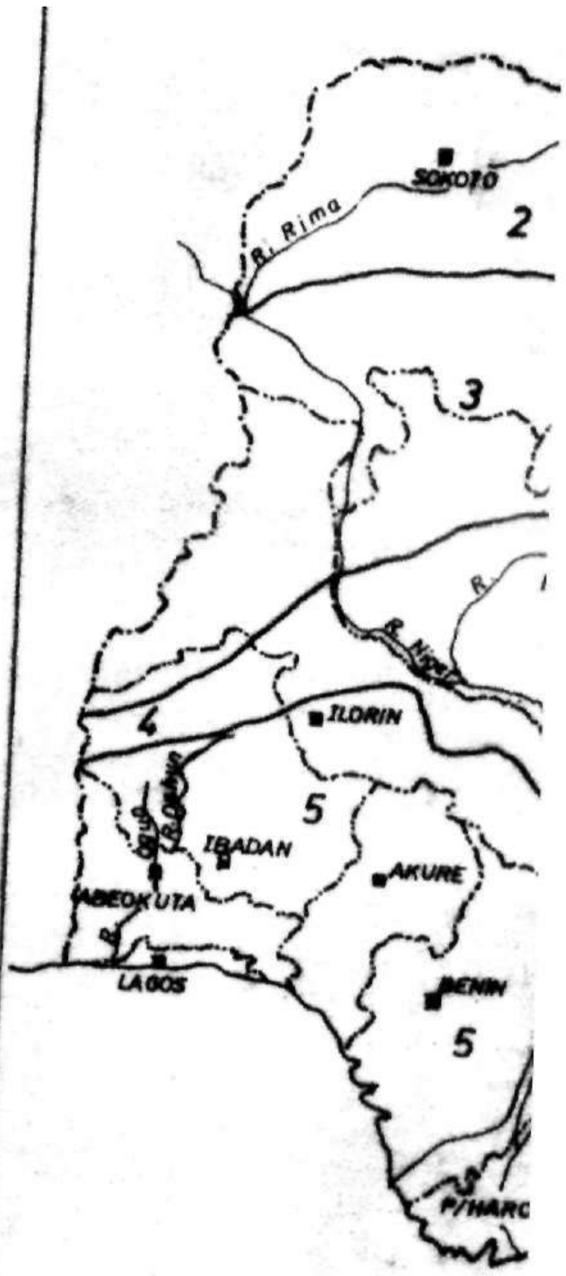

Fig. 1
MAP OF NIGERIA SHOW
EROSION ZONES

rate at which different soils will take in water under different conditions (Parr and Bertrand, 1960). This is because the rate of water entry into the soil fluctuates widely between soil types and even within a single soil type depending upon initial soil moisture content, management and cultivation techniques employed.

2.2.1 Significance of infiltration:

In many cases infiltration is important in determining the disposition of precipitation falling upon a catchment area. It is also inversely related to time. Thus the relationship between rainfall intensity and infiltration rate determines how much of the falling rainfall will flow over the land surface as runoff, possibly directly into streams and rivers. It also determines how much will enter the soil where it may be retained for some period of time before being either passed downwards as percolation or returned to the atmosphere by the processes of evaporation and transpiration.

Information about permeability is essential for the functional classification of soils. A knowledge of the permeability of different soils is useful not only in planning the agronomic phase of the conservation programme for a farm but also in designing and spacing terraces for erosion control and water conservation. It is needed for adequate planning of drainage and irrigation systems. In addition to all these, information about infiltration capacity of soils is also an important factor in certain non agricultural activities such as planning waste-water disposal.

Soils with low infiltration rates would be unsuitable for this purpose because they require extensive areas and long periods for absorption of large volumes of waste water. On the other hand, soils of very high infiltration and percolation rates might not be effective in removing pollutants from the water before passing it to the groundwater storage basin. Site selection and design of water disposal systems are thus dictated largely by infiltration rates of soils.

Similarly if infiltration is too rapid during irrigation, it will be difficult to get water uniformly spread. This can however be improved by making furrows shorter and possibly steeper. If infiltration is too slow, it is also difficult to irrigate without causing poor aeration temporarily.

Thus it can be seen that infiltration is important for both agricultural and non agricultural purposes.

2.2.2 Infiltration theory:

Usually the amount of water infiltrating a soil is greatest when water is first added. However as more water enters the soil, the flow gradient steadily decreases (Coleman and Bodman, 1944). Empirical formulae describing infiltration have been advanced by many workers.

Kostiakov (1932) gave the following equation to explain infiltration:

$$i = Kt^{a}$$

where i = quantity of water infiltrating a unit cross-sectional area of soil.

t = time

K and a = parameters that depend on the soil and its physical condition.

Horton (1933) in his model gave the following equation for infiltration:

$$i = i_{\infty} + (io - i_{\infty}) \exp(-bt)$$

where i = infiltration rate at any time, t;

t = time

io = initial infiltration rate at $t = o$

i_{∞} = final infiltration at infinite time

b = parameter which depends upon the physical properties of the soil profile.

Philips (1957) gave another equation, the s lution of which appears in the form of an infinite series of terms containing powers of $t^{\frac{1}{2}}$

$$I = St^{\frac{1}{2}} + At + Bt^{3/2} + \ldots\ldots$$

where I = cumulative infiltration

t = time

S = sorptivity which is proportional to the increase in soil water content during infiltration and to the square root of the soil water diffusivity.

A and B = constants that depend on soil physical properties.

The drawback of the equation above is that it does not hold for large values of time and for convenience an approximation is achieved by replacing all terms beyond the first by Kt as follows:

$$I = St^{\frac{1}{2}} + Kt$$

where K = hydraulic conductivity of the soil

Darcy's law for infiltration into partially saturated soils may be written in the form:

$$V = K(\theta).\frac{dH}{dz} \quad \ldots\ldots\ldots\ldots (1)$$

where V = macroscopic infiltration velocity.

$K(\theta)$ = hydraulic conductivity of partially saturated soil.

H = total hydraulic head

Z = vertical distance

If gravitational head is negligible, dH becomes $d\psi$ and equation (1) can be written as:

$$V = -D(\theta).\frac{d\theta}{dz} \quad \ldots\ldots\ldots\ldots (2)$$

where

$$D(\theta) = -K(\theta).\frac{d\psi}{d\theta} \quad \ldots\ldots\ldots\ldots (3)$$

θ = volumetric water content

ψ = tension head

$D(\theta)$ is known as the soil water diffusivity and equation (2) is often called the diffusivity equation since it is analogous to Fick's law wherein flux is proportional to a concentration gradient.

Holtan (1961) recognising infiltration to involve both storage and transmission defined infiltration rate as a function of the exhaustion of soil moisture storage:

$$f = a\,(S - F)^n + fc$$

where f = rate of infiltration

S = storage potential of the soil expressed as the volumetric difference between pore saturation and the wilting point.

F = accumulated infiltration

fc = constant infiltration rate after prolonged wetting.

a and n = constants for a particular soil in a given condition.

It must be noted that pore geometry in a real soil is very complex and these concepts of necessity, grossly oversimplified reality (Childs, 1957; Jackson, 1963).

2.2.3 Nature of moisture movement:

The nature of soil moisture movement can be looked at in two phases:

(a) Movement during infiltration

(b) Movement after infiltration has ceased.

James (1975) reviewed the literature on these two phases extensively.

Movement during infiltration.

When water is applied to the soil surface either through rainfall or irrigation or by ponding, the surface becomes rapidly saturated. From there, there is downward movement due to gravity.

During infiltration a distinct flow pattern exists within the profile of a homogeneous soil. Just below the soil surface is the saturation zone and below it is the transition zone of almost constant moisture content. Below this zone and near the limit of downward penetration is a wetting zone where the moisture content is changing rapidly. There appears to be a sharp boundary between newly moistened soil and soil still at the pre-application moisture content. This artificial boundary is known as the wetting front (Coleman and Bodman 1944).

Various stages of water movement can be seen in Fig 2 as given by Bodman and Coleman (1943).

In the early stages of water application, suction will pull the water downward. But as the wetting zone penetrates further and the transmission zone becomes longer, the suction gradient becomes less important; infiltration then is controlled by the hydraulic conductivity of the soil.

As the suction gradient gets negligible, the rate of downward movement decreases rapidly. Several factors are known to be responsible. These include swelling of soil colloids and the closing up of some channels and breakdown of soil structure at the soil surface. Others are disturbance and recompaction and increasing length of transmission zone which means that water has to travel a greater distance. As infiltration continues, the wetting front moves deep into the soil and the transmission zone lengthens. This continues until either an impervious layer or water table is reached.

Movement after infiltration has ceased.

After infiltration has ceased, the wetting front will continue to move down in response to gravity gradient. As it does so, water is taken from the top and redistributed at the bottom of the profile. The nature of redistribution of water in the soil profiles at this stage depends upon the amount of water added initially, and upon whether or not it was sufficient for the advancing wetting front to reach the wet soil below.

During redistribution however, the quantity of water above the wetting front remains constant since supply has been cut off from above. Therefore movement gradually becomes slower and slower and as time increases and wetting front moves deeper into the soil, the average moisture content in the transmission zone decreases. The rate of redistribution also decreases with time.

In theory, redistribution continues until the algebraic sum of all flow gradients equal zero. But in practice however, redistribution ends when the moisture movement is considered negligible. At this stage the soil is said to be at field capacity (Hadas et. al. 1973). Often the period of time taken to achieve this stage is arbitrarily fixed for 2-3 days after water application has stopped.

The processes so far described, do not consider the effects of evapotranspiration. As soon as infiltration stops, evapotranspiration begins which helps to slow down the downward movement, hence creating a suction gradient which tends to draw water upwards. Permeability is also reduced due to reduced saturation. At this stage there are two components of movement:

(a) water which drains down through the profile

(b) water lost by evapotranspiration

A situation may arise when moisture is lost only by evapotranspiration. This is when there is a barrier at the bottom which obstructs infiltration.

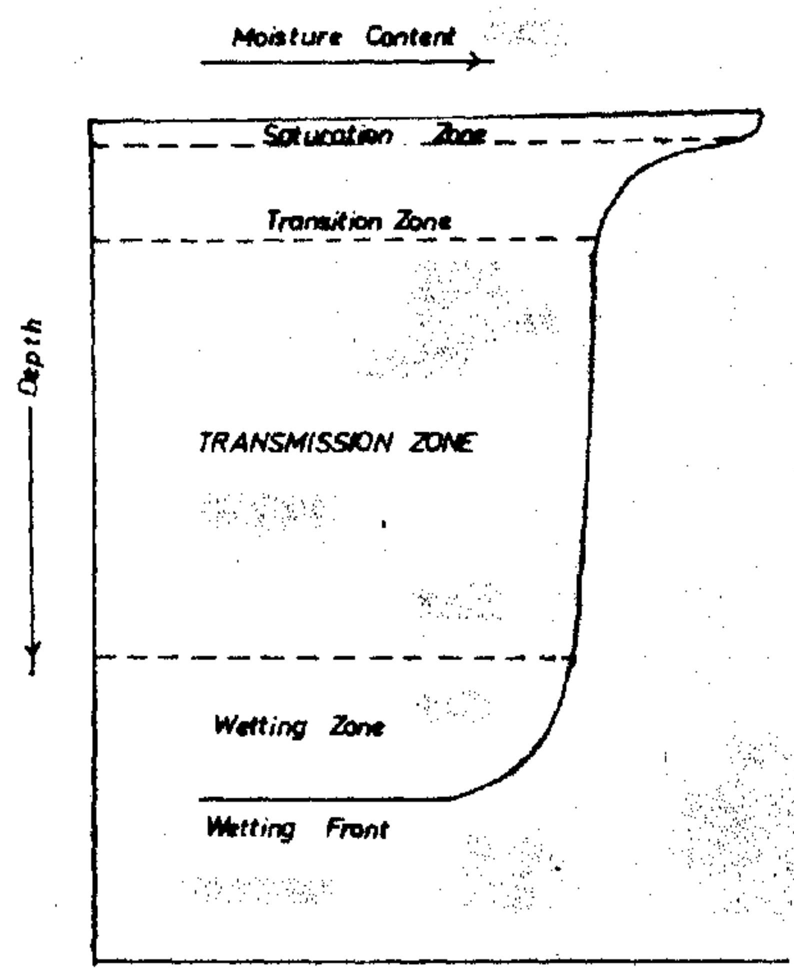

Fig.2: MOISTURE ZONES DURING INFILTRATION

2.3 Factors Affecting Infiltration:

Several factors are known to influence infiltration. Since all infiltration water must pass through the soil surface, the condition of the soil surface and the layers immediately below must be considered as important factors governing infiltration and infiltration capacity (Harrold et. al, 1976).

Lewis and Powers (1938) gave the factors affecting infiltration under two broad headings:

(a) factors influencing the infiltration at a given time and point, like texture, structure and organic matter.

(b) factors influencing the average infiltration rate over a considerable area and period of time like slope, vegetation and surface roughness.

Musgrave (1955) summarised the major factors affecting intake of water as follows:

(a) surface conditions and the amount of protection against the impact of rain.

(b) internal characteristics of the soil mass, including pore size, depth or thickness of the permeable portion, degree of swelling of clay and colloids, content of organic matter and degree of aggregation.

(c) soil moisture content and degree of saturation.

(d) duration of rainfall or application of water.

(e) season of the year and temperature of soil and water.

Dixon (1966) said that the major soil properties affecting infiltration which are influenced by tillage and crop residue management practices are surface storage and soil crusts.

In addition to all these (Harrold et. al., 1976) identified soil hydrologic properties, vegetation and tillage, viscosity of water, soil moisture, hydraulic gradients and frosts (in temperate lands) as factors affecting infiltration of water into soils.

2.3.1 Effect of soil cultivation:

Cultivation often affects infiltration because of its effects on the conducting pores in soil. Compaction from cultivation implements usually results in poorer infiltration, aeration and penetrability of soils.

Cultivation may either increase or decrease infiltration rate. Cultivation practices that leave the soil surface rough, with many pockets of water storage are likely to have more infiltration than where the surface has been worked down and smoothed by cultivation. In the latter case, infiltration continues only so long as water is being applied, whereas, in the former, infiltration continues after the water application has stopped and until water in the pockets is absorbed. This prolonged time for infiltration may be as much as several hours and can lead to increased infiltration and less runoff.

Charreau and Seguy (1969) in Senegal showed that 578mm of 729mm rainfall infiltrated into a ploughed soil but only 459 mm entered into an unploughed soil.

When subsoil permeability determines infiltration rate, clearing and cultivation have little effect, but compaction of the well structured top soil on clearing may cause the infiltration to fall. However clearing bush by mechanical means with all its considerable vehicular traffic appears to hasten the process of surface deterioration and erosion may become serious in the first cropping year.

Sanchez (1976) reported that infiltration rates at 1 and 11 months after clearing averaged 10.5 cm/hour for the slash-and-burn system in contrast to about 0.5 cm/hour for the bulldozed system. The difference is believed to be the result of bulldozing itself in sandy topsoils very susceptible to compaction.

Wilkinson (1975) found that most of the increased infiltration rates during fallow was eliminated during the first seedbed preparation and that all the increase was eliminated by the end of the first cropping season. Similar results were obtained by Wilkinson and Aina (1976).

Traffic from seedbed preparation and post-planting operations often causes surface and subsurface compaction. The result is reduced infiltration and inadequate aeration.

Parker and Jenny (1945) tested the effects of traffic and cultivation on soil compaction by subjecting both dry and wet plots of a dry farmed area to intensive traffic by a track-type tractor and to repeated disking. They found that the effects were very detrimental to water infiltration in both cases. In the wet soil, pronounced compaction was produced. They also found that disking of dry and wet soil, greatly reduced water infiltration.

Smith (1949) observed that cultivation of the soil that causes fragmentation of the B-horizon was often responsible for reduction in infiltration capacity. He maintained that if the A-horizon is thicker than the plough depth, and granular, such treatments do little damage to natural structure and may even permit greater infiltration rate than natural soil, provided there is increased porosity. He also investigated the effect of initial soil moisture content and concluded that infiltration is a function not only of porosity and texture but also of the soil structure and moisture content.

2.3.2 Effect of surface conditions and cultivation.

Diebold (1955) found serious losses of water and soil during the growing season due to poor surface soil condition and to the presence of tillage pans usually at depths of 3-8 inches.

Mc Intire (1958), Tackett and Pearson (1965), stated that formation of surface crusts reduced infiltration and permeability, resulting in greater runoff.

Leopold (1974) likened the soil surface to a sieve made of a very fine screen. Similarly, the soil surface contains many openings of various sizes. The wider the openings the greater is the infiltration rate.

Williams and Allman (1969) observed that smooth, heavily worked surfaces appear to act as a major limitation to infiltration capacity.

The impact of raindrops is known to cause some soils to crust thereby reducing water infiltration and impede aeration. Cultivation is also known to improve the situation by breaking down the surface crusts and subsurface compaction.

Musgrave and Free (1936) found that surface cultivation greatly increased the rate of infiltration which was associated with an increase in the percentage of pore space.

Duley (1939) observed that the removal of a crust 0.3 inch thick increased infiltration from 0.25 to 1.6 inches per hour.

Mannering and Meyer (1966) reported that destruction of surface crusts increased infiltration by eighty percent (80%). Similarly, Meyer and Mannering (1961) found that destroying surface crusts by cultivation increased infiltration.

Miller and Aarstad (1971) also reported that changing the physical condition of the furrow either by incorporation of straw or by a shallow cultivation resulted in greater infiltration.

Deep tillage generally has a loosening effect on soil and it is often believed to be a remedy for infiltration problems thereby increasing the storage capacity. But subsequent shallow tillage during seedbed preparation has a net effect of compaction on the plough layer and therefore a large portion of the increase in storage capacity is lost by the time the crop is planted.

Jamison (1956) pointed out that a moderate soil compaction improves infiltration by increasing unsaturated conductivity. The question that readily comes to mind here is how to know the degree of compaction needed to achieve what Jamison proposed.

Soil crust plays a significant role in modifying infiltration of a particular soil. As a result of its position, a soil crust is capable of masking the infiltration effects of soil texture, soil structure, tillage practices and cropping practices (Dixon, 1966).

