CHAPTER ONE INTRODUCTION

1.1 Introduction to the Study

An investigation on the infiltration characteristics of soils of various landuses, namely forest, rubber (7 and 20 year-old), oil palm (7 and 20 year-old) and bare soils (1 and 5 year-old) is the main purpose of this study. In addition, physical properties of the soils of each landuse, are determined to extricate effects on the infiltration characteristics of the soils.

The determination of infiltration rates are based on the use of drip-type rainfall simulator. The sites chosen in the study are situated in the Felda Gedangsa Resettlement Scheme and the Bukit Belata Forest Reserve, both located in the District of Hulu Selangor, in the State of Selangor , Malaysia.

1.2 Introduction to Infiltration

Infiltration is a process whereby moisture enters the surface stratum of the soils and moves downward towards the groundwater table, mainly through the action of molecular, capillary and gravitational forces (Chebotarev,1962). This water first replenishes the soil water deficiency and thereafter, any excess moves on downward and becomes groundwater. Almost all of the water stored in acquifers comes originally from precipitation. Rain water that infiltrates the soil seeps or percolates slowly downward through the ground to the underlying groundwater (Linsley, Kohler and Paulhus, 1950).

There is a maximum rate at which the soil in a given condition can absorb water; this upper limit is called the infiltration capacity of the soil. If rainfall intensity is less than this capacity, the infiltration rate will be equal to the rainfall rate. Whereas if the infiltration capacity exceeds the ability of the soil to absorb moisture, infiltration occurs at the capacity rate.

Infiltration rates are expressed in units depth per unit time, similar to rainfall intensity. They refer to the depth of water that would soak into the soil within a chosen time interval (Dunne and Leopold, 1978).

1.3 Significance of Infiltration

Measurements of infiltration rates form a vital part of many surveys involving irrigation developement or soil conservation. The results are normally used at the design stage along with other measurements (permeabilities, crop water demand, evaporation data, etc) for determining the most efficient method(s) of application of irrigation water, and attendant details such as furrow length and application rates. The results may also be used in runoff calculations (Landon,1984).

Soil surface is a filter that determines the path by which rainwater reaches a stream channel. Water that does not infiltrate run quickly over the ground surface, whereas water entering the soil move much more slowly underground. The soils, therefore, play a major part in determining the volume of storm runoff, its timing and its peak rate of flow.

These are all of importance to the hydrologist interested in the planning of culverts, bridges and other small structures. In running over the ground surface, water is capable of eroding top soil and important organic residues on the land surface.

The soil conservationist is concerned with either inducing this overland flow to infiltrate or conducting it safely away from fields or farm structures. Geomorphologists are also concerned with the magnitude, frequency and spatial characteristics of infiltration relative to rainfall intensity, because overland flow is an important agent of landscape development. The water that infiltrates the soil controls to some extent the water available for evapotranspiration. This supply of soil moisture is the effective rainfall as far as plants are concerned.

Ecologists and agriculturists , therefore, need to refine their understanding of the relationships between plants and their water supply, especially in term of infiltration and runoff. Infiltration water that is not returned to the atmosphere by evapotranspiration reaches the groundwater system and supplies streamflow. Increasing the amount of infiltration may augment streamflow during dry weather - which is important for water supply, waste dilution and other uses.

Infiltration is a basic element of the hydrologic cycle (Figure 1.1) and is of great hydrologic and practical importance. According to Chebotarev (1962), the hydrologic importance of infiltration is due to the fact that water, infiltrating into the soil, becomes one of the main sources of groundwater supply.

Johnston(1980), stated that in order to understand the response of the catchment area subjected to rainfall events (which is very complex), it is necessary to investigate the individual components of the hydrologic cycle, namely rainfall, infiltration,runoff etc to enable prediction to be made of the overall behaviour of the catchment.

The role played by infiltration in the distribution of precipitation input is an exceedingly important one. It can affect as stated by Viesmann (1977) not only the timing, but also the distribution and magnitude of surface runoff. For this reason, reliable estimates of infiltration must be incorporated in any watershed model. He also stated that infiltrated water is subdivided into interflow groundwater and soil moisture, and it is also pointed out that groundwater is replenished by the infiltration process through the soil surface, while streamflows are sustained by groundwater resources.

