EFFECTS OF IRRIGATION WATER ON INFILTRATION RATE AND SATURATED HYDRAULIC CONDUCTIVITY IN ONION FIELDS; A CASE STUDY OF RUAHA MBUYUNI IRRIGATION SCHEME, IRINGA-TANZANIA.

BY

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ABSTRACT

A study was conducted at Ruaha Mbuyuni farmers' managed irrigation scheme in Iringa region to assess the effect of irrigation water on infiltration rate and hydraulic conductivity and corresponding crop (onion) performance. The study involved assessment of water quality and soil properties in relation to infiltration rate and hydraulic conductivity problems, crop (onion) water requirement at different stages and its performance under different soil types.

The results indicate that water from Lukosi river was low salinity and low sodium water. Chemically, this water have slight effect on infiltration rate and hydraulic conductivity. The concentration of suspended sediments were high where about 25.54 t/ha – 42.15 t/ha of sediment were deposited in the fields over the season. This resulted into sealing and clogging of soil pores hence reducing infiltration and hydraulic conductivity.

The soil texture in the scheme ranged between sandy loam to heavy cracking clays and they are neither saline nor sodic. The soils are slightly alkaline with pH ranging from 7.4 to 7.8. The organic matter content were generally very low ranging from 1.13% to 3.05%. Due to the low organic matter content, the soils had poor structural stability and hence easily dispersed when water is applied. Dispersion effects resulted into reduction of infiltration rate and hydraulic conductivity.

Soil basic infiltration rate ranged from 3.75 mm/h to 52.5 mm/h while saturated hydraulic conductivity ranged from 0.03123 m/d to 0.4236 m/d for clay and sandy loam soils respectively. Basic infiltration rate decreased for an average of 50% while hydraulic conductivity decreased for an average of 52% - 58% over the season in all soils. High deposition of sediment and high dispersion effect of irrigation water on the soils were the main reasons for decreased infiltration rate and hydraulic conductivity over the season.

The crop (onion) performance was generally low in all locations compared to the normal yield of 35-45 t/ha and 8-10 Kg/m^3 for yield per unit area and specific yield respectively. Medium textured soils which had moderate infiltration and hydraulic conductivity had better yield of 31.5t/ha while coarse texture soils with rapid infiltration showed very poor yield of 13.3t/ha. Clay soils had better specific yield of $5Kg/m^3$ while sand soils showed low specific yield of $3Kg/m^3$. Low infiltration rates and hydraulic conductivity resulted in water logging problems in the heavy textured soils. Rapid infiltration in the course textured soils caused water stress to crops and drain of plant nutrient below root zone which contributed to low yields.

It was observed that the water application depended on the available irrigation water and not on crop water requirement. Relative water supply (RWS) ranged from 0.92 to 5.36 per crop development stage. Irrigation intervals which were far spaced was the main reason for excess water application during irrigation.

It was concluded that water from Lukosi river has good quality and can be used for irrigation in all types of soils with slight reduction of infiltration rate and hydraulic conductivity.

DECLARATION

I, AWARIYWA MOSES NNKO, do hereby declare to the Senate of Sokoine University of Agriculture that the work presented here is my own original work and has not been submitted for a degree award in any other University.

Signature.........................

Date....14.7.2000...........

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DEDICATION

To my daughter **NEEMA-VICTORIA** and my sons **GIFT-MOSES** and **FRANK-KAJETAN**

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ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of variance
Ca^{2+}	Calcium
CEC	Cation exchange capacity
CWR	Crop water requirement
CV	Coefficient of variation
DMRT	Duncan's Multiple Range Test
ECe	Soil electrical conductivity
ECw	Water electrical conductivity
ESP	Exchangeable sodium percentage
ET	Evapotranspiration
ETc	Crop evapotranspiration
ETo	Reference evapotranspiration
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit (German Agency for Technical Co-operation)
FAO	Food and Agriculture Organization of United Nations
INT	Irrigation interval
IW	Irrigation water
IRSIS	Irrigation Scheduling Information System
K^{+}	Potassium
kc	Crop coefficient
Mg^{2+}	Magnesium
MS	Mean squares
Na^{+}	Sodium

ns	Not significant
pH	Soil reaction
R	Correlation coefficient
R^2	Coefficient of determination
RAM	Readily available water
RE	Effective rainfall
RWS	Relative water supply
s	Significant
SAR	Sodium adsorption ratio
se	Standard error
SS	Sum of squares
TIP	Traditional irrigation improvement programme
USDA	United State Department of Agriculture

CHAPTER ONE

1. INTRODUCTION

Irrigated agriculture depends on an adequate water supply of usable quality. The usable quality of the irrigation water depends among other things the specific conditions under which it will be used. But the knowledge of the effects which water may cause on soil and crop performance is one of the pre-requisites for proper irrigation water management. Soil infiltration and hydraulic conductivity problems are among the soil properties which are affected by the quality of the applied water and hence some management may be required before applying this water for sustainable agriculture (Eisenhauer *et. al.,*1992).

Infiltration refer to the process of water entry in soil while hydraulic conductivity is the property of soil which governs the movement of water and solutes in the soil. The knowledge of water infiltration and its movement in the soil is one of the important aspects of irrigation water management. This is more important in surface irrigation systems where its effects are more adverse on soil and crop production (Trout, 1991). Surface irrigation is unique among irrigation systems in that infiltration, not the system hardware, essentially determines the system's application rate and strongly influences water distribution. Selection of the most efficient stream size, length of field and set time is dependent on knowledge of infiltration rate of the soil (Foroud *et. al.,*1996). Thus, it is especially important to be able to predict infiltration rates, water movements in the soil and their effect on the availability of water to the crop and corresponding effect on crop yield for designing and operating surface irrigation systems. Unfortunately, infiltration characteristics with surface irrigation may vary considerably within a season (Eisenhauer *et. al.*, 1992). Although farmers may not be directly aware of the effect of infiltration variability on water application, they are aware that the crops on their fields show sign of water stress. Their response is to over-irrigate by extending the application time or increasing the volume of water in their fields. Over-irrigation causes runoff, deep percolation losses and in some cases water logging associated problems such as poor aeration and crop diseases.

About half of the irrigate land in the world is found in arid and semi-arid subtropical zones where more than 90% of this irrigated land use surface irrigation methods (Kay, 1986). According to Abu-Sharar and Salameh (1995) arid and semi-arid soils are generally characterized by reduction in infiltration rate and hydraulic conductivity when employing low salinity / sodicity water. Such reduction are further exacerbated when irrigating with turbid water. These soils are also characterized by poor aggregate stability and crust formation at the surface. Deterioration in soil structure may take place even when irrigating non-sodic soils with waters of low Sodium adsorption ratio (SAR) and salinity (Heil *et. al.*,1997). Because of crust formation and clogging of conducting pores, the resultant infiltration rate tends to decline to a minimum value irrespective of the initial soil moisture content.

Irrigation water affects the hydraulic conductivity of soil and hence movement of water in the soil. Soil pores clogging due to dispersed soil particles caused by low saline/sodic water, destabilization of soil structure due to high sodium contents and filling up of pores by sediments reduces the movement of water in the soil. The low infiltration rate and movement of water in the soil results in poor crop yield due to water stress (Eisenhauer *et. al.*, 1992).

In Tanzania, semi-arid zone occupies about one third of the total area and it extends Northeast and Southwest across the central part of the country (Hatibu *et. al.,* 1995). In semi-arid areas rainfall is inadequate and very erratic (Linsley *et. al.,* 1988; Hatibu *et. al.*, 1997). The agricultural production in this areas is hampered by this low and erratic rainfall. There have been continuous effort of introducing irrigation in these areas where water sources from rivers, ground water and surface reservoirs are used. Ruaha Mbuyuni lies in the semi-arid zone which extends from central part of the country. This area is in Mahenge division which is the driest area of Iringa region and agricultural mainly depend on irrigation (TIP, 1991). Farmers initiated surface irrigation which has been practised in this area for about 40 years. Due to the low and unreliable rainfall in this area, crop production depends on irrigation throughout the year where paddy, maize and beans are grown as food crops and horticultural crops mainly as cash crop.

Farmers from Ruaha Mbuyuni has experienced a continuous reduction of onion in their fields however, the cause is so far unknown. Water ponding for long time after irrigation in the onion fields, high silt deposition in the weir, intake canals and surface crusting has been observed in some of the onion fields especially during the period of heavy floods due to high sediment contents from the water. However no study has been carried on the quality of this water and its effect on the infiltration and hydraulic conductivity and observed onion yield reduction. Onion is sensitive to water deficit with yield response factor (ratio of relative yield decrease to relative evapotransipiration deficit) (ky) of 1.1. Therefore a reduction in water availability will result in poor crop development and hence reduced yield (Doorenbous and Kassam, 1979). This study therefore aimed to assess the effect of irrigation water quality on infiltration rate and hydraulic conductivity and resulting onion yield and suggest management practices required for sustainable crop production.

1.2 Objectives

The main objective of this study was to evaluate the effect of irrigation water on infiltration rate and hydraulic conductivity in onion fields. A case study of Ruaha Mbuyuni irrigation scheme.

Specific objectives

i) To assess the physical and chemical properties of the soils of irrigated area.

ii) To assess the irrigation water properties related to infiltration and hydraulic conductivity problems.

iii) To evaluate infiltration rate and hydraulic conductivity of the soil at different stages of the crop development

iv) To assess the onion crop water requirement and performance for one season.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

This chapter present the survey of literature related to the study which includes irrigation water quality, infiltration and hydraulic conductivity and crop (onion) requirements which includes climate, soil and water requirement and their effects on yield.

2.2 Irrigation water quality

Irrigation water quality is evaluated to know the problems the water may cause to soil, crop and subsequently to animals and management practices that might be required to overcome these problems (Ayers and Westcot, 1976). There have been a number of different water quality guidelines related to irrigated agriculture. Each has been useful but none has been entirely satisfactory because of the wide variability in the field conditions. According to Rhoades, (1972) it is impossible to set precise standards of wide applicability for irrigation water quality. The suitability of an irrigation water needs to be evaluated on the basis of specific conditions under which it will be used including crop being grown, soil properties, irrigation management, cultural practices and climatic conditions. Because of this, the prevailing procedure for evaluating irrigation water quality must be taken as guidelines only, to be used in conjunction with a knowledge of local condition of use.

Salinity, hydrological and toxicity are the most common soil problems associated with irrigation water quality and are used as the basis to evaluate water quality. This study is based on the salinity and hydrological (infiltration and hydraulic conductivity) problems associated with irrigation water quality.

2.2.1 Salinity

Irrigation water from rivers, wells and other sources usually contains dissolved salts. When this water is applied to the field more salts are added to the soil than taken by plants (Rhoades, 1972). If the excess salts in the soil is not removed by leaching, flooding or any other means, saline soils tend to develop. Saline soils tend to coincide with areas where evaporation exceeds precipitation and where there is no lengthy rainy season. In these areas, irrigation is required for crop growth although it may itself induce salinisation if drainage is not adequate. Seasonal variation of weather events can affect surface water salinity. For example streams originating in mountain areas usually have low salt content but high amounts of suspended sediments during rain season because they consist mostly of surface runoff. Later as surface runoff declines ground water based flows to these streams increase their salt content. Surface water salinity is usually lowest near the stream source. A highly mineralized ground water enter a river or stream and/or it is repeatedly used for irrigation, the water becomes more and more saline (Kruse *et, al.*,1999).

Salinity problems related to water quality occur if the total concentration of salts is high enough to accumulate in the crop root zone to the extent of affecting crop growth and eventually yields (Joshi *et. al.*, 1990). The primary effect of salinity is to restrict the availability of soil water to the plant. The presence of salt in soil water increases the energy required by plant to remove water from the soil (Smedema and

Rycroft, 1983; James, 1988). Plants absorb more water from salt-free than from salty soils at the same moisture content because salts have an affinity for water (Wild, 1988). Salinity affects negatively the plant physiology particularly in cell enlargement, cell division, the production of nuclei acid which causes reduction in plant mass and crop yield. All plants do not respond to salinity in a similar manner; some crops can produce acceptable yields at much higher soil salinity than others. Barley for example is highly tolerant to salinity with yield reduction to be expected when irrigation water salinity (ECw) is greater than 5.3 dS/m. On other hand onion is highly sensitive with yield reduction is expected when ECw is greater than 0.8 dS/m and at ECw of 5.0 dS/m the onion yield is reduced to zero (Smedema and Rycroft, 1983; Ayers and Westcot, 1989). A study conducted by Tarimo (1995) on Soils of Mtibwa Sugar Estate, Morogoro to investigate causes for observed decline in sugar production showed that salinity was one of the main problems responsible for the declining sugar production.

High concentrations of salts in the soil changes soil physical properties such as infiltration rate, hydraulic conductivity, diffusivity and sorptivity but increases water retention characteristics (Lima *et. al.,* 1990). A high concentration of salts in the soil moisture compresses the soil colloid layers while the layer expands when the salt concentration decreases. Thus soils are more liable to dispersion when the salt concentration of the soil solution is low than when it is high. When the adsorption cations are mainly divalent especially calcium, the layer is compressed. The layer expands when there is large proportion of monovalent cations especially sodium on the adsorption complex (Rhoades, 1985). Soil particles dispersion leads to low hydraulic conductivity, blockage of pores, and unfavorable consistency. In addition the soil becomes hard when dry and stick when moist and formation of surface crusts which inhibits infiltration and may become water logged due to poor drainage properties (Ben-Hur *et. al.*, 1985; Smedema and Rycroft, 1983).

2.2.2 Infiltration rate

Water intake rate determines the length of time required to wet a soil and to some degree the distribution of moisture within the soil profile. The intake of water is influenced by a number of factors other than texture and profile development, (Donsen and Westcot, 1988), such as tillage operations, or traffic over moist soil soon after irrigation or rainfall. The entry of water at the soil surface is measured as the infiltration rate. The maximum rate at which water can be absorbed by the soil (infiltration capacity) is the factor that determines the rate at which water can be applied to the soil surface without runoff (Masinja, 1995). Water infiltration problem is primarily one related to the easiness with which water enters and moves through the upper few centimeters of soil and is linked to the structural stability of the soil and low calcium content relative to that of sodium in the soil. Infiltration rate of 3mm/hr or less is considered low while a rate above 12mm/hr is relatively high (Ayers and Westcot,1989; James,1988; Landon, 1991).

The ideal situation is to have the infiltrated depth equal over all portions of the field (Walker and Skogerboe, 1987). The lack of knowledge about the infiltration capacity of the soil has in most times undermined the efficiency of many systems (James, 1988). The end result for this has been either under irrigation and/or over irrigation.

If the field is under irrigated, then the crops would receive less water and this would have a direct effect on the crop yields. Over irrigating results in surface runoff and deep percolation. The consequence of high deep percolation and tail water runoff may lead to erosion of top soil, leaching down of crop nutrients, high water table, hence salinity and water logging problems (James, 1988).

Several methods are used to measure the infiltration rate in the field. These methods include ring infiltrometer (single and double rings), sprinkler infiltrometer and volume-balance methods (border and furrow). For double ring infiltrometer method, the following relation is used to determine infiltration rate of the soil (James, 1988):

$$i = at^b \tag{1}$$

where;

i = infiltration rate of the soil (mm/hr)

t = time since infiltration began (hr)

a and b = constants for a given soil intake families.

Cumulative infiltration depth and time is obtained by integrating equation (1) with respect to time to give the following relationship (James, 1988).:

$$I = ct^d \tag{2}$$

Where;

I = cumulative infiltration depth (mm), c and d are constants.

$c = a/(b+1)$

$d = b + 1$

Cumulative infiltration depth against time is normally plotted on log -log paper to form a straight line represented by the following equation:

$$\text{Log } I = \log c + d \log t \tag{3}$$

The constants c and d are obtained from the cumulative line where c is equal to the intercept when $t = 1$ while d is the slope of the line.

2.2.3 Hydraulic conductivity

The rate of water flow and chemical movement in soils is defined by the soil hydraulic properties such as water retention and hydraulic conductivity functions (Zhang, and Kravchenko, 1998). Hydraulic conductivity of the soil is affected by those factors related to the nature of soil, such as soil structure, soil texture and soil water content (Ghildyal and Tripathi, 1987). The hydraulic conductivity of a field may vary considerably across an area as well as in depth due to variations in soil texture and soil structure (Campell, 1985).

Hydraulic conductivity mainly depends on the size, distribution and tortuosity (i.e. the geometry) of the conducting pores. Water flow and infiltration capacity are influenced by the volume of macropores and their continuity down the soil profile. Anything that changes soil structure also changes the hydraulic conductivity. Compaction increases the soil bulk density and changes the volume, size and shape of conducting pores, exerting an effect of smaller magnitude which in turn leads onto rapid reduction of the soil hydraulic conductivity (Kayombo and Lal, 1993).

Several methods have been developed to measure saturated hydraulic conductivity both in laboratory and field. Field methods are more preferable while laboratory methods should only be used to supplement field methods. For field methods, a distinction is made between determination of saturated hydraulic conductivity below the water table and above water table. Inverted augerhole method is one of the widely field methods which is used to determine the saturated hydraulic conductivity of soil above water table and is given by the following relationship (Landon,1991):

$$K_s = \frac{1.15r\left[\log\left(h_o + r/2\right) - \log\left(h_t + r/2\right)\right]}{t} \quad (4)$$

Where ;

K_s = Saturated hydraulic conductivity

h_o = height of water level in the augerhole at time t=0 measured from the bottom of the hole.

h_t = height of water level in the augerhole at time t measured from the bottom of the hole.

r = radius of the augerhole.

2.3. Factors influencing infiltration rate and hydraulic conductivity

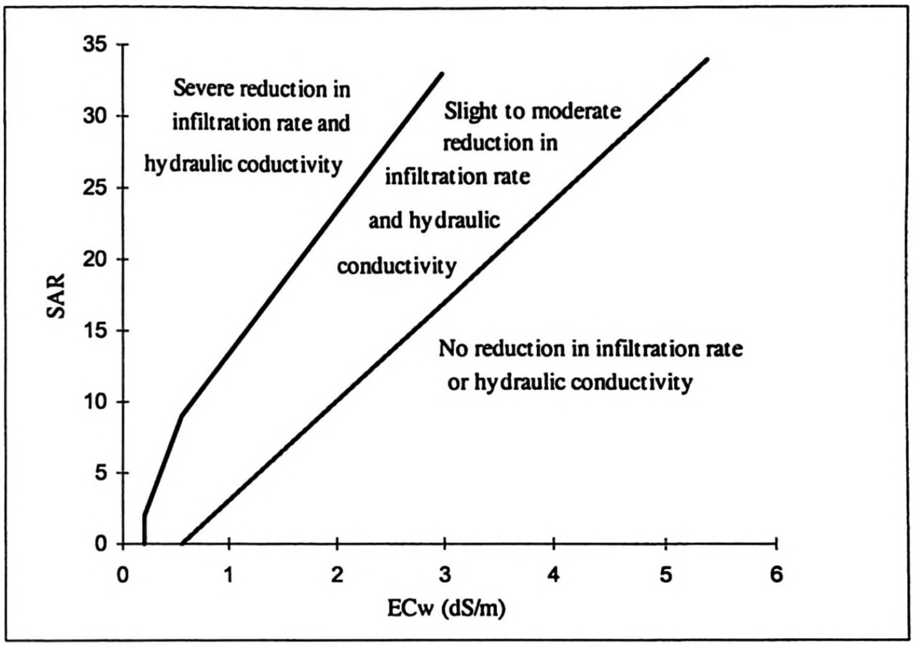
Salinity of the water (total quantity of salts in water), sodium content relative to calcium and magnesium, and the amount of suspended sediments are the common water quality factors which influence the normal infiltration and movement of water in the soil (Heil *et. al.,* 1997; Eisenhauer *et. al.*, 1992). Other factors which has remarkable influence includes soil properties and field operations.

i) Water salinity and sodicity.

Low saline water (less than 0.5 dS/m) is corrosive and tends to leach surface soils free of soluble minerals and salts, especially calcium reducing their strong stabilizing influence on soil aggregates and soil structure. Without salts and without calcium in particular, the soil disperses and soil particles fill the pore spaces, sealing the surface and greatly reducing the rate at which water infiltrates the soil surface. Filling up of the pores which are responsible for water conduction, reduces the water movement in soil (Eisenhauer *et. al.*, 1992). Very low saline water (less than $EC_w = 0.2$dS/m) may results in water infiltration problems regardless of the relative Sodium ratio. Such diluted water not only allows maximum swelling and dispersion of both soil minerals and organic matter but also has tremendous capacity to dissolve and remove calcium, thus affecting infiltration. Irrigated areas frequently experience exceptionally low rates of infiltration of rainfall resulting in excessive runoff due to its low salt content (Ayers and Westcot, 1989).

High concentrations of exchangeable sodium in irrigation water and soils cause the eventual deterioration of soil structure which result reduction in hydraulic conductivity. This occurs only if sodium exceeds calcium by more than a ratio of about 3:1 (Evans *et. al.*, 1990)). Such a relatively high sodium content (> 3:1) often results in severe water infiltration problems due to soil dispersion and plugging and sealing of the surface pores, in much the same way as does the very low salinity water. This is due to lack of sufficient calcium to counter the dispersing effect of the sodium. Excessive sodium may also make it extremely difficult to supply enough water to meet the crop water demand. Other related problems such as soil crusting, poor seedling emergence, lack of aeration, plant and root diseases, weed and mosquito control problems caused by the low rate of infiltration may further complicate crop management (James,1988).

The hydraulic conductivity and infiltration rate generally increase with increasing salinity and decrease with either decreasing salinity or increasing sodium content relative to calcium and magnesium- the sodium adsorption ratio (SAR). Due to their interaction effects, the two factors, salinity and SAR, must be considered together for proper evaluation of the ultimate effect on water infiltration rate and its movement in the soil (Ayers and Westcot,1989). Figure 2.1 is the chart recommended by FAO in evaluating effects of irrigation water salinity (ECw) and SAR on infiltration rate and hydraulic conductivity problems.



Source: Ayers and Westcot (1989)

Figure 2.1 Hydraulic conductivity and infiltration rate evaluation chart.

Moutier *et al.,* (1998) conducted a study on hydraulic gradient, aging and water quality effects of hydraulic conductivity of a vertisol. In their experiment they used different electrolyte concentrations with varying exchangeable sodium percentage (ESP). The result showed that the saturated hydraulic conductivity of the soil decreased with an increase in soil ESP and a decrease in total electrolyte concentration. Aringhier and Capurro (1994) found the same result when investigated the change in the hydraulic conductivity of a sandy-loam as a function of SAR and electrolyte concentration of percolating solution.

In the past, several procedures have been used to predict a potential infiltration problem caused by sodium. The most commonly used method to evaluate the infiltration problem potential and probably still is the Sodium Adsorption Ratio (SAR). In recent literature, SAR is more and frequently being reported as Sodium ratio(R_{Na}.). The terms are synonymous and are given by the following equation (Ayers and Westcot, 1989; Landon,1991).