Edwards and Larson (1969), Hillel and Gardner (1969) presented analyses of crust effects on infiltration. Duley (1939) studying the factors affecting infiltration, concluded that soil crusting had a greater influence on intake of water than soil type, slope, moisture content or profile characteristics. He postulated that this compact surface layer was apparently the result of severe structural disturbance due in part to the beating effect of the raindrops, and in part to an assorting action as water flowed over the surface and the fine particles were fitted around the large ones to form a relatively non-pervious seal.

2.3.3 Effect of crop residues

A sound crop residue management programme can help to alleviate a soil crust problem by improving soil physical properties, increasing infiltration and decreasing runoff.

This contention is supported by data from many studies. For instance (Duley and Russell, 1939) found that by leaving crop residues on the surface, infiltration rate was greatly increased, evaporation from surface soil was reduced, water and wind erosion was also reduced.

Duley and Kelly (1939) also studied the effects of soil types, slope and surface condition on the intake of water. They found that different surface conditions had a far larger effect on water intake than either of the other two factors. They also observed that infiltration was greatly improved by the use of straw mulch in comparison with cultivated bare soil.

Borst and Woodburn (1942) and Free (1952) demonstrated how runoff and erosion may be reduced by the use of mulch.

Kidder et. al. (1943) found that corn stover was more effective in preventing surface sealing and thus maintaining greater infiltration rates than soybean residues.

Working under natural rainfall, Gard et. al., 1956) showed that soil loss from corn plots on 5 and 9 percent slopes was more than 3 times greater when residue were removed than when they were returned.

Williams and Doneen (1960) found that infiltration was 34 percent greater in tractor-travelled irrigation furrows where cornstalk residue was present than where there was no residue.

Mannering and Meyer (1963) observed that applications of wheat straw mulch were very effective in controlling soil erosion on freshly ploughed plots during 6.25 inches of high intensity rainfall applied at an intensity of 2.5 inches per hour in storms over a 3-day period. This was attributed to the mulch's ability in intercepting the falling raindrops, dissipating their energy and thus preventing detachment of soil particles and sealing of the soil surface while improving infiltration.

Van Doren and Klingebiel (1952) showed that straw mulched plots absorbed 1.24 to 1.65 inches of simulated rain applied at a rate of 1.75 inches per hour whereas bare plots absorbed only 0.47 inch for a 60-minute period.

Lawes (1966) demonstrated that mulch cover maintains the infiltration rate of soils at Samaru. Kowal, (1970) also found at Samaru that plant residues intercepted rainfall, absorbed moisture and impeded the flow of runoff and thus effectively controlled surplus water not yet absorbed by the soil. Lal (1976b) working on an Alfisol reported that the runoff from the bare plots was 16 times more than that from the mulched plots due to reduced infiltration.

2.3.4 Effect of soil structure.

Soil structure and particularly the degree of aggregation of the individual particles is also an important factor in determining water transmission. Equally important however is the degree of structural stability and the extent to which the distribution of pore sizes may change with varying moisture conditions.

O'Neal (1949) from his experiment concluded that structure seemed to be the most significant factor in evaluating permeability but that permeability cannot be correctly evaluated on the basis of type of structure alone. He suggested that other characteristics such as structural stability and their relation to one another must be considered.

2.3.5 Effect of soil organisms.

The effect of soil organisms on infiltration must not be overlooked. The presence of earthworms and other burrowing creatures and the decay of root systems may also influence the number of non-capillary spaces withing the soil.

Hopp and Slater (1948) investigated the influence of earthworms on infiltration. They found that where living earthworms had been introduced and the soil surface protected, infiltration rates were 3 to 4 times higher than where living earthworms had not been introduced or where they were introduced but where cover conditions were unsuitable for their survival.

Parr (1959) compared the effects of subsoiling and vertical mulching on bulk density. Bulk density was significantly lower in the vertical mulched soil. This was attributed to apparent increased earthworm activity and the mixing of straw into the soil.

Dixon and Peterson (1971) stressed the great influence of large pores on water movement in soils. They also showed that infiltration could be increased within a few months by undisturbed earthworm activity.

At Samaru, increased infiltration rates in fallow were attributed to earthworm activity which produced fragile water conducting pores and channels (Wilkinson, 1975). Ehlers (1975) working on a loess soil and Wilkinson and Aina (1976) made similar observations.

2.3.6 Effect of solutes and nature of soil profile.

Characteristics of the infiltrating water and nature of soil profiles are also factors that affect infiltration. Most water passing the soil surface collects fine clay and silt particles and carries them in suspension into the soil profile, where blocking of small pore spaces may occur.

Infiltration rates have also been found to vary when infiltrating water is contaminated by salts, particularly in very alkaline soils. This is because the salts affect not only the viscosity of the water but also the rate of swelling of colloids (Musgrave and Holtan, 1964).

The stratification of a soil profile often results in a considerable variation of hydraulic conductivity with depth. Where a coarse layer of higher saturated hydraulic conductivity overlies a finer textured layer, the infiltration rate is initially controlled by the coarse layer. However once the wetting front extends into the finer layer, it is the latter which controls the rate of water movement. If infiltration is prolonged, a perched water table may develop in the coarse soil just above its boundary with an impeding finer layer (Hillel, 1971).

2.3.7 Effect of soil air

The effect of entrapped air on infiltration is most often neglected. It is sometimes assumed that the air escapes easily and that atmospheric conditions prevail. It is also assumed that the viscosity and density of air in comparison to water are negligible.

However entrapped air has been found to influence the movement of water through soil (Slater and Byers, 1931; Baver 1937). If the soil is initially dry, wetting the soil will entrap air in the coarser pores. In fact even if the soil was initially moist, some of the air present in the wide pores may become entrapped. The result of this is that the pores are blocked and slow up the passage of water through the soil.

Powers (1934), Free and Palmer (1940) observed that the rate of infiltration of water was reduced when pore-air was not free to escape from the columns.

Christiansen (1944) found that entrapped air caused a large reduction in permeability compared with fully saturated soils. The presence of air in the soil resulted in permeability values being affected by variations in pressure and temperature. He also observed that the increase in volume of entrapped air with increase in temperature resulted in a relative decrease in flow, which partly compensated for the increase in flow due to the decrease in viscosity of the water.

The maximum effect of trapped air seemed to be more felt in pores of intermediate sizes. However with time, the air bubbles will dissolve in the water and diffuse into the atmosphere.

Pillsbury and Appleman (1945) maintained that the trapped air can be removed only by solution in the water percolating through the soil. They went on to say that, the ease with which the air is dissolved depends on the capacity of the water to absorb air, the time of contact and the amount of percolating water passing through per unit amount of trapped air.

Permeability therefore can reach its highest point only after the trapped air is removed from the soil pores by solution in the percolating water.

Wilson and Luthin (1963) came to the following conclusions:

(a) displacement of air by water during infiltration is not an isothermal process.

(b) during infiltration into homogeneous columns, the air pressure is greater than the atmospheric pressure with the greatest differences occuring during the initial phases.

(c) during infiltration into columns containing barriers that are impermeable to air flow, the air pressure increases continously and approaches a maximum final value while the rate of infiltration decreases and approaches zero as limit.

In summary, it can be said that the ability of a soil to allow water to infiltrate depends on:

(a) condition of the soil surface,

(b) conditions within the cultivated layer,

(c) soil profile characteristics below the cultivated layer, and

(d) moisture content of the soil at the time of water application (rain or irrigation).

2.4 Methods of Measuring Infiltration

Despite the great significance of infiltration in the hydrological cycle, only a limited data is available in some locations and none in others. The possible reason might be connected with a lack of easy and quick methods to estimate the infiltration rates that occur under natural conditions.

Infiltration determinations on disturbed and undisturbed soil samples have been made by some workers. Fireman (1944) was of the opinion that using disturbed samples in the laboratory could save time and money. These however have been of little or no use for field application by the practising hydrologist. In fact their results may be so far from natural field information that they may be misleading (Harrold et. al. 1976).

At present various methods are used to measure infiltration rates. These can be distinguished with respect to the way water is added, the manner in which the area for measurements is delimited and the manner in which the measurements are made. Some of these methods include:

(a) Natural rainfall - runoff plots.

(b) Rainfall simulation infiltrometers.

(c) Ring infiltrometers.

(d) Basin method.

2.4.1 Runoff plots.

They are used to measure runoff and soil losses due to water erosion. Increased runoff is an indication of reduced infiltration and runoff plots may be used to measure infiltration indirectly.

The runoff plots are usually brought to a crust-free seedbed condition although nothing is planted. The slopes are also known. The Universal Standard Plot otherwise called the Unit Plot is usually 72.5 feet long and has 9 percent slope. The difference between the amount of precipitation and runoff is usually taken as the amount of infiltration.

2.4.2 Rainfall simulation/Sprinkling infiltrometers

This method uses artificial rainfall applied from an overhead sprinkling system, consisting of spraying nozzles. The nozzles may point upward or downward and the intensity is usually controlled. For the method to be very effective, it must have the following characteristics:

(a) the distribution of drop sizes must be uniform over the plot area.

(b) the artificial rainfall must be similar to the natural rainfall being simulated in respect of drop size, drop velocity, intensity range and total energy value.

(c) the plot area must be large enough to sample the population and give reproducible results.

(d) The artificial rainfall must be applied not only to the plot but also to an adequate buffer area around the plot.

The difference between the application rates and runoff is often taken as the rate of water intake. Nevertheless, the fact that rainfall simulators cannot meet some of the stated characteristics adequately makes this method less effective. Hence many of the infiltration data reported using this method have little value toward agronomic application.

Wilms (1943), Diebold (1951), Myers (1952), Barnes and Costal (1957) and Bertrand and Parr (1961) described various types of sprinkling infiltrometers. Smith and Leopold (1942) used the North Fork rainfall applicator to investigate infiltration rates for certain soils. Their investigation showed a highly significant positive correlation between the final infiltration rate and vegetal density. The rate of infiltration also showed a highly negative correlation with dispersion ratio, amount of dispersed clay and silt plus clay.

2.4.3 Ring or Cylinder infiltrometers.

Here a constant head of water is maintained and the rate of fall of the surface of water ponded on the soil is taken as the rate of water intake. Usually under most conditions rate of intake is much greater than the rate of evaporation and the error from evaporation can be neglected.

There are various types of cylinder-type infiltrometers. They include:

(a) single cylinders

(b) multiple cylinders

(c) weighing lysimeters

(d) drainage lysimeters.

The metal rings normally used are driven into the soil to depths ranging from 3 to 4 inches to more than a foot, so that lateral flow of water from the rings is reduced to a minimum.

In the past, single rings were used and many of the data indicate a high degree of variability. This is probably due in part to the uncontrolled lateral movement of water from the ring. To correct this anomaly, double-ring infiltrometers were introduced, so that lateral flow could be minimised by means of a buffer area surrounding the central compartment. Infiltration rate measured inside the inner cylinder is usually taken as being indicative of the vertical component of flow.

Marshall and Stirk (1950) studied the effect of lateral movement of water on infiltration rate using both buffered and unbuffered rings ranging from 1-10 feet in diameter. They found that buffered plots gave more consistent results. They also observed that the sprinkled buffer area was effective in preventing a serious amount of lateral flow for a wide range of soil textural conditions.

Aronovici (1955) obtained similar results for small rings varying in diameter from 2 to 30 cm. Burgy and Luthin (1956) however reported results which indicate very little difference between buffered and unbuffered area but their study involved soil of relatively high initial moisture content.

This method like others has its limitations. These include:

(a) Placement methods: Inserting ring infiltrometers often causes a certain degree of disturbance of natural structural conditions. The resulting shattering or compaction may cause a large variation in infiltration rates between replicated runs.

(b) The interface between the soil and the side of the metal ring may cause unnatural seepage which may result in abnormally high infiltration rates. This can however be improved by leaving the rings in place for some time before measurements are made.

(c) Constant head of water may not allow the entrapped air inside the soil column to escape. This may result in impeded downward movement of water (Christiansen, 1944).

(d) The fact that surface soil is protected during measurement does not actually show the true situation when the soil is exposed to direct beating of the rain. The latter condition is likely to cause reduced infiltration as some of the conducting pores may be sealed on the surface.

2.4.3 Basin method.

This method employs a technique similar to the large ring devices, though larger areas are used. Usually, areas as large as 10 square feet or sometimes about a quarter of an acre are used. They are often provided with a border arrangement so that water can be impounded in the basin.

Parker and Jenny (1954) used 0.22 acre basin plots to investigate water infiltration and related soil properties as affected by cultivation and organic fertilisation on land of reasonably uniform shape. Huberty and Pillsbury (1941) used basin plots of 150 square feet to evaluate factors influencing infiltration rates for some California soils. Irrigation water was applied to a height of 4 inches above the ground surface.

Pillsbury (1947) also used 3-feet square basins. Water was supplied through a hose. About 2-4 inches of water was supplied in a period of less than a minute and infiltration was recorded.

Of all these methods, the one used in the present study was the double cylinder infiltrometer. This was mainly because of the ease of obtaining the instruments and water supply and also because the cost was low.

CHAPTER 3

MATERIALS AND METHOD

3.1 Site Description.

The experiments were carried out at Samaru (11° 11' N, 7° 38' E) in the Northern Guinea Savanna Zone of Nigeria with an average annual rainfall of about 1100mm. The climate is characterised by one well defined wet season which normally begins in April/May and ends in late September and sometimes early October. The dry season on the other hand lasts for about 5 months with low relative humidity and a drying north east wind.

The climate of the zone has been described by Walter (1967), Kowal and Kassam (1978), the vegetation by Keay (1959) and Ramsay and de Leeuw (1966) and the pattern of agriculture by Watson (1964) and Goldsworthy (1967).

Samaru soils have been classified as ferruginous tropical soils according to D'Hoore's classification system for Africa (Tomlinson 1965), and as inceptisols (Great Group: Typic Ustropept) according to the U.S.D.A. system (Harpstead 1973).

The particle size analysis carried out (on the site of the main cultivation experiment), shows that the surface texture was sandy loam. This agreed with the description of ˉawes (1961). The surface soil is underlain by a heavier textured subsoil which varies from sandy clay loam to sandy clay.

Table 1 shows the result of the particle size analysis.

Table 1: *Soil Particle Size Analysis

Depth (cm)	% Sand	% Silt	% Clay	Class
0–5	80	8	12	sandy loam
5–10	81	7	12	sandy loam
10–20	75	8	17	sandy loam
20–30	63	8	29	sandy clay loam
30–60	52	7	41	sandy clay
60–90	47	9	44	sandy clay

* The International system of classification was used for this analysis, i.e. the borderline between silt and clay was 20 microns.

3.2 Infiltration Measurements

The following materials were used for the field experiments:

Ring infiltrometers with the following dimensions were made from metal sheets:

	Height	Diameter
Inner cylinder	35 cm	30 cm
Outer cylinder	30 cm	60 cm

(The design and type of material were copied from the specifications given by Bertrand (1965). Other equipment used included a measuring device, looking mirror, buckets for carrying water, 6.7 kg wooden hammer, baft cloth, driving metal plate and wrist-watch. Ready-made ring infiltrometers would have been too costly to purchase and with the limited time and funds available locally manufactured rings were used and found to be adequate.

The measuring device was also made locally, by passing a ruler through two parallel metal strips, one above the other into a flat round wooden float which was about one inch thick (Fig. 3). The free movement of the ruler between the metal strips - and the bouyancy of the float help to overcome the slight friction between the ruler and the metal strips. The wooden float was painted to prevent water from soaking into it. Figures 3 and 4 show the measuring device and the positioning of the ring infiltrometers in the field.