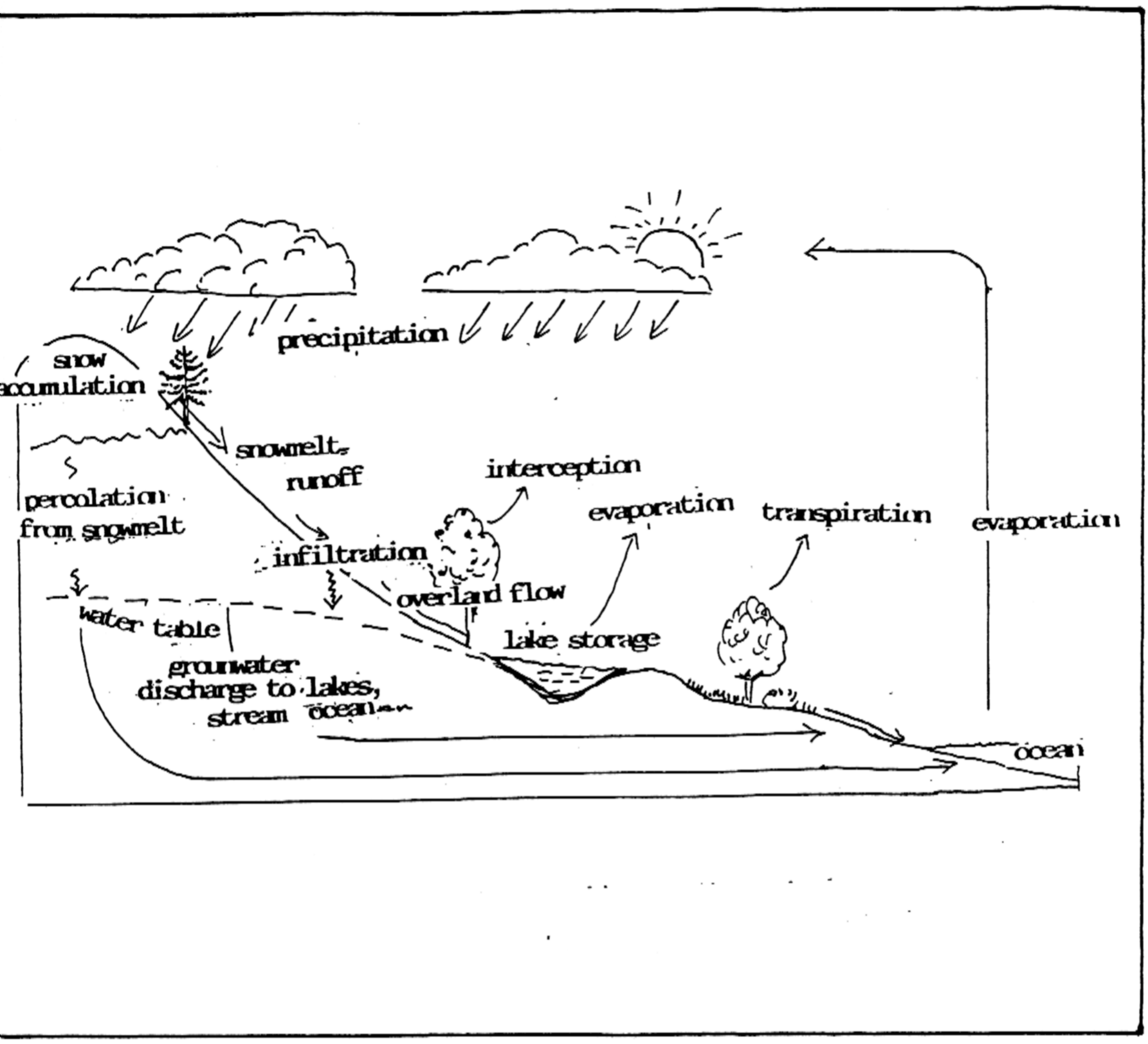

Figure 1.1 Schematic Diagram of the Hydrologic Cycle

Source: Leopold and Dunne, 1978

Miller (1977), added that soil moisture, formed in the process of infiltration, goes into transpiration, while Schwab et.al (1966), said infiltration is the sole source of soil moisture to sustain the growth of vegetation and to sustain groundwater which supplys wells, springs and streams. Through infiltration, the land surface divides rainfall into overland flow, soil moisture and groundwater.

