Analysis of the leaching process in the intensive flower farms around Lake Naivasha.

SULMAC Farm case study Naivasha Basin, Kenya

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By

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DEDICATION

The success of this thesis is dedicated to my beloved wife Winie and our children Malama, Vizi and Allan for having persevered on their own during my 18-month studies at ITC-ENSCHEDE in the Netherlands.

Disclaimer

Abstract

In this study the leaching process in the unsaturated soil zone at the SULMAC Farm has been simulated using the Soil Water Atmosphere and Plant (SWAP) numerical model.

The purpose of this study was to analyse the water and chemical balances of the SULMAC Farm's greenhouses and the drains. Cut roses are grown in greenhouses and to facilitate high productivity, agrochemicals are used mixed in water on the continuous basis

To accomplish this, water and soil samples, agrochemical data and application schedules where collected. Soil moisture profile and the hydraulic conductivities of the soil layers were assessed on the basis of in situ data.

From the particle size distribution, hydraulic properties of the soil were derived from which the pF curve were drawn using the Saxton et al, (1986) equations. From the pF curves the van Genuchten's model parameters were derived. The model was hydraulically calibrated by adjusting the van Genuchten parameters until the modelled soil moisture profile was close to the observed soil moisture profile.

Through a sensitivity analysis the parameters to which the simulation of the leaching process is the most sensitive, were defined. The hydraulic conductivity and the shape factors have shown the largest influence on the simulation of the leaching.

To evaluate the leaching process, four scenarios were used. The first scenario evaluated the effect of continuous use of nitrate fertilisers with irrigation water (7 mm) on the solute flux through the bottom of the modelled soil column. This scenario represents the current horticultural practice.

The second scenario assessed the effect of intermittent use of nitrate fertilisers with irrigation water (7 mm) on the solute flux. This means the use of less fertiliser with the same amount of water that is used now.

The third scenario assessed the effect of continuous use of nitrate fertilisers with lesser irrigation water (4 mm) on the solute flux. This results in saving on both fertilisers and water.

The fourth scenario assessed the effect of intermittent use of nitrate fertilisers with lesser irrigation water (4 mm) on the solute flux. This is a scenario of more fertiliser saving.

By varying the thickness of the calibrated layers (L1 and L2), the spatial variability of the leaching process was also assessed. This was found to be not significant.

From the simulation with SWAP at the present irrigation rate of 7 mm per day, a downward flux of 136.20 cm was defined. In case of an initial concentration of 394.85 mg/l, a downward solute bottom flux of 85.16 mg/cm^2 or 8516 kg/ha of the nutrient was simulated. This is not only an environmental hazard but an economic loss of about US $ 1,050,000 on an annual basis too.

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1 INTRODUCTION

Lake Naivasha, a shallow freshwater lake, is located in the center of the Rift Valley in Kenya. It is not only an important ecological site due to its biodiversity, but also a main economic center of Kenya for its floricultural and horticultural production. With the rapid expansion of cultivation around the lake, considerable quantities of pesticides and fertilizers are applied in the riparian zone.

Flowers are produced in greenhouses, with agrochemicals application on a continuous basis to insure high productivity. Due to generally growing concern about the quality of the environment, it is important to maintain the lowest possible impact of the horticulture on the Lake Naivasha Basin.

1.1 PROBLEM IDENTIFICATION

Nitrate nitrogen (NO_3^- -N), an essential source of nutrient for plants growth, is now considered a potential pollutant by the Environmental Protection Agency (EPA). This is because if applied in excess, nitrate nitrogen can move into groundwater by leaching and eventually into surface waters as base flow, thereby becoming an environmental hazard (Gaines and Gaines, 1994).

Flowers are the most important products in the area and mainly grown for export to European union (EU) especially to the Netherlands, occasionally also to the North American countries.

In the Lake Naivasha Basin floriculture takes up a total of 1566 hectares of the total irrigated area of 5031 hectares (Sayeed, 2001). This is about 31.1 % of the total irrigated area. Of the total land occupied by the flowers, greenhouses occupy a total of 614 hectares, while open fields occupy 952 hectares of the irrigated area.

According to Sayeed (2001), the floriculture sector uses 52 % of the total irrigation water ain the Naivasha Basin, 75 % of the total pesticide (260 tons/year) and 47% of the total fertilizer (3758 tons/year) of the Lake Naivasha agriculture sector.

18 % of the total water outflow from the Lake naivasha is attributed to abstraction by the farms (Sayeed, 2001).

The use of inorganic fertilizers, though essential for increasing crop production, can also prove to be hazardous to the environment, if it finds its way into groundwater. Nitrates become toxic to humans and animals when water or plant materials containing high levels of nitrate are ingested. When nitrates are consumed, it is converted to nitrite in the digestive track and result in a medical condition known as methemoglobinemia or blue baby syndrome. This condition can be fatal. Other toxic consequences of nitrate and nitrite are the formation of nitrosamines, which may cause cancer. When plants do not use up the fertilizer completely, nitrate ions may end up contaminating the ground water. Being negatively charged, nitrate ions are not adsorbed by the negative charged clay colloids, and hence are subject to washing and leaching. Soil water movement controls the rate of the downward movement of nitrates through the soils. Factors such as amount of rainfall, irrigation, soil texture and soil structure can have major effects on water movement.

By excessive use of phosphate fertilizers, large amounts of the phosphate ions may reach streams and lakes by surface runoff and the groundwater through leaching (Kim, 1994).

The continuous use of agrochemicals in the soil could become a source of pollution in form of leaching which is defined as the downward movement of soluble substance through the soil profile with percolating water. Agrochemicals can enter groundwater through leaching and cause the degradation of groundwater. This low-level nonpoint-source leaching of agrochemicals is usually of great concern, because:

- It can be widespread.
- It is difficult to control since neither the sources nor the leaching behavior of the agrochemicals are well understood.

The continuous discharge of untreated flushing water from fertigation equipment into drains is another pollution threat for both surface and groundwater.

The declining of the lake levels has been attributed to the over abstraction of the Lake Naivasha water for irrigation purposes. The significance of water and agro-chemicals in the agricultural sector cannot be underestimated.

In view of the vast expansion of flower production (in greenhouses) more agrochemicals have been consumed in the past five years. However, there has not been any study, which has focused on nutrient pollution of the groundwater through its continuous use in greenhouses and the subsequent pollution through the discharge of the fertigation pumping stations' flush water into the earth drains, despite the rapid expansion of the floriculture and horticultural sector.

Previous studies have tried to qualify and quantify irrigation water requirements and the agro-chemical use in the Lake Naivasha basin for specific crops. Most studies have based their studies in open field and on sprinkler irrigation.

It is therefore the purpose of this study to try and assess the leaching process in the rose production and quantify the various components of the water and chemical budget, assess the spatial and temporal variability of these processes around Lake Naivasha based on the both the soil hydraulic properties.

This study will attempt to fill the research gap left on water and chemical budget in the rose production and the possibilities of polluting the environment with agrochemicals generated in greenhouses and through the drains.

As a part of an integrated management plan, a study of the groundwater pollution potential arising from the agricultural sector, especially from the greenhouses and the drains is very necessary.

1.2 RESEARCH OBJECTIVES AND QUESTIONS

Based on the problems outlined above, the following objectives were set for the research:

- Quantify the water and chemical balances in the irrigated greenhouses.
- Assess the groundwater pollution potential through leaching in greenhouses and the drainage ditches.
- Assess the temporal and spatial variability of leaching.

To meet these objectives the following research questions have to be answered:

- Is there leaching in greenhouses where drip irrigation is applied?
- Can leaching caused by drip irrigation under the greenhouse cultivation lead to the contamination of the groundwater? If so, how much is this contamination?
- Does the flushing of fertilizer residues from drip pumping stations into drainage ditches pose any contamination to groundwater at the SULMAC farms? If so, how much is this contamination?
- How can the process of leaching be monitored, what is required?

1.3 RESEARCH METHODOLOGY

In order to meet the objectives of the research the following tasks were completed:

PRE- FIELD WORK

- Literature review, data acquisition from previous studies and from locally available data banks.
- Satellite imagery/aerial photo interpretation.
- Selection of appropriate models.
- Preparation of the sampling scheme.

FIELD WORK

- Data collection and recording from selected sampling sites.
- Experiments to measure the typical physical on-farm data (soil, water, chemical and crop related).

POST FIELD WORK

- Post-processing of field data.
- Analysis of field data.
- Sample analysis.
- Leaching process simulation.
- Data processing using GIS.
- Statistical analysis.Interpretation and presentation

The research methodology is illustrated in Figure 1-1.