In the main cultivation experiments, measurements were made at the midpoint of each plot in the 5th interrow for

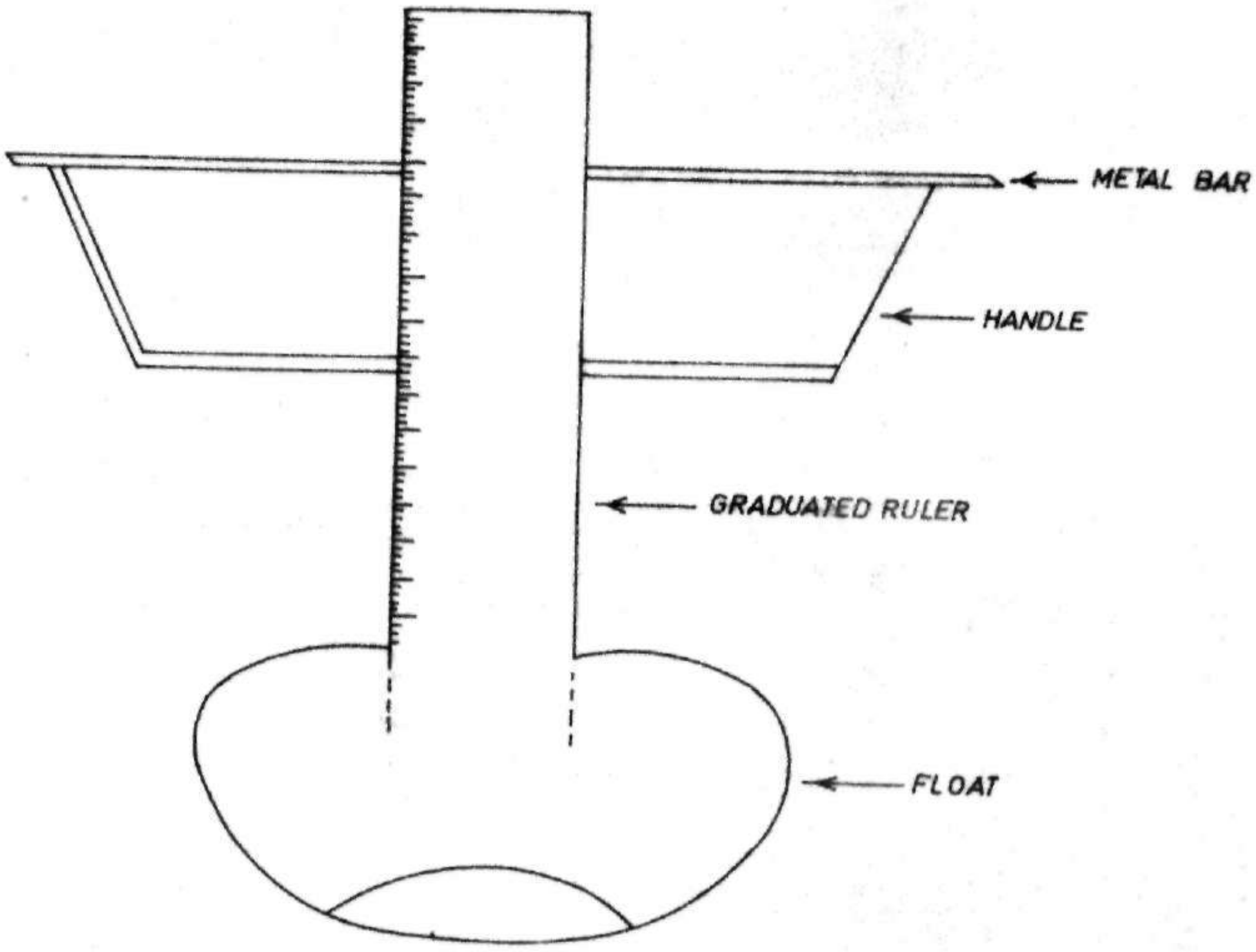

Fig. 3: MEASURING DEVICE

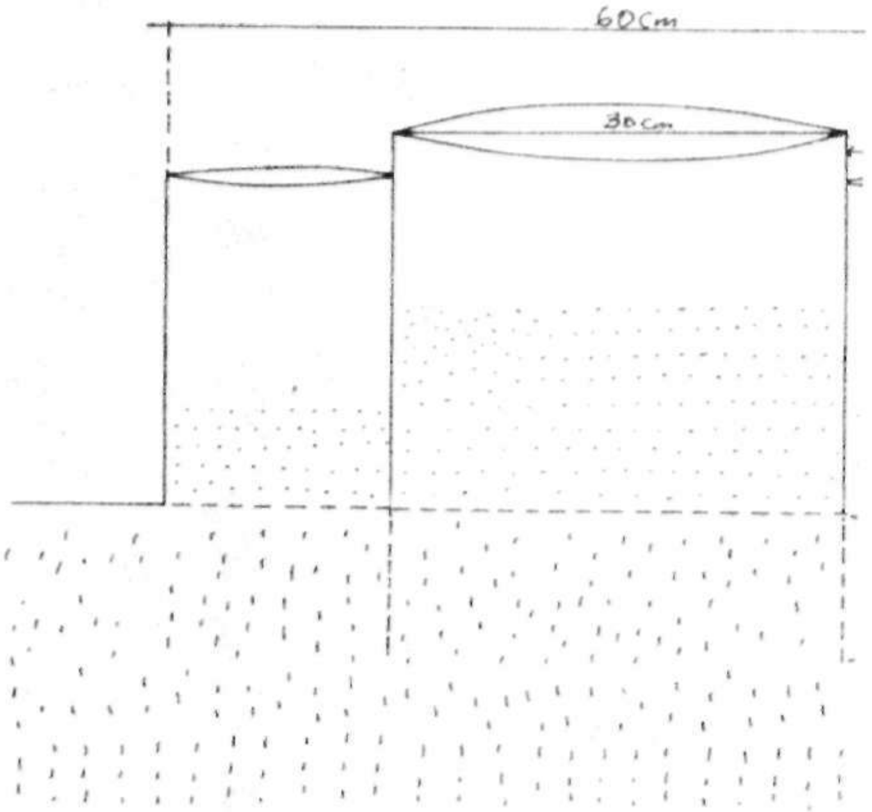

Fig. 4: RING INFILTROMETERS IN PO

the first set of measurement, and 18 metres from the eastern end in the 3rd interrow and on the 3rd ridge for the second set. For the third set, measurements were made at 22 metres from the eastern end in the 3rd interrow and on the third ridge. Lastly for the fourth set, measurements were made at the mid point of each plot in the 5th interrow and on the 5th ridge after cultivations in 1979.

At these positions, the outer cylinder was first set in place and firmly pressed into the soil and the driving metal plate placed on the cylinder. One person was made to stand on the metal plate and the cylinder was driven into the soil by tamping the metal plate with the wooden hammer until it had gone into the soil to a depth of 7.5 cm.

The inner cylinder was then placed centrally inside the outer one and driven into the soil like the former one but to a depth of 10cm. Care was taken to avoid unnecessary soil disturbance and to ensure vertical penetration of the cylinder. During the dry season, the measurement positions were normally wetted about twenty-four hours before the start of the experiment to soften the ground. This was done only during the third set of measurements.

After inserting the cylinders, the baft cloth was placed inside the central cylinder to prevent puddling when water was being added. Water was added first to the buffer zone to a depth of about 5cm. The depth of water in this zone was not critical but it was always topped up whenever the depth of water fell below 2.5cm.

Immediately after adding water to the buffer zone, the central cylinder was filled with water to a depth of about 7.5cm. The level was quickly read using the measuring device and the time recorded using a wrist-watch. It was assumed that the filling was instantaneous and the first reading was at time zero. To reduce error due to parallax, a looking mirror was used in the readings. This ensured that the scale was always viewed horizontally (Fig. 5).

Readings were taken at 15, 30, 60, 120, 180 and 240 minutes after time zero. When the water level in the inner cylinder dropped to about 4cm above the soil surface, sufficient water was added to return the water level to about the starting position. Time and level of water immediately before and immediately after topping up were recorded. Cumulative infiltration was calculated as the total drop in water level up to the times specified above.

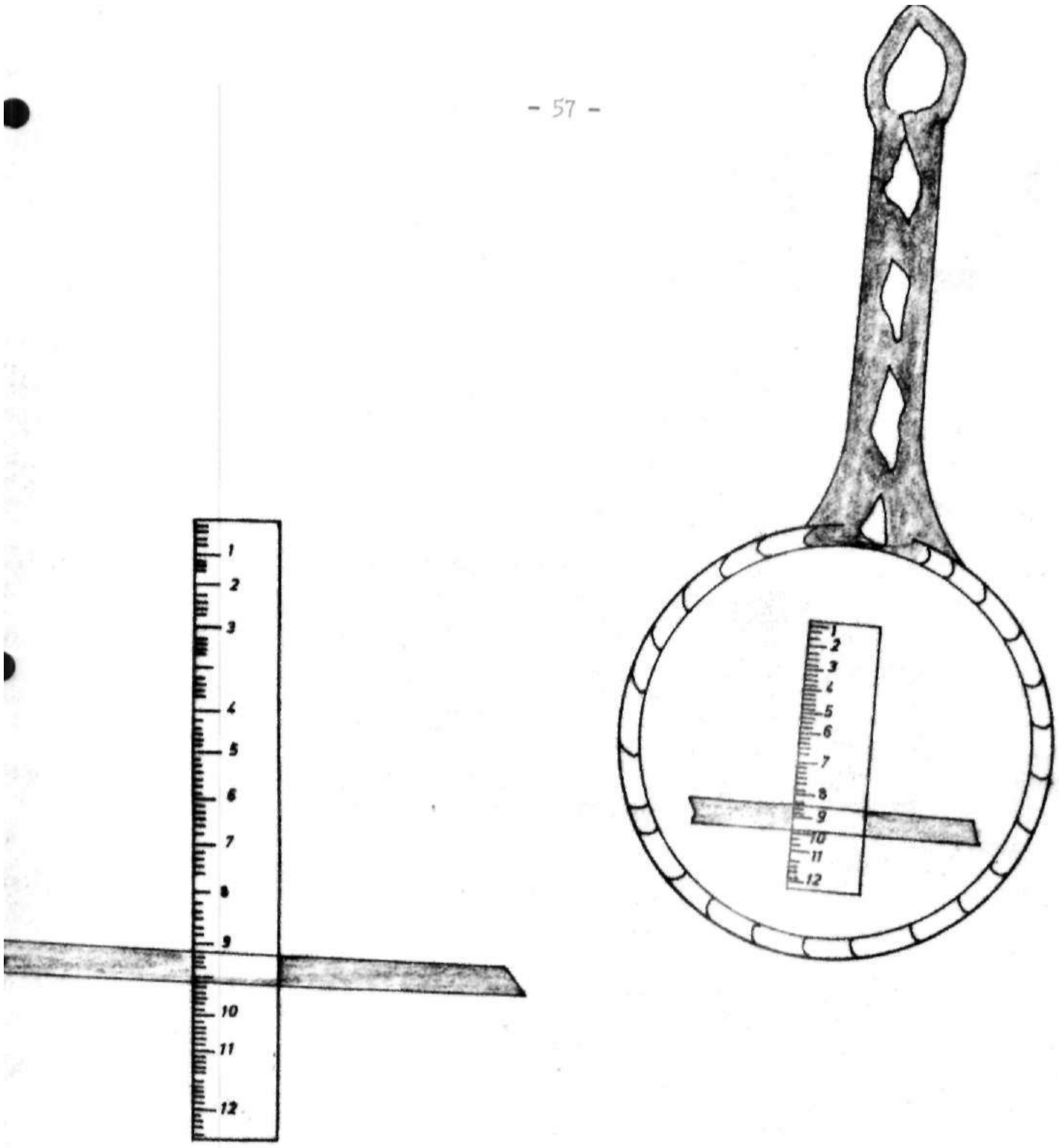

Fig. 5 : LOOKING MIRROR AND GRADUATED RULER

Infiltration measurements were carried out on one block per day i.e. on one plot of each treatment. The infiltrometers were set up one after the other on each plot so as to give enough time to take the readings one after the other. The time interval depended mostly on the rate at which the labourers supplied the water. It must be noted that only one measuring device was used which was moved around all the plots. The edges of the cylinders were also marked to ensure that all subsequent measurements were made at the same point on the cylinders.

Curves were drawn in order to find out the relationship between cumulative infiltration and time. The curves looked straight at about the third hour and in some cases after only the second hour; hence it was assumed that the measured infiltration between the 180 and 240 minutes was the equilibrium infiltration rate.

The times at which equilibrium rates are reached may in fact differ depending on the soil's initial moisture content. However the changes in infiltration rate after 120 minutes were so small that it was assumed that the rates between 180 and 240 minutes were adequate approximation to the equilibrium infiltration rates in all cases.

3.3 Aggregate Stability Measurement.

The materials for this test included soil samples from selected treatments, sieves of different size openings (8mm, 2mm, 1mm and 0.5mm); bucket and a beaker. The method used here is a modified form of the one described by Kemper and Chepil (1965). The modification was due to the unavailability of a Yoder mechanical machine for raising of samples in water.

On the selected plots, six samples were taken from each plot at 0 - 2.5cm using a sampling ring. This was done (on the main cultivation experiment only) at four weeks after planting in 1979. The soil samples were taken when the soil was fairly wet. Samples from different plots of the same treatment were bulked and sieved at the field moisture condition through an 8mm sieve, and later air-dried.

Wet sieving began with placing 50 gram subsamples of the 8mm soil samples on the sieve and wetting gently. The sieve was then raised up and down manually at a rate of thirty times per minute in water. A big beaker was submerged in the bucket of water to standardise the depth to which the downward strokes went which was about 4cm. The essence of the method was to simulate to some extent the disintegration of soil aggregates caused by raindrop impact. The residue on the sieve was carefully collected, oven dried, weighed and calculated as percentage of the initial weight of soil. The initial moisture content of the air dried soil was very low and would have had a negligible effect on the results. For each treatment the test was done in duplicate for each of the three sieve sizes (0.5, 1.0 and 2.0 mm). The results can be seen in Table 22.

CHAPTER 4

MAIN CULTIVATION EXPERIMENT

4.1 Background of the Experiment.

The main experiment in which measurements were made was a cultivation experiment that was already two years old on a site designated as R - Block on IAR farm. The site has a gentle slope of about 2% and had been under fallow for a considerable number of years before the experiment started.

The experiment compares a limited number of cultivation practices chosen to represent the range that can be found in the Northern States of Nigeria. The main treatments are essentially different cultivation systems namely: a manual system, a bullock-powered system, a variety of tractor-powered systems and a system of zero tillage. These are designated as HR, BL, mechanised treatments (DF, DR, DI, DP, CP and MB) and ZT respectively, i.e. there were nine treatments in all.

Each of the treatments was replicated eight times (i.e. 8 blocks) giving a total of seventy-two plots. Each plot was forty metres long and 8 metres wide.

The treatments were arranged according to a balanced 3 x 3 lattice, although for the purpose of statistical analysis the experiment was treated as a randomised complete block design.

Brief details of the cultivation operations since the experiment started are given in Tables 2 and 3.

Table 2: Details of cultivation operations

Treatment code	Power source	Cultivation operation	Ridge or flat planting	Residue management
HR	Manual	Ridging with hoe (1977), ridge splitting over the furrows (1978 and 1979)	Ridge	Removed (1977, 1978).
BL	Bullocks	Ploughing, harrowing ridging (1977). Ridge splitting and remoulding (1978, 1979)	Ridge	Removed (1977, 1978)
DF	Tractor	Disc ploughing, disc harrowing and spring tine cultivation (1977). Disc harrowing, spring tine cultivation (1978, 1979)	Flat	Removed (1977) incorporated (1978)
DR	Tractor	Disc ploughing, disc harrowing ridging (1977), disc harrowing and ridging (1978), ridge splitting and remoulding (1979).	Ridge	Removed (1977, 1978)

Table 2: Contd.

Treatment code	Power source	Cultivation operation	Ridge or flat planting	Residue management
DI	Tractor	Disc ploughing, disc harrowing and ridging (1977), disc harrowing and ridging (1978; 1979).	Ridge	Removed (1977), incorporated (1978).
DP	Tractor	Disc ploughing, disc harrowing ridging (1977, 1978, 1979).	Ridge	Removed (1977), incorporated (1978).
MB	Tractor	Mouldboard ploughing disc harrowing ridging (1977, 1978, 1979).	Ridge (1978).	Removed (1977), incorporated
CP	Tractor	Chisel ploughing (1977), disc ploughing (1978), subsoiling (1979), all followed by disc harrowing and spring time cultivation.	Flat	Removed (1977, 1978).
ZT	-	Use of herbicides (1977, 1978, 1979) with occasional hand pulling of tough grasses.	Flat	Removed (1977), left on the surface (1978).

Table 3: Details of depth of cultivation operations

Treatments	Average maximum depth of primary cultivation (cm)		
	1977	1978	1979
HR	11	11	11
BL	13	*NM	14
DF	15	8	9
DR	15	8	18
DI	15	8	9
DP	14	17	17
MB	14	14	18
CP	28	17	31
ZT	-	-	-

* NM = Not measured.

4.2 Results and Discussion.

4.2.1 Infiltration at 8 weeks after planting - 1978

The results and discussion of other measurements apart from those of the main cultivation experiment will come later. Cumulative infiltration was not analysed statistically but the equilibrium rate (3^{rd} - 4^{th} hour) was. This was because the equilibrium infiltration rate is a more characteristic property of the soil than cumulative infiltration and is preferred for assessing the effect of different cultivation.

Results in Table 4 are means of 8 measurements taken in the interrow position. The full data are given in Appendix 1. In spite of the great variation between replicates within each treatment, the differences between treatments are really striking. It is obvious that the HR treatment was the best. The result of statistical analysis (Table 5) also shows that HR was significantly different from all other treatments at 5%. It also shows that ZT and BL were significantly different from the mechanised treatments at the same level. These measurements incidentally were taken at the peak of rainy season in this area (i.e. July - August).

The mechanised treatments appear to be very detrimetal to water infiltration. For the first thirty minutes of the infiltration run, and taking the average of the mechanised treatments as the reference point, the manual system of cultivation (HR) was 8 times better while the bullock-powered (BL) and zero tillage (ZT) systems were 3 times better. A similar trend was observed even at the end of the 4-hour duration. From these, it is apparent that the mechanised treatments would suffer more soil loss than either bullock - powered, zero tillage or manual system.

The results of the first 30 minutes observation suggest that if there was a storm of about 15mm in 30 minutes, which is not uncommon in Samaru, there was the likelihood of surface runoff and possibly erosion occuring in the plots that were mechanised. The situation is likely to be worsened when the soil is exposed to the direct beating action of the rain that often causes slaking and consequently blocking of the conducting pores.

Dunham (1978) (personal communication) recorded some visual observations of these plots on 27th August 1978 at the end of a storm that lasted for about six hours. The rainfall recorded that day was 12.8mm and 15.9mm for the previous day (i.e. 26th August). This date was close to the time at which the infiltration measurements were being taken. He observed that there was very little water standing in the interrows of HR and it did not form a continuous pond. In the bullock-powered (BL) there was more water in the interrows than in the HR. The standing water was enough to cause a continuous narrow pond.

In the system of zero tillage (ZT) there was virtually no standing water. The mechanised treatments can be divided into two; viz the ridged and the flat treatments. In the ridged treatments, there was water in virtually all the interrows often forming a deep continuous pond. As for the flat treatments (DF and CP), there was water lying on the surface in many places. These visual observations are actually in line with the results obtained from the experiment suggesting that the infiltration measurements adequately represent the soil's behaviour.

One of the soil's properties sometimes associated with infiltration is the bulk density. The results of the interrow bulk density measurements (Table 6) made by Dunham (personal communication) in 1978 showed no significant differences between the treatments, although there were large differences in the cumulative infiltration.

A possible reason is that the tractors used in the cultivation might have caused a significant compaction at the bottom of plough layer which was not detected by the bulk density measurements. Another reason may be that the tractor powered operations caused great discontinuity of major conducting pores between topsoil and subsoil. Finally elimination of connecting macropores even within the cultivated layer may be responsible.

One would expect the water intake in the zero tillage to be higher than any of the other cultivated plots. The underlying reasoning being that disturbance of the conducting pores was at the barest minimum. However the hoe ridging was about two times superior to ZT. An explanation for this would be that the surface of the zero tillage plots were already crusted due to the beating action of the rain. Surface crusts are known to be detrimental to water intake but they can usually be removed by light cultivation. For example, at Samaru Kowal (1972) found that infiltration rates with a soil crust about 7.5mm thick, gave values ranging from 8mm to 13mm/hr. However, when the crust was removed, infiltration rates increased to between 18mm and 30mm per hour.