1.4 Statement of Problem

Infiltration is a basic element of the hydrologic cycle and is of great hydrological and practical importance. It is very important to have a clear understanding of the inter-relationships between the elements of the cycle. Considering the equation of water balance, it is clear that by affecting or changing any one of the variables, would consequently alter the others (Figure 1.2). The equation for water balance (Dunne and Leopold,op.cit), can be written as follows:

$$P = I+AET+OF+SM+GWS+GWR \quad \ldots\ldots\ldots \quad 1.1$$ where,

P	=	precipitation
I	=	infiltration
AET	=	actual evapotranspiration
OF	=	overland flow
SM	=	change in soil moisture
GWS	=	change in groundwater storage
GWR	=	groundwater runoff

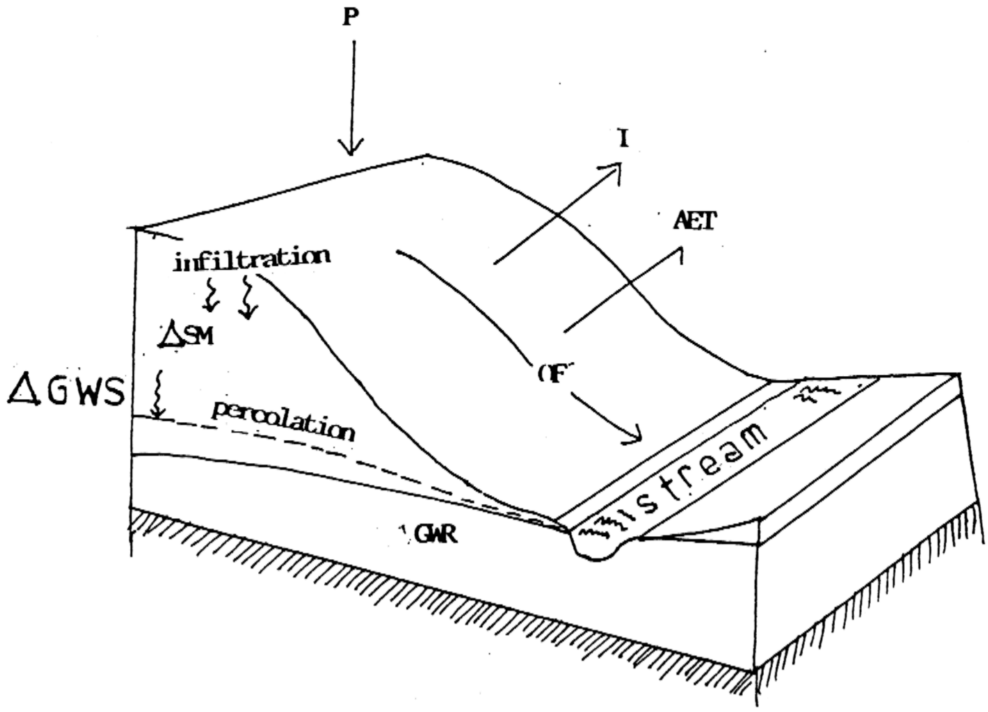

Figure 1.2 Component of a Water Balance on a Hillside or a Small Catchment

Source: Leopold and Dunne, 1978

It is fairly common to see an excess in overland flow, in the form of surface runoff in areas of bare soils. This excess in surface runoff is best explained with reference to the hydrological changes of the area.

With the prolonged exposure to the action of splashing raindrops, which generates total kinetic energy of 960,000 erg/cm/event (Mosley,1982), soil compaction and loss of organic matter content in inevitable. Mc Isaac (1990), reported that rainfall energy of 395 Kg/ha-mm to 640 Kg/ha-mm are often experienced in Nigeria. This energy would in turn greatly affect the physical properties of the soil and consequently reduces the ability of soil to infiltrate water, thus enhancing mass production of surface runoff.

Under young plantations such as those involving the cultivation of rubber or oil palm, the physical properties of the soils have partly improved to some extent due to better management practices and newly established biotic-abiotic inter-relationships, which result in soils of better physical properties. With better permeability and a fairly good structure, the soil can be expected to possess the ability to reduce runoff production, while at the same time, increasing its ability to infiltrate water.