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \qquad (5)$$

Where:

Na, Ca, and Mg are ionic concentrations in me/l of solution.

ii) Suspended sediments

High suspended sediments in irrigation water may cause problems in infiltration and hydraulic conductivity irrespective of the water quality. The major effect is the clogging of the pores and surface crusts formed due to accumulation of finer particles in the water hence reducing water intake and its movement in the soil. For soils that are moderately to highly permeable, reduction of porosity is often regarded as a benefit because the reduced infiltration rate allows longer irrigation runs or faster field coverage than would otherwise be possible. For soils that are initially fine-textured, however, suspended sediments in irrigation water may simply further lower an already low infiltration rate and hydraulic conductivity.

In Ethiopia (Awash river) it has been found that although the chemical quality of irrigation water is good and toxicity hazards due to specific ion are non-existent, however the suspended sediments contained in this water have been a major concern to most projects utilizing it for irrigation and other uses. Suspended sediment content varies widely, ranging from less than 0.5 g/l during the dry months to about 15 –20 g/l during heavy floods. Due to this rich sediment water, the reduced permeability and surface crusting were observed in low-lying areas and along the low portions of farms. Surface crusting has been positively identified as one of the causes of poor seed germination in certain fields in this area. Other serious problems observed is high accumulation of silt in canals which results in reduction of water flows (Ayers and Westcot,1989).

Abu – Sharar (1993) reported that extensive surface runoff and thus soil erosion may be generated from rainstorms of low quantity and intensity due to the low infiltration and poor hydraulic conductivity of the soil. In general, most of the suspended materials in the surface runoff would be made of silt and clay fractions. These suspended materials fill up most of the surfaces pores forming a seal and hence preventing water from entering the soil. Eisenhauer *et. al.*, (1992) mentioned that surface sealing in furrow reduced cumulative infiltration after 5 hours by 46% on silt loam soils. In another study, Trout (1991) showed that surface sealing as a result of irrigation water reduced cumulative infiltration by 50%.

Abu-Sharar and Salameh (1995) conducted a study on reduction in hydraulic conductivity and infiltration rate in relation to aggregate stability, and irrigation water turbidity. The study comprised determination of infiltration rate and hydraulic conductivity when series of decreasing electrolyte concentration and turbid runoff water at constant SAR levels employed. The result showed substantial losses in infiltration rate and hydraulic conductivity (40 - 60%) of semi-arid soils in Muaq'qar area (30 Km East of Jordan capital city - Amaan) when permeating solutions with electrolyte concentration equal to or higher than the respective critical salt coagulation concentration of soil-clay at equivalent SAR. When turbid runoff water of 0.07% fine clay from the same area used, the infiltration rate and hydraulic conductivity dropped to approximately 15 - 20% of their respective maximum values. From these results it can be concluded that one major feature of the proper management of turbid irrigation water should be an early flocculation of suspended clay particles.

Soil sealing is one of the major factors which affects water intake and its movement. The two main soil properties influencing soil sealing are generally particle size distribution and aggregation. Other soil properties such as organic matter (OM) type and content, salt content and flocculation/dispersion conditions may influence soil sealing directly or through their effect on aggregate stability (Heil *et. al.*, 1997). Rachel, (1984) observed that anions in irrigation water effected the structure and hydraulic conductivity of tropical soils which are rich in amorphous material.

iii) Soil properties

Coarse textured soils having high porosity have a corresponding high hydraulic conductivity while the heavy clays which have finer pores have low hydraulic conductivity.

Generally, the hydraulic conductivity of light to heavy textured soils ranges from 10^{-1} to 10^{-6} mm/sec (10^{-2} to 10^{-7} cm/sec), (Ghildyal and Tripathi, 1987). Aggregate stability has been related directly to the organic matter content . A soil with low organic matter content (less than 5%) may contain aggregates that are relatively unstable. When water is applied to this soil, it cannot withstand its dispersion effects (Heil *et. al.*, 1997). McNeal *et al.*, (1982) studied the effect of soil structure and texture on hydraulic conductivity and observed that hydraulic conductivity decreased with an increase of clay content. It was observed that when clay content in the soil increased from 5.7%, 16.2% to 48.5% the average initial hydraulic decreased from 7.13 cm/hr, 1.98 cm/hr to 0.523 cm/hr respectively. From the same study it was found that the hydraulic conductivity in the presence of mixed-salt solutions was strongly dependent on soil texture.

iv) Field operations

Tillage is one of the factors that strongly affect soil macropores and consequently affect the infiltration rate and water movement. However, studies show that tillage effects are not consistent. Azeved *et. al.*, (1998), reported that tillage disrupted the continuity of pore from the surface while Ankeny *et. al,* (1990) as cited by Azeved *et. al.*,(1998), reported that tillage has effect on water intake and movement for first few irrigation or rains after tillage. Freebain, *et. al.*, (1989) reported that tillage reduces infiltration by creating discontinuous pore space in the plough layer and by weakening the structure due to micro fractures.

Mwendera and Feyers (1993) conducted a research on predicting tillage effects on infiltration. Three tillage systems were used namely ploughing (P), ploughing and harrowing (P+H) and ploughing, harrowing and rolling (P+H+R) and untilled

(UNT). The result showed that ploughing maintained higher infiltration rate compared to other treatments. Also it was shown that decrease in infiltration in the tilled soil were more strongly associated with initial tillage-induced surface roughness than with total porosity and water transmission characteristic of the sub-layer. Harrowing and rolling increased the susceptibility of the soil to structural damage. It was concluded that the infiltration enhancing effects produced by those treatments, though initially high, are likely to be overshadowed by rapid structure deterioration at impact of cumulative rainfall or irrigation water. Lindstrom *et. al.*, (1980) found a higher infiltration rate in tilled clay loam soil than in no-till and observed that the low infiltration rate in no-till plots was due to the impending top layer or crust, which had relatively high bulk density because the layer was not disturbed.

2.4 Management of infiltration and hydraulic conductivity problems

Irrigating to fill the soil-water reservoir for later withdrawal by the crop is difficult when infiltration rate and hydraulic conductivity are low. Water ponding for too long gives rise to secondary problems which are as important in causing yield loss as is an actual water shortage caused by low infiltration and hydraulic conductivity. Some of the more troublesome secondary problems are surface crusting of seedbeds, excessive weed growth and surface saturation which can cause root rot, diseases, poor aeration, poor germination and in some cases water ponding has caused mosquito problems (Eisenhauer *et. al.*, 1992).

The management practices available to help maintaining yield can be either chemical or physical. Chemical practices involve changing the soil or water chemistry that influence soil infiltration rates and hydraulic conductivity. This is normally accomplished by adding chemical amendments such as gypsum to either water or soil. Physical methods include cultural practices that can improve or maintain infiltration rate during irrigation or rainfall. Chemical practices requires large resources and are normally expensive for small farmers. In this study the discussion will base on management practices which are within the capacity of small farmers.

i) Organic residues

Addition of manure and mulch such as crop residues or other organic residue in the soils can improve water penetration, water retention properties of soil and nutrient uptake by plant (Dutartre *et. al.*, 1993). These organic residues keep the soil porous by maintaining open channels and voids which improve water penetration into the soil. Crop residues such as from barley, rice, wheat, maize and sorghum have improved soil structure and water penetration into the soil (Gupta,1990). In Kilombero Sugar Estate, Kunda (1996) reported that the addition of byproducts of sugar factory (decomposed bagasse) improved the heavy textured soils for sugar production by reducing their bulk densities and increasing their infiltration rate and hydraulic conductivity. The yield of wheat grown in poorly drained sandy clay loam soils and irrigated with bicarbonate dominant water were reported to have increased by addition of 5 to 20t/ha of cow dung (Puntamkar *et, al.*, 1971).

ii) Cultivation

Cultivation is usually done for weed control rather than to improve water penetration. Where infiltration problems are severe, cultivation or tillage are helpful as they roughen the surface and slow the flow of water, increasing the time during which infiltration can take place. Cultivation breaks up the crust in the upper few centimeter of soil to improve infiltration. A common practice in areas where a water infiltration problem has been caused by water quality, is to cultivate before each irrigation or every second irrigation. This roughens the soil and opens cracks and air spaces that greatly increase the surface area exposed for infiltration. (Lindstom *et. al.*, 1980).

iii) Irrigation management

Irrigating more frequently is a simple and effective approach especially for soils having an initially high infiltration rate but for which rate drops rather quickly. The objective is to supply the crop with adequate water at all time without causing secondary problems (water logging, poor aeration). Irrigating more frequently maintains a higher average soil water content and reduces the possibility of a water stress that might result if irrigation were spaced further apart.

Pre- planting irrigation can be relied upon to fill the rooting depth to field capacity at a time when there is a little chance of causing crop damage. Extending the duration of an irrigation applies more water and is beneficial provided that soil aeration, water logging, runoff and surface drainage problems do not result. This may be attained by reducing the volume of flow to the field and holding the water on the field for a greater period of time.

2.5 Water adequacy for crop development

2.5.1 Reference evapotranspiration (ET_o)

The effect of climate on crop evapotranspiration is estimated by the evapotranspiration of reference crop under standard or reference conditions. Many methods ranging from direct measurement to sosphicated computer packages have been developed to determine reference evapotranspiration (ET_o). The Penman-Monteith methods is now recommended by FAO for estimating ETo.

2.5.2 Crop evapotranspiration (Crop water requirement) (ET_c)

Crop evapotranspiration (ET_c) refer to the condition when water is adequate for unrestricted growth and development. It is also referred as potential evapotranspiration or crop water requirement. The effect of crop characteristics on crop water requirements is given by the crop coefficient which represents the relationship between the reference evapotranspiration (ET_o) and crop evapotranspiration (ET_c) by the following equation: (Raes,1996; James,1988).

$$ET_c = ET_o * k_c \tag{6}$$

Where

ET_o = reference evapotranspiration (mm/day)

ET_c = crop evapotranspiration (crop water requirement) (mm/day)

k_c = crop coefficient.

The values of k_c vary with crop and its stage of growth. For optimum growth and yield, the crop water requirement must be met in all growth stages. When the soil moisture conditions are not optimum the crop is under stress and the actual evapotranspiration (ET_a) will be smaller than the crop water requirement (ET_c). This will result in poor crop growth and consequently low yield.

2.5.3 Water adequacy.

If the water required by a plant for evapotranspiration (ET_c) and its metabolic processes is not adequately available, the plant will experience water stress. Kramer (1972) found that plant water stress is caused by excess loss of water by evapotranspiration or inadequate absorption or a combination of both and observed that a decrease in water absorption by plant led to severe periods of plant stress, which limits the plant growth.

The sensitivity of crop to water deficit differs from one stage of crop development to another. Onion for example is more sensitive to water deficit during the yield formation (60 days after transplanting) while less sensitive at late season stage (Doorenbos and Kassam, 1979).

Adequacy is a measure for determining whether the amount of water supplied met the crop requirement. One parameter that is used to evaluate water adequacy is relative water supply (RWS). Relative water supply (RWS) is the ratio of irrigation water and rainfall to the crop water requirement (CWR). In interpreting RWS values, it is important to establish the critical RWS values below which water supply becomes inadequate. A RWS value of 1.0 means that the water supplied was equal to CWR. Oad and Levine (1985); Makadho (1994) used the following equation to calculate RWS for upland crops.

$$RWS = \frac{IW + RE}{CWR} \qquad (7)$$

Where:

RWS = Relative water supply

IW = Irrigation water applied (mm)

RE = Effective rainfall (mm)

CWR = Crop water requirement per crop development stage (mm)

2.5.4 Crop performance

Crop yield per area has been used to assess the irrigation system performance for long time but this assessment does not reflect an adequate assessment of performance where irrigation water is scarce. Yield per unit area is a complementary measure and more appropriate in areas where water is not a problem. Yield per unit area is most useful indicator in assessing technical efficiency of water use (Batti *et. al.*, 1991). Although yield per unit area reveals irrigator's technical efficiency in irrigation water utilization, specific yield which is crop produced per unit volume of water used (Kg/m^3) is widely used instead of yield per irrigated area (Weller *et. al.*, 1989).

2.6 Onion agronomy

Doorenbous and Kassam (1979); Sys *et al* (1993) reported that onions can grow on a wide variety of soils, provided they are well aerated and friable and as long as sufficient water can be retained. However fertile loam (L), sandy clay loam (SCL) and sandy clay (SC) soils are most suitable. The rooting depth of the crop is 0.50m. The optimum soil pH range is 6.0 - 7.8 however onion may grow in soils with pH ranging from 5.5 - 8.2,. Onion require a soil with percentage organic carbon > 2 (> 3.5% OM); Salinity (ECe) 0 - 2 dS/m; Alkalinity (ESP) 0 - 20%

Onion is sensitive to salinity with yield reduction due to soil salinity (ECe) as shown in Table 2.1 and 50% yield reduction may occur at an exchangeable sodium percentage (ESP) of 35. (Sys *et. al.*, 1993)

Table 2.1 Effect of soil salinity on onion yield.

Soil salinity (ECe)	% yield reduction
< 1.2 dS/m	No yield reduction
1.8dS/m	10%
2.8dS/m	25%
4.3dS/m	50%
6dS/m	100%

The fertilizer requirement range from : 60 - 100kg/ha of Nitrogen (N); 25 - 45kg/ha of Phosphorus (P) and 45 - 80kg/ha of Potassium (K).

Sys *et. al.*, (1993) reported that onion require an optimum temperature of 16 - 22^{0}C for growth, low yields are observed at temperature less than 16^{0}C while early maturity and low yields occur at temperature greater than 22^{0}C. Daylength of 12 -13 hours are required in yield formation.

The onion grown cycle ranges between 100 – 140 days in the field depending on variety, soil and climate. For optimum yield onion requires 350 to 600mm of water per growing cycle. The crop coefficient (kc) relating reference evapotranspiration (ETo) to water requirements (ETc) ranges between 0.6 to 1.1 depending on crop stage and climatical conditions. The crop is most sensitive to water deficit during transplantation and during the yield formation period which occur about 60 days after transplanting (Doorenbous and Kassam, 1979);

Good yield of onion in rainfed areas ranges from 14 - 20t/ha and from 35 - 45t/ha in irrigated areas while specific yield (water utilization efficiency) for harvested bulbs containing 85% to 90% moisture content ranges between 8 -10Kg/m^3 (Doorenbous and Kassam 1979; Sys *et. al.*, 1993)

2.6.1 Irrigation requirement and scheduling

Onion requires frequent, light irrigation which are timed when about 25 percent of available water in the first 0.3m depth has been depleted by crop. Irrigation application every 2 to 4 days is commonly practiced Over-irrigating some times cause spreading of disease such as mildew and white roots. Irrigation can be discontinued 15 to 25 days before harvest (Doorenbous and Kassam, 1979)

2.7 Irrigation interval

Irrigation interval is determined by the soil, crop and climatic factors. Different soils differ in water holding capacity hence different amount of water which crop can extract from its root zone (Sa). The magnitude of water which crop can extract is a function of soil texture and structure. Coarse textured soils have lower Sa than fine textured clays while loam are intermediate. The average total available water for different soil texture are shown in Table 2.2 (Raes, 1996). Crops have different limits at which they can extracting available water from the soil before been affected by water stress (crop water depletion factor p). For onions the crop will suffer water stress if soil water is less than 75 percent of available water (depletion factor is 0.25). The climatic factors are used to calculate the net irrigation requirement. Using soil, crop and net irrigation requirement, the irrigation interval (INT) for a given period is given by the following relationship (Raes, 1996).

$$INT = \frac{pSaD}{In} = \frac{RAM}{In} \tag{8}$$

Where;

p = crop depletion factor

Sa = total available soil moisture (mm(water)/m(soil depth))

D = depth of root zone (m)

In = Net irrigation requirement per day for given period (mm/day)

RAM = Readily available water (mm)

Table 2.2 Available moisture for different soil types.

Texture class	Sa ((mm of water/m of soil))
Sand	80
Sand loam	150
Loam	210
Clay loam	140
Sand clay loam	160
Silt clay	170
Clay	180

Source: Raes, 1996

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Location

The study was carried at Ruaha Mbuyuni traditional irrigation scheme, Iringa Rural District in Iringa region. The scheme is about 100 km North-East of Iringa town along Dar-es-salaam – Mbeya highway and is located at latitude $7^{0}29'$S and longitude $36^{0}33'$E, and an altitude of about 1000m above sea level. (Fig. 3.1).

3.1.2 Climate

The climate of Ruaha Mbuyuni is semi-arid with mean annual rainfall between 430 mm and 500 mm, mean daily temperature ranges from 18.1^{o} C to 31.2^{o} C. The area experiences unimodal rainfall starting in mid November to mid April. The relative humidity ranges from 22.5% in dry season to 87.9% in the rainy season (TIP, 1992).

3.1.3 Soils

The cambisols derived from Great Ruaha and Lukosi river alluvial deposits cover most part of the scheme. Soils of this area have a considerable variation in texture within small areas but generally these soils ranges from coarse textured sandy-loam, to heavy cracking clay (TIP, 1992).

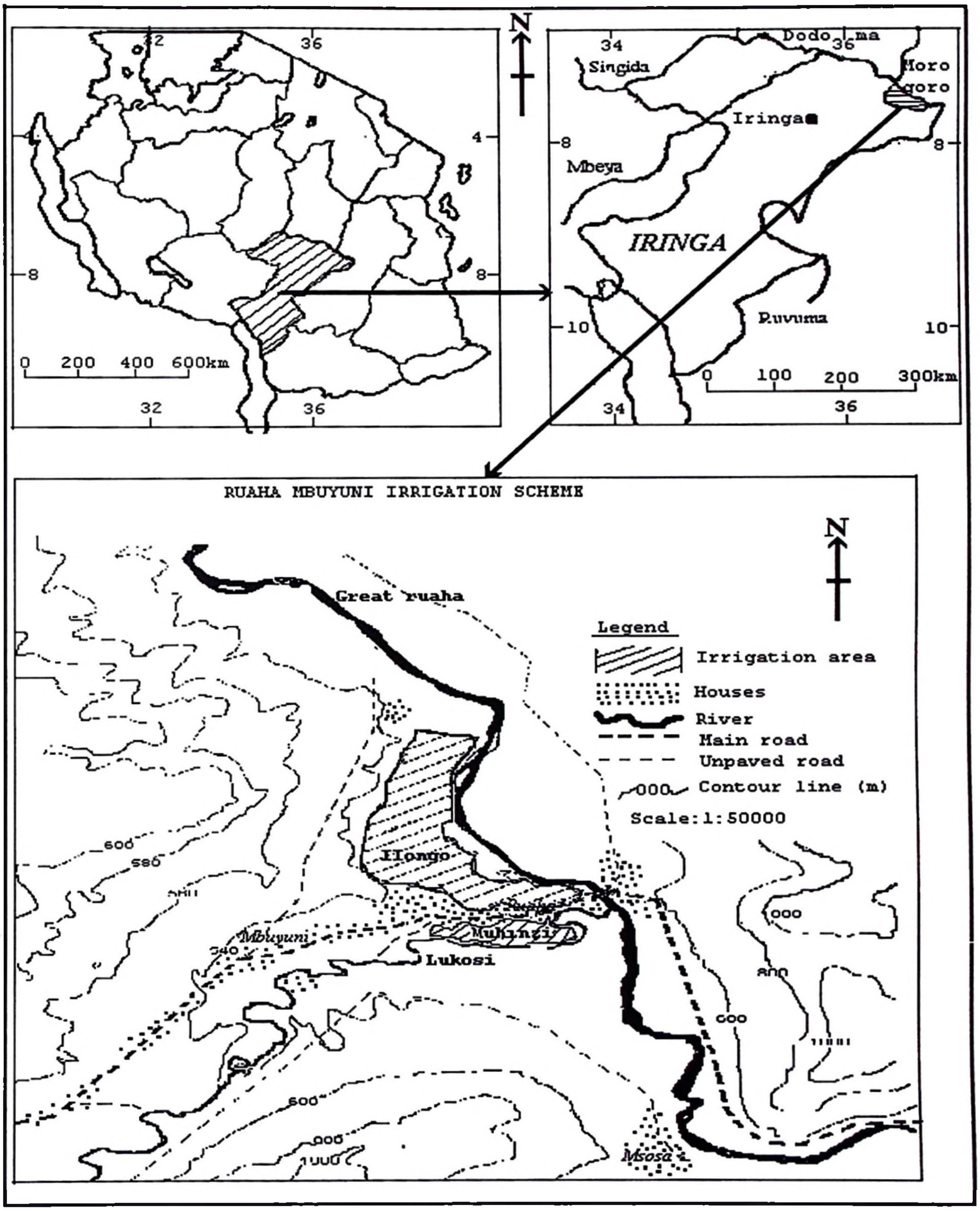


Figure 3.1 Location of Ruaha Mbuyuni

3.1.4 Hydrology

The source of irrigation water for Ruaha Mbuyuni scheme is Lukosi river. The river is a tributary of Great Ruaha river. The river has a large catchment area in south of Iringa and therefore the discharge is considerable. The maximum and minimum discharge varies from $180m^3$/sec and $7m^3$ /sec in April and October respectively. The water level of the river fluctuate strongly throughout the year and is directly related to the water level of the intake canal (TIP, 1992).

3.1.5 Topography and Land use

3.1.5.1 Topography

The area consists of gently slopping lands developed along the banks of Great Ruaha river in the east and Lukosi river in the south. The details of the area's topography is shown in Figure 3.1.

3.1.5.2 Crops and cropping season

The scheme covers a total of about 600 acres (240 ha) and the agricultural activities include the cultivation of paddy rice, onions and maize as major crops while beans and sweet pepper as minor crops. The total rainfall of 430 mm/year is not sufficient for most crops and therefore irrigation is necessary for crop production.

The cropping season starts with maize and paddy rice in January. The two crops are given priority and available irrigation water has to supplement rain. Onion seeds are sown in March and after harvesting maize and paddy in April onion is transplanted. Onion is the main crop out of three and in irrigation season it covers about 75% of the cultivated land. In October the canal is often dry and therefore only about 10% of the area is cultivated between September and October.

3.1.5.3 Fields layout

The scheme is divided into two fields namely; Muhinzi and Ilongo. Ilongo fields occupies about 80% of the total irrigated fields in the scheme (Fig. 3.1).

3.2 Study site layout

The study was conducted in the Ilongo fields. Due to the variation of soil texture in these fields and shortage of irrigation water during the dry months, most of onion fields are located at upper fields (relative to main canal). From these onion fields three sampling locations were identified basing on soil type and their location relative to field canal (Fig. 3.2).