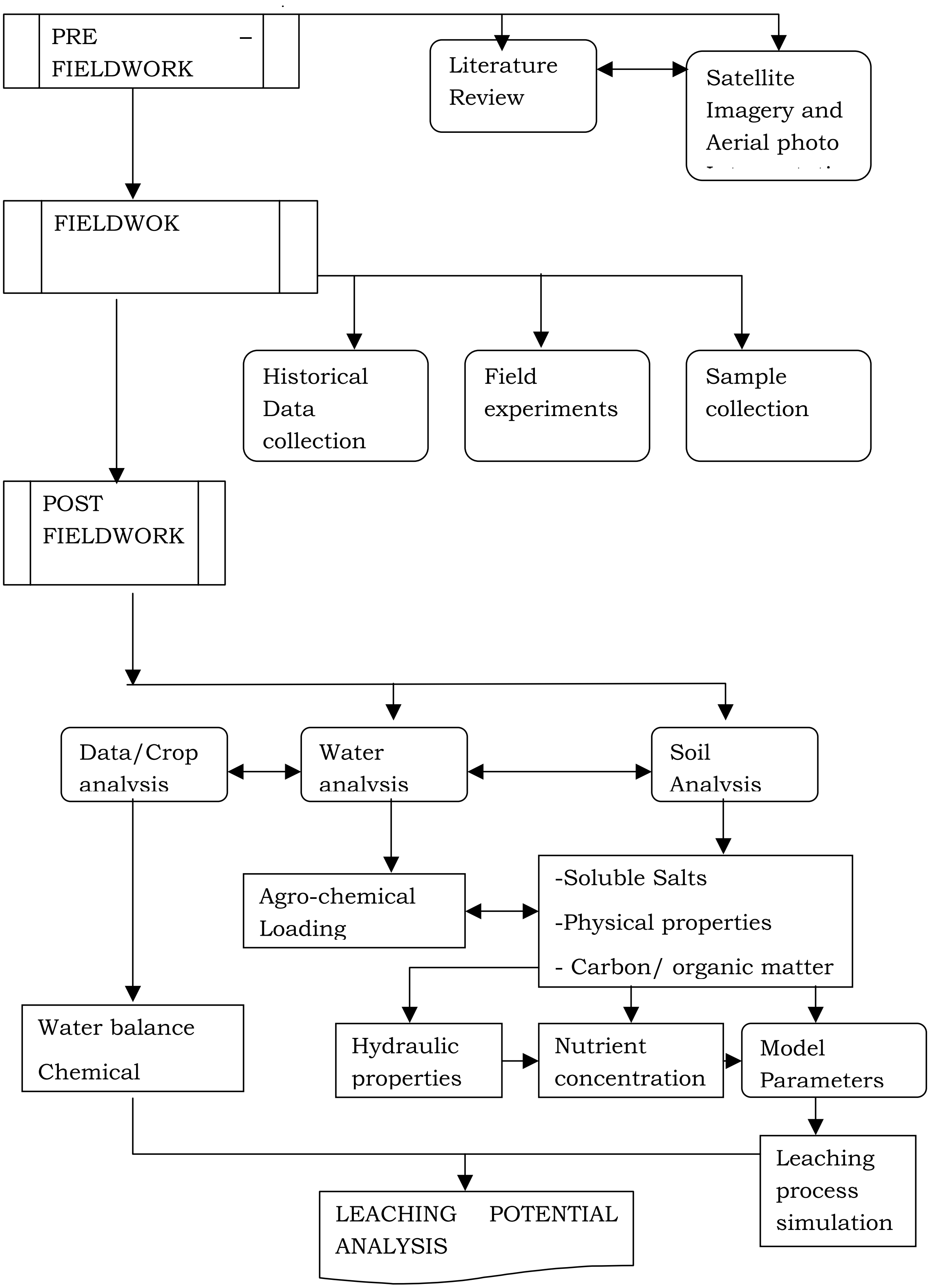


Figure 1-1 Flow chart of the research

2 LITERATURE OVERVIEW

2.1 PHYSICAL PROCESSES IN GREENHOUSES

Greenhouses provide controlled environment for producing crops with natural (or artificial) sunlight when weather conditions are not suitable for crop production or when the crop being grown is too sensitive to the natural conditions.Physical processes in greenhouse include:

- the transmission of light through the greenhouse covers; shortwave and longwave radiative heat transfer among plants, the ground surface, and the cover;
- natural or forced convective heat transfer among plants, the ground surface and the cover;
- Moisture exchange between the ground surface and the air (evaporation/precipitation);
- Moisture (transpiration) and CO_2 (photosynthesis) exchange between the leaves and ambient air;
- And human intervention in the form of ventilation, heating, fertigation and CO_2 enrichment.

Many of these processes are directly affected by light intensity at leaf level in the canopy. For instance, photosynthesis is a direct function of the light level experienced by the plant.

Evapotranspiration is inversely proportional to the stomata resistance of leaves, which in turn is strongly dependent on the light intensity at the leaf level

The temperature of leaves and the transfer of heat from the leaves to the surrounding air by natural convection are also directly related to the absorption of radiation by leaves.

It follows then that light penetrations into a crop stand not only an important component of plant growth, but is also an essential factor that determines the microclimate in plant stands (Thevenard et al 1999)

2.2 SOIL HYDRAULIC PARAMETERS

Rawls et al. (1992) described the hydraulic conductivity and the water retention characteristics as influencing the movement of water in soils. Accordingly, these properties are closely related to the soil physical properties such as:

- Particle size properties (texture),
- Morphological properties (bulk density, organic matter and clay type (Illite or Montmorillonite).

These properties are closely related to the soil structure and soil surface area

2.2.1 Water retention characteristics

Rawls et al. (1992) defined the water retention characteristics, as the relationship between the soil water content and the soil suction or matric potential. Matric potential is the measure of the energy status of water in the soil and is a component of the total soil water potential, which is described by the Equation 2-1

Equation 2-1

$$H_t = h_g + h_p + h_o + ... + h_n$$

Where:

H_t = total potential,

g; p; o = gravitational; matric; osmotic potentials.

Soil water content and matric potential have a power function relationship. Models most frequently used to describe this relationship are those proposed by Brooks and Corey (1964) and van Genuchten (1980)

The van Genuchten proposed model permits a representation of the total water retention curve, where Campbell (1974) and Brooks and Corey (1964) describe only the portion of the curve for matric potentials less than the bubbling pressure. See Appendix 2.1 for the soil water rention and hydraulic conductivity relationships.

Saxton et al. (1986), emphasized the predominance of the soil texture in the determination of the water holding characteristics of most soils.

In their study to examine previous methods for estimating the relationship of soil-water content to potential and hydraulic conductivity for soil textures, Saxton et al (1986) concluded that between 10 and 1500 kPa soil pressure heads, the potential relationship is continuous and nonlinear, while from 10 kPa to air entry potential, it is linear and the water content is constant below the air entry potential. This relationship was summarised as shown in the Appendix 2.2.

2.2.2 Hydraulic conductivity

Rawls et al. (1992), describes this as a measure of the ability of the soil to transmit water. According to Rawls et al. (1992), the hydraulic conductivity depends on both the soil and the fluid. Total porosity, pore size distribution and pore continuity are the important soil characteristics affecting the hydraulic conductivity.

The fluid properties affecting hydraulic conductivities are viscosity and density. These properties are usually considered to be uniform in leaching modelling of fresh water. Density plays a role, e.g., in modelling of salt-water intrusion in coastal areas.

The hydraulic conductivity is a non-linear function of volumetric soil water content and varies with soil texture.

Saxton et al. (1986) referred to the measurement of the soil water potential and hydraulic conductivity as a function of soil water content as being costly, difficult and often impractical. They recommended the use of general estimates, which were based on more readily available information such as soil texture. Saxton et al (1986) used developed statistical correlation between soil texture and selected soil potentials and also between selected soil textures and hydraulic conductivities using a large number of soil samples.

2.3 AGRO-CHEMICALS IN THE LAKE NAIVASHA BASIN

Sayeed (2001) attributed the pollution of the lake and the groundwater to the intensive agricultural practice in the riparian zone of Lake Naivasha, especially to the rapid expansion of horticultural farms around the lake in last ten years (from 981.8 to 5031 hectares). This, according to Sayeed (2001) has resulted in a rapid increase of agrochemical use.

Mineral fertilizers, as water pollutants, endanger the water quality mainly in three ways:

- Nutrient loads through runoff and erosion result in eutrophication of surface water;
- Fertilizers leaching leads to nitrate pollution of groundwater;
- Trace elements can cause heavy metal contamination of surface water and ground water.

Tang (1999) pointed out that water pollution was one of the critical issues in environmental conservation. Tang was of the opinion that there was cause to be concerned about the implications of water quality, where water was being used for agriculture purposes. Agriculture sector as the single largest user of freshwater on a global basis was also a major contributor to the degradation of surface and groundwater resources.

Jolicoeur (2000), besides the comparison of different leaching models, collected several data in the field on soil hydraulic properties. Using different models and scenarios, he assessed pesticide leaching depths as a function of the meteorologic/climatic conditions and the quantities of pesticides applied on flower farms. Through the simulation, the study observed that the threat of potential contamination of the groundwater depended on the pesticide properties. Jolicoeur (2000) in this found SESOIL and SWAP as the only model capable to simulate wide ranges of scenarios occurring in the Naivasha area.

Hornsby (1999) describes the movement of contaminants through soil to groundwater as being affected by many variables, including properties of the contaminant itself, soil conditions and climatic factors. These combinations of factors made the likelihood of groundwater contamination very site-specific. Hornsby (1999), in his paper further alludes to the filtering fuction of the soil as being responsible for the protection of the groundwater quality by "filtering" contaminants out of recharge water. Present knowledge, however, indicates that the capacity of soils and the intermediate vadose zone (the area below the crop root zone and above the permanent water table) to degrade potential contaminants as they move toward groundwater is limited.

Diffusion and mass flow are affected by properties of the contaminants, the soil, the intermediate vadose zone and the aquifer; climatological factors; and vegetation patterns.

2.4 WATER USES IN IRRIGATED AGRICULTURE AROUND LAKE NAIVASHA

Huatuco (1998), in his study of the Naivasha Basin, showed that no formal evaluation for irrigation practices had been carried out in the region, although in most studies, water use for irrigation was referred to. Huatuco alluded to the differences between declared water use and the actual water use for irrigation by farmer for the 5 main types of crops growing in the region. Huatuco also referred to the water use for irrigation by the farmers as being excessive but no quantification was reported.