It was probably the thin compacted surface that was removed by hoe ridging that made water intake better than on zero tillage. Furthermore, zero tillage systems do not provide the opportunity to correct previous damage done to soils caused either by trampling or traffic during harvesting by the previous year. In fact there are some soils which lack the required number of large pores. In such cases cultivations may be employed to improve the situation.

Another point that deserves mentioning in this measurement is that infiltration in BL and ZT are equal. The former was expected to be better than the latter due to the reason already mentioned (i.e. crust on the surface of ZT plots). The low infiltration in BL may be because the benefits obtained by removing the crust was probably destroyed by breakdown of structure due to trampling by the animals used in cultivation.

The result of the statistical analysis shows that there was no significant difference between the mechanised treatments. The DF and DI were a little above others for unknown reasons. A clear picture of the relationship between the treatments can be seen in Fig 6 in which the mechanised treatments are averaged for convenience.

Table 4: Cumulative Infiltration (mm) at 8 weeks after planting in 1978 (interrow position)

Treatments	Time from start of infiltration					
	15mins	30mins	60mins	120mins	180mins	240mins
HR	33	56	92	142	189	233
BL	11	21	35	61	85	107
DF	8	13	22	35	46	56
DR	4	6	9	14	17	20
DI	6	10	15	24	33	41
DP	4	5	7	11	14	17
MB	3	5	8	11	13	15
CP	3	5	8	12	15	18
ZT	13	21	34	59	82	103

Table 5: Equilibrium Infiltration Rates (mm/hr) at 8 weeks after planting in 1978 (interrow position)

Treatments	Mean equilibrium infiltration rates mm/hr.	
	Raw data	Log transformation
HR	44	3.546
BL	22	2.572
DF	10	1.321
DR	4	1.058
DI	8	1.514
DP	3	0.900
MB	2	0.535
CP	3	0.900
XT	22	2.699

Note: The mean of the log transformations is not necessarily equal to the log transformation of the mean of the raw data. Thus the ranking of treatments according to the raw data means may not always be the same as the ranking according to the log transformation means. Examples of this apparent contradiction can be seen in Table 5 and elsewhere.

Analysis of variance (log transformation)

Source of variation	d.f.	S.S.	M.S.	F
Replicates	7	21.296	3.042	4.062
Treatments	8	67.816	8.477	12.823***
Error	56	37.021	0.661	
Total	71	126.133		

$Lsd_{(0.05)}$ treatment = 0.813

Note:

For the analysis of variance here and throughout, the raw data were transformed to natural logarithms due to the very wide range of the measurements. Thus the coefficient of variation was reduced to acceptable limits. For example the coefficient of variation for the raw data above is 120% while that of the log transformation is 48%. This is fairly high though.

*** Significant at 0.1%

Table 6: Bulk Density Measurements g/cm^3 at 9 weeks after planting in 1978.

Treatments	Row		Interrow
	0–6cm	10–16cm	0–6cm
HR	1.27	1.38	1.43
BL	1.23	1.47	1.45
DF	1.37	1.52	1.44
DR	1.26	1.46	1.44
DI	1.25	1.47	1.41
DP	1.26	1.52	1.42
MB	1.30	1.49	1.48
CP	1.39	1.52	1.49
XT	1.43	1.44	1.43
$LSD_{(0.05)}$	0.08	0.10	0.07

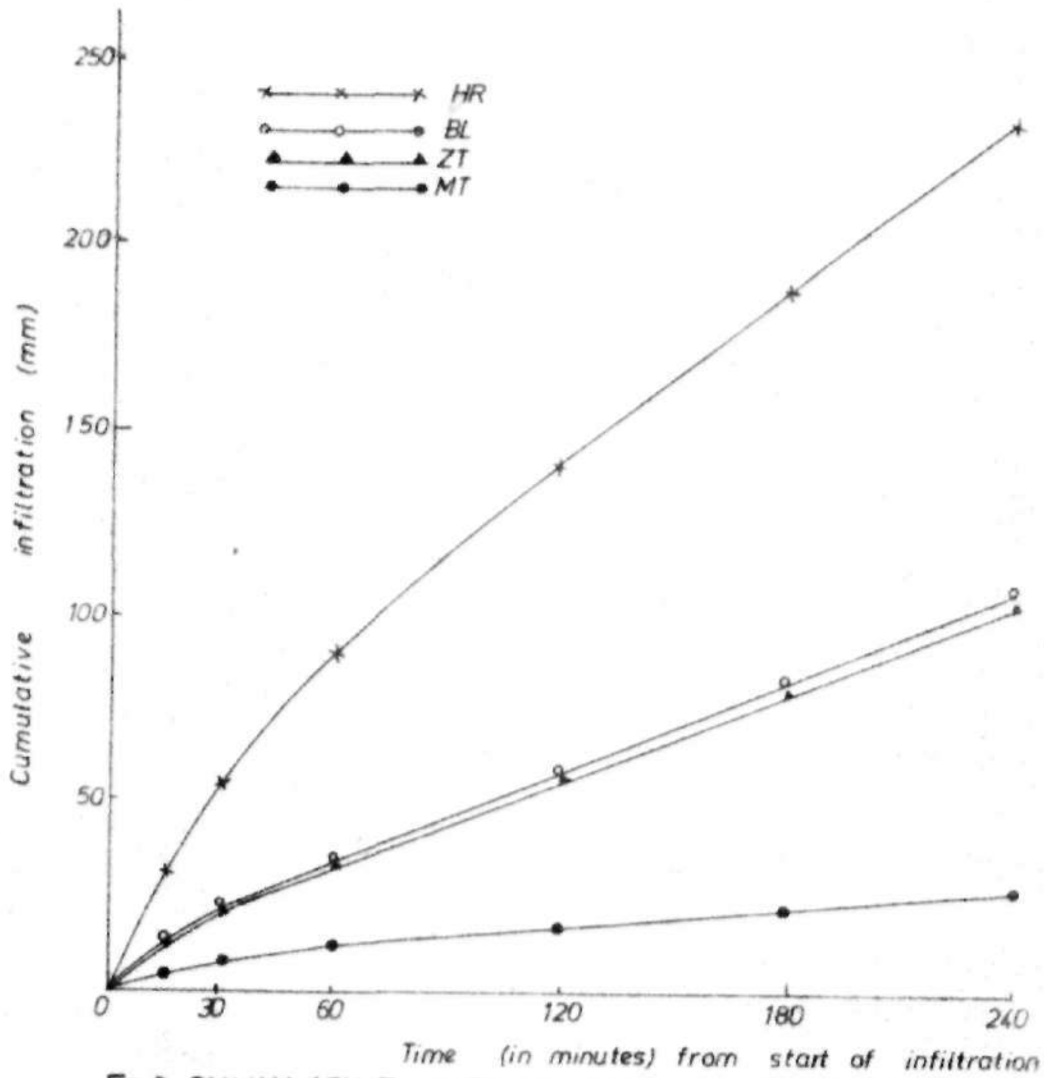

Fig.6 CUMULATIVE INFILTRATION AGAINST TIME AT 8WKS AFTER PLANTING (1978)

4.2.2 Infiltration at 14 weeks after planting - 1978

Table 7 gives measurements made in the interrow, but unlike Table 4, the results in Table 7 are means of 4 replicates only. The results of the statistical analysis for the equilibrium infiltration rates for the interrows and rows can be seen in Tables 8 and 10 respectively. Table 9 gives measurements made in the row position.

Table 7 shows that there was a general increase in infiltration in all the treatments as compared to the measurements at 8 weeks after planting. A critical look however shows that the proportionate increases were not the same in all the treatments. For instance while HR, BL and ZT increased about 2, 2 and 3 times respectively, the average increase for mechanised treatments was about 8 times. This is fairly difficult to explain. The results of th statistical analysis (interrow position) also show that there was a significant difference between HR and DI; HR and MB; HR and CP at 10% level of significance. Similarly, the results of the statistical analysis (row position) show that there was a significant difference between HR and ZT and between HR and all the mechanised treatments at 5% level of significance.

Also BL was significantly different at 5% from all the mechanised treatments except CP.

The reason for the general increase in infiltration may however be due to the time interval allowing roots to open up new channels for water passage. Another possibility is that the activities of soil organisms produced an improvement in soil structure. Yet another possibility is that the soil at this time was drier than it was at 8 weeks after planting. Initially at least, the soil would take more water when it is dry than when it is wet. But it must be noted that the treatment differences in Table 4 were much larger than in Table 7. It can also be said that the mechanised treatments benefitted more from the general increase than other treatments.

In terms of the total water intake, HR was still the best. The ZT also improved considerably probably because the plant canopy helped to protect the soil surface from further beating action of the rain.

One striking result of the 14 week measurements in the interrrow is that one of the mechanised treatments (DF) caught up with BL. In fact it was the highest among the mechanised treatments even at 8 weeks after planting. The reason that can be advanced is that there was washing of soil from the rows into the interrows in other mechanised treatments that were ridged. This undoubtedly could cause a significant decrease in infiltration in the interrows. Unlike the other ridge mechanised treatments, DF was left flat. It was thus not subjected to washing from the rows into the interrows. As for the CP which was chisel ploughed and also left flat, the infiltration though a bit low, was not too far behind DF. Cultivation was deeper here than DF which suggests greater disruption of the conducting pores in the lower horizon, eventhough the CP treatment was supposed to increase subsoil conductivity. This goal was apparently not quite achieved.

The soil at this time was capable of accepting occasional high amounts of rainfall characteristic of this area (Table 12). The assumption is based on the amount of total infiltration for each treatment and the frequency of exceptionally heavy storms. For instance, for the 24-hour totals of the rainfall data analysed, there were only two occasions when rainfall was greater than 100mm in one day in the past 50 years. The presence of crop canopy will also help in protecting the soil from direct beating of the rain thus making the soil to be more receptive.

The degree of variation between the treatments can be seen in Figure 7. The mechanised treatments have been averaged again.

Tables 7 and 9 show cumulative infiltration at the row and interrow positions. The results show that the rows were better than the interrows except in DF and ZT. The CP treatment was expected to follow a similar pattern to DF and ZT but this was not so and the reason is not very clear. The results of the statistical analysis (Table 11) show that there was a significant difference between row and interrow of DF and DI at 10% level of significance. The reason for the big difference in DF is also not very clear.

Table 7: Cumulative Infiltration, (mm) at 14 weeks after planting in 1978 (interrow position).

Treatments	Time from start of infiltration					
	15mins	30mins	60mins	120mins	180mins	240mins
HR	56	97	163	264	358	447
BL	28	45	73	132	181	230
DF	34	56	83	141	195	244
DR	20	32	53	78	101	122
DI	15	24	35	53	70	85
DP	21	32	50	81	107	130
MB	18	34	62	100	132	164
CP	31	50	88	127	163	198
ZT	48	78	118	190	259	326

Note: The full data are given in Appendix 2.

Table 8: Equilibrium Infiltration Rates (mm/hr) at 14 weeks after planting (interrow position).

Treatments	Mean equilibrium infiltration rates (mm/hr)	
	Raw data	Log transformation
HR	90	4.102
BL	49	3.481
DF	50	3.703
DR	22	3.016
DI	16	2.070
DP	24	2.942
MB	32	2.726
CP	34	2.407
ZT	67	4.159

Analysis of Variance (log transformation).

Source of Variation	d.f.	S.S.	M.S.	F
Replicates	3	7.544	2.514	2.462
Treatments	8	17.163	2.145	2.101
Error	24	24.500	1.021	
Total	35	49.206		

$Lsd_{(0.1)}$ treatment = 1.222

C.V. (Raw data) = 39.7%

C.V. (log transformation = 31.8%

Table 9: Cumulative Infiltration (mm) at 14 weeks after planting in 1978 (Row position)

Treatments	Time from start of infiltration.					
	16mins	30mins	60mins	120mins	180mins	240mins
HR	99	173	303	477	643	802
BL	63	110	190	296	393	485
DF	14	19	25	37	48	59
DR	29	46	68	101	132	163
DI	27	45	68	115	158	199
DP	31	48	69	103	133	160
MB	33	54	88	133	170	202
CP	36	60	107	170	227	281
ZT	38	62	108	171	229	284

Table 10: Equilibrium Infiltration Rates (mm/hr) at 14 weeks after planting (row positio)

Treatments	Mean equilibrium infiltration rates (mm/hr)	
	Raw data	Log transformation
HR	159	4.983
BL	92	4.379
DF	10	2.223
DR	31	3.038
DI	41	3.230
DP	27	2.944
MB	32	3.278
CP	55	3.467
ZT	56	3.885

Analysis of variance (log transformation).

Source of Variation	d.f.	S.S.	M.S.	F
Replicates	3	7.984	2.661	4.892
Treatments	8	21.585	2.698	4.959***
Error	24	13.057	0.544	
Total	35	42.626		

$Lsd_{(0.05)}$ treatment = 1.08

*** = significant at 0.1%

C.V. (Raw data) = 59.4%

C.V. (log transformation = 21.8%

Table 11: Equilibrium Infiltration Rates (mm/hr) at 14 weeks after planting in 1978. Row (R) and Interrow (IR) comparison).

Treatments	Mean equilibrium infiltration rates (mm/hr).			
	Raw data		Log transformation	
	R	IR	R	IR
HR	159	90	4.983	4.102
BL	92	49	4.379	3.481
DF	10	50	2.223	3.703
DR	31	22	3.038	3.016
DI	41	16	3.230	2.070
DP	27	24	2.944	2.942
MB	32	32	3.277	2.726
CP	55	34	3.467	2.407
ZT	56	67	3.885	4.159

Analysis of variance (log transformation)

Source of Variation	d.f.	S.S.	M.S.	F
Replicates	3	13.566	4.522	5.84
Treatments	8	27.266	3.408	4.40***
Position	1	1.768	1.768	2.28
Treatment x Position	8	11.481	1.435	1.85
Error	51	39.518	0.775	
Total	71	93.601		

$Lsd_{(0.1)}$ treatment x position = 1.040

*** significant at 0.1%

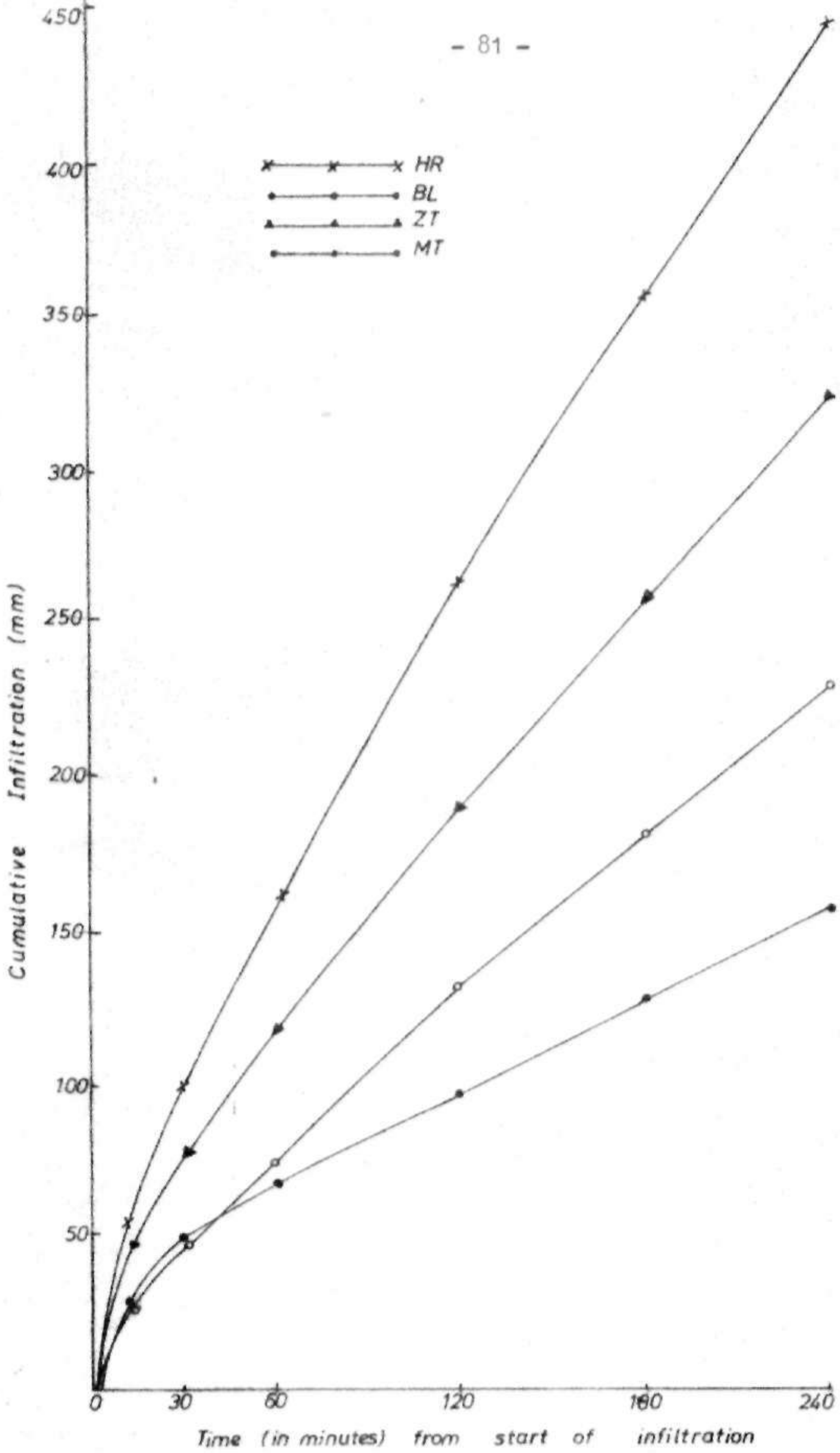

Fig. 7: CUMULATIVE INFILTRATION AGAINST TIME AT 14 WEEKS AFTER PLANTING (1978)

Table 12: Analysis of Samaru rainfall data. Frequency of 24 - hour totals greater than 25mm.