In an old plantation, especially one that has long been abandoned, a more fully developed inter-relationship between the biotic-abiotic factors has been achieved. The soils beneath it are more likely to resemble those found in the mature forest, in term of their physical properties (data on soil physical properties of soils of various landuses are presented in Chapter 3).

In both types of vegetation, (old plantation of rubber and oil palm), it seems that "Hortonian overland flow" is almost absent, suggesting that the infiltration process has proceeded efficiently into the soil.

The relationship between the types of vegetation or landuses and infiltration rates has been investigated by many researchers in the field of hydrology. Physical properties of soils too, have significant roles in influencing the rate of infiltration, as found by many soil scientists and conservationists.

The problems addressed in this study are in some ways related to changes of soil physical properties, and the impact of these changes on infiltration rates of soils of certain landuses.

1.5 Aim of the Study

The aims of the study are:

a. To determine the infiltration rates of water into the soil surface of various landuses. The types of landuses taken into consideration are:

1. Primary forest
2. Rubber - 7 and 20 year-old
3. Oil palm - 7 and 20 year-old
4. Bare soil -
    i. 1 year after clearing of old rubber
    ii. 5 year after land clearing in preparation for construction

b. To examine the relationships between the rates of infiltration and the physical properties of these soils.

c. To evaluate comparatively and quantitatively, the significance of soils under different landuses in terms of water infiltration and their contribution to groundwater storage.

d. To examine factors most likely affecting the infiltration rates.

1.6 Scope and Limit of the Study

The study focusses on the comparative ability of soils of various landuses in infiltrating water based on simulated rainfall, and to established the relationship, between the rate of infiltration and some physical properties of soils.

The data obtained throughout this study is wholly dependant on the type of infiltrometer used, namely the drip-type rainfall simulator. It has been established by many authors (Ward,1967), that there exist a wide variability of infiltration rates both spatially and temporally. It is therefore necessary to note here that this study does not aim to take into account all the factors which are most likely to affect the infiltration rates. Instead, this study limits its scope to several chosen physical properties of soils which will be related to the measured infiltration rates.

Limitations are necessitated by the problems which cropped up during field work such as limited financial support, inadequate manpower, time constraint and the remote location of the study sites. This study does not take into consideration the actual volume of water being infiltrated. By merely substracting the rate of runoff from rainfall intensity to justify the infiltration rates, the measurements clearly neglect the amount of water losses due to evaporation on the soil surface (Baharuddin,1992; Landon,1984).

1.7 The Process of Infiltration

Close examination of a lump of soil or the sides of a pit dug through a soil profile, reveals that soil consists of millions of particles of sand, silt and clay, separated by channels of different sizes (Figure 1.3). These channels include shrinkage cracks, wormholes, root holes, space between

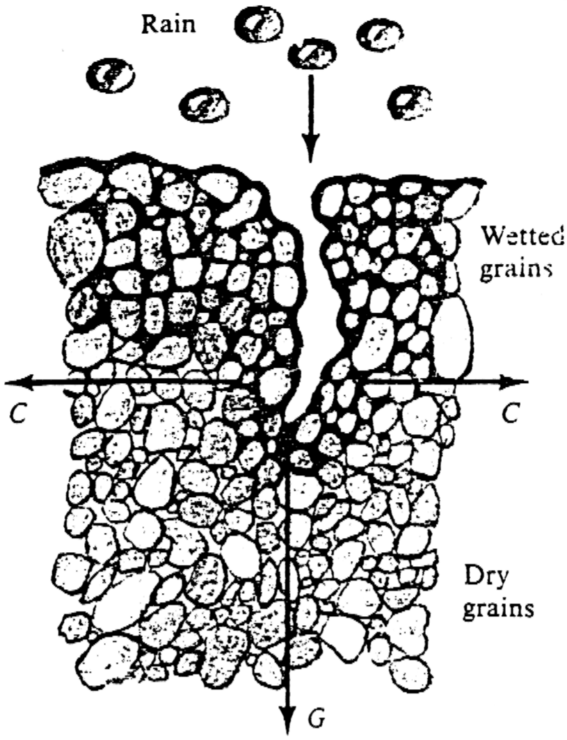

Diagram of the upper layer of a soil being wetted by falling rain. There is large variation in the size of intergrain pores; water is held in the pores by capillary forces; the large wormhole is not completely filled because capillary attraction is greatest in small openings where the radius of curvature of the meniscus is small. The water is subject to a downward gravitational force (*G*) and to capillary forces (*C*) drawing it into the narrower pores.