In each location, 100 basins of 2m by 5m was constructed.

i) 20 basins from each location were randomly selected for discharge and yield measurements.

ii) Out of 20 basins in each location three sampling sites were randomly selected where soil hydraulic conductivity and infiltration rate measurements were taken. Soil samples were also taken from these sites for determination of soil bulk density, particle size distribution, electrical conductivity, and some chemical properties .

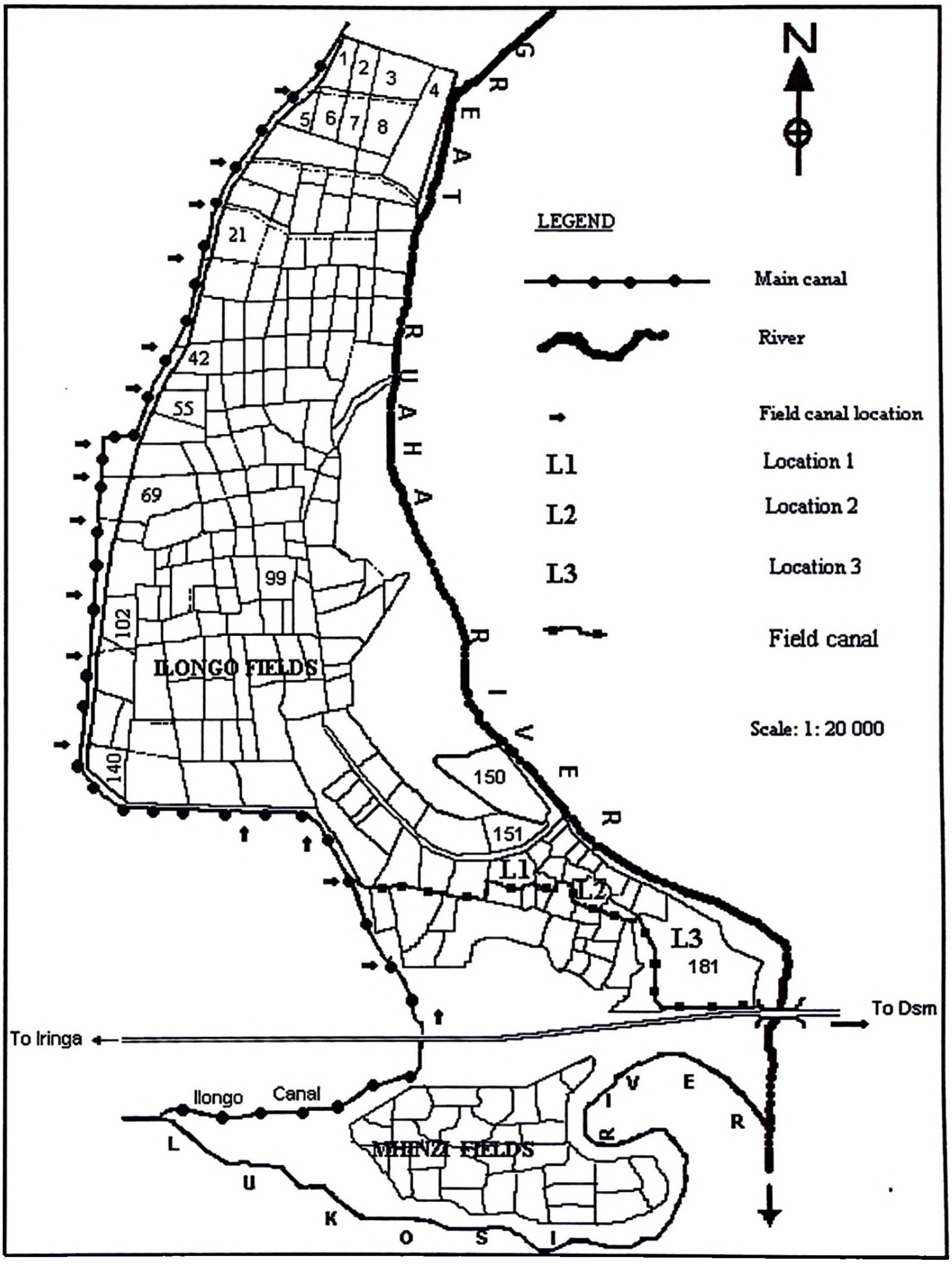


Figure 3.2 Field layout and study locations

3.3 Instrumentation and measurement

3.3.1 Measurement of soil properties

3.3.1.1 Textural classes

A total of 18 samples 6 from each location were collected at a depths of 0-15cm and 15-30cm for determination of particle size distribution and organic carbon. The pipette method as explained by Gee and Bauder (1986) was used to determine particle size distribution.

The percentage of the various soil particles as obtained from the particle size distribution analyses, was used in the textural triangle to obtain the textural class of each sample. The data on organic carbon were used to estimate the organic matter content in each sample.

3.3.1.2 Bulk density

A total of 27 samples, 9 from each location were collected for bulk density determination..

The core method was used to determine bulk density as described by Blake and Hartge (1986). Core samples were taken at different depths in each site, and the depths were 0 - 15 cm, 15 - 30 cm, and 30 - 45 cm. The cores were oven dried at 105°C for 48 hours and bulk density in g/cm^3 was calculated by dividing mass of oven dry soil by volume of core. Bulk density measurement was done before and after field operations for all locations

3.3.1.3 Soil and water chemical properties.

Electrical conductivity

The electrical conductivity of soil extracts and water samples were determined by direct reading from a temperature compensating conductivity meter as explained by Rhoades (1972).

Soil and irrigation water pH

The pH of soil in suspension of 1: 2.5 and water were measured by standard pH meter (Electrometric method) as explained by MacLean (1982).

Exchangeable bases

Exchangeable bases (Na^{+}, Ca^{2+}, and Mg^{2+}) for both soil samples and water samples were determined by ammonium acetate method as explained by Thomas (1982).

Organic matter

Soil organic carbon was measured by the Walkley and Black method outlined by Nelson and Sommers (1982). The soil organic matter was estimated by multiplying the organic carbon by 1.742 as given by Nelson and Sommers (1982).

Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio (SAR) was determined using equation (5) as described by Ayers and Westcot (1989).

Exchangeable sodium percentage (ESP)

Exchangeable sodium percentage of soil was determined by the following equation (Landon, 1991):

$$ESP = \frac{Na^+}{CEC} \times 100\% \tag{9}$$

Where:

Na^+ = Sodium ion concentration in me/100g

CEC = Cation exchange capacity in me/100g

3.3.2 Hydrological properties

3.3.2.1 Infiltration

Infiltration rate was determined using double ring infiltrometer.. The infiltrometer was filled with water to a depth of 10 cm or more and immediately the rate of fall was recorded with time lapse. The readings were taken at time interval of 2 minutes for the first 20 minutes, then the time interval was increased to 10 minutes and after 2 hours the interval was increased to 30 minutes. The measurements continued until the amount of water infiltrated per interval remained constant and this took 3 hours to 4 hours (Plate 3.1). Three replicates tests were conducted and the average values were obtained.

Infiltration measurements were done at an interval of two weeks (14 days) and the mean values were computed for each crop development stage. Infiltration measurement were also done soon after weeding operation.

Infiltration parameters determined include the infiltration rate, basic infiltration and cumulative infiltration. Infiltration rate was determined by using equation (1) while basic infiltration was obtained by assuming that basic infiltration was reached after three hours or more. The cumulative infiltration was obtained by successive addition of water intake corresponding to time interval. The relationship between cumulative infiltration was determined by equation (2).

3.3.2.2 Saturated hydraulic conductivity

Saturated hydraulic conductivity was determined by using inverted auger hole method as described by Landon (1991); Smedema and Rycroft (1983). An auger hole was dug to a depth of 0.7 meters. The hole was filled with water till sufficient water had seeped into the surrounding to create a fairly saturated zone, and this took three to four hours on average depending on soil type and moisture content. The rate of falling water was recorded (Plate 3.2). Three replicate tests were run in each experiment and the average values were used to calculate saturated hydraulic conductivity (Ks) using equation (4). The measurements were done at an interval of two weeks (14 days) and the mean values were computed for each development stage.

Plate 3.1 Measurement of infiltration rate

Plate 3.2 Measurement of saturated hydraulic conductivity.

3.3.3 Suspended solids in water

Turbid water from the field canals was collected at an interval of 14 days from each location using a five litre bucket. Water was then stirred and put into sediment sampler bottles for analysis in the laboratory. The concentration of sediments was determined by the method described by Lundekvam and Skøien (1998).

3.3.4 Crop water requirement and water applied

3.3.4.1. Climatic data

The climatic data was collected from a nearby Mtera automatic weather station which records temperature, relative humidity, wind speed, solar radiation, atmospheric pressure and rainfall.

3.3.4.2 Crop evapotranspiration (ET_c)

Reference evapotranspiration (ET_o) was calculated by the aid of the IRSIS computer package using temperature, relative humidity, wind speed, and solar radiation data. The crop evapotranspiration (of onion) was calculated by using daily reference evapotranspiration (ET_o) data and daily crop factor (k_c) using equation (6). The daily crop factors were obtained from the crop factor curve constructed as described by Raes (1996) using the following information: Total grown time = 95 days (determined from the field), crop factors for initial, mid-season, late-season stages as shown in Table 3.1

Table 3.1 Onion development stages

Stage	Description	No. of days	k_c
1^{st}	Initial stage	20	0.7
2^{nd}	Crop development stage	45	-
3^{rd}	Mid-season stage	20	0.95
4^{th}	Late season stage	10	0.75

Source: Raes, (1996).

3.3.4.3 Measurement of irrigation water

Irrigation water depth was measured in 20 basins in each location in every irrigation. Measurement was done using calibrated wooden pegs fixed in each basin. The pegs were calibrated using parshall flume. A rating curve was developed which was used to determine the discharge into each basin.

3.3.4.4 Adequacy of irrigation water supply

The relative water supply (RWS) was used to determined adequacy water supply at different crop development stage using equation (7).

3.3.4.5 Crop performance

The crop (onion) was assessed by the following methods:

Crop yield per unit area (tons/hectare) and water utilization efficiency (Ey) or Specific yield (yield per unit volume of water used) (Kg/m^3). Yield was determined by weighing harvested bulbs in each basin while water utilization efficiency was calculated from the yield per unit volume of water used in each basin. Measurements were done in each of 20 basins for all locations.

3.3.4.6 Irrigation interval

The required irrigation interval was determined for each crop development stage using equation (8) and available soil moisture (Sa) for different soil textures obtained from Table 2.2 as follows: Sa = 150mm for location one (Sandy loam), 160mm for location two (Sandy clay loam) and 180mm for location three (Clay). Although the maximum rooting depth of onion is 0.5m, but the water should be applied when 25% of available water in the first 0.3m depth has been depleted by crop (Sys *et. al*, 1993). Hence crop depletion factor p = 0.25 and D = 0.3m were used in equation (8) for determination of required irrigation intervals. The values obtained were compared with the actual irrigation interval practiced in the study area.

3.4 Field operations

Land clearing, land preparation, and basin making were done by hand hoe while weeding was done by trowel or uprooting weeds using hands. Seed sowing, transplanting and harvesting were conducted manually.

Red Bombay onion seeds (*Allium cepa*) were used in all locations. The seedlings were transplanted in a space of 10cm by 10 cm. About 20 kilograms of UREA were used for top dressing in each location. The summary of field operations is given in Table 3.2 below.

Table 3.2 Summary of field operations

Location	Field clearing	Land preparation	Basin making	Transplanting	1st weeding	Top dressing	2nd weeding	Harvesting
1	20/3 to 25/3/99	3/4 to 6/4/99	12/4/99	13/4/99	23/4 to 24/4/99	27/4/99	14/5 to 15/5/99	23/7/99
2	4/3 to 10/3/99	21/3 to 26/3/99	29/3 to 2/4/99	12/4/99	27/4 to 30/4/99	1/5/99	18/5 to 21/5/99	21/7/99
3	15/3 to 18/3/99	26/3 to 28/3/99	7/4 to 9/4/99	12/4/99	30/4/99	1/5/99	26/5/99	26/7/99

3.4.1 Water application

Rotational method of irrigation is practiced where water is allocated to each location after every seven days for three hours in each field. The water application in the study fields followed the same scheduling. Water was applied at an interval of seven days for the 1^{st} and 2^{nd} stages of crop (1-65 days) followed by interval of 14 days for 3^{rd} and 4^{th} stages (66-95 days). The irrigation was stopped about 16 days before harvesting. The amount of applied water during irrigation was estimated by the irrigator by filling up the basis.

3.5 Statistical data analysis

The MSAT-C and MS-EXEL statistical computer packages were used for statistical data analysis. MSAT-C package was used for analysis of variance (ANOVA) for soil properties. Duncan's Multiple Range Test (DMRT) was used to separate means of the analysed parameters.

MS-EXEL program was used for analysis of variance (ANOVA) for hydraulic conductivity, infiltration rate, crop water, and yield at different locations. A correlation test and simple linear regression analysis were performed between infiltration rate and saturated hydraulic conductivity while the correlation test was used to see the effect of infiltration rate and hydraulic conductivity on yield. Chi-squared tests were performed to analyze the variation between calculated irrigation interval and practised one.

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results and discussion in relation to four specific objectives: evaluation of hydraulic conductivity and infiltration rate which include their variation with time and soil type; assessment of soils in study area which include soil texture, bulk density and chemical properties; measurement of suspended sediments in irrigation water, its concentration and variation over time for one season, crop water requirement (CWR), water applied, adequacy and corresponding yield at different fields.

4.2 Infiltration rate and hydraulic conductivity

Table 4.1 shows the mean basic infiltration and saturated hydraulic conductivity measured from three locations and their corresponding soil texture while Figures 4.1 and 4.2 shows the variation of basic infiltration rate and hydraulic conductivity over the season respectively.

Table 4.1 Infiltration rate and saturated hydraulic conductivity (K_s).

Location	Mean basic infiltration (mm/h)	Mean K_s (m/d)	Texture class
1	52.5 a	0.4236 a	SL
2	36.0 b	0.3646 a	SCL
3	3.75 c	0.03123 b	C

SL = Sandy loam; SCL = Sand clay loam C = Clay.

Means followed by the same letter along the column are not significantly different at $P< 0.05$

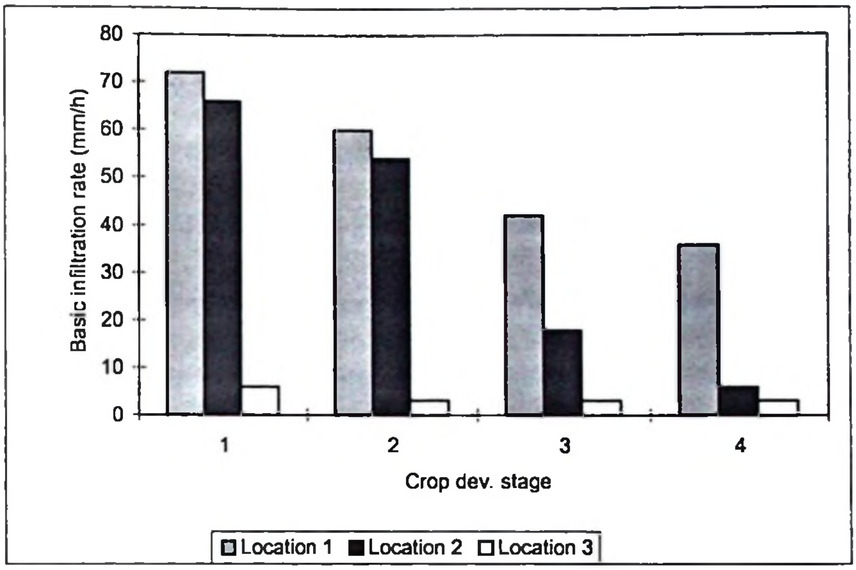


Figure 4.1 Basic infiltration rate

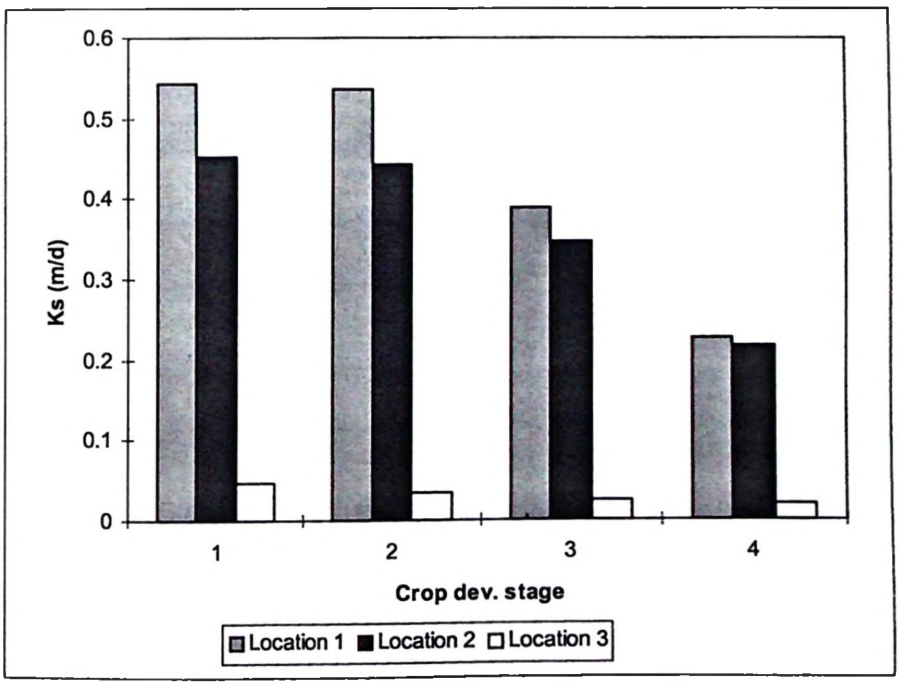


Figure 4.2 Saturated hydraulic conductivity (K_s)

The infiltration rate and hydraulic conductivity varied significantly between locations. The mean values for basic infiltration rate were 52.5mm/h, 36.0mm/h and 3.75mm/h for location one, two and three respectively while mean values for saturated hydraulic conductivity were 0.4236m/d, 0.3646m/d and 0.03123m/d respectively. According to Bai (1979) as cited by Landon (1991), the basic infiltration rate can be rated as moderately rapid, moderate and slow for sandy loam, sandy clay loam and clay soils respectively while saturated hydraulic conductivity are moderately low for sandy loam and sandy clay loam and very low in clay soils. The infiltration rate ranges in all soils are within acceptable values for surface irrigation (3mm/h to 65mm/h) given by Landon (1991) as shown in Table 4.2

Table 4.2 Rating of infiltration rates for surface irrigation.

Basic inf. Rate (mm/h)	Suitability for surface irrigation
< 1	Unsuitable (too slow) but suitable for rice
1 – 3	Marginally suitable (too slow); marginally suitable for rice.
3 – 7	Suitable; unsuitable for rice
7 – 35	Optimum
35 – 65	Suitable
65 – 125	Marginally suitable (too rapid).Small basins required
125 – 250	Suitable only under special conditions. Very small basins required.
> 250	Unsuitable (too rapid); recommended for overhead methods only.

Source: Landon(1991)

Infiltration rate and hydraulic conductivity showed a similar trend in all location and over the season (Figures 4.1 and 4.2). The magnitude of both infiltration rate and hydraulic conductivity followed the trend of decreasing from location one to location three. The correlation test between basic infiltration rate and saturated hydraulic conductivity gave high correlation coefficient (R) values ranging from 0.92 for location one, 0.94 for location two, 0.85 for location three and an overall value of 0.92. The observed high values of correlation coefficient indicate a strong association between infiltration rate and saturated hydraulic conductivity in all locations. This is possibly because both infiltration rate and hydraulic conductivity are affected by same factors such as soil properties and irrigation water. This results also suggests that infiltration rate and saturated hydraulic conductivity of the soils in study area are closely related hence one can be predicted from another using simple linear equations shown in Appendix 2.2.

Higher values of infiltration rate and hydraulic conductivity were recorded in location one soils while the lowest values were recorded in location three soils. This is possibly due to the differences in soil textures between the locations. Location one was dominated by sandy loam (SL) soils while location three was dominated by clay (C) soils. Difference soil texture has difference influences on infiltration and hydraulic conductivity due to variation in size and distribution of water conducting pores.

During the study it was observed that the infiltration rate and saturated hydraulic conductivity decreased with time (crop development stages) in all locations (Figures

4.1 and 4.2). Basic infiltration decreased by an average of 50% over the season while saturated hydraulic conductivity decreased by an average of 52% - 58% over the season (Appendices 1 and 2).

The observed differences of infiltration and hydraulic conductivity between location and their variation over the season can be related to the soil properties and the effect of irrigation water.

4.3 Influence of soil properties on infiltration rate and hydraulic conductivity

4.3.1 Texture.

According to Smedema and Rycroft (1983), infiltration rate and hydraulic conductivity under saturated conditions are well correlated with soil texture and structure. The size of soil particles and their spacing determine how much water can enter and flow through the soil. The larger the spacing, or pore size, the greater the infiltration rate and hydraulic conductivity. Coarse textured soils have large particles which are far spaced compared to fine soil particles. The size and amount of pores in any soil increase with an increase of sand content or decrease of clay content. Thus when the irrigation water is applied in sand dominated soils, it enters and flows more freely than in clay dominated soils. It was observed that the location one soils had relatively high infiltration rate and hydraulic conductivity followed by location two while location three soils had low values of both infiltration and hydraulic conductivity. The infiltration rate and hydraulic conductivity showed a decrease with an increase of clay content or decrease of sand particles. Soils of location one had high proportions of sand followed by location two soils while location three soils were dominated by clay particles (Table 4.3). The amount of sand showed a decreasing trend from location one to three while clay particles increased from location one to three (Table 4.3). The mean clay content increased significantly ($P< 0.01$) from 18% in location one soils, 29.3% in location two to 62.4% in location three soils while sand decreased significantly ($P< 0.01$) from 67% in location one soils, 50.7% in location two to 16.3% for location three soils (Table 4.4 and Appendix 3). The decreasing of sand particles or increasing of clay particles means decreasing of amount and size of water conducting pores in the soil hence when the irrigation water is applied, its entrance and flow into the soil is reduced. The above results indicates that also the water conducting pores decreased significantly from location one to three. The above variations of texture and hence variation of size and amount of conducting pores corresponds to variation of the basic infiltration rate and saturated hydraulic conductivity as explained in Section 4.2. Clay and sand proportions showed a non-significant ($P<0.05$) increase with depth in all location (Table 4.5).

The correlation test between soil proportions in the soil with infiltration rate and hydraulic conductivity showed a high positive coefficients for sand and negative coefficients for clay proportions (Table 4.6). High correlation coefficients show a strong correlation between infiltration rate and hydraulic conductivity and soil texture indicating that sand particles had positive effect on infiltration rate and hydraulic conductivity while clay particles had negative effects.