Ahmah (1999) showed that applied irrigation was almost double compared to the actual evapotranspiration. He alluded the excessive water usage from the lake to the use of theoretical crop evapotranspiration to evaluate crop water demand. Ahmah (1999) further referred to the abstraction for irrigation as contributing to the 20% of the outflow from the lake. The Kenya Power Generation Company was identified as a major consumer of water from Lake Naivasha too. The other three outflow components (direct evaporation, evapotranspiration from the papyrus weeds, seepage out of the lake) were considered natural.

Gitonga (1999) in his long-term water balance of Lake Naivasha showed that the difference between predicted lake level and actual lake level had changed abruptly after mid 1980.Coincidentally, the expansion of irrigated agriculture also took place after mid 1980 with the planting area increasing some 250% and with volume doubling.

WRAP survey of the 1996-97 supported the notion that abstraction for irrigation contributed significantly to the outflow of the lake and eventually contributing to the lake level fluctuations.

2.5 APPLICATION OF GIS AND IN IRRIGATION

D'Urso (2001) analysed multiyear satellite data to provide spatial and temporal distributed information on irrigated area, cropping pattern and crop performance. By integration of remote sensing techniques and simulation modelling of water flow in the soil and in the conveyance system, multispectral satellite images can be used to infer crop potential evapotranspiration, which is the main input for water balance simulations.

Moran (1994) provided an example of how an irrigation district could combine the satellite data with a model to assist in irrigation scheduling using Landsat satellite, which has a thermal band. However, the large pixel size and infrequent repeat cycle limited the use of satellite to real-time, site-specific irrigation management.

Most applications of multi-spectral data to irrigation management have been in the thermal infrared portion of the spectrum as this region of the spectrum can be directly related to surface temperature.

A major limitation to the use of remote sensing techniques for water management has been the availability of data (Jackson, 1984). In order for the data to be of use, it must:

- Provide frequent coverage of the area of interest (daily is ideal for irrigation scheduling),
- Be delivered to the irrigation manager in a timely manner (< 24 hours),
- Provide sufficient spatial resolution to accurately portray the management unit,
- Be calibrated and geometrically registered to a known coordinate system, and
- Provide data in the thermal or microwave portion of the spectrum for real-time irrigation management.

2.6 APPLICATION OF SOIL- WATER – ATMOSPHERE- PLANT ENVIRONMENT NUMERICAL MODEL (SWAP)

2.6.1 Background

SWAP simulates transport of water, solutes and heat in unsaturated/saturated soils. Swap was developed from agro-hydrological models SWATRE, SWACROP and its numerous derivations e.g. SWASALT for salt transport and FLOCR for shrinking and swelling clay soils

The model is designed to simulate the transport processes at field scale level and during entire growing seasons (Figure 2-1). The model offers a wide range of possibilities to address both research and practical questions in the field of agriculture, water management and environmental protection.

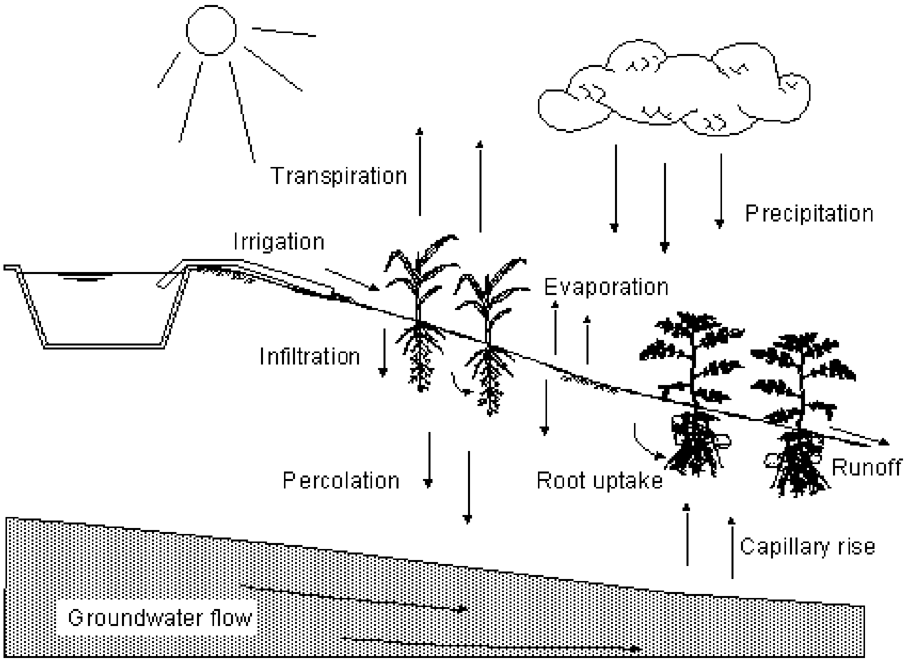


FIGURE 2-1: Hydrological processes at field scale

2.6.2 SWAP system definition

SWAP is a computer model that simulates transport of water, solutes and heat in variably saturated topsoils. Transport processes at field scale and during whole growing seasons are considered. System boundaries at the top are defined by the soil surface with or without a crop and the atmospheric conditions. The lateral boundary simulates the interaction with surface water systems. The bottom boundary is located in the unsaturated zone or in the upper part of the groundwater and describes the interaction with regional groundwater. The overview of the modelled system is shown above (Figure 2-1) as described in van Dam et al (1997).

Spatial differences of the soil water potential cause flow of soil water. Darcy's equation is used to quantify these soil water fluxes. For one-dimensional vertical flow, Darcy's equation can be written as:

Equation 2-2

$$q = -K(h)\frac{\partial(h+z)}{\partial z}$$

where:

q = soil water flux (cm/d)

K = hydraulic conductivity (cm/d)

h = soil water pressure head (cm) ; z = vertical co-ordinate (cm).

is soil water flux (positive upward) (cm d^{-1}), K is hydraulic conductivity (cm d^{-1}), h is soil water pressure head (cm) and z is the vertical co-ordinate (cm), taken positively upward.

Equation 2-3

$$H = h + z$$

where:

H is the hydraulic head which is the energy per unit weight of water.

Equation 2-4

$$h = \frac{p}{\gamma}$$

where:p is the soil water pressure (kPa) γ is the specific weight of water ($kg/m^2/s^2$)

Equation 2-5

$$\gamma = \rho * g$$

Where:

ρ = Density of water

g = Acceleration due to gravity

NOTE:

Darcy's law is applied to a saturated soil, which is homogeneous and isotropic. Therefore for a multilayered soil, it can be applied separately for each layer where the value of K and the gradient dh/dz varies from layer to layer (Maidment, 1992).

Water balance considerations of an infinitely small soil volume result in the continuity equation for soil water:

Equation 2-6

$$\frac{\partial\theta}{\partial t} = \frac{\partial q}{\partial z} - S(h)$$

where: θ is volumetric water content ($cm^3\ cm^{-3}$), t is time (d) and S is soil water extraction rate by plant roots ($cm^3\ cm^{-3}\ d^{-1}$).

Combination of Equations 2-2 and 2-6 results in the well-known Richards' equation:

Equation 2-3

$$\frac{\partial \boldsymbol{\theta}}{\partial \boldsymbol{t}} = \boldsymbol{C}(\boldsymbol{h})\frac{\partial \boldsymbol{h}}{\partial \boldsymbol{t}} = \frac{\partial\left[\boldsymbol{K}(\boldsymbol{h})\left(\frac{\partial \boldsymbol{h}}{\partial z}+1\right)\right]}{\partial z} - \boldsymbol{S}(\boldsymbol{h})$$

where: *C* is the water capacity ($d\theta/\mathrm{d}h$) (cm^{-1}).

Richards' equation has a clear physical basis at a scale where the soil can be considered as a continuum of soil, air and water. SWAP solves Equation 2-7 numerically, subject to specified initial and boundary conditions and with known relations between θ, h and K. These relationships, which are generally called the soil hydraulic functions, can be measured directly in the soil, or might be obtained from basic soil data. The Richards' equation is solved using an implicit finite difference scheme as described by Belmans et al. (1998); Van Dam et al (1997). This scheme has been adapted such that the solution applies both to the unsaturated and saturated zone, that water balance errors due to non-linearity of the differential water capacity are minimised and that calculated soil water fluxes at the soil surface are more accurate. Phreatic or perched groundwater levels are found at the transition from negative to positive soil water pressure heads.

SWAP simulates convection, diffusion and dispersion, non-linear adsorption, first order decomposition and root uptake of solutes. This permits the simulation of ordinary pesticide and salt transport, including the effect of salinity on crop growth. In case of detailed pesticide or nutrient transport, daily water fluxes can be generated as input for other groundwater-quality models

3 DESCRIPTION OF THE STUDY AREA

3.1 LOCATION

Lake Naivasha is a Shallow freshwater Lake Situated in the Eastern Rift Valley in Kenya in Nakuru District, 100 km Northwest of Nairobi (Figure 3-1). The central coordinates of the region are:

Latitude 00. 46’ S

Longitude 36.0 22’ E

Figure 3-1 Map of Kenya showing Naivasha

3.2 GEOLOGY, GEOMORPHOLOGY, SOILS AND GROUNDWATER

Naivasha is located within the Rift Valley of East Africa, which starts from Syria and expands to Mozambique through Ethiopia, Kenya and Tanzania successively.

Ase et al. (1986) characterized the Rift Valley as one of the most remarkable features of the earth crust. Through eruptions of volcanoes such as the Longonot, Eburu, etc., which are geologically Young (quaternary) most rocks and soils around the lake can trace their origins from this phenomenon.

The study of the geology of the area is give the basis to the study of agro - chemical leaching in the soils. Information is needed about the geomorphologic origin of the soil layers between the ground surface and the groundwater. Leaching, the vertical water movement in the soil takes place in this medium.