Figure 1.3 Diagram of the Upper Layer of a Soil

Source: Strahler, 1975

lumps or "crumbs" of soil and very fine spaces between the individual particle themselves.

Such cracks, holes and fine spaces are called soil pores. When rainfall reaches the ground surface, some or all of it enters soil pores. It is drawn into soil by the force of gravity and capillary attraction. The rate of entry of water by free gravity flow is limited by the diameters of the pores. As water moves along such pores, it is subject to flow resistance, which increases as the diameter of the pores decreases.

Under the influence of gravity, water moves vertically downward through the soil profile. On the other hand, capillary forces may move water vertically up or down or with a horizontal component. They act to draw water into the narrower pores, just as capillary forces drawing water up a narrow glass tube are greater than those in a wide tube.

Although such forces are strongest in soils with very fine pores, the pores may be so small that there is considerable resistance to flow through them. In large pores, such as wormholes or root holes, capillary forces are negligible and water moves downward under free gravity drainage. While flowing down through these passages, water is subject to lateral capillary forces, which draw it into the finer inter-granular spaces leading off from the larger channel.

Infiltration, therefore, involves three interdependent processes; entry into the soil surface, storage within the soil and transmission through the soil. Limitation in any of these processes can reduce the infiltration rates. It is important to realize that infiltration and the sub surface storage and movement of soil moisture are closely interrelated.

1.8 Factors Controlling Infiltration

Many factors influence the shape of the infiltration capacity curve, but the most important variables are rainfall characteristics, soil properties, vegetation and landuses.

1.8.1 Rainfall Intensity

An increase in rainfall capacity is normally accompanied by production of an increased raindrop size and consequently in an increase in their compacting force as the drops strike the ground surface. Long, intense rainfall packs down the loose soil surface, disperse fine soil particles and causes them to plug soil pores.

Rainstorms of long duration fill up the storage potential of the soil and cause clay to swell or may even saturate the soil completely, resulting in the reduction of infiltration rates (Ward,1967).

1.8.2 Vegetation Cover

Vegetation cover and landuses are very important in controlling infiltration. Vegetation and litter protect the soil from packing through raindrops and provide organic matter for binding soil particles together in open aggregates. Soil fauna that live on the organic matter assist this process by churning together the mineral particles and the organic material. In particular, the stripping of forests and their replacement by crops that do not cover the ground efficiently, result in low organic content of the soil which consequently often lowers the infiltration capacity drastically.

A vegetation cover tends to increase infiltration in contrast with an area of bare soil (Ward,op.cit), not only by retarding surface flow, thus allowing more time for water to enter the soil, but also by shielding the soil surface from the direct impact of raindrops, thereby reducing surface compaction.

The most extreme reduction in infiltration capacity of course involves the replacement of vegetation by an ashpalt or concrete cover in urban areas.

Complex root systems increase the permeability of the surface layers of the soil, encouraging more rapid passage of infiltrating water. In the case of woodlands particularly, the presence of a layer of ground litter normally has a pronounced effect on infiltration. Even a comparatively shallow layer of ground litter will encourage high rates of infiltration by protecting the soil surface from the direct impact of raindrops or throughfall raindrops, and by filtering the water trickling into it, so that soil pores in the surface layers are less likely to become clogged with fine dust and silt particles.

1.8.3 Slope

It might be expected that the slope of the ground surface would indirectly influence the infiltration rate. On steep slopes, water moves rapidly over the surface, allowing little time for infiltration, whereas on gentle slopes of flat surfaces, water either moves slowly or is ponded back, thereby encouraging higher total of infiltration (Ward,op.cit).

1.8.4 Soil Moisture Content

Soil moisture content tends to affect infiltration rates in three ways. Firstly, as moisture content increases, more of the available pore spaces in the soil become filled, thus reducing the capacity of the soil for further infiltrating water.

Secondly, when rain wets the surface of a dry soil, strong capillary forces are created which tend to pull water into the soil at rates which are much higher than those resulting from gravity alone.

Thirdly, soil moisture content affects infiltration indirectly through such factors as collodial swelling and the consequent reduction of infiltration as the soil becomes wetter and the pore spaces are reduced (Linsley,Kohler and Paulhus,1949).