From these results it could be deduced that the coarse textured soils recorded higher infiltration rate and hydraulic conductivity due to their relatively larger pores hence irrigation water enters and flows more freely in these soils compared to finer pores in high clay content soils in which are easily clogged. Hence the observed different of infiltration rate and saturated hydraulic conductivity is due to different in soil textures in three locations. McNean *et. al.*, (1982) studied the effect of soil texture on hydraulic conductivity and observed that when the clay content in the soil increased from 5.7% to 48.5%, the average initial hydraulic conductivity decreased from 7.13cm/h to 0.523cm/h respectively. Tarimo (1995) observed a similar trend soil infiltration rate with soil texture.

Table 4.3 Soil texture classes

Location	Site	Depth Cm	%SAND	%SILT	%CLAY	%OM	Texture classes	
1	1	0-15	73	11	16	1.05	SL	SL
		15-30	74	5	21	0.05	SCL	
	2	0-15	63	15	22	2.65	SCL	SCL
		15-30	68	11	21	0.29	SCL	
	3	0-15	45	38	17	2.22	L	SCL
		15-30	77	11	12	0.52	SL	
2	1	0-15	53	20	27	2.89	SCL	SCL
		15-30	65	17	18	0.52	SL	
	2	0-15	52	21	27	3.51	SCL	SCL
		15-30	64	12	24	0.89	SCL	
	3	0-15	38	28	34	3.41	CL	CL
		15-30	32	25	43	1.32	C	
3	1	0-15	26	27	47	4.64	C	C
		15-30	14	18	68	1.57	C	
	2	0-15	13	25	62	3.97	C	C
		15-30	13	20	67	0. 33	C	
	3	0-15	16	20	64	4.68	C	C
		15-30	15	20	65	3.13	C	

SCL = Sandy Clay Loam, SL = Sandy Loam, C = Clay, L =Loam, OM = Organic matter.

Table 4.4 Soil textural variation between locations.

Location	%Sand	%Silt	%Clay	%OM	Texture
1	67.0 a	15.0 a	18.0 c	1.13 c	SL
2	50.7 b	20.0 a	29.3 b	2.09 b	SCL
3	16.3 c	21.3 a	62.4 a	3.05 a	C
	se = 3.6863	Se = 2.619	se = 2.8855	se = 0.2690	
	CV = 20.29%	CV = 33.57%	CV = 19.42%	CV = 31.51%	

se = Standard error

CV = Coefficient of variation.

Means followed by the same letter along the column are not significantly different at $P < 0.05$.

Table 4.5 Variation of soil proportion with depth

Depth(cm)	%Sand	%Silt	%Clay	%OM
0 – 15	42.11 a	22.78 a	35.11 a	3.224 a
15 – 30	46.89 a	15.44 b	37.67 a	0.958 b
	se = 3.01	Se = 2.138	Se = 2.356	se = 0.2196
	CV = 20.29%	CV = 33.57%	CV = 19.42%	CV = 31.51%

se = Standard error

CV = Coefficient of variation.

Means followed by the same letter along the column are not significantly different at

$P < 0.05$.

Table 4.6 Correlation between soil particle proportions, Ir and Ks

	Correlation coefficient	
	% Sand	% Clay
Infiltration rate (mm/h)	0.9998	-0.9958
Hydraulic conductivity(m/d)	0.9837	-0.9942

Furthermore it was observed that the soils of study area had low aggregate stability due to low organic matter (<3.1%) (Table 4.4). Heil, *et. al.*, (1997) observed that soil with low organic matter (< 5%) contains aggregates which are relatively unstable and can not withstand the dispersion effect when water is applied. This low aggregate stability may be one of the factors which contributed to the observed trend of decreasing of infiltration rate and hydraulic conductivity with time for the whole season in all locations (Figures 4.1 , 4.2 and Appendices 1 and 2). When irrigation water is applied to unstable soils it results in dispersing soil into fine particles which enter and fill many of conducting pore. Filling and sealing some of conducting pores due to applied water results into reduction of amount of water entering and flowing into the soils. Thus due to their low aggregate stability, the soils in the study area were easily dispersed when irrigation water was applied resulting in clogging of water conducting pores. Continuous filling and clogging of conducting pores as water is applied reduces the amount of water entering and flowing into the soil. Michael, (1978) reported that dispersed soils usually have low permeability, they tend to shrink, crack and become hard on drying and become plastic on wetting. Although the amount of organic matter showed a trend of increasing with the increase of clay particles, the amount was still low to overcome the clogging effect of finer particles of clay soil which indicated by a decrease of infiltration rate and hydraulic conductivity with increase of clay.

4.3.2 Bulk density

A summary of bulk density results determined before and after field operations in three sites in each locations and at three depths is presented in Table 4.7 while detailed result and statistical analysis is presented in Appendix 3.2. The bulk density of the soil sampled site ranged from 1.2 to 1.56g/cm^3 with mean of 1.51g/cm^3, 1.35g/cm^3 and 1.284 for location one, two and three soils respectively (Appendix 3.2). According to Landon, (1991) the observed range of bulk density reflects the suitability of land for agriculture since will not cause hindrance to root penetration. Bulk densities above 1.75g/cm^3 for sands, or 1.46g/cm^3 to 1.63g/cm^3 for silts and clays causes hindrance to root penetration. The bulk density varied significantly ($P<0.01$) between locations and depths as shown in Table 4.7. The mean bulk density also varied significantly ($P<0.01$) between sampling period with mean of 1.354g/cm^3 and 1.409g/cm^3 before and after field operation respectively

Table 4.7 Variation of Bulk density with locations and depth.

Location	Mean b.d (g/cm^3)	Depth (cm)	Mean b.d (g/cm^3)
1	1.510 a	0-15	1.342 b
2	1.351 b	15-30	1.372 b
3	1.284 c	30-45	1.431 a
	se =0.0175		se=0.0175
	CV=5.38%		CV=5.38%

se = Standard error

CV = Coefficient of variation

Means followed by the different letters along the column are significantly different at $P< 0.05$.

The observed differences of bulk density between locations is due to different in soil textures. Soils in location one which have high percentages of sand had the highest bulk density while location three soils which are dominated by clay had lowest bulk density and the density decreased with increase of clay contents. Holtan and Musgrave (1964) reported that the soils with high percentage of clay have low bulk density, low infiltration rate and low hydraulic conductivity. The low bulk density in location three is partly due to relatively both high organic matter content and clay percentage (Table 4.4). Uriyo *et, al.,* (1979) observed that bulk density decrease with increase of organic matter. Generally the bulk density increased with depth (Table 4.7). This trend may be due to decrease in soil organic matter with depth and an increase in sand proportion with depth. Some researchers have observed a similar trend of bulk density with depth (Hatibu *et al,* 1995; Mahoo, 1992).

The observed increase of bulk density after field operation (Table 4.7) indicates that the field operations compacted the soil to some extent. Hatibu *et. al.,* (1995) observed the same trend of bulk density with field operations. Soil compaction changes the volume, size and shape of the conducting pore hence resulting in reduction of water intake rate and its movement into the soil. Thus soil compaction indicated by the increase in bulk density over the season (Table 4.7) is one of the factors which contributed in the reduction of infiltration rate and hydraulic conductivity over the season. Kayombo and Lal (1993) observed that soil compaction increases the soil bulk density and which resulted into rapid reduction of the soil hydraulic conductivity while Kayombo *et. al.,* (1991) reported the traffic

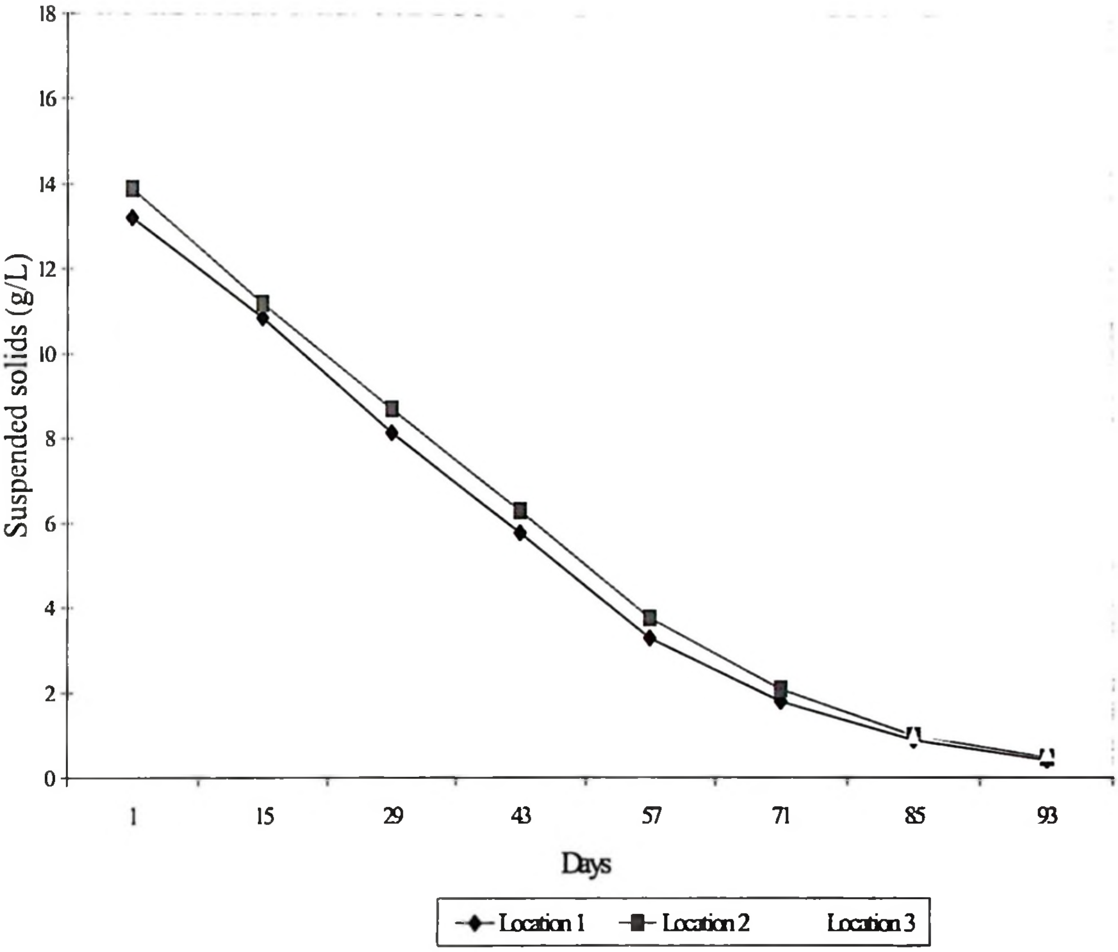


Figure 4.6 Variation of suspended sediments with time

Although sediments measured in the same period showed that there was no significant variation between locations, it can be seen from Table 4.10 and Figure 4.6 that highest values were recorded from location three while the lowest were recorded in location one. This indicates that more sediments were collected by water while flowing from the source to the fields. This is possibly due to the dispersion of soils particle because of its low stability aggregate resulting from low organic matter contents (Heil, *et. al.,*1997).

4.5 Effect of field operations on infiltration rate and hydraulic conductivity.

The initial and cumulative infiltration increased after weeding operation (Appendix 1 and Appendix 8) although generally decreased with time (crop stage). The result suggest that the tillage operation has positive effects on initial and cumulative infiltration as it reduces the sealing effect of fine particles and roughening the soil surface hence allowing more entry of water. This effect does not last long as the dispersed soil particle and suspended solids in irrigation water soon filled up the conducting pores which can be seen from non significant effect of overall trend of basic infiltration rate (Figure 4.1; Appendix 1). Azeved *et. al*., (1998) observed the same effect of tillage on infiltration.

4.6 Crop yield.

4.6.1 Yield per unit area

The mean crop yield per hectare and specific yield (water utilization efficiency) are presented in Table 4.11. Appendix 4 shows the required water, applied water, relative water supply and corresponding yield for each basin.

Table 4.11 Crop yield.

Location	Yield (t/ha)	Specific yield (Kg/m^3)
1	13.270 c	3.11 b
2	31.495 a	4.98 a
3	26.845 b	5.05 a
	se = 0.6468	se = 0.0319

se = Standard error

Means followed by the same letter along the column are not significantly different at P< 0.05.

It was observed that the mean crop yield from all locations shown in Table 4.11 were low compared to the normal range of 35 to 45 t/ha (Doorenbous and Kassam, 1979) . The crop yield differed significantly (P< 0.01) between location in which location two soils showed relatively higher yield ranging from 26.8 t/ha to 40.9 t/ha while location one had the lowest yields ranging from 6.1 to 22.8 t/ha (Appendix 4). The observed variation of yield between locations can be attributed to the differences of soil properties between locations and variation of infiltration rate and saturated hydraulic conductivity between locations. The soils in location one are coarse, while location two are medium textured soils and location three soils are fine textured (Table 4.3). Onion crop requires a medium soil textured soils which has moderate infiltration rate and hydraulic conductivity for optimum yields (Sys *et. al*, 1993; Landon,1991; Ayers and Westcot,1989). Thus soils in location two which had moderate infiltration rate and hydraulic conductivity were more favorable to the onion. The rapid infiltration rate and high hydraulic conductivity in location one soils may have resulted water stress due to the drain of water below crop root zone while low infiltration rate and hydraulic conductivity in location three soils may have resulted water logging problems which lead to relatively low yield observed in these locations.

4.6.2 Specific yield

The observed mean specific yields which ranged from 3.11 kg/m^3 to 5.05 kg/m^3 were generally low than the normal range of 8 to 10 kg/m^3 (Doorenbous and Kassam, 1979). Location one had significant low (P< 0.01) specific yield compared to location two and three (Table 4.11; Appendix 4).

Low water utilization efficient observed in this area is possibly due to high water application rate. It was observed that water application rate (discharge) during irrigation ranged between 1127 mm/h to 1934 mm/h which was much higher than infiltration rate which ranged between 3 mm/h and 72 mm/h (Table 4.12) This means that is only small fraction of the applied water infiltered into the soil and hence useful to the crops while the rest of water was waste. This may also contributed to low yield per unit area. The variation of specific yield between the locations is possibly due to the differences in water retention capacities between different textures. Location three soils had better water retention capacity due to relatively high clay content and showed higher specific yield while location one having lowest amount of clay content hence low water retention capacity had lowest water utilization efficient.

Table 4. 12 Irrigation water application rate

Location	Crop stage	Water application rate (mm/h)	Infiltration rate (mm/h)	Hydraulic conductivity (mm/h)
1	1	1656	72	22.7
	2	1891	6	22.3
	3	1934	42	16.18
	4	1672	36	9.4
2	1	1677	66	18.85
	2	1611	54	18.4
	3	1510	18	14.5
	4	1291	6	9.03
3	1	1473	6	1.94
	2	1329	3	1.43
	3	1232	3	1.03
	4	1127	3	0.8

4.7 Effect of crop water on yield.

Table 4.13 summarizes the results of crop water requirement (CWR), applied water (IW+RE) and relative water supply (RWS) for three locations at different crop development stages and for the whole season. Figure 4.7 shows the comparison of RWS for each crop stage and critical RWS. The daily crop water requirements for the whole season are shown in Appendix 5 while Appendices 6.1, 6.2 and 6.3 shows the RWS at every irrigation for three locations.

The results show that crop water requirement (CWR) ranged from 37.7 mm per stage to 145.2 mm per stage while applied water ranged from 47.9 mm per stage to 265 mm per stage. The stage RWS ranged from 0.92 to 5.36 and mean season RWS ranged from 1.59 to 2.28 (Table 4.13).

The RWS equal to or greater than 1.0 indicate that water supply met the theoretical minimum irrigation requirement. Therefore, adequacy can be assessed on the basis of satisfying the theoretical minimum requirement. The mean season RWS indicates that all locations received adequate irrigation water. Since the sensitivity of water deficit differs from one stage to another, the season RWS does not give a good indication of water adequate to the crop. Thus stage RWS gives a better indication of water adequacy to the crop. However from Table 4.13 and Figure 4.7 it can be shown that in all crop development stages the RWS were nearly or greater than critical RWS. These results indicate that the applied water was adequate in all crop development stages in all location.

Table 4.13 Crop water.

Location	Crop stage	CWR (mm)	IW+RE (mm)	Crop development stage RWS	Season RWS
1	1	61.2	184.2	3.01	1.59
	2	141.8	146.7	1.03	
	3	55.4	50.8	0.92	
	4	37.7	53.6	1.42	
2	1	57.9	310.4	5.36	2.28
	2	127.5	229.3	1.80	
	3	47.4	47.9	1.01	
	4	63	61.8	0.98	
3	1	58.5	171.3	2.93	1.73
	2	145.2	265.7	1.83	
	3	46.4	55.1	1.19	
	4	58.3	56.7	0.97	

Although the RWS indicates that the theoretical crop water requirement were met in all crop development stages, it was observed that most of the applied water was not useful for crop development due the water application rate during irrigation which was much higher than infiltration rate and hydraulic conductivity (Table 4.12). This means that most of applied water was a waste and not used by crops. This may have contributed.to observed low specific yield and crop yield in general.

The higher RWS than critical one shows that excess water was applied which could be used in other places for production. Over irrigation which is indicated by higher

RWS may be the cause of the observed mildew disease observed in location three fields and some of location two fields which might have contributed to low yields.

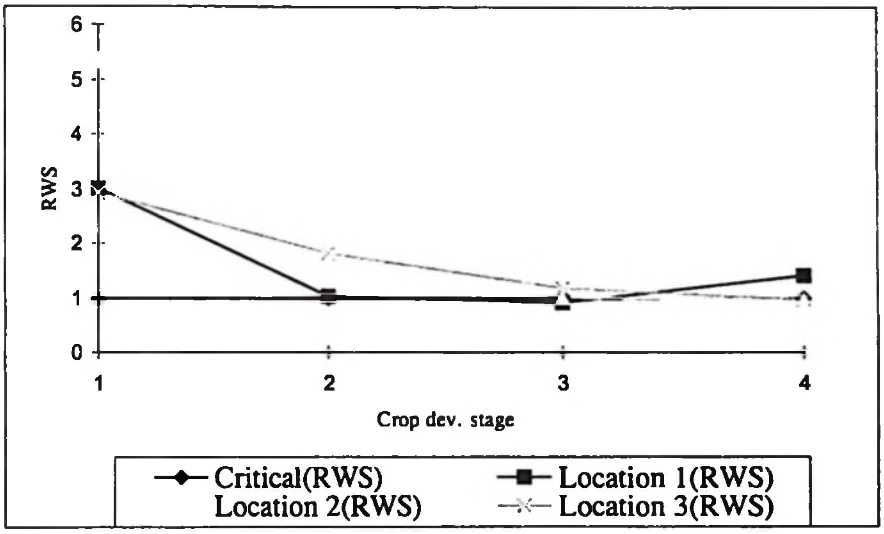


Figure 4.7. Relative water supply (RWS)

Further more it was observed that during the first stage RWS was higher in all locations and generally RWS decreased with crop development stages (Figure 4.7). This trend shows that the application of water in the field based on the available water and not on crop water requirement. At the beginning of the onion growing season, there were no water scarcity while as time went on the water levels in the canal also dropped while the time allocated for each field remained the same. Oad and Levin (1985) observed a similar trend of RWS with water supply. The decrease of the RWS with time reflects an increase in demand as well as decrease in water supply. The location of onion fields relative to the main canal may be another reason for observed high RWS. Most of the onion field are located at upper and middle part of the scheme and as in most of other irrigation schemes these areas gets relatively high amount of water compared to lower fields.

4.7.1 Effect of irrigation scheduling on water supply

During the research it was observed that the interval of water application ranged between 7 to 14 days. This was because of a fixed rotation method practiced in this area. However the required (calculated) interval ranged from two to six days depending on soil type and crop development stage (Table 4.14). Chi-square goodness of fit (χ^2) show the required (calculated) and observed (practiced) irrigation interval differed significantly (P<0.01) in all location (Table 4.15).

Table 4.14 Irrigation interval

Stage	Location 1		Location 2		Location 3	
	Required (days)	Actual (days)	Required (days)	Actual (days)	Required (days)	Actual (days)
1	4	7	4	7	5	7
2	4	7	4	7	4	7
3	4	14	5	14	6	14
4	3	14	2	14	2	14

Table 4.15 Irrigation interval Chi-square test.

Location	χ^2_{cal}	$\chi^2_{3,0.01}$	Comment
1	69.83	11.345	s
2	92.7	11.345	s
3	85.7	11.345	s

s = significant difference

The observed far spaced irrigation interval compared to the required interval may be one of the causes of over-irrigation as indicated by higher RWS in almost at every irrigation (Appendix 6). When the irrigation interval is far spaced, farmers tend to apply excess water in the field which will be enough up to next irrigation. Application of excess water results into water logging problems in low permeability soils while may result leaching down of nutrients on rapid infiltration soils. The far spaced irrigation interval also resulted water stress in some fields which had rapid infiltration rate and high hydraulic conductivity soils where may have resulted in yields reduction. Sys *et. al.*, (1993) reported that onion require light irrigation which is closely spaced of about two to four days.

From the above results it can be shown that the applied water was adequate in all crop development stage although due to much higher water application rate compared to infiltration rate, most of the applied water was not useful to the crops. Rapid infiltration rate and hydraulic conductivity in course textured soils and far spaced irrigation interval may have resulted water stress to crop while low infiltration rate and hydraulic conductivity in clay dominated soils resulted water logging problems which contributed to low yields.

4.7.2 Relationship between relative water supply (RWS) and crop yield.

Figures 4.8, 4.9, and 4.10 shows the relationship between the relative water supply (RWS) crop (onion) yield for location one, two and three respectively. It was observed that the maximum yields were 22.8 t/ha and 4.52 kg /m^3 corresponding to the RWS of 1.7 for location one, 40.1 t/ha and 6.04 kg /m^3 corresponding to the RWS of 2.28 for location two and 32.3 t/ha and 7.21 kg/m^3 corresponding to RWS of 1.45 for location three (Appendix 4).