Year	25-50mm	50-75mm	75-100mm	100-150mm	>150mm	Total amount in the year(mm)	Days of rainfall in the year
1928	10	2	1	-	-	1262	97
1929	13	2	-	-	-	1292	100
1930	8	1	1	-	-	1047	96
1931	14	2	-	-	-	1198	86
1932	15	2	-	-	-	1198	82
1933	11	3	1	-	-	1322	101
1934	11	1	-	-	-	1079	89
1935	9	-	-	-	-	996	98
1936	14	2	-	-	-	1150	91
1937	10	2	-	-	-	983	86
1938	10	-	1	-	-	987	93
1939	11	1	-	-	-	1129	101
1940	7	-	-	-	-	911	78
1941	8	2	-	-	-	1034	83
1942	6	2	-	-	-	936	75
1943	18	3	-	-	-	1273	91
1944	8	3	-	-	-	929	69
1945	8	-	1	-	-	984	86
1946	17	3	1	-	-	1425	97
1947	12	3	-	-	-	1150	90
1948	6	-	-	-	-	897	92
1949	9	1	1	-	-	989	76
1950	5	1	-	-	-	899	82
1951	10	2	1	-	-	1160	96
1952	13	-	-	-	-	1106	85
1953	14	2	1	-	-	1156	83

Table 12: Contd.

Year	25-50mm	50-75mm	75-100mm	100-150mm	>150mm	Total amount in the year(mm)	Days of rainfall in the year
1954	14	5	-	-	-	1482	98
1955	20	1	2	-	-	1345	98
1956	11	2	-	-	-	930	84
1957	18	3	-	-	-	1395	97
1958	9	1	-	-	-	889	76
1959	8	3	1	-	-	1064	85
1960	9	2	1	-	-	1091	91
1961	9	-	1	-	-	824	78
1962	16	-	1	-	-	1302	96
1963	14	1	-	-	-	1091	85
1964	8	2	1	-	-	1055	85
1965	13	-	-	-	-	978	83
1966	10	3	1	-	-	1332	100
1967	11	-	-	-	-	968	85
1968	9	1	-	-	-	1059	85
1969	9	2	-	-	1	1218	93
1970	13	1	-	-	-	948	76
1971	11	1	-	-	-	884	71
1972	6	1	1	-	-	907	75
1973	12	2	-	-	-	974	69
1974	7	3	-	1	-	1115	89
1975	10	1	-	-	-	989	88
1976	14	1	-	-	-	1196	88
1977	7	-	-	-	-	746	70
1978	11	1	-	-	-	1149	86

Source: Meteorological Office I.A.R., Samaru

4.2.3 Infiltration just before the start of rainy season (1979).

The results of measurements made in March 1979 can be seen in Tables 13 to 17.

As in the measurements at 14 weeks after planting, the results in Table 13 are means of 4 replicates measured in the interrows. The results show that high cumulative infiltration was maintained as it was at 14 weeks after planting (compare Tables 7 and 13). In fact there was much less difference between these two sets of measurements than between those at 14 and 8 weeks after planting (compare Tables 4 and 7). Cumulative infiltration in the interrow in some treatments like HR, DF, DP and CP even dropped. Those that increased did so negligibly.

These sets of infiltration measurements were carried out in March 1979 when the soil profile was at its driest. One might therefore have expected infiltration rates to be much higher than at 14 weeks after planting because the soil moisture content was lower. The small difference observed may be connected with the behaviour of dry soils when water is suddenly added. When this occurs, air bubbles may be entrapped in the coarser pores. The result of this is that the pores will be blocked and infiltration reduced considerably.

Russell (1973) wrote interalia: "the crumbs and walls of the coarse pores in some soils may collapse spontaneously on wetting, and this is particularly liable to happen if a dry soil is suddenly flooded . . . . " All these point to possible explanations of the small difference between the measurements at 14 weeks after planting and those at the end of dry season when soil moisture content was very low.

One other reason that can be considered for the slight difference between the two measurements is that at the end of dry season when soil moisture content is low the activities of the soil organisms may be reduced. This may mean that there were fewer channels opening to the surface and the net result is reduction in infiltration.

Infiltration rates were high during the first 30 minutes. This is because infiltration is always very high when water is first added to dry soils. This invariably decreases with time due to various factors (already covered in the introduction).

One abnormal case that was recorded was that of DI. Infiltration in the interrow in March 1979 was over seven times that at 14 weeks after planting. It is fairly difficult to explain but it is thought that the presence of crop residue provided nutrient for soil organisms thereby increasing their activities. A similar deduction can be made for ZT catching up with HR at this time.

The results of the statistical analysis for both the rows and interrows however show that there was no significant difference between the different treatments. This may be due to the dryness of the soil at the time of measurements. Another reason could be that replicate measurements were highly variable (see coefficients of variation Tables 14 and 16). Figure 8 shows the comparison between the treatments. As in other measurements, all the mechanised treatments were averaged.

Comparing the rows and the interrows (Tables 13 and 15), the rows were superior to the interrows except in DF, DI and ZT. The case of DI has been mentioned earlier on. For DF and ZT, a possible explanation is that washing from the rows to the interrows as occurred in the ridged treatments, was absent in the flat treatments. In this case, CP would be similar to DF and ZT. This was not so however, for reasons unknown.

Table 13: Cumulative Infiltration (mm) just before the rainy season 1979 (interrow position).

Treatments	Time from start of infiltration					
	15mins	30mins	60mins	120mins	180mins	240mins
HR	51	84	128	199	262	319
BL	31	53	90	144	194	239
DF	31	44	64	93	119	144
DR	33	50	81	119	153	185
DI	85	151	231	375	512	643
DP	23	34	47	72	92	110
MB	38	58	82	126	164	199
CP	36	51	61	82	97	112
ZT	31	83	130	212	279	338

Note: The full data are given in Appendix 3

Table 14: Equilibrium Infiltration Rates (mm/hr) just before the rainy season 1979 (interrow position).

Treatments	Mean equilibrium infiltration rates (mm/hr)	
	Raw data	Log transformation
HR	57	4.042
BL	45	3.551
DF	25	2.656
DR	32	3.163
DI	46	3.522
DP	18	2.791
MB	35	3.133
CP	15	2.425
ZT	59	3.820

Analysis of variance (log transformation)

Source of Variation	d.f.	S.S.	M.S.	F.
Replicates	3	2.953	0.984	1.57
Treatments	8	9.518	1.190	1.90
Error	24	15.064	0.628	
Total	35	27.535		

$Lsd_{(0.1)}$ treatment 0.959

C.V. (Raw data) = 87.1%

C.V. (Log transformation)=24.5%

Table 15: Cumulative Infiltration (mm) just before the rainy season in 1979 (row position)

Treatments	Time from start of infiltration					
	15mins	30mins	60mins	120mins	180mins	240mins
HR	84	142	226	373	509	639
BL	62	107	143	214	277	335
DF	20	32	41	61	78	93
DR	77	116	172	254	330	397
DI	50	77	121	187	243	305
DP	68	104	158	258	340	418
MB	93	141	209	313	405	448
CP	61	98	146	222	288	349
ZT	46	69	108	174	235	294

Table 16: Equilibrium Infiltration Rates (mm/hr) just before the rainy season 1979 (row position)

Treatments	Mean equilibrium infiltration rates (mm/hr).	
	Raw data	Log transformation
HR	131	4.506
BL	70	3.890
DF	17	2.728
DR	67	3.974
DI	142	4.269
DP	78	3.777
MB	84	4.167
CP	61	3.530
ZT	58	3.970

Analysis of variance (log transformation)

Source of variation	d.f.	S.S.	M.S.	F.
Replicate	3	5.193	1.731	1.50
Treatments	8	8.412	1.052	0.91
Error	24	27.760	1.157	
Total	35	41.366		

C.V. (Raw data) = 106.0%

C.V. (log transformation) = 27.8%

Table 17: Equilibrium Infiltration Rates (mm/hr) just before the rainy season 1979 (row (R) and interrow (IR) comparison).

Treatments	Mean equilibrium infiltration rates (mm/hr)			
	Raw data		Log transformation	
	R	IR	R	IR
HR	130	57	4.506	4.042
BL	58	45	3.890	3.551
DF	17	25	2.728	2.656
DR	67	32	3.974	3.163
DI	142	46	4.269	3.522
DP	78	18	3.777	2.791
MB	84	35	4.167	3.133
CP	61	15	3.530	2.425
ZT	58	59	3.970	3.820

Analysis of variance (log transformation)

Source of Variation	d.f.	S.S.	M.S.	F.
Replicates	3	6.743	2.248	2.59
Treatments	8	15.500	1.937	2.23*
Position	1	7.239	7.339	8.35**
Treatment x Position	8	2.431	0.304	0.35
Error	51	44.228	0.867	
Total	71	76.141		

* Significant at 5%

** Significant at 1%

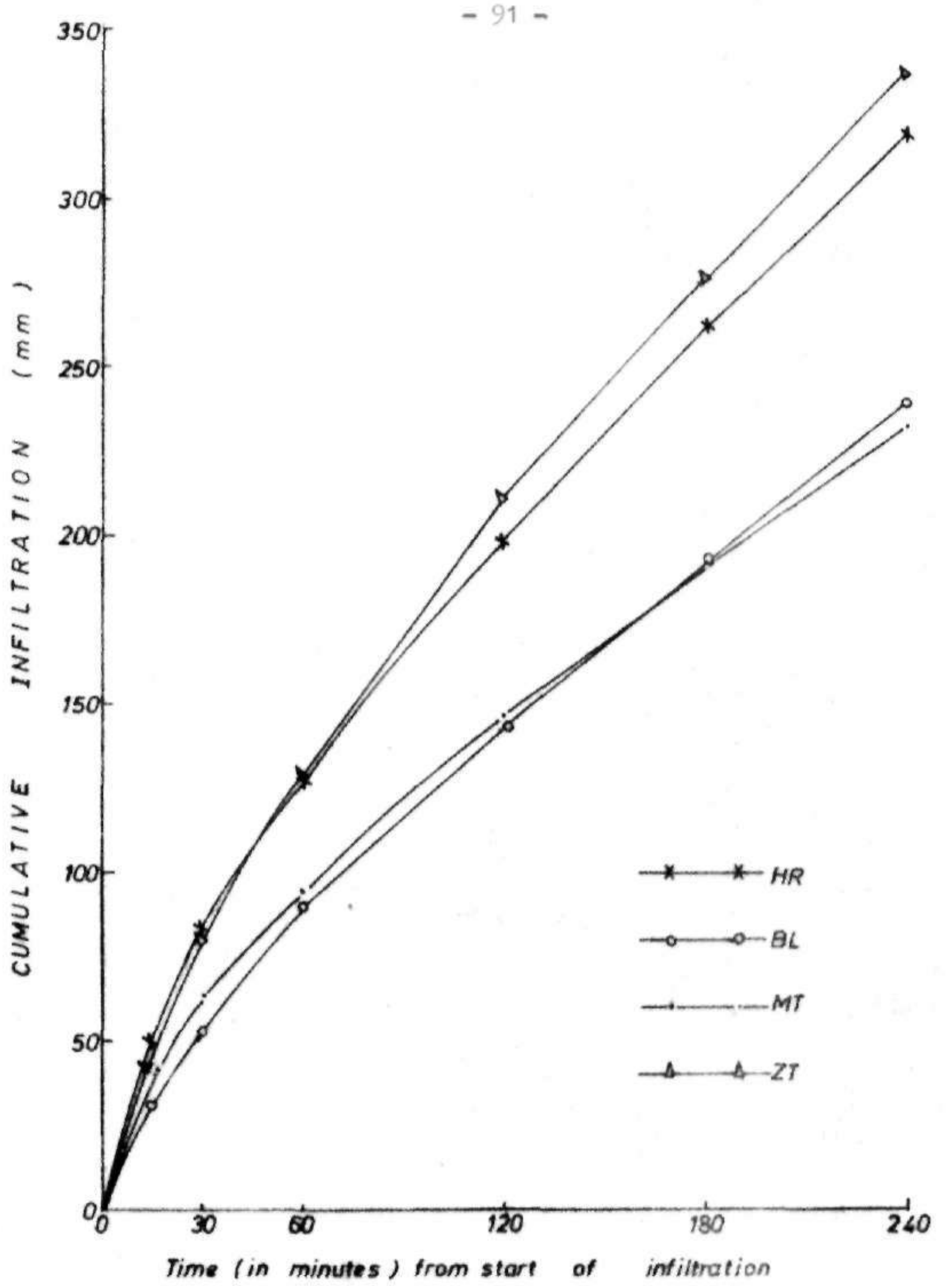

FIG. 8 : CUMULATIVE INFILTRATION AGAINST TIME JUST BEFORE THE RAINS (1979)

4.2.4 Infiltration at 1 week after planting - 1979.

The results in Table 18 were means of 8 replicates. They are thus directly comparable with the results at 8 weeks after planting (Table 4) which were also measured in the interrows.

Table 18 shows that HR and ZT were superior to BL and all the mechanised treatments. This is confirmed by the statistical analysis (Table 19) which shows that there was a significant difference between HR and BL, between HR and each of the mechanised treatments; also between ZT and BL and between ZT and each of the mechanised treatments. It also shows that there were no significant differences among the mechanised and bullock-powered treatments nor between HR and ZT.

As with the previous measurements, the results may be due to compaction below the cultivation layer and destruction of conducting pores in the top soil. It is worth noting that the condition of the soil has returned to a situation similar to the 8 weeks measurement in 1978 except that BL has changed place. In fact it fell below the average of the mechanised treatments. This is fairly difficult to explain but it is thought that recompaction had not taken place in the mechanised treatments before the measurements were made since the measurements were taken shortly after cultivation.

On the whole, infiltration was much higher than it was the previous year at 8 weeks after planting (compare Tables 4 and 18). A possible reason may be similar to what has just been said as regards recompaction not having taken place before the measurements were made. Another possible reason concerns the initial soil moisture content. The measurements taken at 8 weeks after planting (Table 4) were done in the second half of the month of August when the rainy season was at its peak. On the other hand, the measurements taken at 1 week after planting were done at the beginning of July. This was just before the peak of rainy season was reached. Thus the initial soil moisture content during the measurements at 8 weeks after planting was higher than that at 1 week after planting. As other workers (e.g. Tisdall 1951 and Lugo-Lopez <u>et</u>. <u>al</u>. 1968) have found, initial soil moisture content had a profound effect on infiltration.

A further possible explanation for the difference between Tables 4 and 18 is that the soil was exposed to the beating action of the rain for a longer period before the measurements were taken at 8 weeks after planting than at 1 week after planting. This means that there could have been greater crust formation in the former than in the latter.

A further look at the results in Tables 4 and 18 reveals that the gap between ZT and HR treatments at 8 weeks was wider than it was at 1 week after planting the following year. This may be due to the fact that crop residues of the 1978 crop were left on the surface of ZT. This could undoubtedly increase the activities of soil organisms thereby opening up new channels. The result of this is increased infiltration. The residues themselves might also be responsible for protecting the soil surface from getting crusted. Many workers (e.g. Van Doren et. al. 1952, Lawes, 1962; and Lal 1976) have reported a positive influence of surface mulch on infiltration.

Figure 9 shows the cumulative infiltration at 1 week after planting with the six mechanised treatments (MT) averaged.

Table 20 below shows cumulative infiltration differences between the rows and interrows measured in 4 replicates. The result is difficult to explain as it did not follow any consistent pattern. The DP treatment is a case in point where infiltration in the interrow greatly exceeded that of the row. However the interrows of ZT and DF still remain superior to the rows.

The statistical analysis (Table 21) for equilibrium infiltration rates (row and interrow) shows that HR and ZT were significantly different from BL and all the mechanised treatments except DP (IR) at 0.1% level of significance. Also the rows of HR, BL and DP were significantly superior to the interrows at 5% level.

Table 18: Cumulative Infiltration (mm) at 1 week after planting in 1979 (interrow position).

Treatments	Time from start of infiltration					
	15mins	30mins	60mins	120mins	180mins	240mins
HR	41	70	119	194	261	322
BL	14	22	33	55	73	88
DF	11	17	27	44	57	70
DR	13	20	33	52	81	83
DI	22	39	68	116	157	193
DP	18	33	55	96	129	158
MB	9	14	23	37	48	58
CP	13	21	35	60	80	97
ZT	25	44	80	148	211	272

Note: The full data are given in Appendix 4.