1.8.5 Soil and the Biotic Factor

Starr (1990), stated that infiltration of water into soil is controlled by a complex set of soil and biotic factors. Soil factors that affect the rate of infiltration include pore size distribution, bulk density, structure and topography. Gotway and Cressie (1990), noted that in a given location in the field, the ability of water to infiltrate soil depends on existing soil-water distribution, the depth of the soil surface and the rate of water application on the soil surface.

Smith and Levy and Shainberg (1990), noted that crust formation due to water-droplet energy acting on the land surface also caused a reduction in the infiltration rate.

1.9 Infiltration Behaviour

Infiltration general statement means the downward entry of water into the soil profile. The infiltration characteristics of the soil is one of the dominant variables influencing irrigation. The infiltration rate, or the rate at which water can enter the soil under specific conditions; and the cumulative infiltration, or the total quantity of water that enters the soil in a given time, are the two parameters more commonly used in evaluating the infiltration characteristics of soil.

The infiltration rate decreases during irrigation. The rate of decrease is rapid initially and then tends to appproach a constant value (Figure 1.4(a), Figure 1.4(b) and Figure 1.4(c)).

The process of downward vertical infiltration into the soil is due to the combined influence of gravity gradients and suction forces. Among the factors that affect infiltration characteristics are the physical and chemical properties of soils, vegetative cover, duration of irrigation or rainfall and initial moisture content (Parr and Bertrand,1969).

The rate of water entry into the soil fluctuates widely between soil types, depending on soil moisture level and management practices. Adequate determination of the infiltration characteristics of a soil is by far the biggest stumbling block in accurately describing or predicting the infiltration process.

Theoretical infiltration formulae are of little use because they inadequately describe the conditions of the soil surface that tend to dominate the infiltration process during surface irrigation. These surface conditions often change