In general, two types of quaternary deposits cover the study area: one of lacustrine and the other of volcanic origin (Thompson and Dodson, 1958). Lithologically, the volcanic rocks and deposits in the area consist of basalts, phonolites, tephrites, trachytes, rhyolites, comendites and pyroclastics of acidic nature.

3.2.1 Geomorphology

Morphologically, two main landscapes have been identified in the lowland areas, among others, by Kwacha (1998): the lacustrine plains and the volcanic plains. The lacustrine plains occur mainly in the north and northeast part of the lake and formed by a number of terraces due to fluctuations of the lake water levels. Whereas, the volcanic plains, which were a result of the lava flow from eruptions of the Longonot volcano, occur mainly at the southern part and are associated with the lacustrine plains sometimes in an intricate pattern (Jolicoeur, 2000).

3.2.2 Soils

Several soil surveys have been conducted in the study area. The levels of detail of these studies have always differed. Siderius (1998) described the distribution of soils in the area as complex. The soil map resulted from previous researches shows that soil types are influenced by the extensive variation in relief, climate and volcanic activity and underlying rocks. The soils are derived mainly from weathered volcanic and basement rock system. Generally soils of the study area can be grouped into the above-mentioned two groups according to their occurrence in the landscape and the parent material: soils developed on the Lacustrine plain and those developed on the volcanic plain.

Siderius (1998), classified soils developed on the lacustrine plain as being moderately well drained to well drained, very deep, very dark greyish brown to pale brown, clay - clay loam to loam. These types of soil are found in the north-northeast part of the lake.

Kwacha (1998) classified those formed on the volcanic plain as being well drained, moderately deep to very deep, dark brown to pale brown soils, with non-calcareous to moderately calcareous topsoil, and moderately to strongly calcareous deep soil. The volcanic soil is mainly allocated in the south-southwest area of the lake (Sulmac, Sher, Oserian farms). The Kenyan Soil Survey (KSS)defined further these soils as loam to clay loam.

Soil type in the northern part of the lake is mainly silty clay to silty clay loam while in the southern part, where many farms for rose growing are located, the soil type is sandy loam to sandy clay loam.

The common characteristics of most of the soil types around the lake are very low organic content, in most of the cases as under 1 % and rather high infiltration rates.

3.2.3 Groundwater depth

The aquifers in the sub-catchment of Naivasha occur mainly in the fractured volcanic formations, or along the weathered contacts between different lithological units (Gressando, 1999). These aquifers are often unconfined close to the lake and confined or semi confined further away from the lake. High permeabilities and high yield are generally found in the vicinity of the lake.

Data from about 67 boreholes were used to assess the depth of the groundwater within the study area. The depths were measured from 1980 to 1999. The outcome of the above is the interpolated ground water table map as shown as Figure 4-1

3.3 SIGNIFICANCE OF THE LAKE

Although Lake Naivasha is a relatively small lake compared to other Rift Valley lakes, it is important for the region’s biological diversity and freshwater resources. It is located in a catchment, which has an area of approximately 3200 km^2. The lake has a fluctuating area varying from 102 km^2 during dry cycles to 150 km^2 during wet cycles. The main lake is relatively shallow (average depth 4.4 m) and it deepens towards its southwestern part to a maximum of 8 m. The deepest part of the lake is about 16 m off the Crescent Island.

The Volume of the Lake varies between 50×10^6 m^3 and 600×10^6 m^3.

The area around Lake Naivasha supports several significant economic activities. These are:

- Intensive irrigation based agriculture; livestock and dairy farming,
- Geothermal power generation,
- Fishery and
- Tourism.

Nakuru and Naivasha townships and other adjoining human settlements abstract their water supplies from the Lake Naivasha's watershed.

Due to the intense use of the land and the Lake waters and being almost a closed basin, it is extremely susceptible to pollution from farmlands, settlements and industries and river inflows.

3.4 TOPOGRAPHY

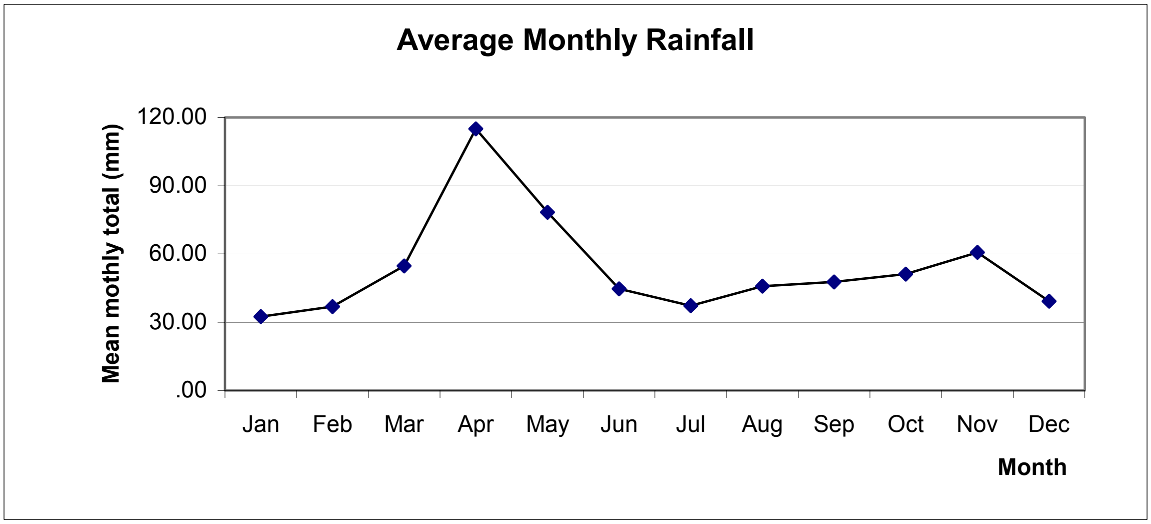
The topographic map shows that, the area near the lake where most of agricultural activities take place is flat and part of the recent lacustrine plain. The dominant slopes are within the range 0-2% and 2-5% in some places. Away from the lake the land rises gradually and slopes increase between 2 to 30%. Observation from the fieldwork showed that, irrigated land is rather flat and almost surround the lake.

3.5 CLIMATE OF THE STUDY AREA

3.5.1 RAINFALL

Rainfall is one of the most important variables in the assessment of surface- and groundwater contamination potential by nutrients and pesticide through surface runoff and leaching.

The climate of the study area is a typical equatorial tropical climate with two rainy seasons (Bimodal) that is followed by a dry season. The first rainy season is from March to May and is referred to as the "long rains". The second the "short rains" and it is from October to November. The "long rains" bring more precipitation compared to the second "short rains". The dry seasons are from December, January to February and from June to September. Relief controls the rainfall pattern (orographic) with much more rains in the higher altitude (Mmbui, 1999)

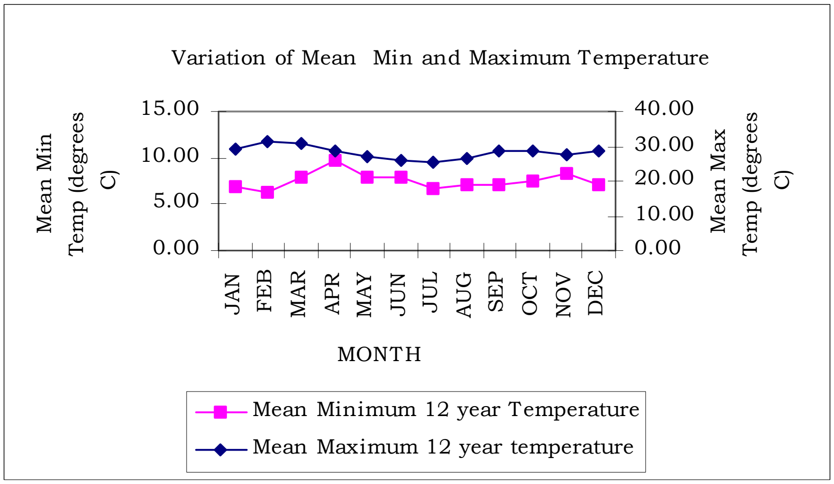


SOURCE: Mmbui, 1999

Figure 3-2: Variation of the monthly rainfall for a 42 - year period

3.5.2 TEMPERATURE

The mean maximum monthly temperature within the area is about 29°C and the mean minimum temperature is about 9°C. The temperature can be as low as 1 or 2° during the night. The warmest months are generally January, February and March whereas the coldest months are July and August.

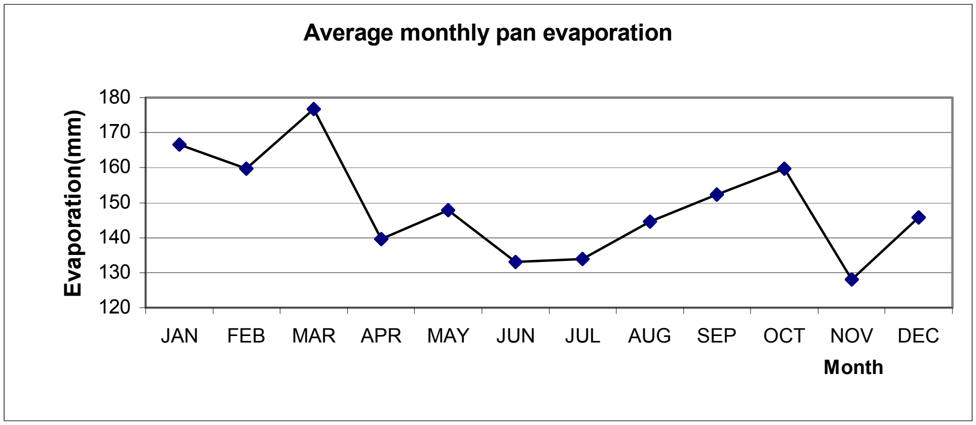


SOURCE:SULMAC FARMS

Figure 3-3 Minimum and Maximum Temperature for a 12 year period (1990 - 2001) EVAPORATION

The evaporation rate has been assessed using pan evaporation data from the Naivasha DO station. Result of an average over 33 years of data from 1957 to 1990 is presented. An American class A pan was used and the pan coefficient considered was 1. The average monthly evaporation calculated by Ashfaque (1999), was 5mm/day. The highest evaporation rate occurred in March and the lowest could be observed in November.