Table 19: Equilibrium Infiltration Rates (mm/hr) at 1 week after planting in 1979 (interrow position)

Treatments	Mean equilibrium infiltration rates (mm/hr)	
	Raw data	Log infiltration
HR	62	3.935
BL	16	2.654
DF	13	2.208
DR	15	2.247
DI	36	2.981
DP	29	2.965
MB	10	2.176
CP	18	2.642
ZT	61	3.883

Analysis of Variance (log transformation)

Source of Variation	d.f.	S.S.	M.S.	F.
Replicates	7	10.452	1.493	2.86
Treatments	8	26.420	3.302	6.32***
Error	56	29.279	0.523	
Total	71	66.151		

$Lsd_{(0.05)}$ treatment = 0.725

*** = Significant at 0.1%.

C.V. (raw data = 84.9%

C.V. (log transformation = 25%

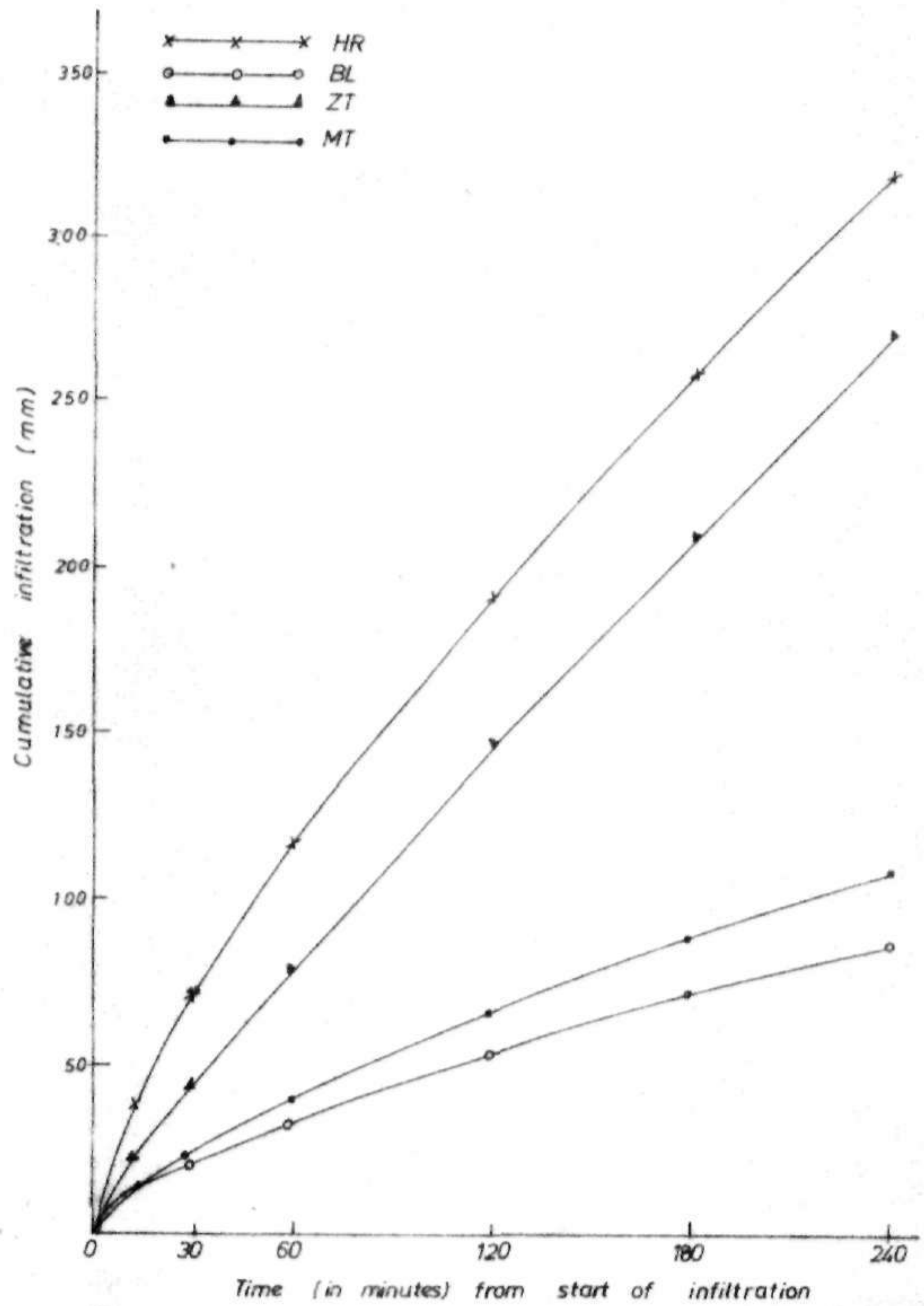

Fig.9 : CUMULATIVE INFILTRATION AGAINST TIME AT 1 WEEK AFTER PLANTING (1979)

Table 20: Cumulative Infiltration (mm) at 1 week after planting 1979 (row (R) and interrow (IR) comparison).

Treatments		Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
HR	R	81	137	243	415	569	711
	IR	55	93	153	241	318	292
BL	R	27	45	78	131	176	218
	IR	15	23	35	56	73	87
DF	R	10	15	22	36	48	58
	IR	12	19	30	46	60	72
DR	R	20	35	56	86	115	142
	IR	21	31	49	73	93	110
DI	R	18	26	41	65	86	105
	IR	30	52	91	154	207	255
DP	R	9	12	18	30	40	48
	IR	29	54	94	163	219	266
MB	R	14	19	28	43	55	66
	IR	12	20	32	49	62	74
GP	R	17	26	39	64	85	104
	IR	14	21	36	58	79	97
ZT	R	33	58	102	178	248	311
	IR	38	65	119	215	307	396

Note: The full data are given in Appendix 5.

Table 21: Equilibrium Infiltration Rates (mm/hr) at 1 week after planting 1979 (row (R) and interrow (IR) comparison).

Treatments	Mean equilibrium infiltration rates (mm/hr).			
	Raw data		Log transformation	
	R	IR	R	IR
HR	142	75	4.950	4.118
BL	41	15	3.522	2.536
DF	10	12	2.233	2.218
DR	27	19	3.200	2.736
DI	18	48	2.826	2.934
DP	8	48	1.958	3.799
MB	11	12	2.312	2.237
CP	19	18	2.860	2.591
ZT	63	89	4.059	4.311

Analysis of variance (log transormation)

Source of Variation	d.f.	S.S.	M.S.	F.
Replicates	3	7.718	2.573	6.16***
Treatments	8	39.476	4.935	11.82***
Position	1	0.043	0.043	0.10
Treatments x Position	8	10.803	1.350	3.23***
Error	51	21.294	0.418	
Total	71	79.335		

$Lsd_{(0.001)}$ treatment = 1.118

$Lsd_{(0.05)}$ treatment x position = 0.646

*** Significant at 0.1%

C.V. (raw data) = 63.8%

C.V. (log transformation) = 21.1%

4.2.5 Aggregate stability at 4 weeks after planting in 1979:

Frequent working of the soil surface has been found by many workers to lead to deterioration of its structure and reduced water intake. This was confirmed by the aggregate stability test (Table 22).

The results indicate that the surface soil under ZT was significantly more stable than the surface soil of all other treatments. Similarly there was a significant difference between HR and BL on the one hand and the three mechanised treatments tested on the other hand.

To some extent lower structural stability in the surface soil appears to reflect the rate of water intake. Thus ZT, HR and BL were all better than the mechanised treatments (as per infiltration data). However unlike with the infiltration data, ZT in terms of structural stability was significantly better than both HR and BL.

The structural stability test gave highly reproducible results, low standard errors and a high level of significance. The trends were the same whether the test was done with 0.5, 1.0 or 2.0mm sieves.

Table 22: Result of Aggregate Stability Test (%)

Treatments	Sieve openings			
	0.5mm	1.0mm	2.0mm	Mean
ZT	57.3	41.7	38.1	45.7
CP	18.0	14.8	11.5	14.8
DF	33.3	19.3	14.6	22.4
DP	23.8	13.2	9.3	15.4
HR	35.9	32.6	27.6	32.0
BL	38.9	30.4	24.6	31.3

Analysis of Variance

Source of Variation	d.f.	S.S.	M.S.	F.
Treatments	5	4170.611	834.122	95.974***
Sieve opening	2	1125.421	562.710	64.745***
Error	28	243.352	8.691	
Total	35	5539.384		

$Lsd_{(0.001)}$ treatment = 6.253

*** = Significant at 0.1%

C.V. = 11%

4.2.6 Effects of date, cultivation method and row/interrow position on infiltration.

Looking at the interrow results generally it can be seen that the cumulative infiltration for the four different dates was highest at 14 weeks after planting and just before the rainy season. These were closely followed by that at 1 week after planting. The measurements at 8 weeks after planting were very much lower than others. This means that infiltration can improve with time due to reasons already covered in the preceding discussion. Statistical analysis (Table 23) for the equilibrium infiltration rates confirmed this. The measurements at 8 weeks after planting were significantly different from the 3 other dates at 5% level of significance. They also show that there was no significant difference between the latter (i.e. 14 weeks after planting, just before the rainy season and 1 week after planting in 1979). Figures 10 and 11 illustrate these points in greater detail.

Effect of treatments at the interrow are summarised in Table 23 which shows that HR and ZT were significantly superior to BL and all the mechanised treatments. Table 23 also shows that there were no significant differences between the mechanised treatments.

Data for three dates and both the row and interrow positions are summarised in Table 24 which shows that there was a significant difference between the measurements at 1 week after planting and those at just before the rains and at 14 weeks after planting. It also shows that the rows were significantly different from the interrows at 5% level of significance. In addition, it shows that there was a significant difference between HR and BL, HR and all the mechanised treatments and between ZT and all the mechanised treatments.

Overall differences between cultivation methods are clear (Tables 23 and 24). In terms of equilibrium infiltration rates, the cultivation methods can be summarised as follows: HR > ZT > BL > mechanised.

Table 23: Equilibrium infiltration rates (mm/hr) averaged over four dates (interrow position only)

Treatments	Mean equilibrium infiltration rate (mm/hr)	
	Raw data	Log transformation
HR	73	4.097
BL	32	3.088
DF	26	2.718
DR	20	2.671
DI	31	2.733
DP	23	2.678
MB	20	2.136
CP	18	2.105
ZT	61	3.859

Analysis of Variance (log transformation)

Source of Variation	d.f.	S.S.	M.S.	F.
Replicates	3	14.120	4.707	6.25
Treatments	8	60.233	7.529	9.999***
Dates	3	29.109	9.703	12.886***
Treatments x Dates	24	30.126	1.255	1.67
Error	105	79.061	0.753	
Total	143	212.649		

$Lsd_{(0.05)}$ treatment = 0.607
$Lsd_{(0.05)}$ dates = 0.405

Date		means	
1	2	3	4
1.128	3.179	3.234	3.053

Note:

Date 1: 8 weeks after planting (1978)
Date 2: 14 weeks after planting (1978)
Date 3: Just before the rains (1979)
Date 4: 1 week after planting (1979)

Date	Untransformed means	Transformed means
1	18.583	2.128
2	42.389	3.179
3	36.833	3.234
4	37.000	3.053

Table 24: Equilibrium Infiltration Rates (mm/hr) averaged over three dates (Row and interrow combined)

Treatments	Mean equilibrium infiltration rates (mm/hr)	
	Raw data	Log transformation
HR	109	4.450
BL	52	3.560
DF	21	2.627
DR	33	3.188
DI	52	3.142
DP	36	3.080
MB	34	2.976
CP	33	2.880
ZT	65	4.034

Analysis of Variance (log transformation)

Source of Variation	d.f.	S.S.	M.S.	F.
Replicates	3	9.654	3.218	4.10***
Treatments	8	65.837	8.230	10.47***
Position	1	6.320	6.320	8.04***
Dates	2	8.116	4.058	5.16***
Treatments x Position	8	10.824	1.353	1.72
Treatment x Dates	16	15.692	0.981	1.25
Position x Dates	2	3.083	1.542	1.96
Treatments x Position x Dates	16	13.686	0.855	1.09
Error	159	124.951	0.786	
Total	215	258.163		

$Lsd_{(0.05)}$ position = 0.236
$Lsd_{(0.05)}$ treatment = 0.502
$Lsd_{(0.05)}$ dates = 0.289

Date means: (2) - 3.350 (3) - 3.551
(4) - 3.078

Date	Untransformed means	Transformed means
2	49.778	3.350
3	57.708	3.551
4	37.306	3.078

Note:

Date 2 = 14 weeks after planting (1978)
Date 3 = Just before the rains (1979)
Date 4 = 1 week after planting (1979)

Position means:

Row - 3.497
Interrow - 3.155

*** - Significant at 0.1%

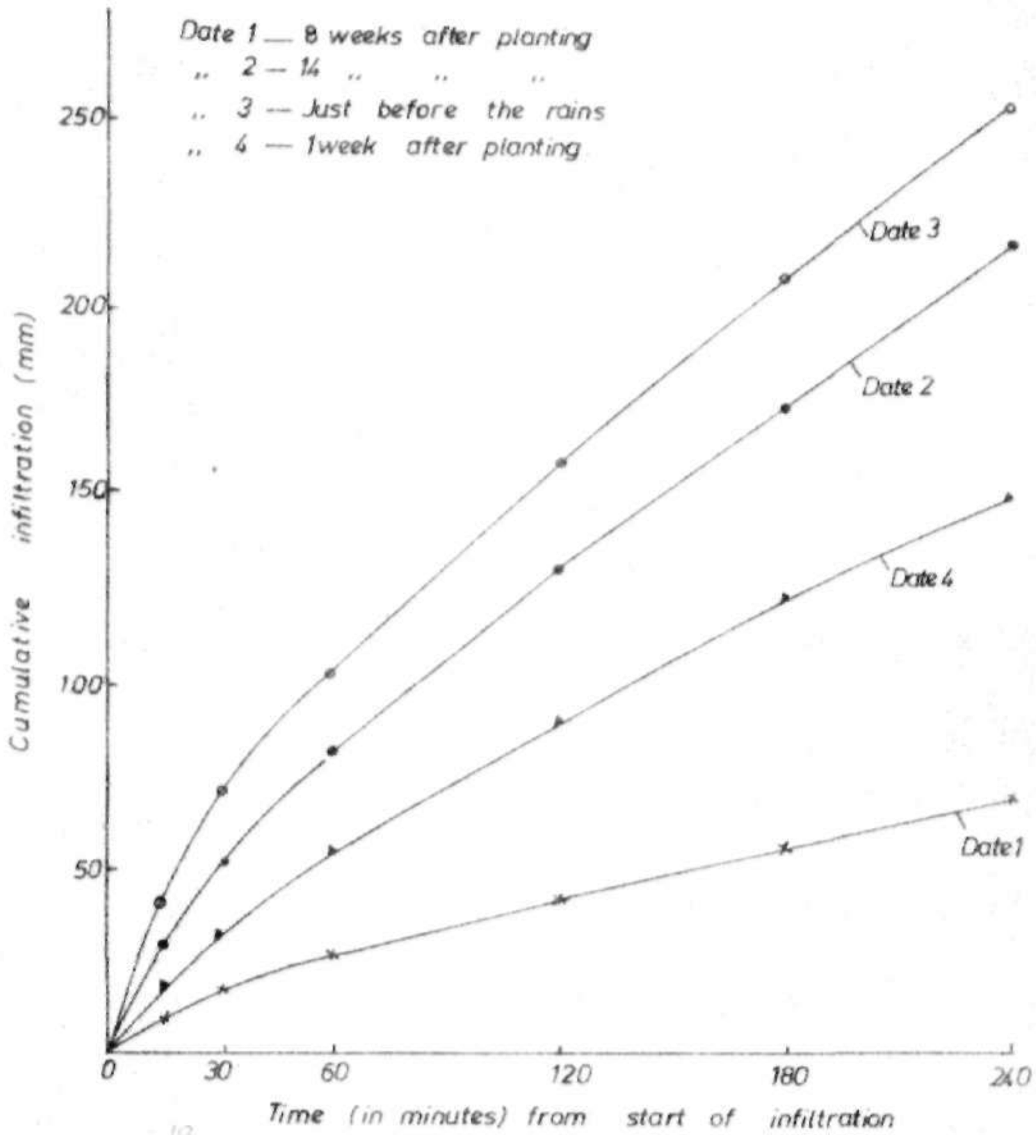

Fig. 10 CUMULATIVE INFILTRATION AGAINST TIME
(All treatments averaged for each date)

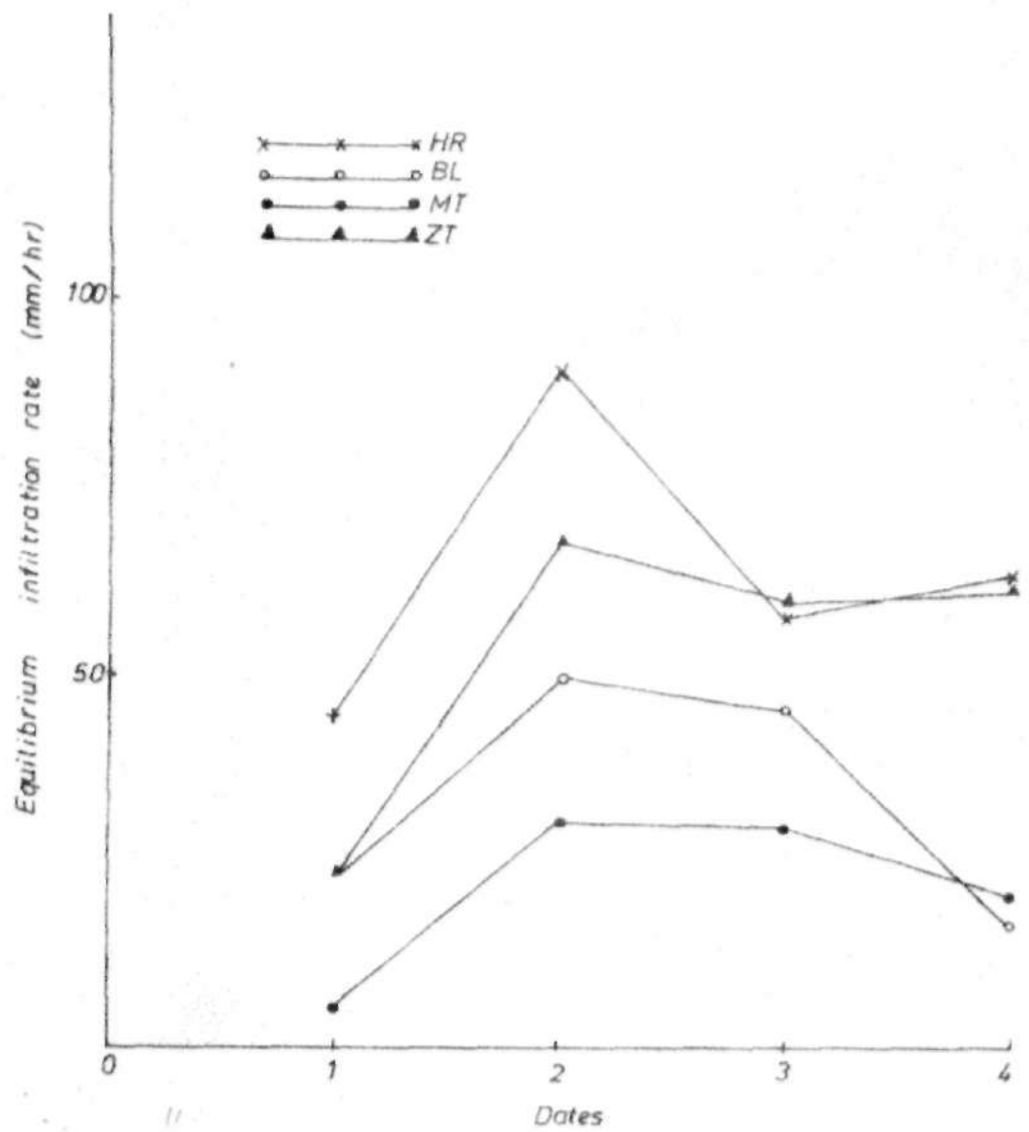

Fig11 : EQUILIBRIUM INFILTRATION RATE AGAINST DATES

CHAPTER 5

ZERO TILLAGE AND CONVENTIONAL TILLAGE COMPARISON

5.1 Background of the Experiment

This small experiment was located at the IAR farm (S-Block) close to the site of the main cultivation experiment (R-Block). There were two treatments viz: zero tillage (ZT) and conventional tillage (CT) both applied annually. Each treatment was replicated twice. By 1978, the experiment had been in progress for six years. In 1977 and 1978 the test crop was maize and in 1979, cotton. Maize residues were always returned as mulch on ZT and incorporated in CT. In 1978, CT plots were treated to disc ploughing disc harrowing plus spring tine cultivation and left flat; while in 1979, they were disc harrowed plus spring tine cultivator and also left flat.