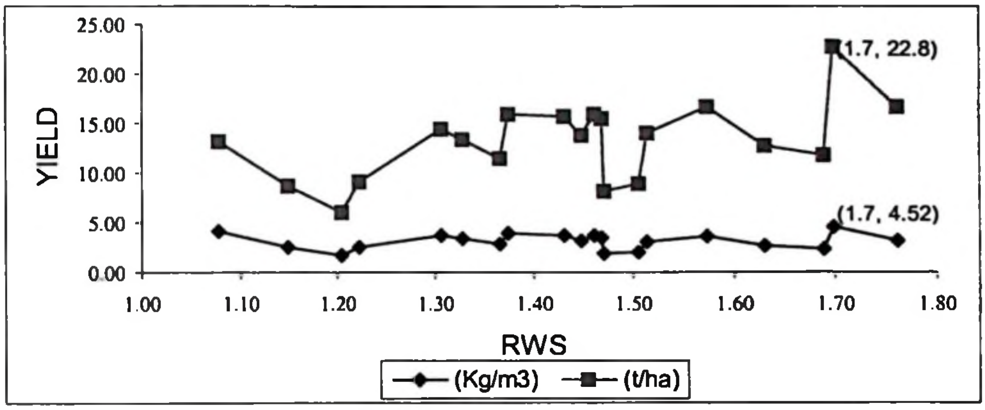


Figure 4.8 Relative water supply (RWS) and crop yield - Location 1

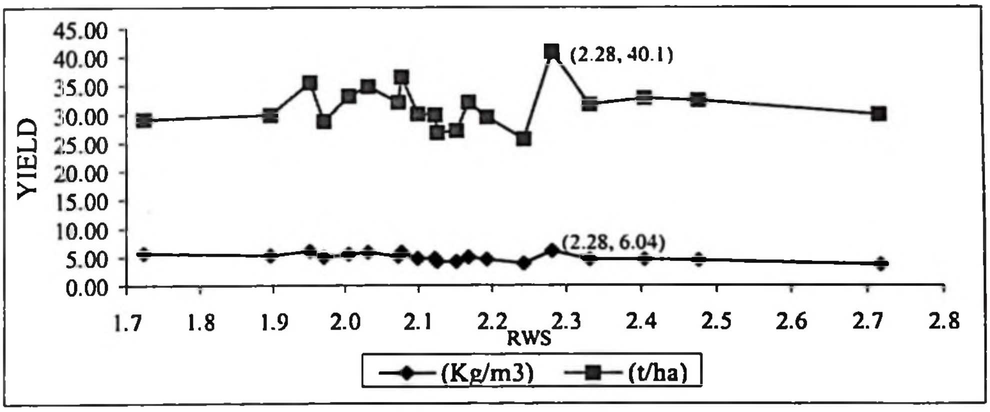


Figure 4.9 Relative water supply (RWS) and crop yield - Location 2

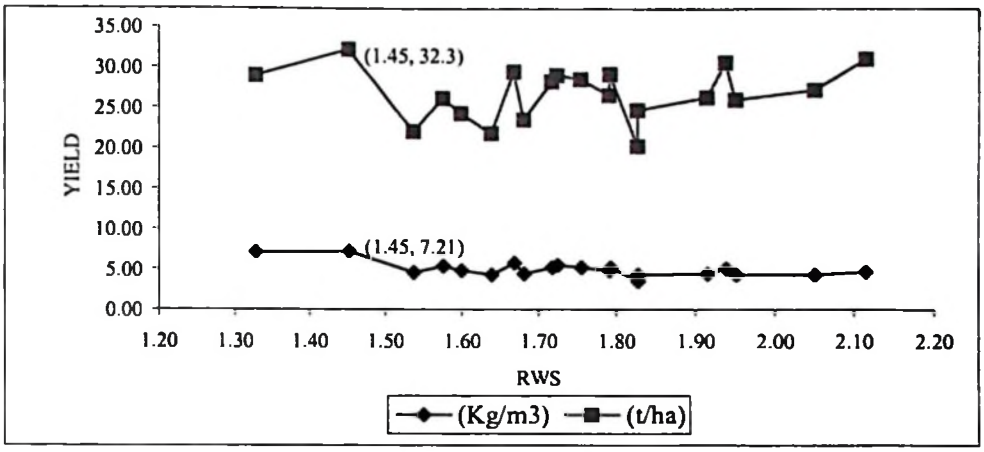


Figure 4.10 Relative water supply (RWS) and crop yield - Location 3

It can be observed that the RWS higher than the one produced maximum yield resulted constant or reduction of yield (Figures 4.8 – 4.10). From this results it can be shown that the supply of more or excess irrigation water does not necessary mean higher yield particularly if the water exceed crop water requirement or not properly managed. Furthermore it was observed that yields were maximized at 1.7 RWS for location one (sandy loam) soils, 2.28 RWS for location two (sandy clay loam) soils and 1.45 RWS for location three (clay) soils. This indicate that different soil textures have different RWS for maximum yield.

4.8. Effect of infiltration rate and saturated hydraulic conductivity (K_s) on yield

The effect of saturated hydraulic conductivity and infiltration rate on crop yield were analysed by correlation test. The results showed a correlation coefficient (R) of 0.4036 for saturated hydraulic conductivity and 0.5767 for infiltration rate (Table 4.16).

Table 4.16 Relation between infiltration rate, Ks and crop yield.

Factor	Correlation coefficient
Hydraulic conductivity (m/d)	0.4036
Infiltration rate (mm/h)	0.5767

The correlation test showed positive coefficients for both factors indicating that the yield increased with the increase of infiltration rate and saturated hydraulic conductivity. Alva and Petersen (1979) reported a similar observation of increase of yield with increase of saturated hydraulic conductivity. However too low infiltration rate and hydraulic conductivity leads to poor soil water drainage which affects the crop yield negatively. The effect of low infiltration rate and hydraulic conductivity was evidenced by observed water logging for three to four days after irrigation which also caused poor aeration and mildew disease to onion in all fields of location three and some from location two which may have contributed on low yields.

In course textured soils, rapid infiltration rate and high hydraulic conductivity leads rapid drain of water hence causing water stress to the crops and leaching of plant nutrients below root zone which affects yield negatively. In location one a sign of wilting was observed five to six days after irrigation showing that crops were suffering from water stress although the relative water supply (RWS) was nearly or greater than critical in every irrigation (Appendix 6.1 to 6.3) This indicates that due to rapid infiltration and high hydraulic conductivity, water drained below onion root zone.

Water logging due to low infiltration rate and hydraulic conductivity in clay dominated soils, application of excess water during irrigation which resulted poor aeration and crop disease such as mildew in low permeability soils and rapid infiltration and hydraulic conductivity in course textured soils which resulted water stress to the crops may be the main reasons for the low yields of onion in the study area.

4.9 Effect of soil properties on crop yield

Summary of soil chemical properties measured before and after field operations and at two depths in three locations is given in Table 4.17. The details and statistical analyses are shown in Appendix 7.

Cation exchange capacity

The mean cation exchange capacity (CEC) of the soils was 11.09 me/100g, for soils in location one, 20.14 me/100g for location two and 19.17 me/100g for location three (Table 4.17). The observed range of CEC during the study can be rated according to Landon, 1991; Baize (1993) as medium. This rating implies that the ability of exchangeable cations in study area soils to neutralise negative charge of the soil was at medium level. The CEC values of location one were significantly low ($P<0.001$) compared to other locations while the CEC of location two and three were not significantly different from each other (Table 4.17).

The CEC measurements are normally done to indicate the overall potential fertility of the soils. High levels indicate the high fertility of the soil while low levels indicate the low soil fertility status. Soils in location one were found to have low CEC values (<15) indicating the low fertility status. Soils in location two and three had significantly relatively higher CEC values indicating relatively soil fertility status. The low fertility status of soils in location one can be attributed to the low percentage of clay particles which are responsible for nutrient holding. The rapid infiltration rate and high hydraulic conductivity in observed in location one may have also contributed to low CEC. Rapid infiltration results in downward leaching of plant nutrients. Therefore nutrients are easily leached downward in location one compared to others. Due to rapid infiltration rate and hence leaching of plant nutrients, location one had marginal values of CEC for surface irrigation (Landon, 1991).

It can be observed that CEC decreased significantly ($P< 0.05$) with depth (Table 4.17). Since CEC gives an indication of the overall potential fertility of the soil, the top soil is more fertile and the fertility decrease with depth. Normally topsoil with high organic matter content retains more cation exchange. In subsoil, the opposite is the case since there is less retention and exchange of cations. Kimaro *et al.* (1995) observed a similar trend of soil fertility with depth.

Generally the observed values of CEC indicate the soils are fairly potential for crop production (Landon,1991).

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

On the basis of this study, the following conclusions can be made:

1. Application of irrigation water from Lukosi river in onion fields caused the dispersion of soil into finer particles which resulted into filling and sealing many of the conducting pores. Substantial amount of suspended sediments which ranged between 25.5t/ha to 42.15t/ha from irrigation water were deposited on onion fields over the season. This resulted soil crusting and sealing of conducting pores.

Continuos filling and sealing of conducting pores due to dispersion effect and high amount of suspended sediments caused the infiltration rate and hydraulic conductivity to decrease for over 50% over season. Low infiltration rate and hydraulic conductivity resulted water logging problems in heavy texture soils while rapid infiltration and high hydraulic conductivity caused water stress to crops in coarse textured soils. Water logging problems and water stress contributed into low yield of onion observed in the study area.

The irrigation water from Lukosi river was low salinity and low sodium water. The electrical conductivity (ECw) varied from 0.86dS/m to 1.475dS/m while SAR varied from 4.01me/l to 7.69me/l over the season. The concentration of suspended sediments was high ranging from 0.412g/l to 16.213g/l over the season. This water can be used for irrigation with most crops without causing salinity problems.

2. The soils in the area ranged between sandy loam and heavy cracking clay. The soils are neither saline nor sodic. The soils are slightly alkaline with pH ranging from 7.4 to 7.8. Soils had generally very low organic matter (OM) ranging from 1.13% to 3.05%. Due to the low organic matter, the soils had poor structural stability therefore easily dispersed when water is applied. In some parts of the area the soils had very low infiltration rate and hydraulic conductivity particularly in the fields with high clay contents. In such soils, permeability and drainage properties are not adequate and water logging was observed during irrigation. Water logging caused poor aeration and crop disease that contributed to low yields in these soils. Rapid infiltration rate and high hydraulic conductivity in course textured soils caused drain of water below crop root zone. This resulted into water stress to the crop particularly in those crop stages which are more sensitive to water deficit hence poor crop development and reduced yield.

3. The irrigation water application was adequately high with relative water supply (RWS) ranging from 0.92 to 5.36 per crop stage. The water application rate was much higher compared to the infiltration rate, which caused most of the water to be waste, and not used by crops. The higher RWS were observed at the beginning of the season when there was no water scarcity. This shows that the water application depended on the

available water from the source and not crop water requirement. Over irrigating resulted in other management problems such as water logging, poor aeration and crop diseases in low permeability soils. The irrigation interval of 7 days was the main reason of applying excess water to the fields.

4. The crop performance was generally low when compared to the normal ranges of 35 - 45t/ha and 8-10Kg/m^3 for yield per unit area and specific yield respectively. The medium textured soils had better yield of 31.495t/h followed by heavy textured soils with mean yield of 26.845t/h while the coarse textured soils had very low yield of 13.270t/h. The clay dominated soils showed better specific yield (water utilisation efficient) of 5.05, and 4.98 for medium textured soil while coarse soils had very low specific yield of 3.11. Clay dominated soils have very poor water permeability which causes poor aeration and water logging problems. Soils which are dominated by sand have rapid infiltration, high hydraulic conductivity and low water retention capacity thus resulting water stress to crops and plant nutrients are easily leached below root zone. This could be the reason for low yield of onion in this area. Crop (onion) was favored by medium textured soils that have moderate infiltration rate and hydraulic conductivity. High water application rate was the main reason for low specific yield in the area.

5.2 Recommendations

Water from Lukosi river has good quality and it can be used for irrigation in all types of soils. Thus to ensure this water is used properly for irrigation without causing permeability problems, the following recommendations can be used in order to improve yield and sustainable production of onion.

1. In fields with high percentages of sand hence rapid infiltration and hydraulic conductivity, small basin should be used to ensure that the water is uniformly distributed during irrigation. The use of large basin result in poor water distribution due to rapid downward movement of water while low lateral flow. This is more serious when the volume of water is low and the basin area is large.

2. Onion requires the first 30cm of the soil to be kept moist for almost throughout the season. Over irrigating cause poor aeration and crop diseases such as root rot which results into yield reduction. Therefore light irrigation which is closely spaced interval of about 3 to 5 days is recommended in onion field as opposed to currently practised interval of 7 to 14 days. In additional to this, water holding capacity of the soils should be improved by additional of organic materials. This will enhance the readily available water to the crop and ensure that crops receive adequate water all the time without causing secondary problems in the soil or crop. In the soils with low permeability, in

addition to closely spaced interval, low volume with extended duration of irrigation should be practised to ensure more water supply which will meet crop requirement.

3. Low infiltration rate and hydraulic conductivity in clay dominated soils and poor water retention capacity in sandy soils can be improved by improving the soil structure. This can be attained by addition of organic residues. Manure, crop residues such as rice and maize will improve soil infiltration, permeability and water retention capacity properties of the soils. This practice is within the farmers' capacity and they only need to be mobilized. Addition of organic residues will also improve the fertility of the soils.

4. Unless the permeability properties have been improved, the fields that are dominated by sandy soils should be used for other crops such as beans and maize rather than onions which is shallow rooted and sensitive to water deficit. Onion requires the top soils to be kept wet most of the time which is not possible in sandy soils which has poor water retention capacity.

5. Irrigation water drainage should be given special attention especially in low permeability soils rather than depending on natural drainage. This will reduce the accumulation of salts that may later on hinder the growth of salinity sensitive crops like onion.

6. There is a need of conducting a study on the impact of the scheme on environment and its effect on health.

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APPENDICES

Appendix 1 INFILTRATION .

Location	Stage	Date	Init. Inf. (mm/h)	Basic. Inf. (mm/h)	Cum. Inf. (mm).	Mean values per stage Init. Inf. (mm/h)	Basic. Inf. (mm/h)	Cum. Inf. (mm)
1	1	13/4/99	440	84	340	420	72	295
		*25/4/99	420	72	295			
		27/4/99	400	60	250			
	2	11/5/99	390	60	250	345	60	276
		*16/5/99	420	60	320			
		25/5/99	360	60	280			
		8/6/99	210	60	228			
	3	*20/6/99	270	48	194	240	42	183
		26/6/99	210	36	172			
	4	10/7/99	180	36	167	180	36	167
2	1	12/4/99	360	78	264	310	66	246
		26/4/99	210	60	221			
		*2/5/99	360	60	254			
	2	10/5/99	270	60	219	280	54	224
		*23/5/99	330	60	238			
		7/6/99	240	42	214			
	3	21/6/99	66	18	64	60	18	50
		5/7/99	54	18	36			
	4	13/7/99	48	6	31	48	6	31
3	1	11/4/99	124	6	36	120	6	35
		25/4/99	96	6	31			
		*1/5/99	140	6	38			
	2	9/5/99	78	3	23	90	3	23
		*27/5/99	120	3	27			
		6/6/99	72	3	20			
	3	20/6/99	60	3	22	60	3	20
		4/7/99	60	3	18			
	4	12/7/99	30	3	16	30	3	16

* Indicate the measurement were done after weeding operation.

Appendix 1.1 Variation of basic infiltration between locations

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Location 1	4	210	52.5	273
Location 2	4	144	36	816
Location 3	4	15	3.75	2.25

ANOVA

Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2	4918.5	2459.25	6.760824742	0.016120942	4.256492048
Within Groups	9	3273.75	363.75			
Total	11	8192.25				

Appendix 2 SATURATED HYDRAULIC CONDUCTIVITY

Location	Stage	Date	K_s (m/d)	Stage K_s (m/d)	Loc. K_s (m/d)
1	1	13/4/99	0.5472	0.5442	0.4236
		27/4/99	0.5412		
	2	11/5/99	0.5416	0.5354	
		25/5/99	0.5388		
		8/6/99	0.5258		
	3	26/6/99	0.3884	0.3884	
	4	10/7/99	0.2264	0.2264	
2	1	12/4/99	0.4616	0.4524	0.3646
		26/4/99	0.4432		
	2	10/5/99	0.4428	0.4416	
		23/5/99	0.4423		
		5/6/99	0.4397		
	3	21/6/99	0.3615	0.3476	
		5/7/99	0.3337		
	4	13/7/99	0.2167	0.2167	
3	1	11/4/99	0.0478	0.0466	0.03123
		25/4/99	0.0454		
	2	9/5/99	0.0356	0.0344	
		27/5/99	0.0362		
		6/6/99	0.0314		
	3	20/6/99	0.0239	0.0247	
		4/7/99	0.0255		
	4	12/7/99	0.0192	0.0192	

Appendix 2.1 Variation of K_s between locations

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Location 1	4	1.6944	0.4236	0.02239
Location 2	4	1.4583	0.364575	0.011934
Location 3	4	0.1249	0.031225	0.000145

ANOVA

Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2	0.358086	0.179043	15.58319	0.001193	4.256492
Within Groups	9	0.103405	0.011489			
Total	11	0.461491				

Appendix 2.2 Regression equations of Ir on Ks

Location	Regression equation	R^2	se	Probability
1	$K_s = 101.44Ir + 9.5311$	0.844	30.85	0.08136 ns
2	$K_s = 244.77Ir - 53.236$	0.876	65.06	0.06395 ns
3	$K_s = 106.365Ir + 0.4287$	0.727	46.1	0.147 0 ns
Overall	$K_s = 122.992Ir - 2.8432$	0.852	16.2	$1.86*10^{-5}$ s

where:

K_s = saturated hydraulic conductivity (m/d).

Ir = basic infiltration rate (mm/h)

R^2 = coefficient of determination

se = standard error

ns = not significant at $P < 0.05$

s = significant at $P < 0.001$

Appendix 3 SOIL PHYSICAL PROPERTIES.

Appendix 3.1 Variation of soil proportions with location and depth

i) Sand

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	7993.000	3996.500	49.0168	0.0000	s
Depth	1	102.722	102.722	1.2599	0.2879	ns
Error	10	815.333	81.533			

Coefficient of Variation: 20.29%

ii) Silt

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	144.111	72.056	1.7508	0.2229	ns
Depth	1	242.000	242.000	5.8801	0.0358	s
Error	10	411.556	41.156			

Coefficient of Variation: 33.57%

iii) Clay

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	6321.778	3160.889	63.2740	0.0000	s
Depth	1	29.389	29.389	0.5883		ns
Error	10	499.556	49.956			

Coefficient of Variation: 19.42%

iv) Organic matter (OM)

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	11.098	5.549	12.7827	0.0018	s
Depth	1	23.120	23.120	53.2610	0.0000	s
Error	10	4.341	0.434			

Coefficient of Variation: 31.51%

Appendix 3.2 Bulk density.

Location	Site	Depth (cm)	Before field operations B.D G/cm^3	Av. B.D g/cm^3	% M.C %	After field operations Bulk dens. (g/cm^3)	Av. B.D (g/cm^3)	% M.C %
1	1	0-15	1.445	**1.49**	15.58	1.58	**1.54**	7.65
		15-30	1.441		13.15	1.52		8.98
		30-45	1.574		5.07	1.52		8.99
	2	0-15	1.484	**1.56**	16.59	1.32	**1.48**	7.86
		15-30	1.613		14.59	1.50		9.16
		30-45	1.594		7.13	1.61		10.84
	3	0-15	1.54	**1.48**	13.18	1.54	**1.51**	12.23
		15-30	1.39		11.27	1.48		14.65
		30-45	1.51		6.83	1.51		15.84
2	1	0-15	1.275	**1.38**	23.78	1.39	**1.38**	18.35
		15-30	1.405		23.69	1.35		20.25
		30-45	1.47		14.65	1.38		13.72
	2	0-15	1.203	**1.27**	27.97	1.35	**1.46**	20.42
		15-30	1.238		18.89	1.52		16.79
		30-45	1.356		8.47	1.52		11.35
	3	0-15	1.214	**1.2**	26.63	1.38	**1.42**	22.56
		15-30	1.147		16.72	1.35		18.46
		30-45	1.243		10.27	1.53		16.25
3	1	0-15	1.18	**1.3**	35.47	1.27	**1.31**	38.17
		15-30	1.329		35.35	1.31		26.69
		30-45	1.245		33.94	1.36		23.85
	2	0-15	1.27	**1.3**	35.56	1.21	**1.29**	41.09
		15-30	1.336		34.55	1.27		31.47
		30-45	1.323		31.203	1.38		32.23
	3	0-15	1.209	**1.2**	43.21	1.28	**1.3**	42.21
		15-30	1.206		38.27	1.3		32.84
		30-45	1.306		36.17	1.32		26.83

Appendix 3.2.1 Variation of bulk density with location, depth and time.

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	·2	0.487	0.243	44.0723	0.0000	s
Depth	2	0.073	0.037	6.6493	0.0037	s
Sampling period	1	0.041	0.041	7.4856	0.0098	s
Error	34	0.188	0.006			

Coefficient of Variation: 5.38%

Appendix 4 RELATIVE WATER SUPPLY (RWS) AND YIELD.