The yearly evaporation based on this record is estimated to be 1804.2 mm about 2.7 times greater than the annual rainfall in the area.



SOURCE: Mmbui, 1999

Figure 3-4 Daily mean pan evaporation (Naivasha D.O)

3.6 DRAINAGE

Three major rivers drain the Basin namely Malewa, Gilgil and Karati. Malewa is the biggest, with a catchment area of about 1600km^{2}and contributing about 80% of the discharge into the lake. Gilgil with a catchment area of 527 km^2 and Karati with a catchment area of about 149 km^2 contribute the remaining 20 % of discharge into the lake. The lake and the surrounding catchment drained by ephemeral streams which disappear underground before reaching the lake have a catchment area of about 1000 km^2. This makes the total basin area to be about 3376 km^2.

3.7 LANDUSE

Five major landuse units can be identified in the area:

- Agriculture (horticulture and flower growing)
- Settlements,
- Game sanctuaries,
- Rangeland (dairy) and natural vegetation.

- Forests

Horticulture and flower growing is concentrated around the lake. Vegetable and dairy farming is practiced on large estates mainly in the northeast shores of the lake. Game sanctuaries are mainly present in the west of the study area. However wildlife occupies most of the barren shrub, grasslands. Settlement is mainly concentrated in Naivasha town but scattered homes and villages are present on estates within the study area. The natural vegetation surrounding the lake is mainly papyrus swamp vegetation. Natural vegetation outside of the lake surroundings are shrub, acacia, cactus trees and savannah.

3.8 DESCRIPTION OF THE FIELD WORK AREA

3.8.1 The Sulmac farm

The Study site was the SULMAC farm. This farm is located is located within the following coordinates:

Table 3-1 Coordinates of the Sulmac farm

	UTM X	UTM Y
Maximum	210000	9909000
Minimum	203500	9904400

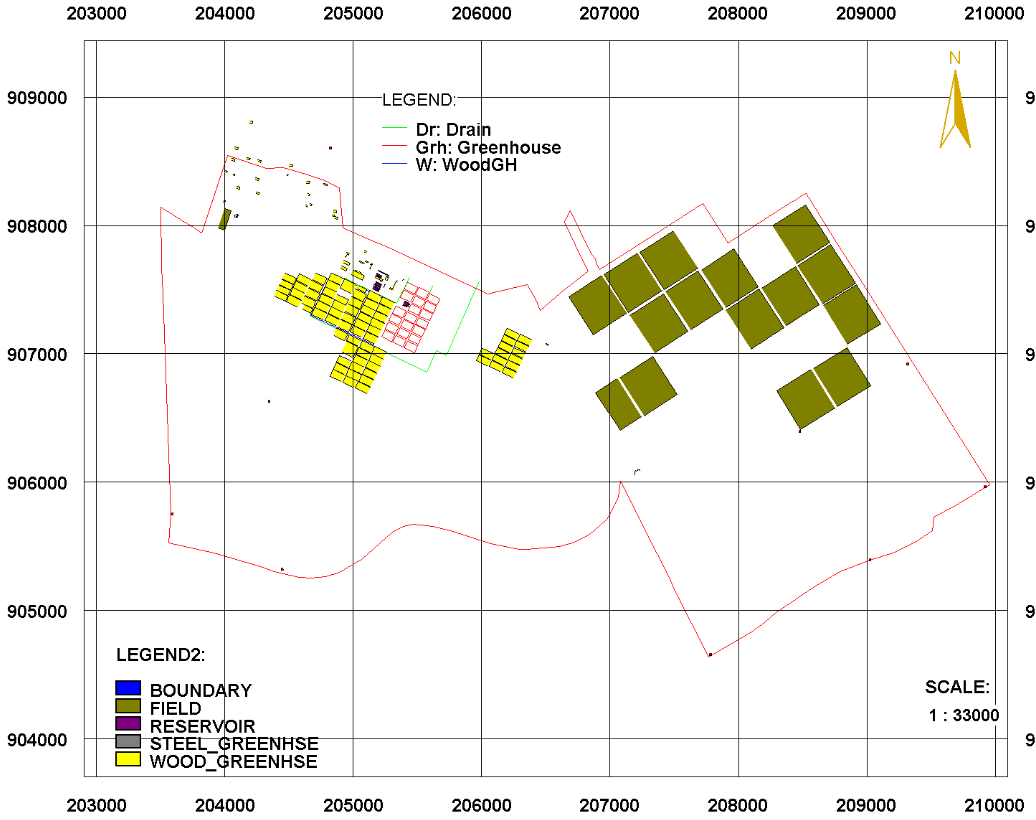


Figure 3-5 SULMAC FARM

The SULMAC Farm is mostly engaged in floriculture. The following flowers are currently being grown at the SULMAC Farm are listed in Table 3-2.

Table 3-2 Flower types and the corresponding surface area

Crop	Area (ha)
Rose (GH)	43.32
Carnation	6.56
Hyperican	20
Gypsofilia	3.24
Lilies	0.612
Total	73.732

The above listed flowers are grown under greenhouses covered with a single plastic (poly ethylene) claddings. The areas occupied by the Roses make up the largest proportion of the enterprise. This is attributed to the fact that it contributes 70% of the total income earned by the company, (verbal discussion with the Management).

3.8.2 SAMPLING SITE

The selected sampling site was Rose IV. It is a new rose project and commonly referred to as “Israeli” or “steel greenhouse” because of the steel frames over which single sheet plastic claddings are covered as compared to old greenhouses that have wooden frames. This projected was started in 1999. The current crop was planted in the July of the 1999.

Rose IV consists of 20 greenhouses of 5000 square meters in size and located at the following coordinates:

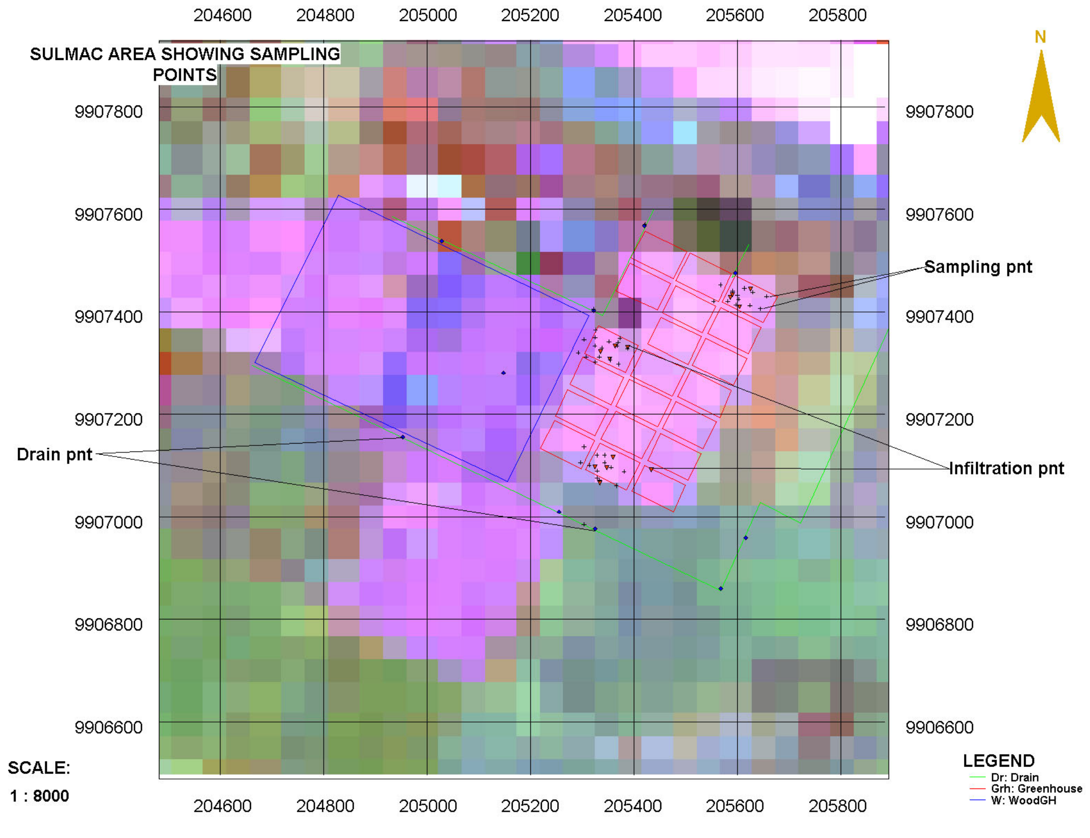


Figure 3-6 Sampling Locations

Each greenhouse has 38 x 2 beds separated by a path in the middle as illustrated by the sketch in figure 3.7

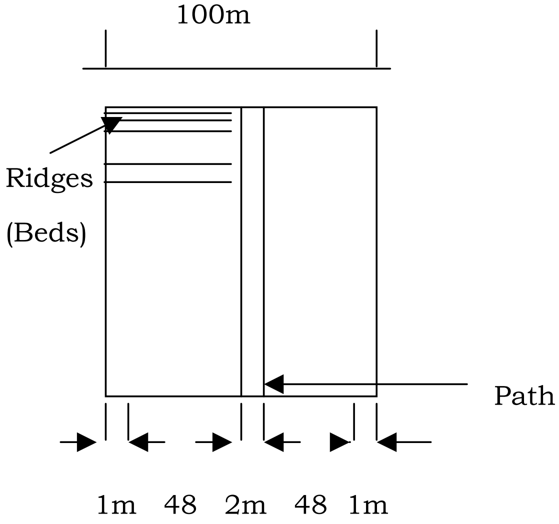


Figure 3-7 Layout of the greenhouse (not to scale)

The crop density per greenhouse can be described as follows:

- Area of GH = 5000 m2
- Crop: Roses grown on ridges (Beds)
- Number of beds 38 x 2
- Width of Bed = 100 cm
- Width of furrow (Path) 60 – 80cn
- Number of plants per bed 222 x

The conceptual model of the water fluxes in the study site is shown in Figure 3-8.