5.2 Results and Discussion

The results presented in Tables 25 to 28 are means of 4 interrow measurements for each treatment (i.e. two per plot). As in the main cultivation experiment, in which zero tillage and various conventional tillage operations were compared, the results in this small experiment also show great differences due to treatments.

The results in Table 25 show that total infiltration in zero tillage at 8 weeks after planting in 1978 was about 10 times better than that in the conventional tillage. Similarly in 1979 (Table 26), total infiltration in the interrow though low in both cases was 5 times better in zero tillage than in conventional tillage. Also the equilibrium infiltration rates (Tables 27 and 28) were of the ratios 11:1 in 1978 and 6:1 in 1979, again showing the superiority of zero tillage over the conventional tillage. The statistical analysis also showed that the equilibrium infiltration rates under zero tillage were significantly higher than under conventional tillage at 1% level of significance in 1978 and at 10% in 1979. Figure 12 shows the results graphically for the two occasions.

The low cumulative infiltration and equilibrium infiltration rates in the conventional tillage could be explained by the fact that the treatment experienced the sealing of conducting pores by the beating action of the rain. Closely connected with this is the disruption of conducting pores and degradation of soil structure due to frequent cultivation.

These three problems can either be removed or minimised by protecting the surface with mulches and reducing the frequency of cultivation. The difference between the two treatments may therefore be because the zero tillage satisfied these conditions to some extent. This is because the zero tillage had little soil disturbance except during planting. The fact that the herbicides used still left some weeds standing helped to protect the soil surface from the beating action of the rain. The roots of weeds may also have influenced the stability of the conducting pores and thus improved infiltration. Another major factor that helped in protecting the soil surface was the crop residue of the previous year that was left on the soil surface. The results confirm those of other workers (e.g. Lal 1976 b) who have pointed out the beneficial roles of mulches on infiltration, runoff and erosion.

One observation worth pointing out is that the infiltration in 1978 was very much higher than that of 1979. It is striking because one does not expect such an abrupt fall in infiltration within so short a time, especially in the zero tillage. What may have caused this large difference was a heavy storm in the night preceding the 1979 measurements. Probably the majority of the conducting pores were still saturated on the following day. This indicates that the amount of water intake by the soil was therefore limited as compared with the drier situation in the preceding year. Similarly, Lugo-Lopez et. al. (1968) found that the greater the initial moisture content, the lower the infiltration rate.

Table 25: Cumulative Infiltration (mm). Zero/Conventional tillage comparison at 8 weeks after planting in 1978.

Treatments	Time from start of infiltration					
	15mins	30mins	60mins	120mins	180mins	240mins
ZT	42	74	130	214	280	335
CT	9	13	17	23	28	33

Note: The full data are given in Appendix 6.

Table 26: Cumulative Infiltration (mm). Zero/Conventional tillage comparison at 1 week after planting in 1979. (Interrow only)

Treatment	Time from start of infiltration.					
	15mins	30mins	60mins	120mins	180mins	240mins
ZT	6	10	16	31	43	55
CT	2	3	4	7	9	11

Table 27: Equilibrium Infiltration Rates (mm/hr). Zero/Conventional tillage comparison at 8 weeks after planting in 1978.

Treatment	Mean equilibrium infiltration rates (mm/hr)	
	Raw data	Log transformation
ZT	55	3.963
CT	5	1.386

Analysis of variance (log transformation).

Source of variation	d.f.	S.S.	M.S.	F
Treatment	1	13.282	13.282	58.487**
Error	6	1.362	0.227	
Total	7	14.644		

$Lsd_{(0.01)} = 1.309$

** significant at 1% level

C.V. = 29.1%

Table 28: Equilibrium Infiltration Rates (mm/hr). Zero/Conventional tillage comparison, at 1 week after planting in 1979. (Interrow only)

Treatments	Mean equilibrium infiltration rates (mm/hr)	
	Raw data	Log transformation
ZT	12	2.221
CT	2	0.173

Analysis of Variance (log transformation).

Source of Variation	d.f.	S.S.	M.S.	F
Treatments	1	5.739	5.739	13.249***
Error	6	2.599	0.433	
Total	7	8.338		

$Lsd_{(0.1)}$ = 1.683.

C.V. 60.1%

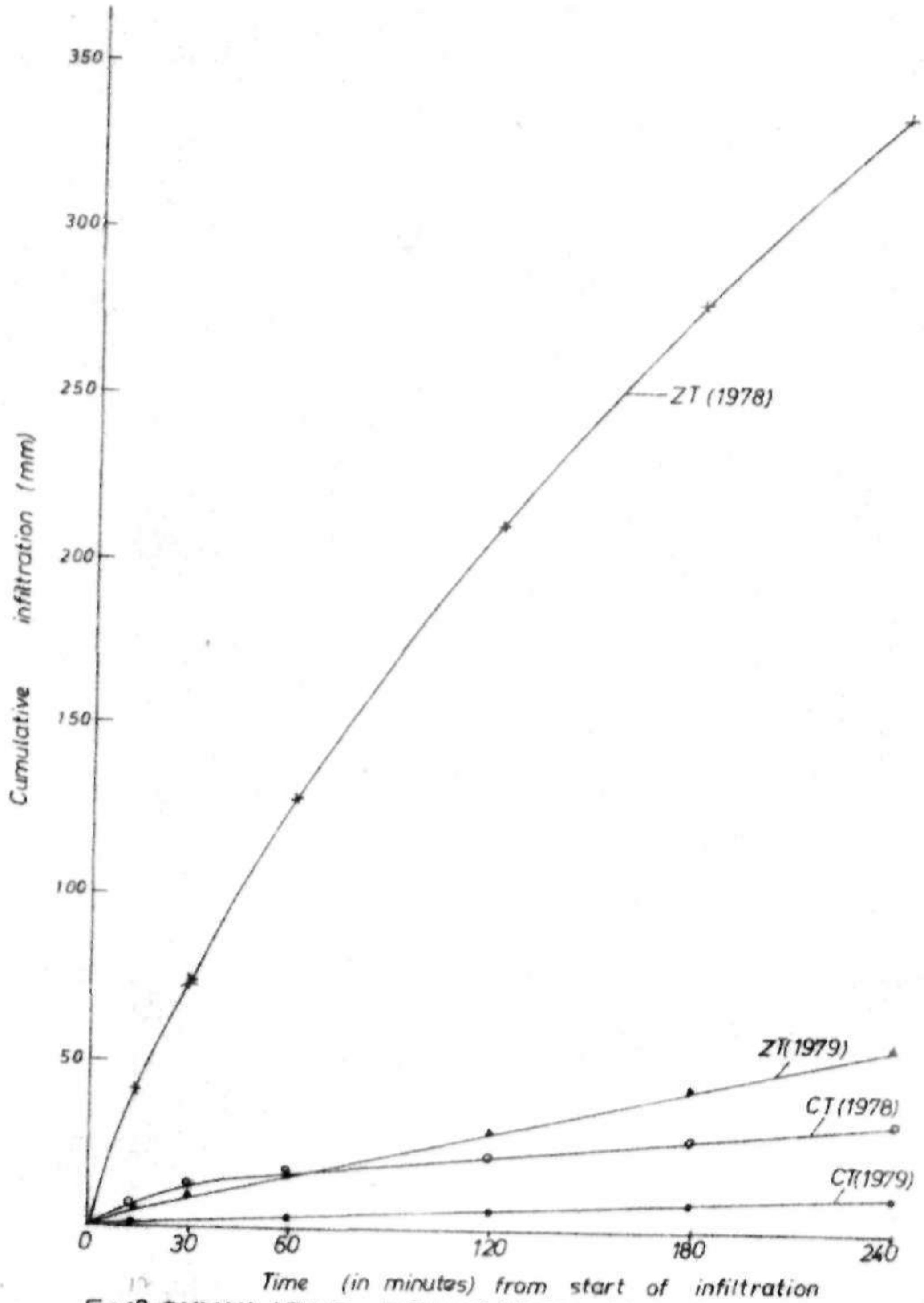

Fig.12 CUMULATIVE INFILTRATION AGAINST TIME CONVENTIONAL/ZERO TILLAGE COMPARISON AT 8WKS (1978) AND 1 WK.(1979) AFTER PLANTING.

CHAPTER 6

CONTINUOUS CULTIVATION AND GRASS FALLOW COMPARISON.

6.1 Background of the Experiment.

This other small experiment was located at the IAR Agronomy Farm. Infiltration was measured in a field that had been continuously cultivated (time cultivation, disc harrowing and ridging) for 30 years and in another that had been under grass fallow for about 20 years and possibly longer. Measurements were taken at 4 weeks after planting in 1979. The cultivated field was used for a long term fertility trial while the fallow was just adjacent to it and regularly grazed.

Equipment (i.e. double ring infiltrometers, measuring device etc) and methodology were the same as those used in the main cultivation experiment. For each of the two treatments, five measurements were made, scattered over an area of about 600 square metres. Measurements in the cultivated plots were done in the interrow. All these measurements were made in July 1979. As was the case on the previous occasions, the measurements between the third and fourth hour were taken as the equilibrium infiltration rates.

6.2. Results and Discussion.

The results of the continuous cultivation versus grass fallow comparison can be seen in Table 29 and Fig. 13.

The results are means of 5 replicates. The equilibrium infiltration rates are 3 mm/hr and 73 mm/hr for continuous cultivation and grass fallow respectively.

Since infiltration rate is a sensitive indicator of changes in the physical properties of soil (Pereira, 1955), the results in Table 29 and equilibrium infiltration rates show the degree to which the physical properties of the soil have been affected by annual cultivation. Cumulative infiltration at 30 minutes, shows that infiltration was 16 times better in grass fallow than in the cultivated plot. The margin was even wider after 4 hours with a ratio of 19 to 1. The equilibrium infiltration rates show a ratio of 24 to 1 in favour of grass fallow. Figure 13 shows graphically the wide differences between the two treatments.

In an observation made on the cultivated field about 2 days after a heavy storm, ponds of standing water could still be seen. In fact in some places, crop growth was affected by waterlogging. Unlike the cultivated field, the fallow had no standing water on the surface.

A possible explanation for the low infiltration in the cultivated field may be due to the deterioration of soil aggregates caused by cultivation. Also washing of the ridge into the furrows thereby blocking the conducting pores and compaction at the bottom of the plough layer could also have contributed to the reduced infiltration.

Various workers (e.g. Martin (1944) and Mazurak et. al. (1960) have demonstrated the beneficial effect of grass cover on water entry. Usually the roots of grass facilitate water entry into soil through the stabilisation of its pores. Also pore sizes are apparently larger and there is better continuity in the fallow than in the cultivated soils.

Wilkinson (1975) working in Samaru attributed the increase in infiltration rates in fallow to earthworm activity. A similar conclusion was drawn by Hurault (1971) who found that increased termite activity led to increased infiltration in savanna grassland of the Northern Cameroon.

No matter what is responsible for increased infiltration in fallow, the fact still remains that infiltration rates are often higher in fallows than in cultivated soils. The pity of it all however is that all the beneficial effects of fallow are often destroyed soon after a year or two of cultivation. Pereira et. al. (1954) found that rainfall infiltration rates were comparatively low after only one year of arable cropping from grass fallow. Wilkinson (1975) also found that most of the increase in infiltration during fallow was eliminated during the first seedbed preparation and that all the increase was eliminated by the end of the first cropping season. He therefore maintained that the benefits of crop production from the practice of grass fallow in the savanna zone of the tropics are mostly derived from improved nutrient status and very little from improved physical properties. Wilkinson and Aina (1975) working under forest condition in Southern Nigeria recorded similar results. Though the present experiment did not investigate the decline in infiltration immediately after ploughing up a grass fallow, it is envisaged that similar result would have been obtained.

Table 29: Cumulative Infiltration (mm). Continuous Cultivation Versus Grass Fallow Comparison.

Treatments	Time from start of infiltration					
	15mins	30mins	60mins	120mins	180mins	240mins
Continuous Cultivation	3	4	7	12	15	18
Grass Fallow	36	64	117	198	276	349

Note: The full data are given in Appendix 7.

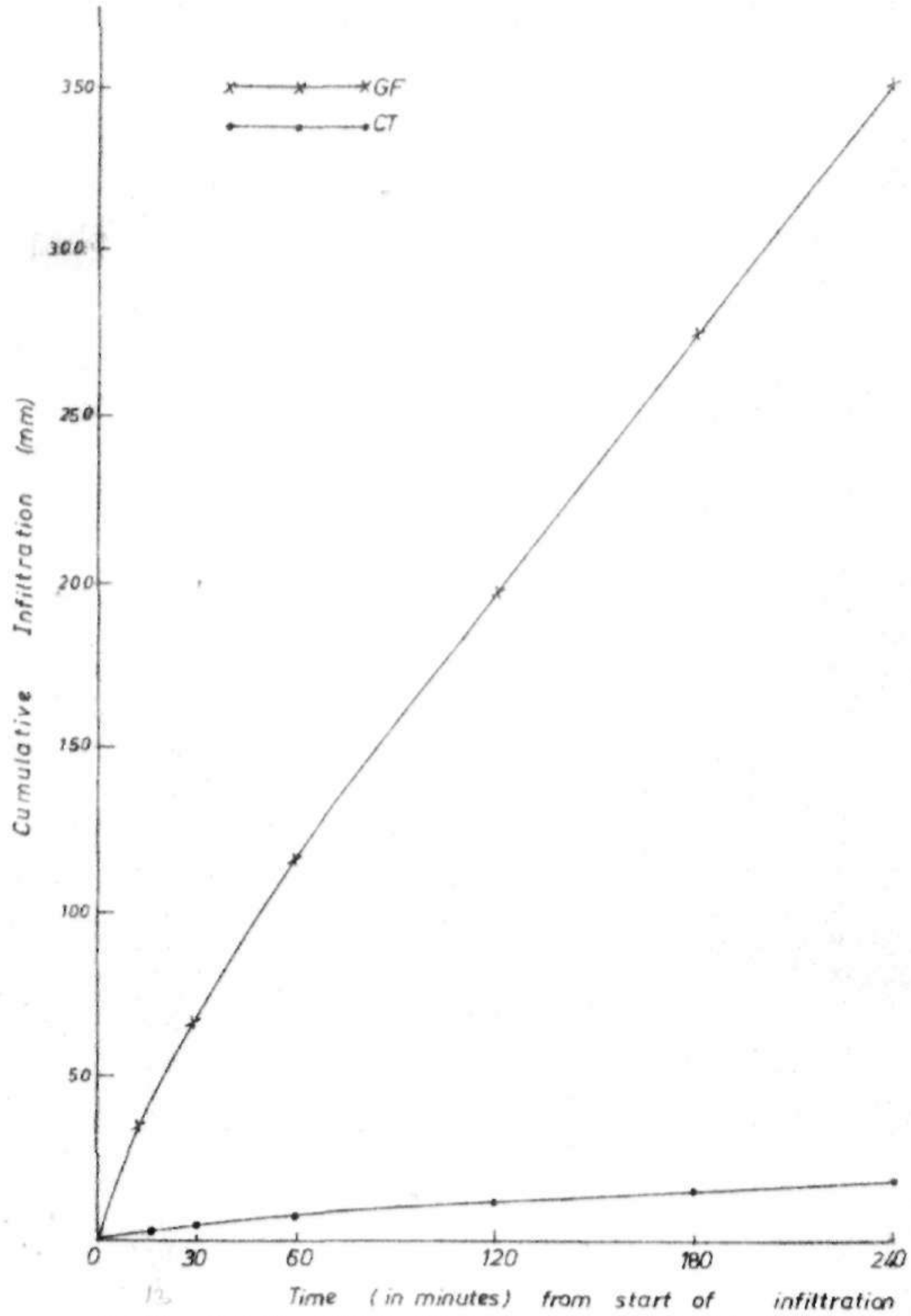

Fig 13 CUMULATIVE INFILTRATION AGAINST TIME : CONTINUOUS CULTIVATION / GRASS FALLOW COMPARISON

CHAPTER 7

SUMMARY AND CONCLUSIONS

The results of the main cultivation experiment (R-block) demonstrate the pronounced effects which different cultivation techniques can have on physical soil properties like infiltration. Of all the treatments, the manual system (HR) was the best. This was followed by the zero tillage (ZT) system, the bullock-powered (BL) system and then the mechanised treatments. The HR treatment will no doubt be the best in terms of effective water intake during heavy downpours. Consequently it is the least likely to cause surface runoff and soil erosion.

The results of the small experiment on S11 in which zero tillage was compared with conventional tillage were similar to those of the main cultivation experiment. Comparing grass fallow with conventional tillage infiltration in the former was by far greater than in the latter. The mechanised treatments would need special means of surface runoff control due to low infiltration especially at the peak of the rainy season occuring between July and September. This may mean extra cost.

Table 30 summarises the comparison between equilibrium infiltration rates of mechanised treatments and two undisturbed treatments i.e. zero tillage and grass fallow.

Table 30: Comparison between equilibrium infiltration rate of mechanised treatments and two undisturbed treatments i.e. zero tillage and grass fallow.

Experiment	Date of Measurement	Equilibrium Infiltration Rate (mm/hr.) A (Mechanised)	B (Undisturbed)	Ratio as % (A/B) x 100
Main cultivation	(1) 8 weeks after planting	5	22	22.7
	(2) 14 weeks after planting	30	67	44.8
	(3) Just before the rainy season	29	59	49.2
	(4) 1 week after planting	20	61	32.8
Small zero tillage experiment	(1) 8 weeks after planting	5	55	9.1
	(2) 1 week after planting	2	12	16.7
Grass fallow/ conventional tillage experiment	4 weeks after planting	3	73	4.1

The table above shows that even the highest infiltration rates obtained for tractor powered cultivation were less than 50 percent of zero tillage and this occured when the soil was dry. In one case when the soil was wet, infiltration on the mechanised plots was less than 5 percent of that of the undisturbed site. This shows that mechanical cultivation does a lot of havoc to water infiltration.