	Basin No.	Water (mm)			Yield	
		Required	Applied	RWS	(t/ha)	(Kg/m3)
Location 1	1	296.8	466.85	1.57	16.7	3.58
	2	296.8	522.73	1.76	16.7	3.19
	3	296.8	362.87	1.22	9.1	2.51
	4	296.8	387.69	1.31	14.5	3.74
	5	296.8	320.03	1.08	13.2	4.12
	6	296.8	504.19	1.70	22.8	4.52
	7	296.8	435.84	1.47	15.5	3.56
	8	296.8	394.12	1.33	13.4	3.40
	9	296.8	433.68	1.46	16	3.69
	10	296.8	449.28	1.51	14	3.12
	11	296.8	483.80	1.63	12.8	2.65
	12	296.8	340.87	1.15	8.7	2.55
	13	296.8	424.56	1.43	15.7	3.70
	14	296.8	405.50	1.37	11.5	2.84
	15	296.8	429.63	1.45	13.8	3.21
	16	296.8	446.67	1.50	8.9	1.99
	17	296.8	407.98	1.37	16	3.92
	18	296.8	357.37	1.20	6.1	1.71
	19	296.8	501.15	1.69	11.8	2.35
	20	296.8	436.57	1.47	8.2	1.88
	Mean		**425.57**	**1.43**	**13.27**	**3.11**
Location 2	1	296.8	691.72	2.33	31.8	4.60
	2	296.8	638.57	2.15	27.2	4.26
	3	296.8	630.50	2.12	29.9	4.74
	4	296.8	650.83	2.19	29.6	4.55
	5	296.8	602.39	2.03	34.9	5.79
	6	296.8	629.64	2.12	26.8	4.26
	7	296.8	614.91	2.07	32.1	5.22
	8	296.8	806.40	2.72	29.9	3.71
	9	296.8	735.15	2.48	32.5	4.42
	10	296.8	584.71	1.97	28,8	4.93
	11	296.8	665.75	2.24	25.7	3.86
	12	296.8	511.61	1.72	29.2	5.71
	13	296.8	622.87	2.10	30.1	4.83
	14	296.8	643.40	2.17	32.1	4.99
	15	296.8	562.93	1.90	30	5.33
	16	296.8	616.20	2.08	36.6	5.94
	17	296.8	594.86	2.00	33.3	5.60
	18	296.8	578.75	1.95	35.6	6.15
	19	296.8	677.03	2.28	40.9	6.04

	20	296.8	713.63	2.40	32.9	4.61
	Mean		**638.59**	**2.15**	**31.495**	**4.98**
Location 3	1	308.4	474.10	1.54	22.1	4.66
	2	308.4	505.68	1.64	21.9	4.33
	3	308.4	563.70	1.83	20.2	3.58
	4	308.4	518.42	1.68	23.5	4.53
	5	308.4	493.31	1.60	24.3	4.93
	6	308.4	486.19	1.58	26.2	5.39
	7	308.4	531.74	1.72	28.3	5.32
	8	308.4	553.08	1.79	26.6	4.81
	9	308.4	632.46	2.05	27.3	4.32
	10	308.4	541.47	1.76	28.6	5.28
	11	308.4	590.85	1.92	26.3	4.45
	12	308.4	552.59	1.79	29.2	5.28
	13	308.4	598.12	1.94	30.7	5.13
	14	308.4	529.61	1.72	29.1	5.49
	15	308.4	601.75	1.95	26	4.32
	16	308.4	563.82	1.83	24.7	4.38
	17	308.4	652.28	2.12	31.1	4.77
	18	308.4	448.00	1.45	32.3	7.21
	19	308.4	409.80	1.33	29	7.08
	20	308.4	514.62	1.67	29.5	5.73
	Mean		**538.08**	**1.74**	**26.845**	**5.05**

Appendix 4.1 Variation of yield (t/ha) between locations

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Location 1	20	265.4	13.27	14.86747
Location 2	20	629.9	31.495	13.13103
Location 3	20	536.9	26.845	10.80682

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*Comment*
Between Groups	3587.025	2	1793.513	138.6547	1.27E-22	s
Within Groups	737.301	57	12.93511			
Total	4324.326	59				

Appendix 4.2 Variation of water utilisation efficiency between locations.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Location 1	20	62.22656	3.111328	0.607869
Location 2	20	99.53027	4.976514	0.523661
Location 3	20	101.0046	5.050228	0.781868

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Comment*
Between Groups	48.29121	2	24.14561	37.85768	3.46E-11	s
Within Groups	36.35456	57	0.637799			
Total	84.64578	59				

Appendix 5 DAILY CROP WATER REQUIREMENT (ETc)

Date	Day No.	ETo	Kc	ETc
11 -Apr-99	1	4	0.7	2.8
12 -Apr-99	2	3.8	0.7	2.7
13 -Apr-99	3	4.8	0.7	3.4
14 -Apr-99	4	3.8	0.7	2.7
15 -Apr-99	5	3.6	0.7	2.5
16 -Apr-99	6	4.3	0.7	3.0
17 -Apr-99	7	3.8	0.7	2.7
18 -Apr-99	8	4.5	0.7	3.2
19 -Apr-99	9	3.4	0.7	2.4
20 -Apr-99	10	4	0.7	2.8
21 -Apr-99	11	4	0.71	2.8
22 -Apr-99	12	4.7	0.71	3.3
23 -Apr-99	13	4.5	0.72	3.2
24 -Apr-99	14	4.1	0.73	3.0
25 -Apr-99	15	5.7	0.74	4.2
26 -Apr-99	16	4.1	0.74	3.0
27 -Apr-99	17	3.6	0.75	2.7
28 -Apr-99	18	3.3	0.76	2.5
29 -Apr-99	19	3.9	0.76	3.0
30 -Apr-99	20	3.5	0.76	2.7
1-May-99	21	3.5	0.77	2.7
2-May-99	22	3.4	0.78	2.7
3-May-99	23	3.6	0.79	2.8
4-May-99	24	3	0.8	2.4
5-May-99	25	3.2	0.8	2.6
6-May-99	26	3.3	0.8	2.6
7-May-99	27	2.4	0.81	1.9
8-May-99	28	3.2	0.82	2.6
9-May-99	29	4	0.83	3.3
10-May-99	30	3.2	0.83	2.7
11-May-99	31	3.9	0.84	3.3
12-May-99	32	3.6	0.84	3.0
13-May-99	33	1.9	0.84	1.6
14-May-99	34	3.5	0.85	3.0
15-May-99	35	3.5	0.86	3.0
16-May-99	36	3.7	0.86	3.2
17-May-99	37	3.2	0.87	2.8
18-May-99	38	4.3	0.87	3.7
19-May-99	39	4.1	0.88	3.6
20-May-99	40	3	0.88	2.6
21-May-99	41	4	0.89	3.6
22-May-99	42	4	0.9	3.6
23-May-99	43	4.1	0.9	3.7
24-May-99	44	3.6	0.91	3.3
25-May-99	45	4.2	0.91	3.8
26-May-99	46	4.3	0.91	3.9
27-May-99	47	4.3	0.92	4.0
28-May-99	48	3.7	0.92	3.4
29-May-99	49	3.5	0.92	3.2
30-May-99	50	3.5	0.93	3.3

31-May-99	51	3.4	0.93	3.2
1-Jun-99	52	3.4	0.94	3.2
2-Jun-99	53	3.2	0.95	3.0
3-Jun-99	54	2.6	0.95	2.5
4-Jun-99	55	2.3	0.95	2.2
5-Jun-99	56	3.1	0.96	3.0
6-Jun-99	57	3.2	0.96	3.1
7-Jun-99	58	3	0.96	2.9
8-Jun-99	59	3.2	0.96	3.1
9-Jun-99	60	3.1	0.96	3.0
10-Jun-99	61	3.4	0.97	3.3
11-Jun-99	62	3.8	0.97	3.7
12-Jun-99	63	3.1	0.98	3.0
13-Jun-99	64	3.2	0.98	3.1
14-Jun-99	65	4	0.98	3.9
15-Jun-99	66	4.1	0.99	4.1
16-Jun-99	67	3.2	1	3.2
17-Jun-99	68	3.2	1	3.2
18-Jun-99	69	2.3	1	2.3
19-Jun-99	70	3.7	1	3.7
20-Jun-99	71	3.6	1	3.6
21-Jun-99	72	3.8	1	3.8
22-Jun-99	73	2.9	1	2.9
23-Jun-99	74	3.9	1	3.9
24-Jun-99	75	3.3	1	3.3
25-Jun-99	76	3.3	1	3.3
26-Jun-99	77	2	0.99	2.0
27-Jun-99	78	3.4	0.98	3.3
28-Jun-99	79	2.6	0.98	2.5
29-Jun-99	80	3.3	0.98	3.2
30-Jun-99	81	2.4	0.97	2.3
1-Jul-99	82	3.1	0.96	3.0
2-Jul-99	83	3	0.96	2.9
3-Jul-99	84	3.3	0.95	3.1
4-Jul-99	85	3	0.94	2.8
5-Jul-99	86	3.1	0.93	2.9
6-Jul-99	87	3	0.92	2.8
7-Jul-99	88	3	0.91	2.7
8-Jul-99	89	2.6	0.9	2.3
9-Jul-99	90	2.7	0.88	2.4
10-Jul-99	91	3.2	0.84	2.7
11-Jul-99	92	3.1	0.82	2.5
12-Jul-99	93	3.4	0.8	2.7
13-Jul-99	94	2.6	0.77	2.0
14-Jul-99	95	2.8	0.75	2.1
15-Jul-99	96	2.9	0.75	2.2
16-Jul-99	97	3.4	0.75	2.6
17-Jul-99	98	2.6	0.75	2.0
18-Jul-99	99	2.5	0.75	1.9
19-Jul-99	100	2.3	0.75	1.7
20-Jul-99	101	3.1	0.75	2.3
21-Jul-99	102	3.1	0.75	2.3
22-Jul-99	103	4.4	0.75	3.3

23-Jul-99	104	4.5	0.75	3.4
24-Jul-99	105	3.6	0.75	2.7

Appendix 6.1 RELATIVE WATER SUPPLY (RWS)
LOCATION 1.

RWS =(RE + IW)/(ETc)
RE = Effective rainfall

Date	Day No.	ETo (mm/day)	ETc (mm/day)	Total ETc	RE (mm)	IW (mm)	(RE + IW) (mm)	RWS
11 -Apr-99		4	2.8		2.4			
12 -Apr-99		3.8	2.7		2.4			
13 -Apr-99	1	4.8	3.4	14.2	2.4	69.6	74.9	5.27
14 -Apr-99	2	3.8	2.7		2.4			
15 -Apr-99	3	3.6	2.5		1.1			
16 -Apr-99	4	4.3	3.0		0			
17 -Apr-99	5	3.8	2.7		0			
18 -Apr-99	6	4.5	3.2	28.0	0	47.1	47.1	1.68
19 -Apr-99	7	3.4	2.4		0			
20 -Apr-99	8	4	2.8		0			
21 -Apr-99	9	4	2.8		0			
22 -Apr-99	10	4.7	3.3		0			
23 -Apr-99	11	4.5	3.2		0			
24 -Apr-99	12	4.1	3.0		0			
25 -Apr-99	13	5.7	4.2		0			
26 -Apr-99	14	4.1	3.0		0			
27 -Apr-99	15	3.6	2.7	19.0	0	27.9	27.9	1.46
28 -Apr-99	16	3.3	2.5		0			
29 -Apr-99	17	3.9	3.0		0			
30 -Apr-99	18	3.5	2.7		0			
1-May-99	19	3.5	2.7		0			
2-May-99	20	3.4	2.7		0			
3-May-99	21	3.6	2.8		0			
4-May-99	22	3	2.4	32.0	0	54.1	54.1	1.69
5-May-99	23	3.2	2.6		0			
6-May-99	24	3.3	2.6		0			
7-May-99	25	2.4	1.9		0			
8-May-99	26	3.2	2.6		0			
9-May-99	27	4	3.3		0			
10-May-99	28	3.2	2.7		0			
11-May-99	29	3.9	3.3		0			
12-May-99	30	3.6	3.0		0			
13-May-99	31	1.9	1.6		0			
14-May-99	32	3.5	3.0		0			
15-May-99	33	3.5	3.0		0			

16-May-99	34	3.7	3.2	65.7	0	48.6	48.6	**0.74**
17-May-99	35	3.2	2.8		0			
18-May-99	36	4.3	3.7		0			
19-May-99	37	4.1	3.6		0			
20-May-99	38	3	2.6		0			
21-May-99	39	4	3.6		0			
22-May-99	40	4	3.6		0			
23-May-99	41	4.1	3.7		0			
24-May-99	42	3.6	3.3		0			
25-May-99	43	4.2	3.8		0			
26-May-99	44	4.3	3.9		0			
27-May-99	45	4.3	4.0		0			
28-May-99	46	3.7	3.4		0			
29-May-99	47	3.5	3.2		0			
30-May-99	48	3.5	3.3		0			
31-May-99	49	3.4	3.2		0			
1-Jun-99	50	3.4	3.2		0			
2-Jun-99	51	3.2	3.0		0			
3-Jun-99	52	2.6	2.5		0			
4-Jun-99	53	2.3	2.2		0			
5-Jun-99	54	3.1	3.0	44.8	0	44.0	44.0	**0.98**
6-Jun-99	55	3.2	3.1		0			
7-Jun-99	56	3	2.9		0			
8-Jun-99	57	3.2	3.1		0			
9-Jun-99	58	3.1	3.0		0			
10-Jun-99	59	3.4	3.3		0			
11-Jun-99	60	3.8	3.7		0			
12-Jun-99	61	3.1	3.0		0			
13-Jun-99	62	3.2	3.1		0			
14-Jun-99	63	4	3.9		0			
15-Jun-99	64	4.1	4.1		0			
16-Jun-99	65	3.2	3.2		0			
17-Jun-99	66	3.2	3.2		0			
18-Jun-99	67	2.3	2.3		0			
19-Jun-99	68	3.7	3.7	55.4	0	50.8	50.8	**0.92**
20-Jun-99	69	3.6	3.6		0			
21-Jun-99	70	3.8	3.8		0			
22-Jun-99	71	2.9	2.9		0			
23-Jun-99	72	3.9	3.9		0			
24-Jun-99	73	3.3	3.3		0			
25-Jun-99	74	3.3	3.3		0			
26-Jun-99	75	2	2.0		0			
27-Jun-99	76	3.4	3.3		0			
28-Jun-99	77	2.6	2.5		0			
29-Jun-99	78	3.3	3.2		0			
30-Jun-99	79	2.4	2.3		0			
1-Jul-99	80	3.1	3.0		0			
2-Jul-99	81	3	2.9		0			
3-Jul-99	82	3.3	3.1		0			
4-Jul-99	83	3	2.8		0			
5-Jul-99	84	3.1	2.9		0			
6-Jul-99	85	3	2.8		0			
7-Jul-99	86	3	2.7	37.7	0	53.6	53.6	**1.42**

8-Jul-99	87	2.6	2.3		0
9-Jul-99	88	2.7	2.4		0
10-Jul-99	89	3.2	2.7		0
11-Jul-99	90	3.1	2.5		0
12-Jul-99	91	3.4	2.7		0
13-Jul-99	92	2.6	2.0		0
14-Jul-99	93	2.8	2.1		0
15-Jul-99	94	2.9	2.2		0
16-Jul-99	95	3.4	2.6		0
17-Jul-99	96	2.6	2.0		0
18-Jul-99	97	2.5	1.9		0
19-Jul-99	98	2.3	1.7		0
20-Jul-99	99	3.1	2.3		0
21-Jul-99	100	3.1	2.3		0
22-Jul-99	101	4.4	3.3		0
23-Jul-99	102	4.5	3.4		0
24-Jul-99	103	3.6	2.7		0

Appendix 6.2 RELATIVE WATER SUPPLY (RWS)
LOCATION 2.

RWS = (RE + IW)/(ETc)

RE = Effective rainfall

Date	Day No.	ETo (mm/day)	ETc (mm/day)	Total ETc	RE (mm)	IW (mm)	(RE + IW) (mm)	RWS
11 -Apr-99	1	4	2.8	19.7	2.4	122.1	132.8	**6.75**
12 -Apr-99	2	3.8	2.7		2.4			
13 -Apr-99	3	4.8	3.4		2.4			
14 -Apr-99	4	3.8	2.7		2.4			
15 -Apr-99	5	3.6	2.5		1.1			
16 -Apr-99	6	4.3	3.0		0			
17 -Apr-99	7	3.8	2.7		0			
18 -Apr-99	8	4.5	3.2	17.7	0	97.4	97.4	**5.49**
19 -Apr-99	9	3.4	2.4		0			
20 -Apr-99	10	4	2.8		0			
21 -Apr-99	11	4	2.8		0			
22 -Apr-99	12	4.7	3.3		0			
23 -Apr-99	13	4.5	3.2		0			
24 -Apr-99	14	4.1	3.0	21.1	0	80.2	80.2	**3.81**
25 -Apr-99	15	5.7	4.2		0			
26 -Apr-99	16	4.1	3.0		0			
27 -Apr-99	17	3.6	2.7		0			
28 -Apr-99	18	3.3	2.5		0			
29 -Apr-99	19	3.9	3.0		0			
30 -Apr-99	20	3.5	2.7		0			
1-May-99	21	3.5	2.7	17.7	0	61.0	61.0	**3.44**
2-May-99	22	3.4	2.7		0			

3-May-99	23	3.6	2.8		0			
4-May-99	24	3	2.4		0			
5-May-99	25	3.2	2.6		0			
6-May-99	26	3.3	2.6		0			
7-May-99	27	2.4	1.9		0			
8-May-99	28	3.2	2.6	42.0	0	50.7	50.7	**1.21**
9-May-99	29	4	3.3		0			
10-May-99	30	3.2	2.7		0			
11-May-99	31	3.9	3.3		0			
12-May-99	32	3.6	3.0		0			
13-May-99	33	1.9	1.6		0			
14-May-99	34	3.5	3.0		0			
15-May-99	35	3.5	3.0		0			
16-May-99	36	3.7	3.2		0			
17-May-99	37	3.2	2.8		0			
18-May-99	38	4.3	3.7		0			
19-May-99	39	4.1	3.6		0			
20-May-99	40	3	2.6		0			
21-May-99	41	4	3.6		0			
22-May-99	42	4	3.6	25.7	0	70.1	70.1	**2.73**
23-May-99	43	4.1	3.7		0			
24-May-99	44	3.6	3.3		0			
25-May-99	45	4.2	3.8		0			
26-May-99	46	4.3	3.9		0			
27-May-99	47	4.3	4.0		0			
28-May-99	48	3.7	3.4		0			
29-May-99	49	3.5	3.2	42.5	0	47.5	47.5	**1.12**
30-May-99	50	3.5	3.3		0			
31-May-99	51	3.4	3.2		0			
1-Jun-99	52	3.4	3.2		0			
2-Jun-99	53	3.2	3.0		0			
3-Jun-99	54	2.6	2.5		0			
4-Jun-99	55	2.3	2.2		0			
5-Jun-99	56	3.1	3.0		0			
6-Jun-99	57	3.2	3.1		0			
7-Jun-99	58	3	2.9		0			
8-Jun-99	59	3.2	3.1		0			
9-Jun-99	60	3.1	3.0		0			
10-Jun-99	61	3.4	3.3		0			
11-Jun-99	62	3.8	3.7		0			
12-Jun-99	63	3.1	3.0	47.4	0	47.9	47.9	**1.01**
13-Jun-99	64	3.2	3.1		0			
14-Jun-99	65	4	3.9		0			
15-Jun-99	66	4.1	4.1		0			
16-Jun-99	67	3.2	3.2		0			
17-Jun-99	68	3.2	3.2		0			
18-Jun-99	69	2.3	2.3		0			
19-Jun-99	70	3.7	3.7		0			
20-Jun-99	71	3.6	3.6		0			
21-Jun-99	72	3.8	3.8		0			
22-Jun-99	73	2.9	2.9		0			
23-Jun-99	74	3.9	3.9		0			
24-Jun-99	75	3.3	3.3		0			

25-Jun-99	76	3.3	3.3		0			
26-Jun-99	77	2	2.0	63.0	0	61.8	61.8	**0.98**
27-Jun-99	78	3.4	3.3		0			
28-Jun-99	79	2.6	2.5		0			
29-Jun-99	80	3.3	3.2		0			
30-Jun-99	81	2.4	2.3		0			
1-Jul-99	82	3.1	3.0		0			
2-Jul-99	83	3	2.9		0			
3-Jul-99	84	3.3	3.1		0			
4-Jul-99	85	3	2.8		0			
5-Jul-99	86	3.1	2.9		0			
6-Jul-99	87	3	2.8		0			
7-Jul-99	88	3	2.7		0			
8-Jul-99	89	2.6	2.3		0			
9-Jul-99	90	2.7	2.4		0			
10-Jul-99	91	3.2	2.7		0			
11-Jul-99	92	3.1	2.5		0			
12-Jul-99	93	3.4	2.7		0			
13-Jul-99	94	2.6	2.0		0			
14-Jul-99	95	2.8	2.1		0			
15-Jul-99	96	2.9	2.2		0			
16-Jul-99	97	3.4	2.6		0			
17-Jul-99	98	2.6	2.0		0			
18-Jul-99	99	2.5	1.9		0			
19-Jul-99	100	2.3	1.7		0			
20-Jul-99	101	3.1	2.3		0			
21-Jul-99	102	3.1	2.3		0			
22-Jul-99	103	4.4	3.3		0			
23-Jul-99	104	4.5	3.4		0			
24-Jul-99	105	3.6	2.7		0			

Appendix 6.3 RELATIVE WATER SUPPLY (RWS) LOCATION 3.

RWS =(RE + IW)/(ETc)

RE = Effective rainfall

Date	Day No.	ETo (mm/day)	ETc (mm/day)	Total ETc	RE (mm)	IW (mm)	(RE + IW) (mm)	RWS
11 -Apr-99	1	4	2.8	25.2	2.4	72.8	83.5	**3.31**
12 -Apr-99	2	3.8	2.7		2.4			
13 -Apr-99	3	4.8	3.4		2.4			
14 -Apr-99	4	3.8	2.7		2.4			
15 -Apr-99	5	3.6	2.5		1.1			
16 -Apr-99	6	4.3	3.0		0			
17 -Apr-99	7	3.8	2.7		0			

18 -Apr-99	8	4.5	3.2		0			
19 -Apr-99	9	3.4	2.4		0			
20 -Apr-99	10	4	2.8	19.4	0	42.7	42.7	**2.20**
21 -Apr-99	11	4	2.8		0			
22 -Apr-99	12	4.7	3.3		0			
23 -Apr-99	13	4.5	3.2		0			
24 -Apr-99	14	4.1	3.0		0			
25 -Apr-99	15	5.7	4.2		0			
26 -Apr-99	16	4.1	3.0	13.9	0	45.1	45.1	**3.25**
27 -Apr-99	17	3.6	2.7		0			
28 -Apr-99	18	3.3	2.5		0			
29 -Apr-99	19	3.9	3.0		0			
30 -Apr-99	20	3.5	2.7		0			
1-May-99	21	3.5	2.7	17.7	0	67.6	67.6	**3.81**
2-May-99	22	3.4	2.7		0			
3-May-99	23	3.6	2.8		0			
4-May-99	24	3	2.4		0			
5-May-99	25	3.2	2.6		0			
6-May-99	26	3.3	2.6		0			
7-May-99	27	2.4	1.9		0			
8-May-99	28	3.2	2.6	28.4	0	50.9	50.9	**1.79**
9-May-99	29	4	3.3		0			
10-May-99	30	3.2	2.7		0			
11-May-99	31	3.9	3.3		0			
12-May-99	32	3.6	3.0		0			
13-May-99	33	1.9	1.6		0			
14-May-99	34	3.5	3.0		0			
15-May-99	35	3.5	3.0		0			
16-May-99	36	3.7	3.2		0			
17-May-99	37	3.2	2.8		0			
18-May-99	38	4.3	3.7	31.9	0	41.3	41.3	**1.30**
19-May-99	39	4.1	3.6		0			
20-May-99	40	3	2.6		0			
21-May-99	41	4	3.6		0			
22-May-99	42	4	3.6		0			
23-May-99	43	4.1	3.7		0			
24-May-99	44	3.6	3.3		0			
25-May-99	45	4.2	3.8		0			
26-May-99	46	4.3	3.9		0			
27-May-99	47	4.3	4.0	23.2	0	64.8	64.8	**2.79**
28-May-99	48	3.7	3.4		0			
29-May-99	49	3.5	3.2		0			
30-May-99	50	3.5	3.3		0			
31-May-99	51	3.4	3.2		0			
1-Jun-99	52	3.4	3.2		0			
2-Jun-99	53	3.2	3.0		0			
3-Jun-99	54	2.6	2.5	44.0	0	41.1	41.1	**0.93**
4-Jun-99	55	2.3	2.2		0			
5-Jun-99	56	3.1	3.0		0			
6-Jun-99	57	3.2	3.1		0			
7-Jun-99	58	3	2.9		0			
8-Jun-99	59	3.2	3.1		0			
9-Jun-99	60	3.1	3.0		0			

10-Jun-99	61	3.4	3.3		0			
11-Jun-99	62	3.8	3.7		0			
12-Jun-99	63	3.1	3.0		0			
13-Jun-99	64	3.2	3.1		0			
14-Jun-99	65	4	3.9		0			
15-Jun-99	66	4.1	4.1		0			
16-Jun-99	67	3.2	3.2		0			
17-Jun-99	68	3.2	3.2	46.4	0	55.1	55.1	1.19
18-Jun-99	69	2.3	2.3		0			
19-Jun-99	70	3.7	3.7		0			
20-Jun-99	71	3.6	3.6		0			
21-Jun-99	72	3.8	3.8		0			
22-Jun-99	73	2.9	2.9		0			
23-Jun-99	74	3.9	3.9		0			
24-Jun-99	75	3.3	3.3		0			
25-Jun-99	76	3.3	3.3		0			
26-Jun-99	77	2	2.0		0			
27-Jun-99	78	3.4	3.3		0			
28-Jun-99	79	2.6	2.5		0			
29-Jun-99	80	3.3	3.2		0			
30-Jun-99	81	2.4	2.3		0			
1-Jul-99	82	3.1	3.0		0			
2-Jul-99	83	3	2.9	58.3	0	56.7	56.7	0.97
3-Jul-99	84	3.3	3.1		0			
4-Jul-99	85	3	2.8		0			
5-Jul-99	86	3.1	2.9		0			
6-Jul-99	87	3	2.8		0			
7-Jul-99	88	3	2.7		0			
8-Jul-99	89	2.6	2.3		0			
9-Jul-99	90	2.7	2.4		0			
10-Jul-99	91	3.2	2.7		0			
11-Jul-99	92	3.1	2.5		0			
12-Jul-99	93	3.4	2.7		0			
13-Jul-99	94	2.6	2.0		0			
14-Jul-99	95	2.8	2.1		0			
15-Jul-99	96	2.9	2.2		0			
16-Jul-99	97	3.4	2.6		0			
17-Jul-99	98	2.6	2.0		0			
18-Jul-99	99	2.5	1.9		0			
19-Jul-99	100	2.3	1.7		0			
20-Jul-99	101	3.1	2.3		0			
21-Jul-99	102	3.1	2.3		0			
22-Jul-99	103	4.4	3.3		0			
23-Jul-99	104	4.5	3.4		0			
24-Jul-99	105	3.6	2.7		0			

Appendix 7 SOIL CHEMICAL PROPERTIES.