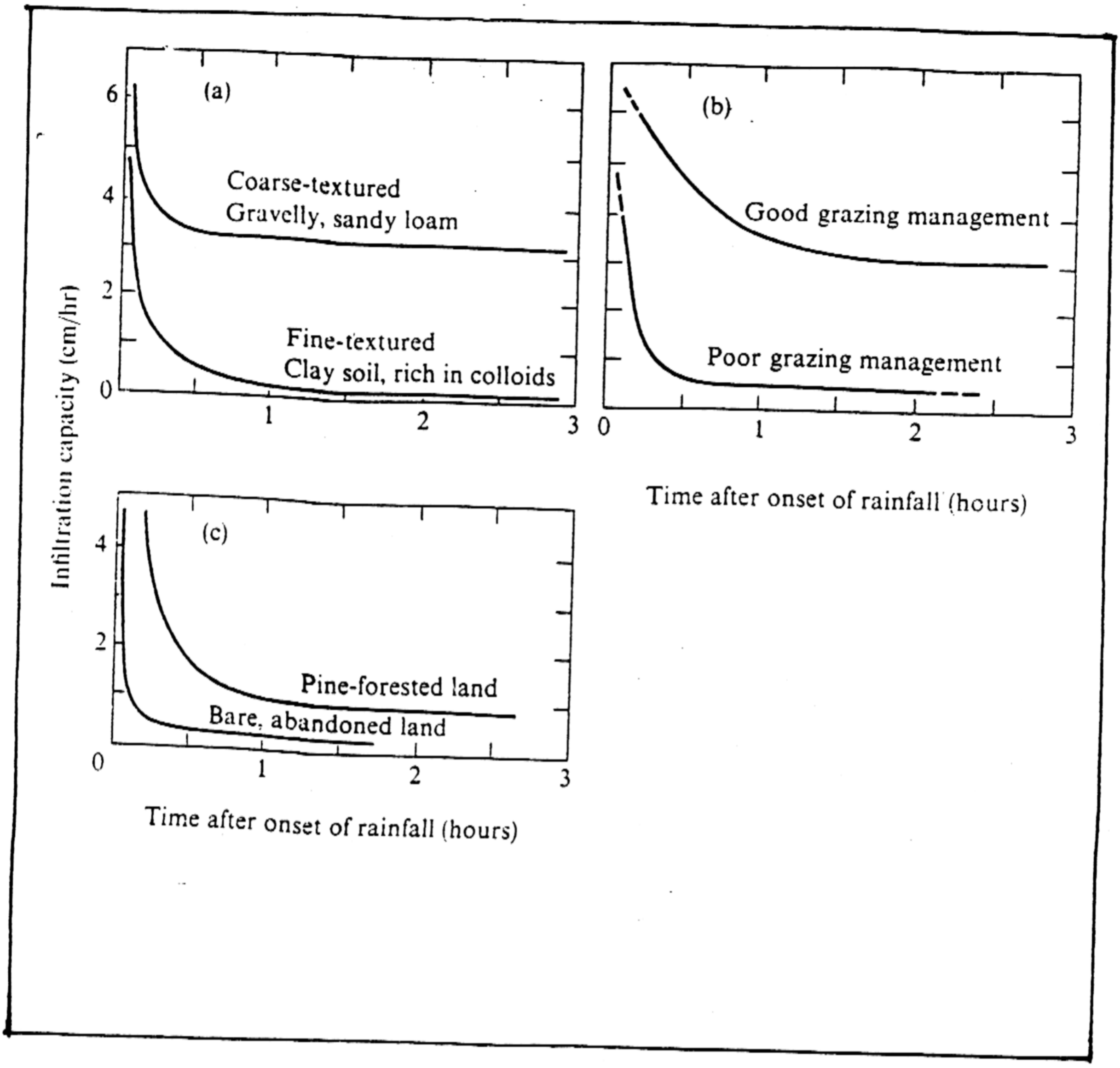

Figure 1.4 Infiltration Capacity Curves for Soils of a) Different texture b) Vegetative cover and c) Landuse practice

Source: Strahler, 1975

drastically from irrigation to irrigation as well as from time to time and place to place.

The spatial and temporal variations of infiltration characteristics are well known by all irrigators. Thus, empirical methods are most often used in the field as a guide while practical judgement still seems to be the best rule of thumb by all irrigators.

Horton (1940) stated that the reduction in infiltration rates with time after the initiation of infiltration are largely controlled by factors operating at the soil surface. They include swelling of soil colloids and closing of small cracks which progressively seal the soil surface. He also assumed that air entrapment and incomplete saturation of the soil are responsible for the steady state infiltration values which are often smaller than the saturated hydraulic permeability of the soil.

Philips (1957), noted that when water is first ponded on a dry soil, the rate of infiltration is comparatively rapid but decreases with time to an asymptotic or steady state which is a function of the hydraulic conductivity of the soil.

Gardner and Widtsoe (quoted by Gavin,1984), noted that the rate at which water moves through the soil surface during ponded infiltration is initially quite large and decreases with time, finally approaching some constant, non zero limiting value. This final condition is usually called steady-stated infiltration.

Hilel (1971), stated that the decrease of infiltration rate with time is originally attributed either to a gradually decreasing hydraulic conductivity of the soil (brought about by phenomena such as compaction of the surface layer, inwashing and accumulation of colloids, or breakdown of structure) or to increasing compression of air ahead of the wetting front. He also found that, within the limits of accuracy of their results, the infiltration rate is directly proportional to the potential gradient in the transmission zone and that the constant of proportionality did not change with time. He concluded that the asymptotically approach limit of the infiltration rate is equal to the hydraulic conductivity in the transmission zone, which is assumed must be the constant of proportionality between the infiltration rate and the total potential gradient.

Erie (1962), suggested that surface soil conditions, internal characteristics of the soil mass, soil moisture content, hydrostatic head, time of the year, temperature of soil and water and duration of application of water are the factors determining infiltration rates.

Agarwal et.al (1974), noted that as the sand content decreases and silt plus clay content increases, infiltration rates decrease. The effect of silt and clay is partially additive. Greater dispersion of the soil due to disruptive action of water, or slaking of aggregates seem to reduce the infiltration rates.

1.10 Conclusion

Studies on infiltration characteristics have been conducted by many researchers because of its importances in the hydrological process and the fact that it is a basic component of the hydrologic cycle. Therefore, knowing how the process takes place is very important, especially for hydrologists, agriculturists, geomorphologists, soil conservationists etc. Infiltration rates are controlled by many factors, of which the most important are the soil's physical and chemical properties, vegetation/landuses and duration of rainfall.

In this study, the physical properties of soil would be examined to determine their influence on infiltration characteristics of soil of various landuses. The results could hopefully be applicable to other types of landuses of the same topography and geographical conditions.