The ZT takes after HR in effective water intake but its disadvantage is that, apart from being a new system, the number of crops that can be grown using this method is limited. For instance root crops and groundnuts cannot be expected to do well if planted on the flat.

The HR also has its own disadvantage in terms of limited acreage that can be covered by an individual per unit of time. This is of great importance to this country especially if one considers the growing population and the need for more food. Increased food production can be achieved by increasing the area of cultivated land, and this suggests that our agriculture has to be mechanised. Given improved seeds, fertilisers and adequate crop protection, farmers' output under traditional systems would undoubtedly increase. But the fact still remains that if all these inputs are provided under mechanised systems, total output is likely to be greater than from the existing manual systems.

Under the soil and climatic conditions found in Samaru, it can be said that for large scale mechanisation to take place without serious side effects of runoff and erosion, sound soil conservation practices must be employed. Remedies that readily come to mind are means of keeping mechanised operations to the absolute minimum. It might still be necessary to take extra precautions to reduce surface runoff; for example by early establishment of crops to keep exposure of bare soil to a minimum, by using mulches to protect the soil or in severe cases by installing systems of graded terraces.

Further general conclusions that can be drawn are that infiltration varies not only with differences in cultivation techniques but also with the season. It was lowest in the mid-season when rainfall was at its peak. This was clearly illustrated by Figures 10 and 11. It can also be seen that soil cultivation improves infiltration only if it does not cause compaction in the cultivated layer. Reduced compaction was probably responsible for higher infiltration in the manual system than in either the mechanised system or the zero tillage system.

Basic causes of reduced infiltration due to mechanised cultivation appear to be complex. They include surface compaction, compaction at the bottom of cultivated layer, discontinuity of conducting pores between those at the cultivated layer and those in the subsoil layers, mixing of the cultivated layer and so on. However further studies are needed to find out the exact causes of reduced infiltration in particular cases.

It must also be said in final conclusion that the results obtained from these experiments are in line with those obtained elsewhere including the only previous study of equilibrium infiltration rate at Samaru as reported by Wilkinson (1975). In view of the importance of infiltration rate with respect to surface runoff and soil erosion, the conclusions about effects of different cultivation techniques on infiltration should be tested for all major soil types in Nigeria.

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Appendix 1: Cumulative Infiltration (mm). 8 weeks after planting in 1978 (interrow position)

Treatments	Plot No.	Time from start of infiltration 15mins	30mins	60mins	120mins	180mins	240mins
	16	40	60	95	157	219	278
HR	26	14	24	38	61	81	101
	32	22	36	64	101	136	169
	41	105	185	326	456	582	700
	51	45	78	113	178	238	292
	63	13	19	29	54	74	94
	75	9	13	19	33	44	55
	86	17	30	51	96	138	177
	12	10	19	33	56	78	98
BL	21	4	7	13	20	26	31
	36	15	24	38	64	86	106
	42	2	4	7	11	15	19
	54	19	40	64	97	127	153
	69	3	5	6	9	11	13
	73	26	46	79	151	220	283
	85	11	22	43	81	119	152

Appendix 1: Contd.

Treatments	Plot No.	15mins	30mins	60mins	120mins	180mins	240mins
	19	6	10	21	36	49	58
DF	22	3	5	7	9	11	12
	33	4	7	11	14	17	19
	49	2	3	5	7	8	9
	58	28	43	70	115	155	195
	65	4	5	8	11	13	15
	78	2	3	5	6	7	8
	84	14	26	48	79	108	135
	14	7	9	15	25	34	43
DR	23	2	3	4	6	8	10
	38	2	3	4	6	7	8
	45	5	9	11	16	20	24
	56	9	14	19	31	43	54
	62	2	4	5	8	11	13
	77	1	2	3	4	5	6
	82	5	7	9	13	16	19
	17	3	7	10	20	29	37
DT	24	2	3	4	7	9	10
	35	8	12	15	18	20	22
	46	4	7	10	18	25	32
	53	8	10	14	27	37	46
	67	4	7	11	15	18	20
	79	4	6	8	11	14	17
	89	18	27	44	79	114	144

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	11	30	52	100	171	238	303
2T	25	6	10	13	19	25	30
	39	6	11	18	27	33	38
	48	10	16	24	41	57	71
	52	17	27	49	86	120	152
	66	17	27	32	65	95	125
	72	9	13	21	35	48	159
	81	6	10	17	27	37	47

Appendix 2: Cumulative Infiltration (mm). 14 weeks after planting in 1978. (Row (R) and interrow IR).

Treatments	Plot No.	15mins	30mins	60mins	120mins	180mins	240mins
		Time from start of infiltration					
	16R	127	219	389	626	856	1081
HR	41R	130	222	392	622	832	1031
	51R	90	170	289	439	585	715
	86R	49	81	141	222	298	374
	16IR	43	76	140	225	308	391
	41IR	30	54	97	184	264	334
	51IR	125	225	373	588	788	978
	86IR	25	33	41	59	73	84
	12R	51	100	177	287	393	498
BL	42R	112	190	339	509	665	808
	54R	47	89	147	247	341	431
	85R	43	62	96	139	174	204
	12IR	26	38	63	119	174	227
	42IR	25	43	72	113	148	183
	54IR	48	81	143	260	360	460
	85IR	14	18	25	36	43	49

Appendix 2: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	19R	10	15	24	40	54	67
DF	49R	12	16	21	28	33	38
	58R	15	21	25	33	40	47
	84R	18	22	30	48	66	82
	19IR	63	108	162	267	372	472
	49IR	34	54	84	143	198	249
	58IR	27	41	63	99	132	160
	84IR	12	22	32	55	77	96
	14R	51	90	139	213	287	361
DR	45R	44	63	85	123	157	189
	56R	11	16	23	33	43	52
	82R	10	15	23	34	42	50
	14IR	21	38	74	108	142	174
	45IR	23	31	48	70	89	108
	56IR	20	28	43	62	77	90
	82IR	17	30	46	70	94	116

Appendix 2: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	17R	35	69	121	229	332	425
DI	46R	39	62	86	143	195	245
	53R	10	17	24	36	47	58
	89R	23	31	40	50	58	66
	17IR	5	9	14	22	30	37
	46IR	6	8	9	11	13	15
	53IR	7	10	13	20	27	33
	89IR	43	69	105	158	209	256
	13R	12	18	26	53	79	105
DP	44R	14	20	28	40	52	63
	59R	18	30	45	55	62	69
	88R	78	122	178	262	338	403
	13IR	20	20	36	71	99	127
	44IR	10	15	19	32	44	54
	59IR	23	33	51	66	78	88
	88IR	41	60	95	154	206	252

Appendix 2: Contd.

Treatments	Plot No.	Time from start of infiltration 15mins	30mins	60mins	120mins	180mins	240mins
	15R	68	121	213	319	399	465
MB	47R	21	30	46	67	88	106
	55R	15	19	22	37	50	63
	87R	28	44	70	107	141	173
	15IR	50	104	202	322	427	528
	47IR	6	8	10	18	25	32
	55IR	8	12	18	30	41	52
	87IR	9	13	18	28	36	43
	18R	70	119	223	343	458	567
CP	43R	40	76	146	247	339	427
	57R	10	15	21	35	46	56
	83R	23	30	39	53	64	75
	18IR	98	158	291	421	545	662
	43IR	10	15	24	38	51	64
	57IR	7	13	20	28	35	40
	83IR	10	12	16	20	22	24

Appendix 2: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	11R	40	71	126	204	279	353
ZT	48R	18	26	41	68	91	113
	52R	34	54	94	149	192	232
	81R	59	98	172	264	352	438
	11IR	40	77	106	174	238	302
	48IR	49	77	109	174	235	296
	52IR	77	122	208	318	422	522
	81IR	25	36	49	94	139	182

Appendix 3: Cumulative Infiltration (mm). Just before the rainy season in 1979. (Row (R) and Interrow (IR)).

Treatments	Plot No.	15mins	30mins	60mins	120mins	180mins	240mins
		Time from start of infiltration					
	16R	164	296	497	856	1188	1514
HR	41R	61	88	139	210	272	326
	51R	69	115	175	288	297	503
	81R	46	67	94	139	177	213
	16IR	55	90	133	196	256	314
	41IR	38	63	111	180	237	290
	51IR	80	131	186	274	349	416
	81IR	30	51	80	147	206	257
	12R	47	74	112	173	222	265
BL	42R	65	102	164	206	243	273
	54R	107	210	239	400	553	701
	85R	27	40	56	75	88	100
	12IR	59	109	199	313	423	530
	42IR	28	40	60	102	139	169
	54IR	20	29	46	72	98	121
	85IR	18	34	54	88	115	135

Appendix 3: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	19R	14	20	29	42	54	66
DF	49R	24	28	35	45	53	61
	58R	19	33	53	86	116	146
	84R	24	36	47	69	89	108
	19IR	64	95	150	231	310	386
	49IR	24	31	40	50	58	66
	58IR	22	32	43	58	69	78
	84IR	14	18	24	32	38	44
	14R	135	210	327	485	640	790
DR	45R	68	104	151	213	270	312
	56R	54	76	103	161	213	262
	82R	50	73	106	157	198	224
	14IR	30	46	67	96	119	139
	45IR	28	38	62	79	94	114
	56IR	56	90	157	248	331	409
	82IR	19	26	36	53	66	76

Appendix 3: Contd.

Treatments	Plot No.	15mins	30mins	60mins	120mins	180mins	240mins
		Time from start of infiltration					
	13R	20	29	40	47	54	59
DF	44R	71	101	147	281	400	514
	59R	31	47	75	119	163	205
	88R	151	240	371	578	743	895
	13IR	20	29	38	52	60	68
	44IR	29	43	62	98	125	149
	59IR	21	29	40	62	80	96
	88IR	21	35	47	77	104	127
	17R	30	43	61	83	105	125
DI	46R	51	68	94	132	163	187
	53R	38	53	78	126	171	214
	89R	79	143	252	406	553	695
	17IR	123	204	296	401	507	604
	46IR	22	32	56	73	88	97
	53IR	173	331	521	926	1316	1699
	89IR	21	35	52	98	137	172

Appendix 3: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	15R	87	140	232	343	451	554
MB	47R	141	220	326	503	643	772
	55R	111	155	214	317	416	503
	87R	34	48	64	90	108	123
	15IR	25	33	50	65	80	93
	47IR	22	29	40	53	66	77
	55IR	78	129	195	299	398	495
	87IR	25	39	56	86	110	130
	18R	77	136	201	315	422	525
CP	43R	25	29	35	41	45	49
	57R	88	147	227	360	475	581
	83R	53	79	122	171	208	239
	18IR	34	54	77	116	152	186
	43IR	9	11	15	23	29	35
	57IR	66	92	104	117	126	134
	83IR	34	45	53	70	82	94

Appendix 3: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	11R	28	46	77	150	219	285
ZT	48R	21	33	47	79	108	134
	52R	69	102	171	266	358	448
	81R	66	96	136	201	256	307
	11IR	24	36	58	97	131	163
	48IR	22	40	60	106	148	175
	52IR	34	52	73	116	155	191
	81IR	125	203	328	528	682	821

Appendix 4: Cumulative Infiltration (mm). 1 week after planting in 1979 (interrow position)

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	16	86	133	193	254	308	358
HR	26	34	60	108	180	250	310
	32	14	26	43	74	102	126
	41	12	23	42	69	94	118
	51	51	88	149	233	317	400
	63	18	31	50	85	118	146
	75	44	74	141	247	341	423
	86	70	127	226	406	554	697
	12	23	37	57	93	121	144
BL	21	5	9	17	33	47	61
	36	13	21	33	57	76	91
	42	5	7	10	16	21	26
	54	14	23	38	60	79	96
	69	22	31	42	62	77	90
	73	12	19	36	64	92	116
	85	16	26	34	53	69	82

Appendix 4: Contd.

Treatments	Plot No.	Time from start of infiltration 15mins	30mins	60mins	120mins	180mins	240mins
	19	23	35	49	71	92	109
DF	22	3	5	8	13	16	19
	33	16	26	45	80	109	135
	49	5	10	18	28	36	45
	58	15	24	40	69	89	105
	65	8	11	15	20	24	28
	78	15	20	29	51	72	94
	84	6	8	11	16	21	24
	14	30	45	73	114	149	170
DR	23	5	9	17	31	144	55
	38	3	5	10	20	28	35
	45	38	56	88	121	149	176
	56	8	12	21	35	45	55
	62	5	8	14	25	34	43
	77	9	17	30	54	72	90
	82	6	9	13	22	30	37
	17	8	10	14	19	22	25
DI	24	16	27	50	92	125	155
	35	29	49	89	149	203	249
	46	5	7	11	18	23	28
	53	53	93	164	287	397	500
	67	9	18	23	42	54	66
	79	5	8	16	31	42	53
	89	53	99	173	293	387	468

Appendix 4: Contd.

Treatments	Plot No.	15mins	30mins	60mins	120mins	180mins	240mins
		Time from start of infiltration					
	13	18	33	52	93	125	153
DP	29	12	20	30	50	69	87
	31	4	7	10	19	26	33
	44	21	38	74	124	172	212
	59	39	72	124	219	301	375
	61	4	8	11	19	24	29
	71	5	9	17	30	41	49
	88	39	73	124	217	277	325
	15	9	13	19	30	39	47
MB	27	7	10	17	28	39	50
	34	3	6	9	20	30	39
	47	7	10	15	24	30	34
	55	29	50	83	119	148	172
	64	7	10	15	24	30	36
	76	6	10	18	30	40	48
	87	4	6	11	21	31	41
	18	10	14	20	30	38	46
CP	28	15	26	46	81	102	121
	37	23	42	60	110	148	183
	43	8	12	23	34	144	53
	57	27	45	79	135	185	229
	68	7	10	15	27	36	44
	74	6	8	13	23	33	41
	83	9	14	22	37	50	60

Appendix 4: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	11	40	67	108	180	252	322
ZT	25	10	17	32	64	93	122
	39	10	20	35	69	100	127
	48	25	43	74	133	183	232
	52	61	110	207	407	602	789
	66	21	36	61	117	170	216
	72	10	20	36	69	100	128
	81	24	39	85	141	191	239

Appendix 5: Cumulative Infiltration (mm) at 1 week after planting in 1979. (Row (R) and Interrow (IR)).

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	16R	95	170	299	492	647	785
HR	41R	65	106	192	362	520	670
	51R	98	163	284	482	659	819
	86R	64	109	197	324	448	568
	16IR	86	133	193	254	308	358
	41IR	12	23	42	69	94	118
	51IR	51	88	149	233	317	400
	86IR	70	127	226	406	554	697
	12R	8	11	21	35	46	56
BL	42R	35	60	101	159	201	240
	54R	36	61	100	164	226	283
	85R	28	49	90	164	232	291
	12IR	23	37	57	93	121	144
	42IR	5	7	10	16	21	26
	54IR	14	23	38	60	79	96
	85IR	16	26	34	53	69	82

Appendix 5: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	19R	14	22	33	49	63	75
DF	49R	10	13	18	25	30	35
	58R	8	12	19	37	52	66
	84R	6	11	17	32	45	54
	19IR	23	35	49	71	92	109
	49IR	5	10	18	28	36	45
	58IR	15	24	40	69	89	109
	84IR	6	8	11	16	21	24
	14R	20	27	41	57	72	86
DR	45R	23	41	69	98	126	151
	56R	21	32	48	77	103	126
	82R	25	38	65	112	159	204
	14IR	30	45	73	114	149	170
	45IR	38	56	88	121	149	176
	56IR	8	12	21	35	45	55
	82IR	6	9	13	22	30	37

Appendix 5: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	15R	17	21	28	34	39	44
MB	47R	13	21	32	49	62	72
	55R	20	26	38	58	74	90
	87R	4	6	14	30	44	57
	15IR	9	13	19	30	39	47
	47IR	7	10	15	24	30	34
	55IR	29	50	83	119	148	172
	87IR	4	6	11	21	31	41
	18R	11	17	25	38	49	59
CP	43R	18	30	50	86	116	143
	57R	15	23	33	56	76	91
	83R	22	32	48	75	99	122
	18IR	10	14	20	30	38	46
	43IR	8	12	23	34	44	53
	57IR	27	45	79	135	185	229
	83IR	9	14	22	37	50	60

Appendix 5: Contd.

Treatments	Plot No.	Time from start of infiltration					
		15mins	30mins	60mins	120mins	180mins	240mins
	11R	29	53	86	150	205	250
ZT	48R	15	26	49	89	124	157
	52R	33	55	107	198	287	372
	81R	55	96	165	275	374	463
	11IR	40	67	108	180	252	322
	48IR	25	43	74	133	183	232
	52IR	61	110	207	407	602	789
	81IR	24	39	85	141	191	239

Appendix 6: Cumulative Infiltration (mm). Zero tillage and conventional tillage comparison.

Treatments	Plot No.	Time from start of infiltration 15mins	30mins	60mins	120mins	180mins	240mins
(8 weeks after planting in 1978).							
ZT	ZT_1	47	88	154	257	234	405
	ZT_2	36	60	106	171	225	265
CT	CT_1	12	15	20	29	36	42
	CT_2	5	10	13	17	20	23
(1 week after planting in 1979)							
ZT	ZT_1	6	10	16	32	45	58
	ZT_2	6	10	16	29	40	51
CT	CT_1	1	2	3	6	8	10
	CT_2	2	3	4	7	9	11

Appendix 7: Cumulative Infiltration (mm): Continuous cultivation (at 4 weeks after planting in 1979) and Grass fallow comparison.

Treatments	Replicate No.	Time from start of infiltration 15mins	30mins	60mins	120mins	180mins	240mins
Continuous Cultivation	1	4	6	11	18	23	28
	2	2	3	5	9	11	13
	3	2	3	4	7	9	11
	4	3	5	11	17	21	25
	5	2	3	6	9	12	14
Grass Fallow	1	25	43	80	147	210	268
	2	20	36	68	133	189	241
	3	38	67	122	191	258	323
	4	41	76	144	249	347	441
	5	57	97	172	282	384	481