Appendix 7.1 Variation of soil chemical properties with location, depth and time

i) CEC

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	592.338	296.169	55.4149	0.0000	s
Depth	1	56.075	56.075	10.4920	0.0038	s
Sampling period	1	2.695	2.695	0.5043		ns
Error	22	117.581	5.345			

Coefficient of Variation: 13.76%

ii) ECe

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	3.534	1.767	15.3132	0.0001	s
Depth	1	4.523	4.523	39.1895	0.0000	s
Sampling period	1	0.030	0.030	0.2603		
Error	22	2.539	0.115			

Coefficient of Variation: 19.91%

iii) pH

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	1.464	0.732	4.2601	0.0273	s
Depth	1	0.570	0.570	3.3181	0.0821	ns
Sampling period	1	0.079	0.079	0.4618		ns
Error	22	3.779	0.172			

Coefficient of Variation: 5.41%

iv) Calcium

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	274.626	137.313	36.6491	0.0000	s
Depth	1	27.161	27.161	7.2495	0.0133	s
Sampling period	1	1.071	1.071	0.2859		ns
Error	22	82.427	3.747			

Coefficient of Variation: 18.61%

v) Magnesium

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	24.723	12.361	35.1604	0.0000	s
Depth	1	2.560	2.560	7.2816	0.0131	s
Sampling period	1	0.075	0.075	0.2125		ns
Error	22	7.735	0.352			

Coefficient of Variation: 24.05%

vi) Sodium

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	1.687	0.843	17.4086	0.0000	s
Depth	1	0.000	0.000	0.0002		ns
Sampling period	1	0.000	0.000	0.0009		ns
Error	22	1.066	0.048			

Coefficient of Variation: 22.23%

vi) Potassium

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	2.306	1.153	17.9004	0.0000	s
Depth	1	0.128	0.128	1.9937	0.1719	ns
Sampling period	1	0.334	0.334	5.1932	0.0327	s
Error	22	1.417	0.064			

Coefficient of Variation: 26.22%

vii) ESP

ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	1.745	0.873	0.3167		ns
Depth	1	7.380	7.380	2.6787	0.1159	ns
Sampling period	1	1.562	1.562	0.5671		ns
Error	22	60.613	2.755			

Coefficient of Variation: 27.32%

viii) SAR

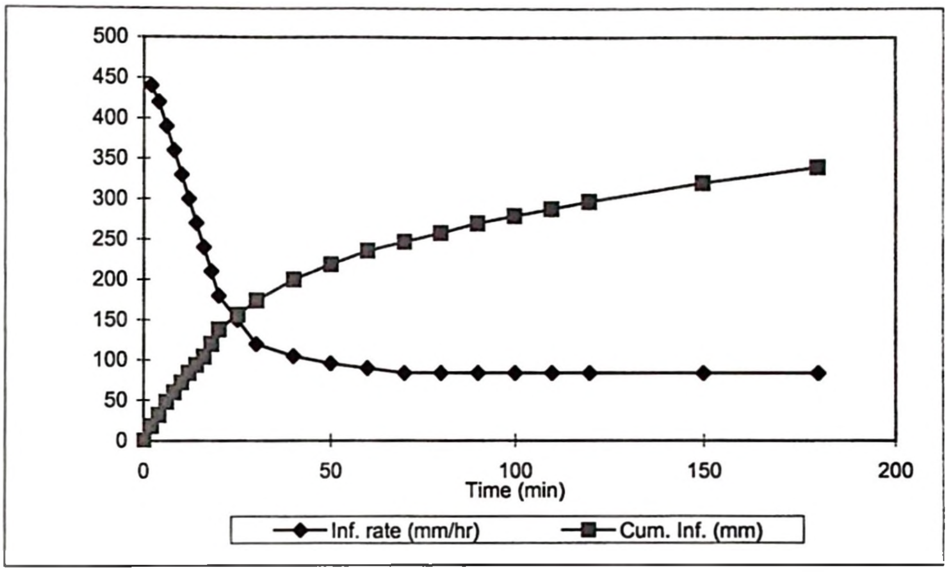
ANOVA

Source of variation	df	SS	MS	F-Value	Prob	Remark
Location	2	0.040	0.020	2.0061	0.1584	ns
Depth	1	0.010	0.010	1.0384	0.3193	ns
Sampling period	1	0.001	0.001	0.1231		ns
Error	22	0.219	0.010			

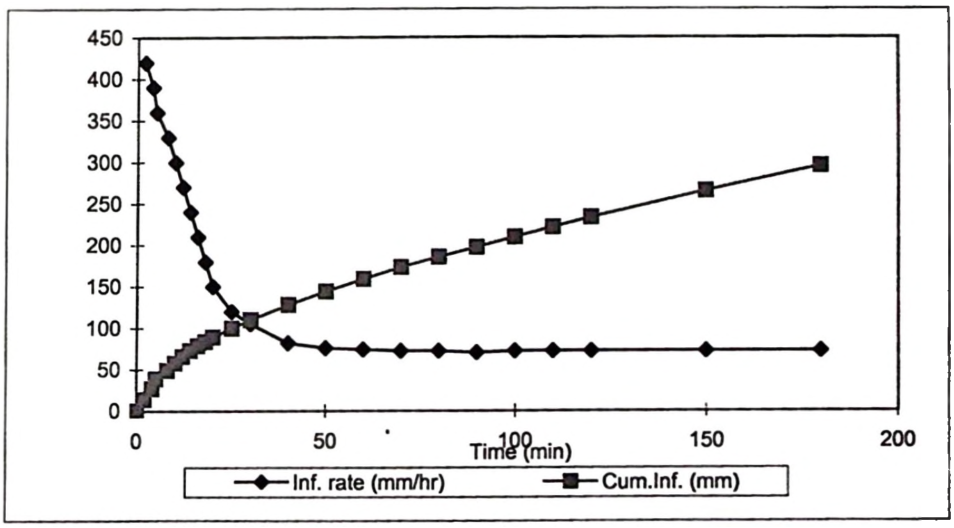
Coefficient of Variation: 25.13%

APPENDIX 8 INFILTRATION PATTERNS

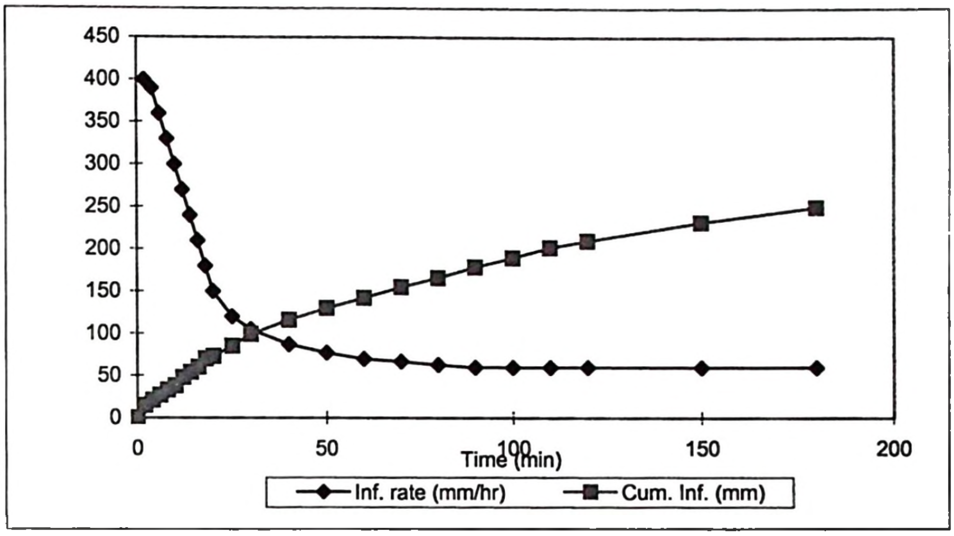
Appendix 8.1 Infiltration patterns - Location 1



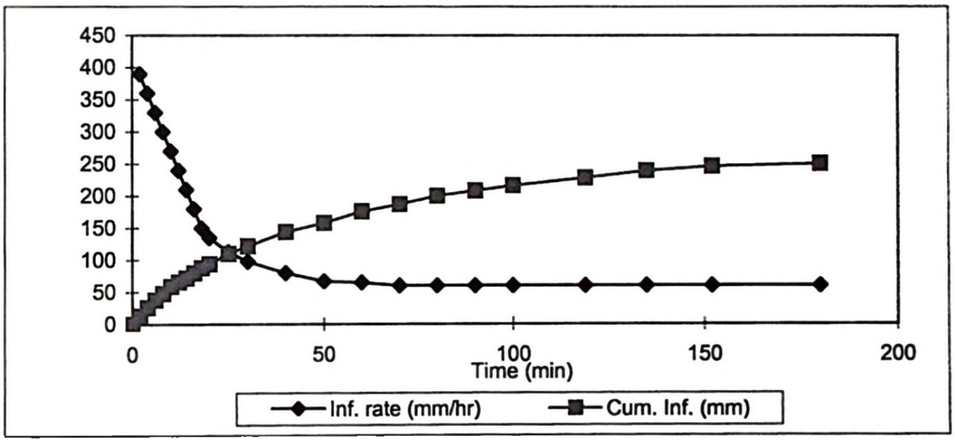
Location 1 13/4/1999



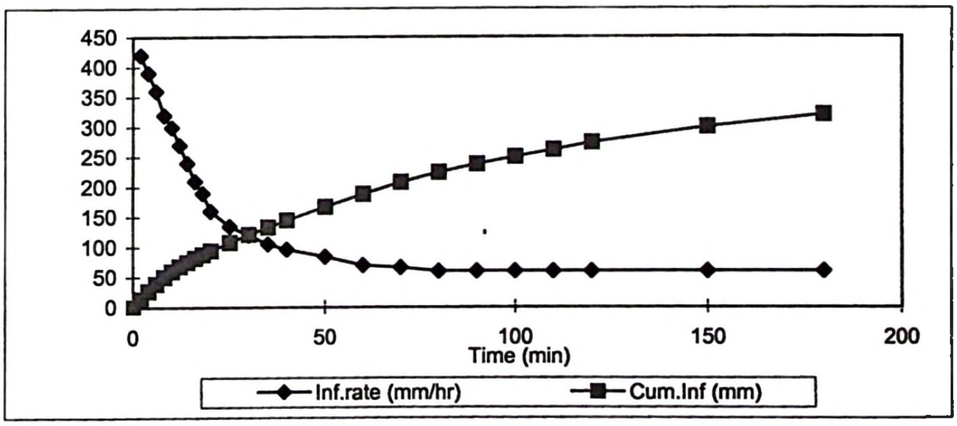
Location 1 25/4/1999



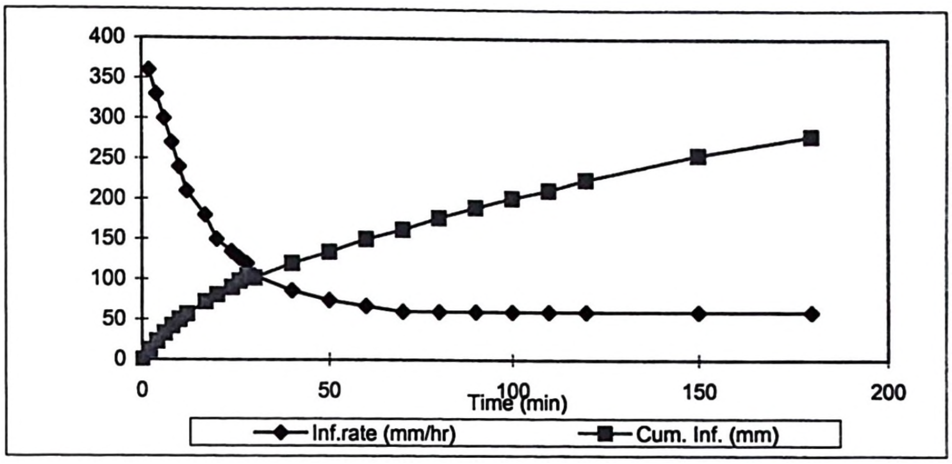
Location 1 27/4/1999



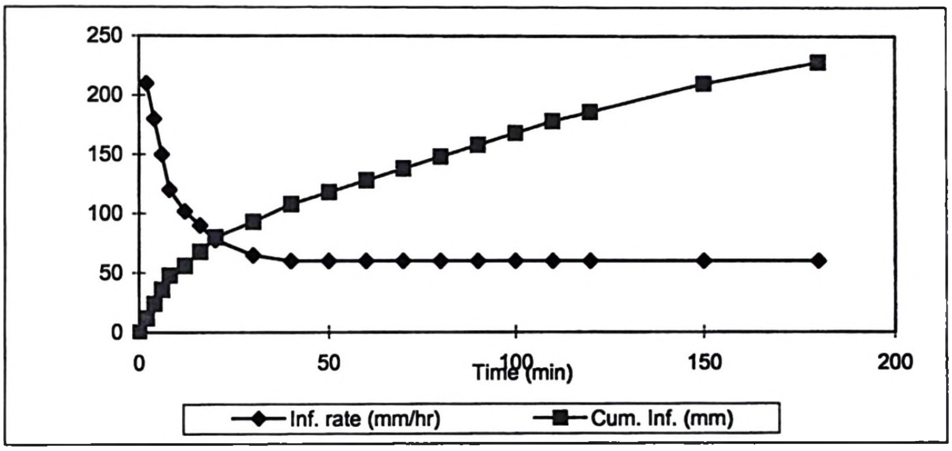
Location 1 11/5/1999



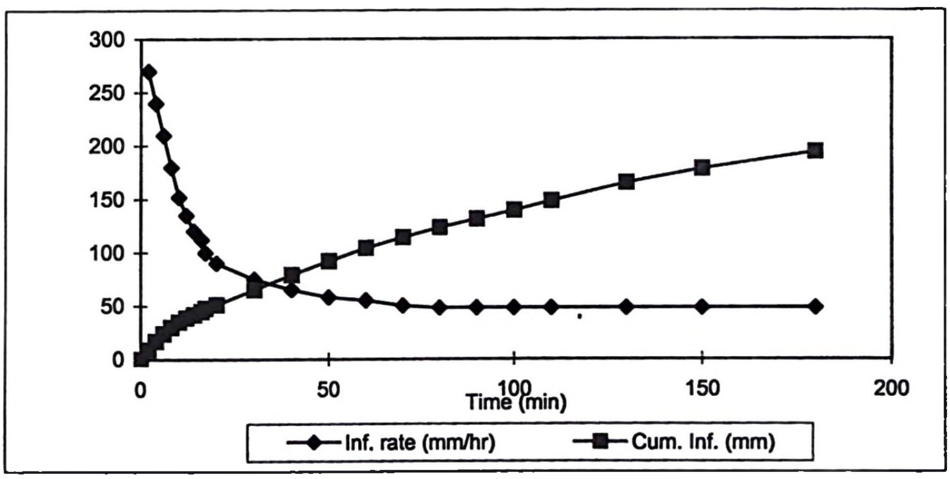
Location 1 - 16/5/1999



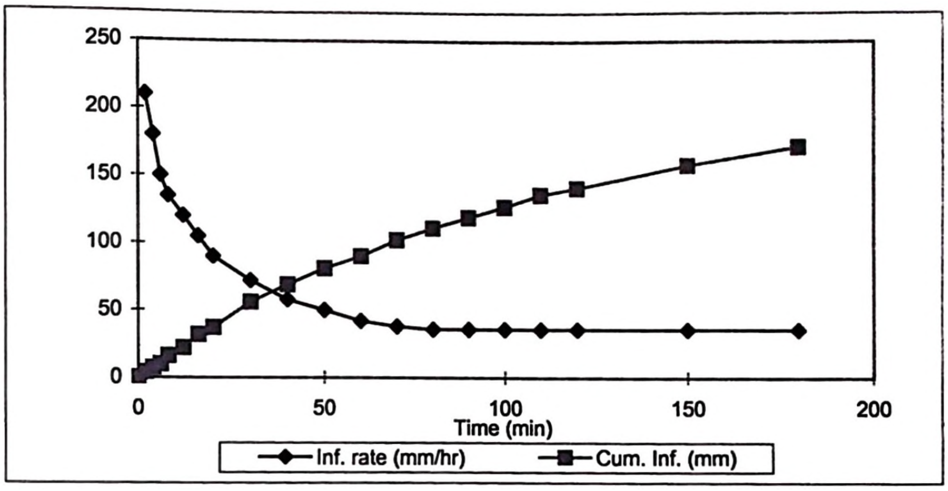
Location 1 25/5/1999



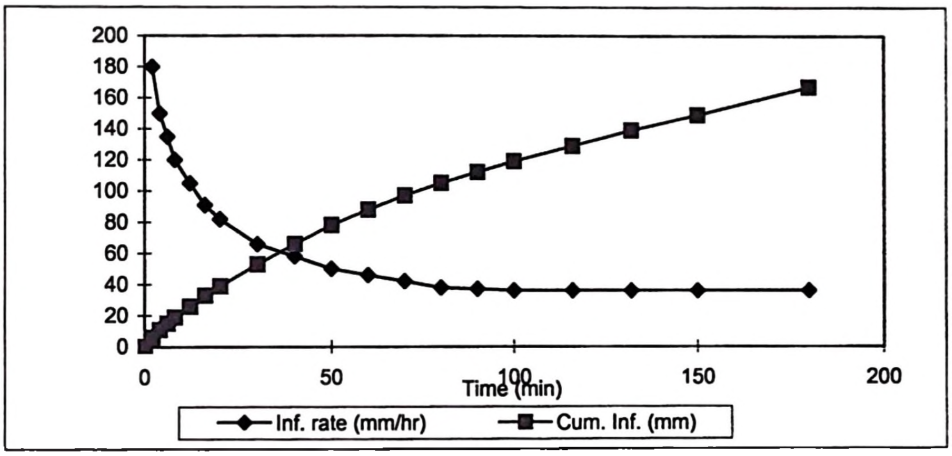
Location 1 8/6/1999



Location 1 20/6/1999

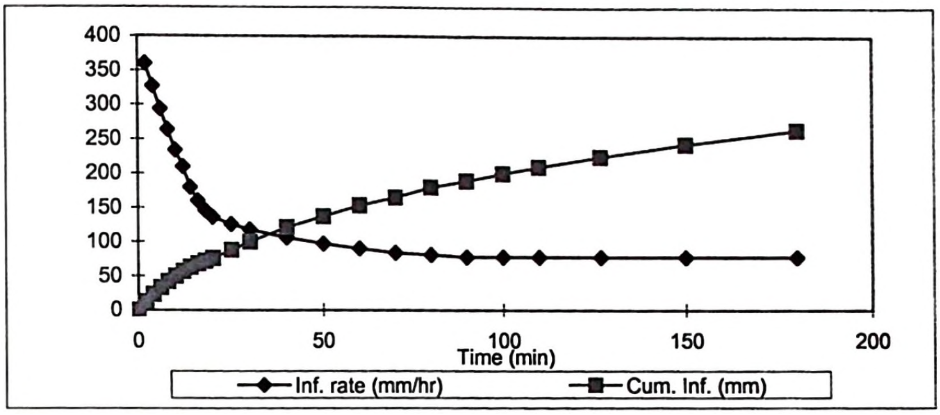


Location 1 26/6/1999

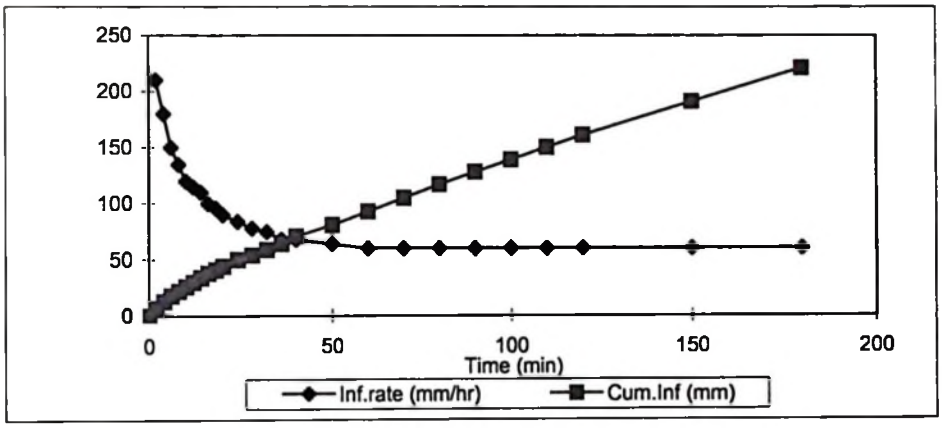


Location 1 10/7/1999

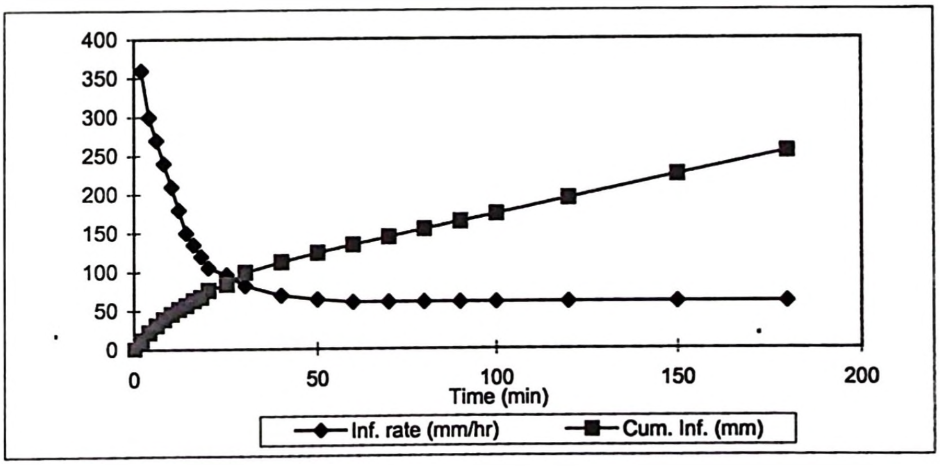
Appendix 8.2 Infiltration patterns - Location - 2