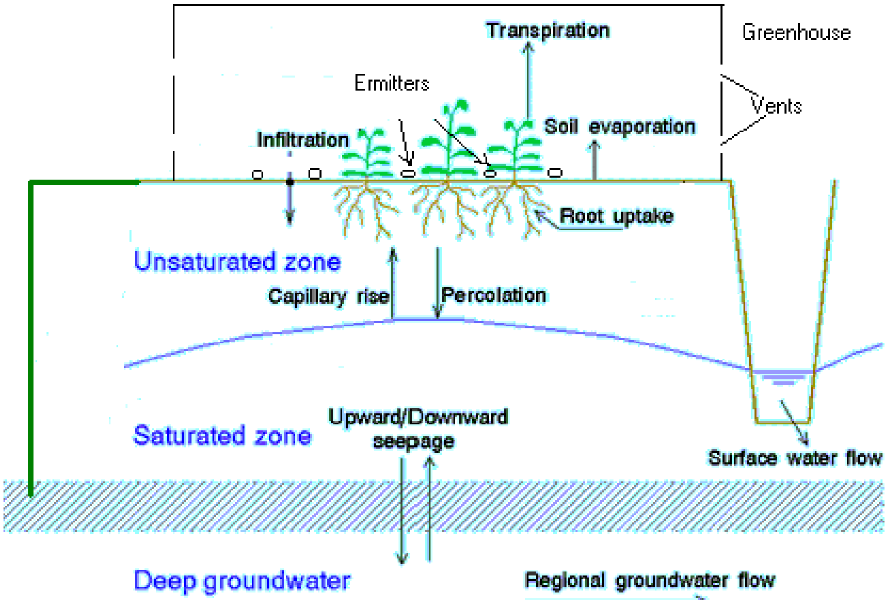


Figure 3-8 Conceptual model of the problem in the greenhouse (Source: Kroes et al., 1998)

4 DATA ACQUISITON AND PRIMARY ANALYSIS

In order to simulate nitrate-nitrogen leaching with the model SWAP several parameters are required .To acquire these, onsite and offsite (remote sensing) methods are used. Onsite methods will include field measurements carried out to get site-specific data. In this study field measurements, field sampling, and literature review have been carried out to acquire the necessary data.

To run the SWAP model, additional data such as the groundwater depth in the study area, the initial solute concentration in each soil layer, the number and thickness of soil layers in the soil profile, the number and thickness of compartments in each soil layer were required.

From Oppong-Boateng (2000), data of groundwater levels around the Lake were derived, from Sayeed (2000), data on landuse based on GPS record for farm boundary and the total irrigated land area interpreted from satellite image, from Mekkonnen the relationship between incoming shortwave radiation and incoming shortwave radiation inside the greenhouse, while from Dao, (2001) and Jolicoeur, (2000) soil types in the SULMAC farm area were derived.

DATA ACQUISITION

Data acquisition includes primary and secondary data collected before, after and during the fieldwork period (11th September to 5th October) and at the SULMAC Farm in the Lake Naivasha Basin. It includes:

- Meteorological data,
- Irrigation and water use data,
- Agro-chemical inventory and application data,
- Soil samples and soil hydraulic properties data
- Crop data

The information from these data were used to derive parameters required to calibrate the Soil Water Atmosphere and Plant (SWAP) model. In order to simulate the vertical transport of water and solutes in the vadose zone, SWAP requires the following:

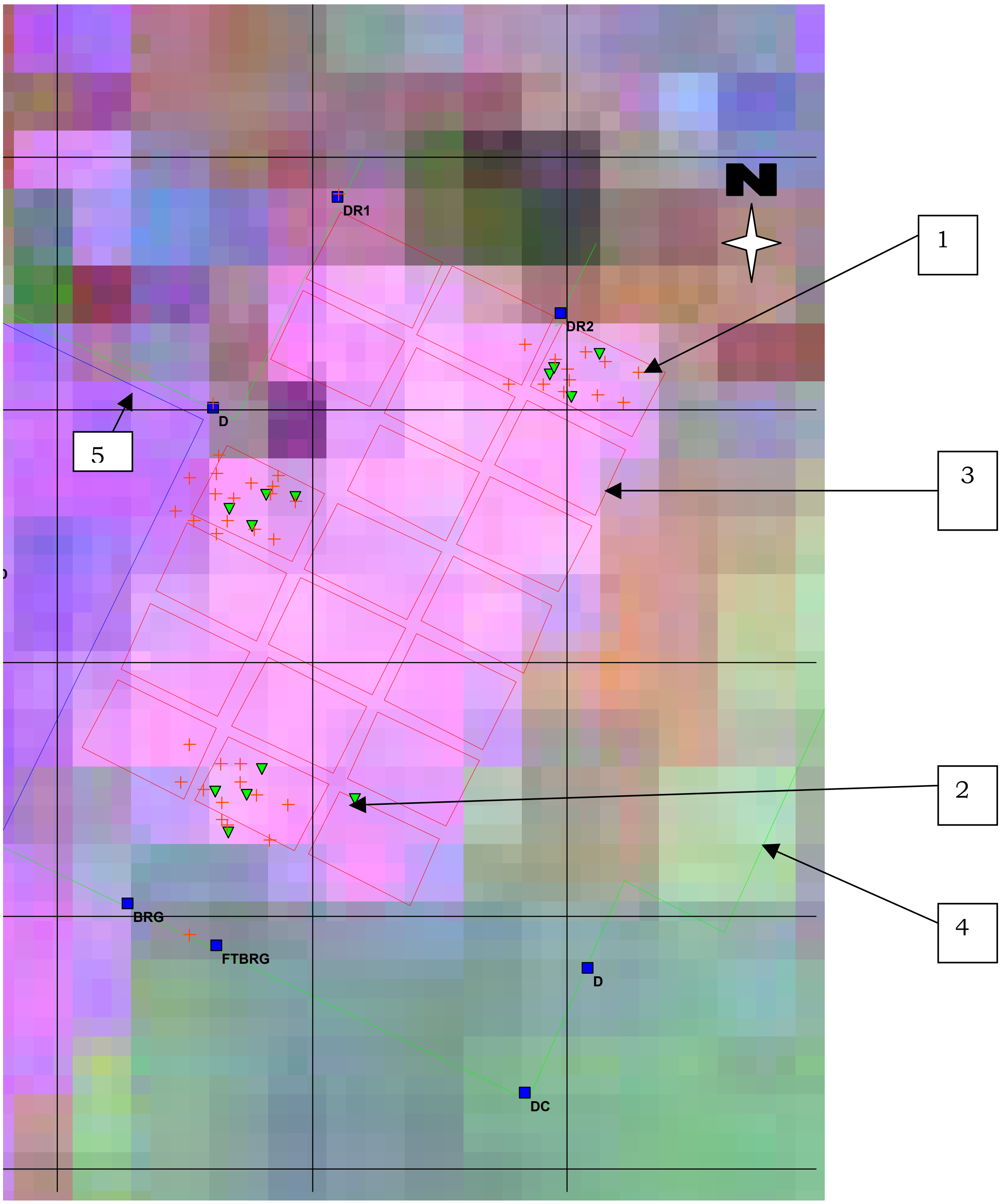
- daily minimum and maximum temperatures,
- relative Humidity,
- radiation,
- wind speed at 2 m above the ground
- and rainfall and
- the soil hydraulic properties.

The daily climatic data was collected from SULMAC weather station. Use was made of the climatic data set of the year 2000, collected by Dao (2001). In view of difficulties encountered in acquiring radiation data, it had to be calculated using the Angstrom formula, which is based on the temperature, latitude and longitude, altitude, humidity and Julian day (FAO, 1998).

4.1.1 Sampling and experiments

Three greenhouses were made available for carrying out experiments and sampling. These are Houses 3, 13 and 14 of SULMAC's Roses IV section. As can be seen in Figure 4-1, Greenhouse 3 is almost in the middle of the section, while house 13 and 14 are located at the lower and upper ends. In order to ascertain leaching possibilities, soil samples were collected from 4 depths (15, 50, 90 and 150 cm). The root depth of the roses is 50 cm.

To ascertain the effect of the discharging of flush water from the drip pumping stations into drainage ditches, water and soil samples were collected from the drains with the soil samples collected at 4 depths (50, 100, 150 and 200 cm).



1. Soil sampling site
2. Inverse Auger test site
3. Roses IV (steel framed Greenhouses)
4. Drain
5. Wooden Greenhouse

FIGURE 4-1 Sampling sites at the SULMAC farms (distance between gridlines = 200m)

From the figure 4-1 above some sampling points are located outside the greenhouses due to the GPS – accuracy that was 10m. This has been presented here without any modification.

4.1.2 Irrigation and water use

An average daily irrigation of 35 m^3 per greenhouse was being applied by drip irrigation and about 10 m^3 was applied for the humidification purposes as shown in the tables in Appendices 4.3a and 4.3b. In the following, taking into account the area of the greenhouses an irrigation depth of 7 mm is adopted for the leaching modelling. The total irrigation depth is distributed in 5 cycles everyday (see Appendix 4.1).

Water for irrigation is abstracted from lake Naivasha into storage reservoirs referred to as lagoons to settle. The water is pumped from the lagoon, through a filter bank, through a fertilizer injector (fertigation unit) into the main irrigation line, which delivers the irrigation water to the individual greenhouses

In order to establish the general moisture profile of the soil in the greenhouses, several soil samples were collected before and after an irrigation input. The general trend was as shown by the Figure 4.6.

4.1.3 Drainage ditches

The drains are earth ditches lined with short grass. They have a trapezoidal cross section with varying sizes. The details of a cross section can be found as Appendix 4.2.

The major purposes of the drains at SULMAC farms as observed during the fieldwork in 2001, are to divert runoff during and after precipitation events. The drains also receive and discharge flush water from the 12 drip stations.

Flushing of the drains is done on hourly basis of each working day (and working time which is 12 hours). The duration of flushing is about 2 minutes and a volume of 0.8 m^3 of water is discharged into the drain. During the dry season most lengths of the drains are dry except near discharge points where ponding is evident. At these sections of the drains, flush water flows at velocity of less than 1 m/s. The water at this section only seems to flow when the drip stations are discharging its flush water into the main drainage ditch. From the fieldwork observation, most of the flush water infiltrates into this drain within a distance of about 800 m from the discharge point.

4.2 AGRO-CHEMICAL INVENTORY AND APPLICATION DATA

Agro-chemicals consist of fertilisers, pesticides, and fungicides, insecticides whose function is to facilitate high agricultural productivity. Agro-chemicals avail the nutrient the crop in form of fertilizers, they also prevent and protect the crops from diseases and insect attacks.

4.2.1 Fertilisers

A total of 12 soluble fertilizers and 3 foliar fertilizers are being applied. The soluble fertilizers are dissolved in 2 tanks (A and B) of 1000 litre capacity to make stock solutions, while foliar fertilizers are sprayed on to the crop according to the spraying schedule. It was also learnt that on the daily basis the fertilisers shown in Table 4-1 are applied as liquid feed.

Table 4-1 Daily fertiliser application rate

Fertiliser type	Quantity (kg/1000 l)	Tank	Concentration in the stock solution (mg/l)	Concentration in Irrigation Water (mg/l)
$Ca(NO_3)_2$	43.1	A	43100	1.2314
Urea	2.1	A	2100	0.0600
Fe (11%)	1.8	A	1800	0.0514
Urea	1.4	B	1400	0.0400
$(NH_4)_2SO_4$	11.3	B	11300	0.3229
K_2SO_4	6.7	B	6700	0.1914
KNO_3	26	B	26000	0.7429
$MgSO_4$	23.7	B	23700	0.6771
$CuSO_4$(25%)	0.024	B	24	0.0007
Solubor (Bo) 20%	0.1105	B	110.5	0.0032
Zn (15%)	0.0165	B	16.5	0.0005
Mn(13%)	0.2	B	200	0.0057
Sodium Molybdate	0.002	B	2	5.7143E-05

4.2.2 Pesticide

A total of 140 biocides are being used at SULMAC. During the time of the fieldwork (September to October 2001) the chemicals listed in Table 4-2 were used in the sampling site (Roses IV).

Table 4-2 Pesticides currently in use

PRODUCT NAME	ACTIVE INGREDIENT	Dose g/Ltr	TOXICITY WHO	TOXICITY EPA	SEPTEMBER pesticide Consumption QTY (kg)	kg/ha
AVAUNT	indoxacarb	150			30.9	0.71
BAVISTIN 50 DF	50% carbendazim	500	IV		12.3	0.28
RUFAST 15 EC	15% acrinathrin	150	III	IV	1.2	0.03
DECIS 25 EC	2.5% deltametrin	24	II	II	10.8	0.25
EQUATION PRO DF	famoxate/cympxanil	525	III		12.08	0.28
MAGISTER	fenazaquin	200			96.5	2.23
MILRAZ 76WP	76% cymaxanil+propineb	760	IV		39.2	0.90
NIMROD 250EC	25% bupirimate	250	III	III	129.6	2.99
ROUVRAL 250FLO	25.5% Iprodione	500	IV	IV	78.5	1.81
TEDION V-18EC	80% Tetradifon	75.2	III	III	154.25	3.56
THIOVIT 80WP	80% sulphur	800	IV	IV	93.6	2.16
SULFUR DUST	Sulphur	980	IV			

Table 4-3 Other chemicals used in the roses program

PRODUCT NAME	ACTIVE INGREDIENT	Dose g/Ltr	TOXICITY WHO	TOXICITY EPA	SEPTEMBER pesticide Consumption QTY (kg)	kg/ha
Dursban 4 EC	48% Chlorpyiphos	480	II	II	8.00	0.18
Dynamec 1.8 EC	80% abamectin	18	Ib	I	85.60	1.98
Karate 17.5 EC	17.5% lambda- cyhalothrin	17.5	II	II	25.00	0.58
Lannate 90 SP	90% Methomyl	900	I	I	23.00	0.53
Meltatox 40 EC	42% dodemorph acetate	400	III	III	148.15	3.42
Nissorum 10 EC	hexythiazox	100	IV	?	1.50	0.03
Nomolt 15C	15% teflubenzuron	150	T5	IV	0.45	0.01
Nuster 40 EC	40% flusilazole	400	II	III	3.38	0.08
Oscar 20 SC	tebufenpyrad	200	?	?	4.00	0.09
Ridomil MZ 63.5	63.5% Metalaxy/mancozeb	635	III	III	17.00	0.39
Rubigan 12 EC	12% Fenarimol	120	IV	III	17.99	0.42
Scala 40 SC	40% pyrimethanil	400	?	?	14.88	0.34
Spore-kill	12.5% Quaternary Ammonium Chloride	120	IV		2.00	0.05
Teldor	fenhexamid	500			4.00	0.09
Thiodan 35 EC	endosulfan	350	I	I	19.00	0.44
Benlate 50 WP	50% Benomyl	500	IV	IV	47.80	1.10
Dithane M 45	Mancozeb	750	IV	IV	78.60	1.81

WHO toxicity classification:

- Ia: extremely hazardous
- Ib: highly hazardous
- II: moderately hazardous
- III: slightly hazardous

EPA (USA) persistence classification (ETN, 1993)

- Low: 0-30 days

Medium: 30-60 days

High: >100 days

4.3 SOILS TESTS

Several soil samples were collected during the fieldwork, from the three greenhouses, from drains and outside of the green houses, at the sites shown in figure 4-1.

The preliminary pH was established for the topsoil using the field methods as shown in Table 4-4 and also in the SULMAC laboratory as shown in Appendix 4.8. The soil reaction as an indicator of the carbonate contents of the matrix material was assessed by the addition of 10% of hydrochloric acid to the topsoil sample and then comparing the colour to a Munsell soil colour chart (colorimetric method). The soil sample exhibited visible Effervescence, which is a typical characteristic of the moderately calcareous soils.

For determining the grain size distribution of the soil samples, during the fieldwork a sieve analysis was attempted. However, because of lacking appropriate equipment, the process could not be concluded. This was later on concluded at the ITC laboratories as shown in Appendix 4.5.

Table 4-4 Field pH and Carbonates Measurements (field method)

	Green House number	**pH**	**Carbonate (soil reaction)**
1	3	5	Moderately calcareous
2	13	4	Moderately calcareous
3	14	5	Moderately calcareous

Soil moisture content was defined using the gravimetric oven method while an attempt for measuring infiltration rate was made using a theta probe moisture meter and a double ring infiltrometer.

4.3.1 In situ estimates of saturated hydraulic conductivity

Saturated hydraulic conductivity (K_{hsat}) is one of the main parameters in the flow of water. This parameter was determined using the inverse auger-hole method.

For a multi-layered unsaturated soil zone as observed at the SULMAC farm, the value of K_{hsat} was determined for each separate layer. A hole of a diameter d=8 cm was augured down to the specific layer at a depth D as shown by table below. The hole was filled with water (initially several times for a duration of not less than 30 minutes) up to a required height in order to remain within the layer. The draw down $h'(ti)$ of the water level was measured at each time step and recorded successively.