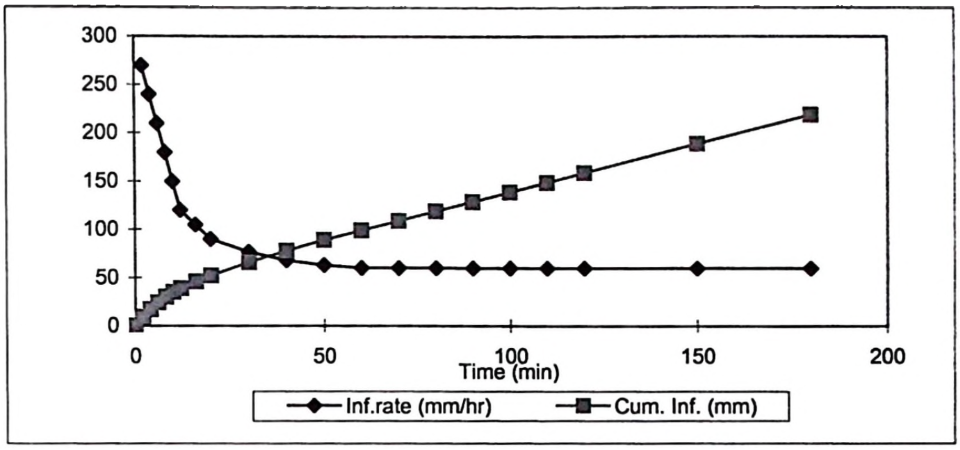
Location 2 12/4/1999



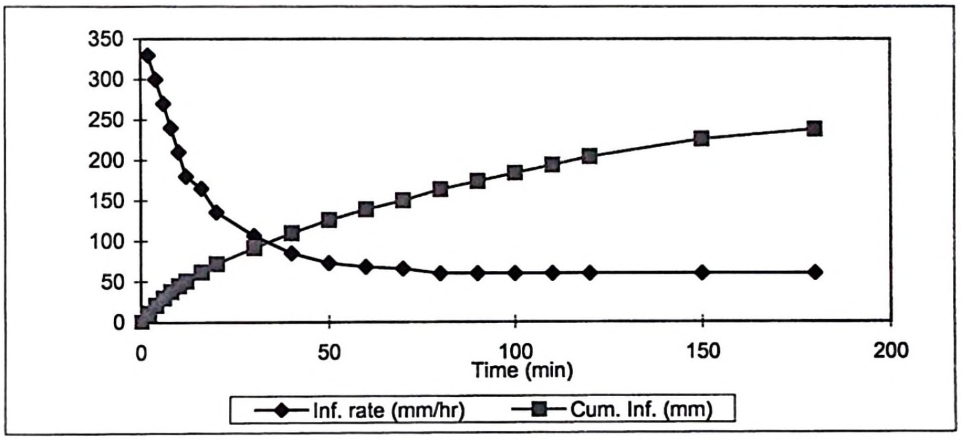
Location 2 26/4/1999



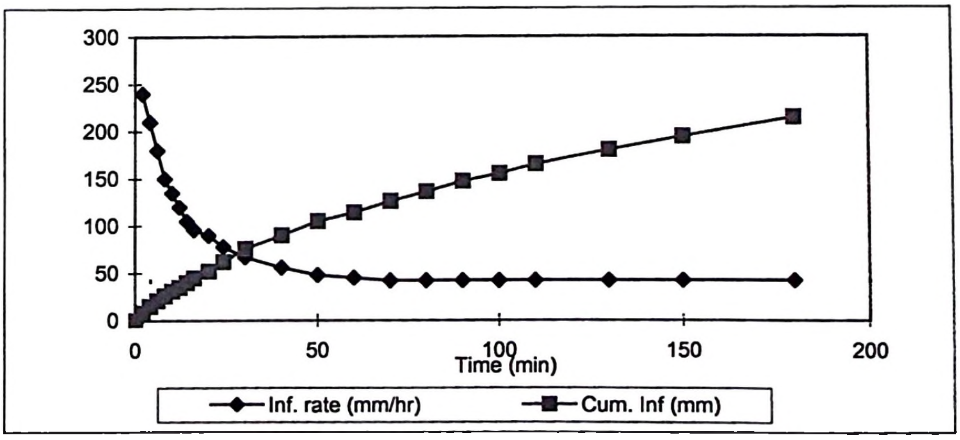
Location 2 2/5/1999



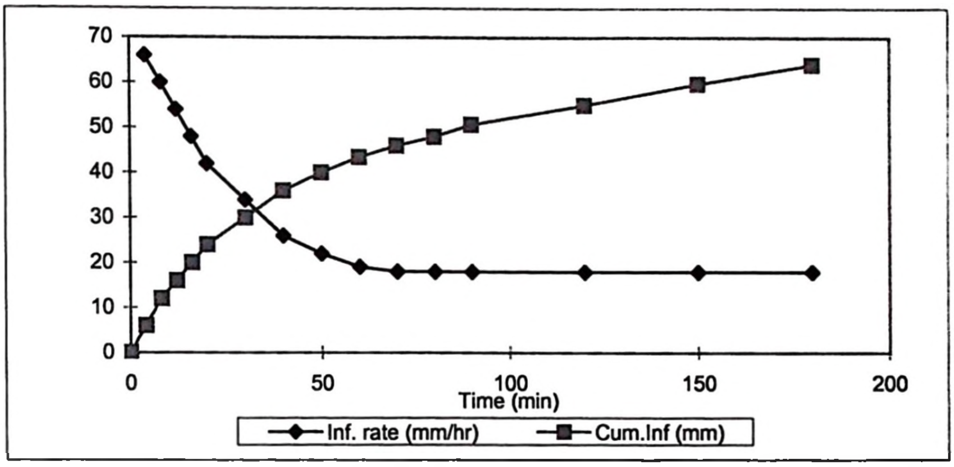
Location 2 10/5/1999



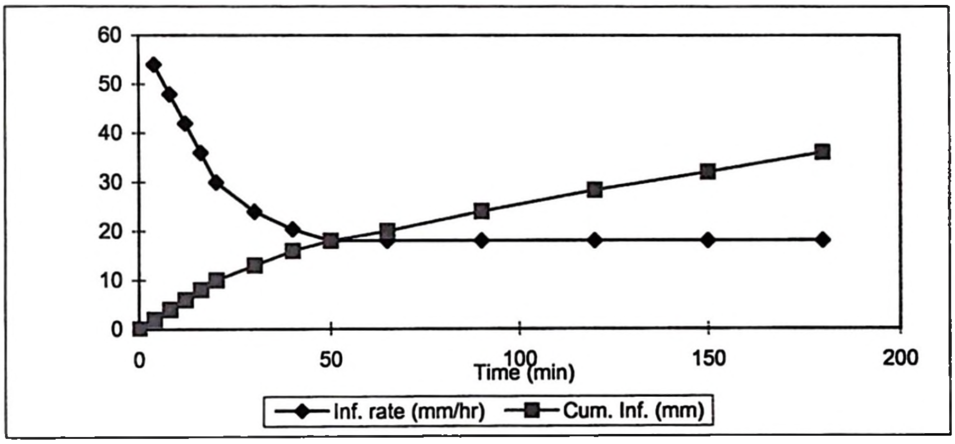
Location 2 23/5/1999



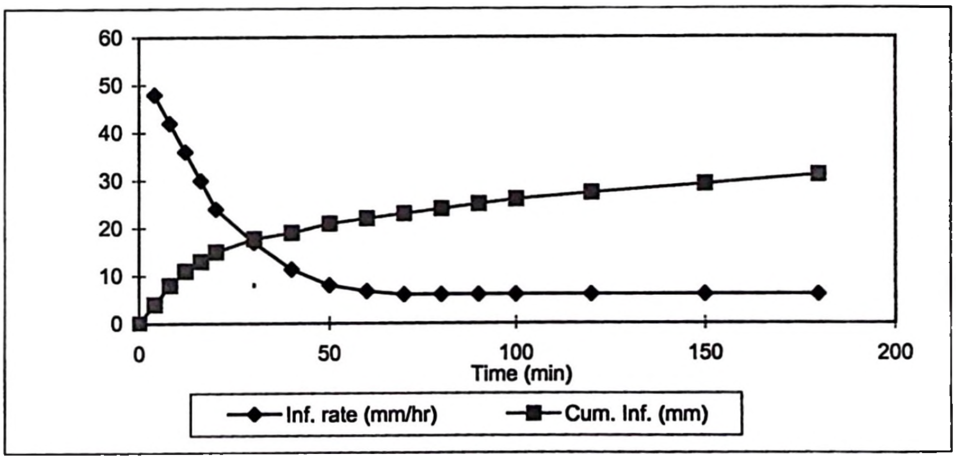
Location 2 7/6/1999



Location 2 21/6/1999

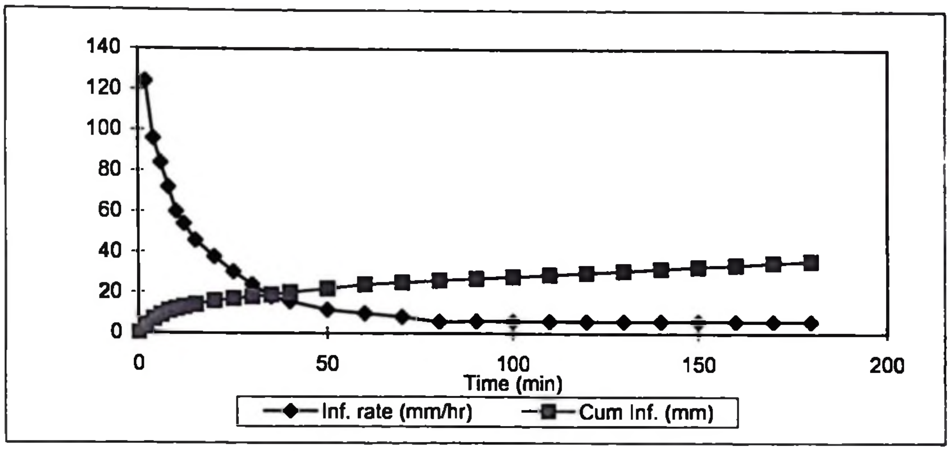


Location 2 5/7/1999

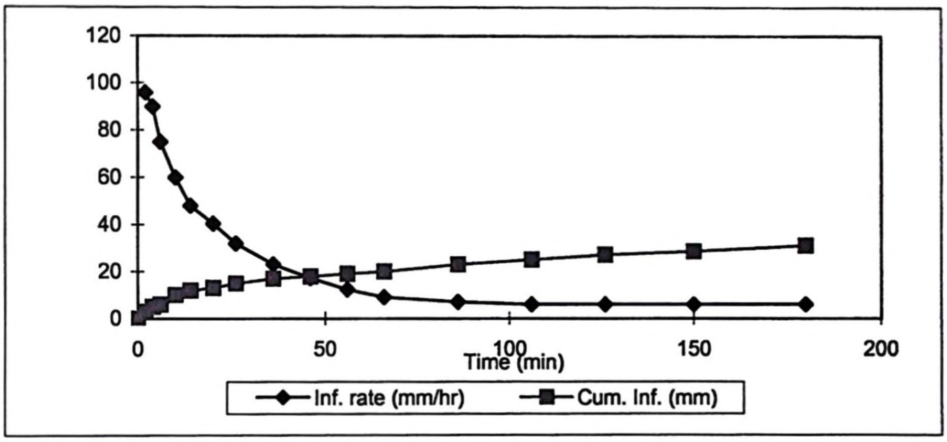


Location 2 13/7/1999

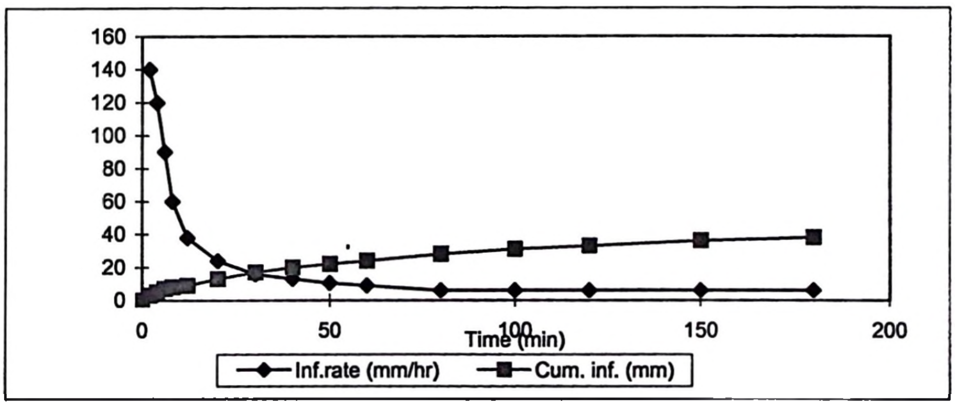
Appendix 8.3 Infiltration patterns - Location 3



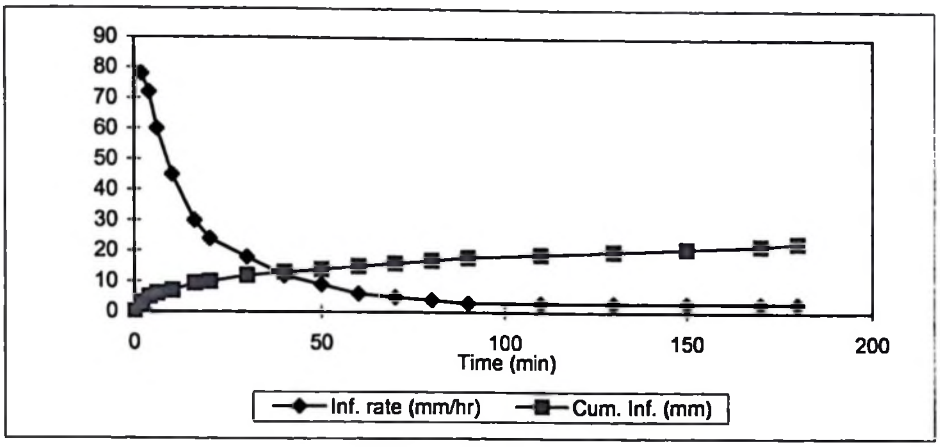
Location 3 11/4/1999



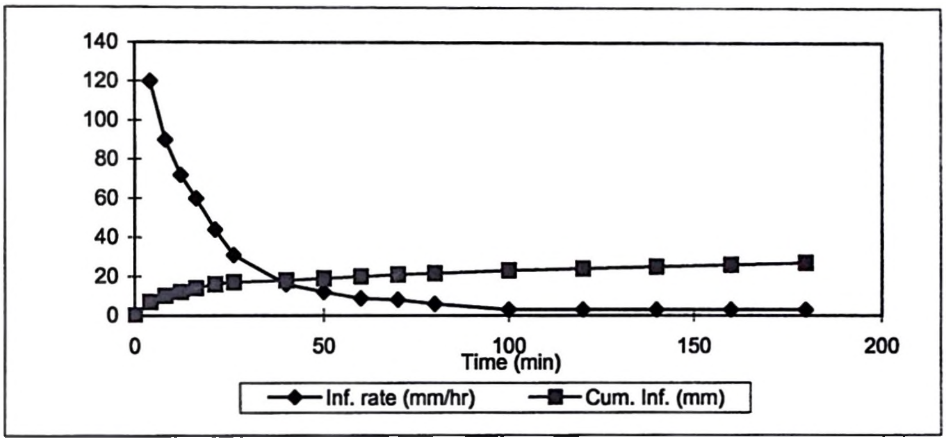
Location 3 25/4/1999



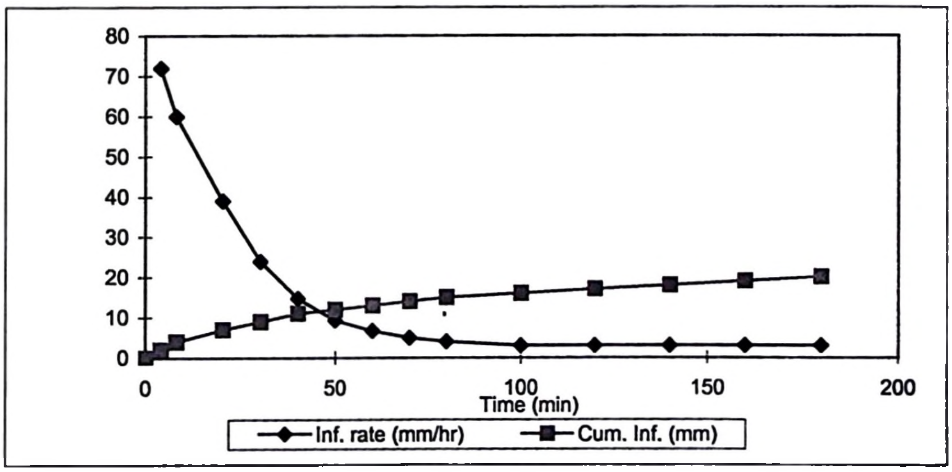
Location 3 1/5/1999



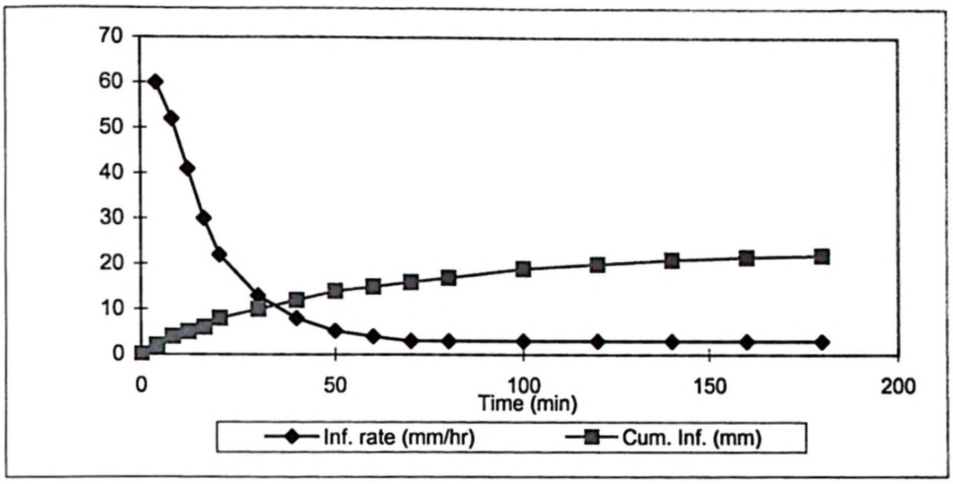
Location 3 9/5/1999



Location 3 27/5/1999



Location 3 6/6/1999



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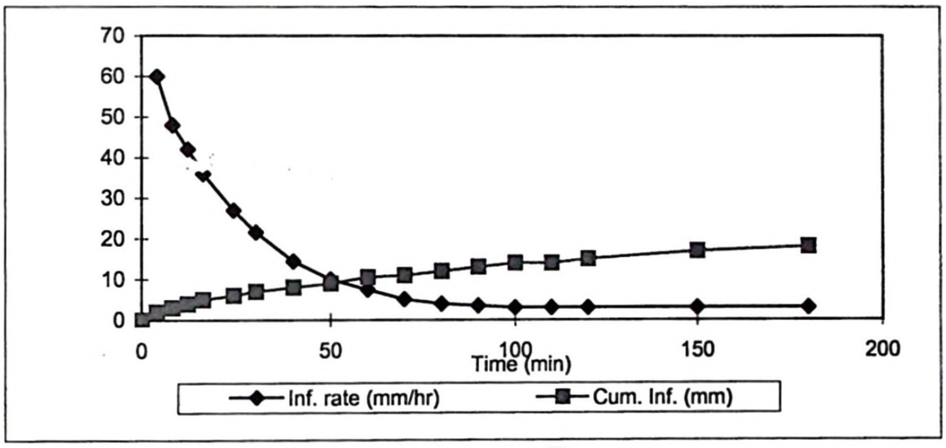
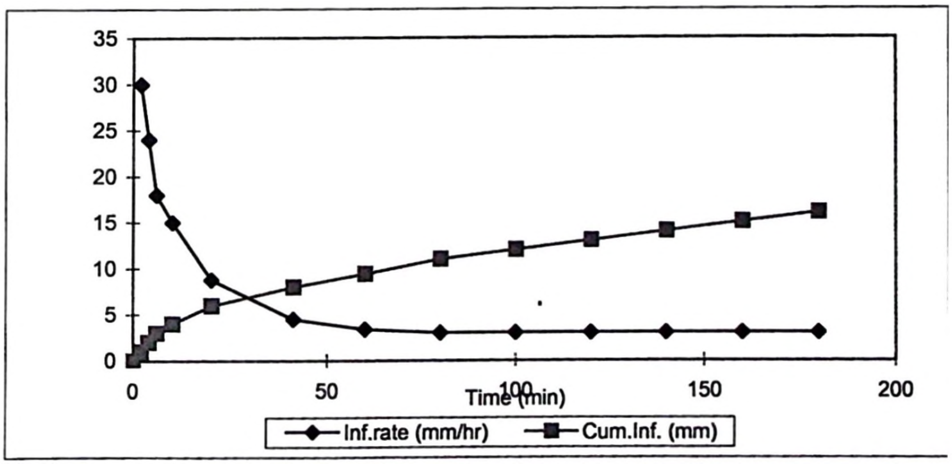


Location 3 4/7/1999



Location 3 12/7/1999