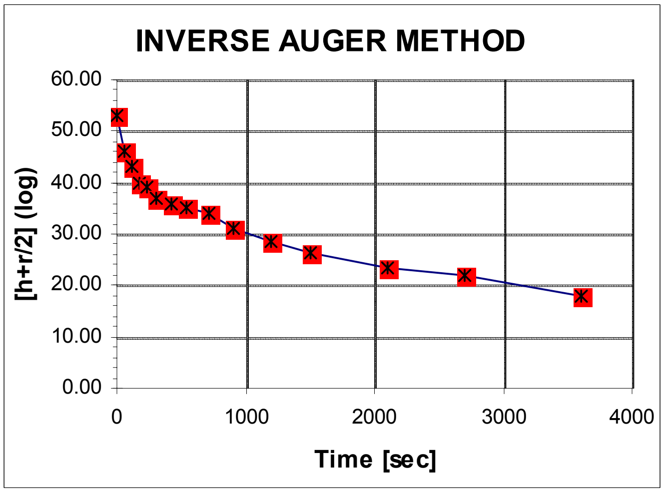
Subsequently, *h(ti)* was obtained by subtracting *h'(ti)* from the total depth *D*. The log(*h(ti)*+*d*/2) was plotted against the time *t*. In the beginning, until the layer gets saturated, the drawdown gradually slows down (resulting in a curved line on the plot) then on saturation, the plotted line becomes straight. The saturated hydraulic conductivity can be obtained as the slope of this straight part, ε. Equation 4-1 gives the expression of the hydraulic conductivity:

Equation 4-1

$$K_{hsat} = 1.15 * r * \log \varepsilon$$

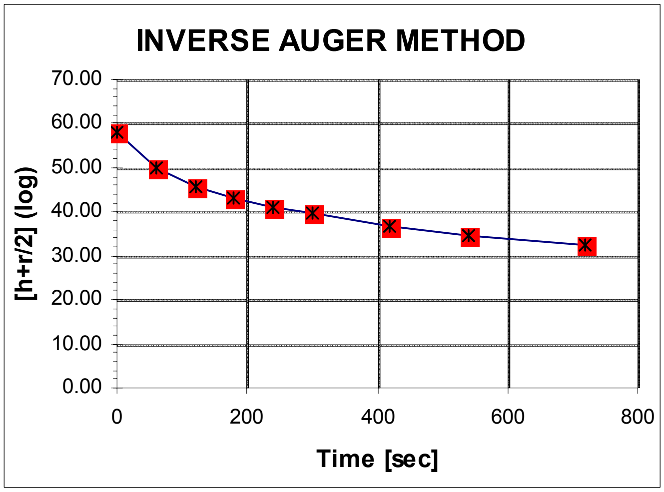
Figures 4-2 – 4-5 show the graphical representations of the drawdown values and the calculated saturated hydraulic conductivities, for selected boreholes. In the figures, GH stands for greenhouse and SP stands for soil pit.

Figure 4-2 Saturated Hydraulic Conductivity for GH3



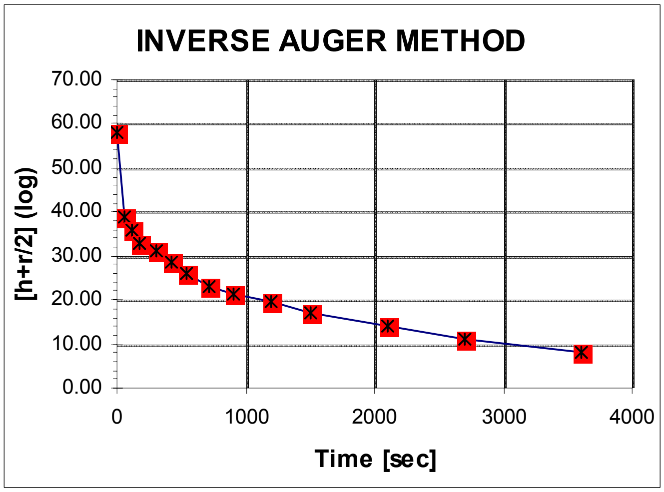
K_{hsat} = 31.8 cm/d

Figure 4-3 Saturated Hydraulic conductivity for GH13



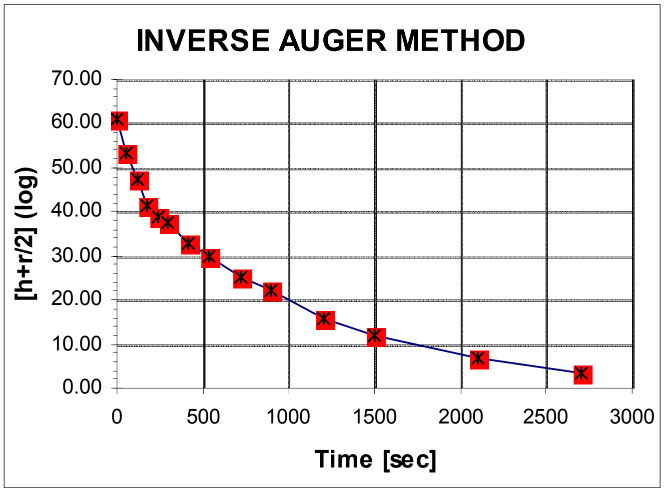
K_{hsat}= 39.7 cm/d

Figure 4-4 Saturated hydraulic conductivity for GH14



K_{hsat} = 79.5 cm/d

Figure 4-5 Saturated Hydraulic conductivity for SPL4



K_{hsat} = 159 cm/d

The following Hydraulic conductivities were measured for the sample sites at between 45 and 70 cm depth.

Table 4-5 Soil Saturated Conductivities from the Greenhouses (GH)

GH no:		Test1	Test2	Test3	Test4	Mean GH Khsat	Soil type
03	Khsat (cm/d)	31.8	27.8	38.7	35.8	33.5	Loamy Sand
13	Khsat (cm/d)	39.7	39.7	39.7	39.7	39.7	Sandy Loam
14	Khsat (cm/d)	39.7	79.5	31.8	31.8	45.7	Loamy Sand

For the soil pit, the hydraulic conductivities were as shown in Table 4-6:

Table 4-6 Soil properties from the soil pit (SP Li)

Depth *D* (cm)	Name	Thickness (in cm)	Mean MC (cm^3/cm^3)	K_{hsat} (cm/d)
15	Top soil	30	0.283	159
50	Second layer	50	0.060	516.7
110	Third layer	70	0.120	39.7
167	Fourth layer	50	0.248	159

Where:

MC – Moisture content

K_{hsat} – Hydraulic conductivity

4.3.2 The greenhouse soil moisture profile

Several soil samples were collected from greenhouses using the soil auger. These were weighed and then oven dried at 105 C for a duration of 24 hours at the

SULMAC laboratory. After re-weighting, the fraction of water on mass basis was established (w).

Equation 4-2

$$w = \frac{m_w}{m_s}$$

Where:

w = fraction of moisture content on the mass basis (g/g)

m_w = mass of water in the soil sample (g)

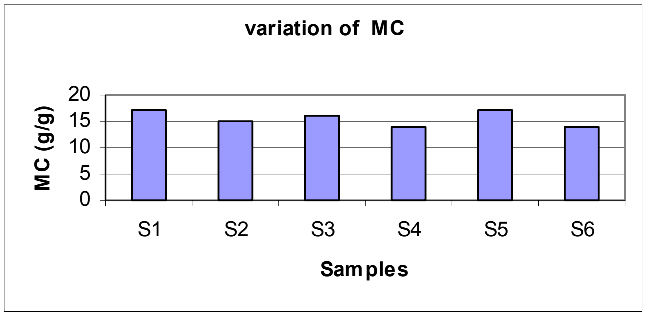
m_s = mass of solids in the soil sample (g)

Tables 4-7 to 4-9 illustrate the temporal variation moisture contents in the greenhouses.

Table 4-7 Variation in MC in GH3

GREEN HOUSE no.3					
SAMPLE	Initial Mass (g)	Final Mass (g)	Moisture Content (g)	Mass Wetness w	$\boxed{V_w = \frac{m_w}{\rho_w}}$
S1	100	83	17	0.20	17
S2	100	85	15	0.18	15
S3	100	84	16	0.18	16
S4	100	86	14	0.20	14
S5	100	83	17	0.17	17
S6	100	86	14	0.17	14

Figure 4-6 Graphical Representation of Table 4-7



During the observation period the average moisture content on dry basis (θ g) was 15 g/g while the standard deviation was 1.4 for greenhouse 3 and 1.2 for house 13. For House 14 the average volumetric moisture content was 19.33 g/g while the standard deviation was 2.7.

Table 4-8 Variation in MC in GH13

GREEN HOUSE no:13					
SAMPLE	Initial Mass (in g)	Final Mass (in g)	Moisture Content (g)	Mass Wetness w	$\boxed{Vw = \frac{m_w}{\rho_w}}$
S7	100	83	17	0.20	17
S8	100	85	15	0.18	15
S9	100	85	15	0.18	15
S10	100	83	17	0.20	17
S11	100	86	14	0.16	14
S12	100	85	15	0.18	15

Table 4-9 Variation in MC in GH14

GREEN HOUSE no:14					
SAMPLE	Initial Mass (in g)	Final Mass (in g)	Moisture Content (g)	Mass Wetness w	$\boxed{Vw = \frac{m_w}{\rho_w}}$
S13	100	83	17	0.20	17.00
S14	100	83	17	0.20	17.00
S15	100	81	19	0.23	19.00
S16	100	82	18	0.22	18.00
S17	100	79	21	0.27	21.00
S18	100	76	24	0.32	24.00

Notes:

Depth of sampling is 50 cm.

Samples S1, S7 & S13 were collected in order to ascertain the crop water consumption from the previous day's irrigation (cycle 5).

Samples S2, S8 & S14 were collected as a way of monitoring the water input (first cycle: 2mm)

Samples S3, S9 & S15 were collected to monitor the water consumption (first cycle).

Samples S4, S10 & S16 collected to verify the water input (Second cycle: 1mm).

Samples S5, S11 & S17 collected to monitor the water consumption (Second cycle).

Samples S6, S12 & S18 collected to verify the third cycle input.

Between S1 and S6; S7 and S12 and S13 and S14 a difference of about 8 hours was observed.

4.3.3 Undisturbed soil samples

In order to determine other important soil properties such as dry bulk density (ρb) porosity (Φ), volumetric soil moisture content (θv) and the water holding capacity of the soil (SWC), undisturbed samples of known volume (100 ml) were obtained using stainless steel core rings.

The undisturbed soil samples were collected from the greenhouses 3, 13 and 14 from a depth of 30 cm and from the 5 horizons of the soil pit. The samples were processed in the SULMAC laboratory according to the standard procedure.

The undisturbed samples from the soil pit where brought to the Netherlands in the hope of establishing the soil moisture characteristic curve (MRC or pF- curve) of the different soil layers. However due to technical and time constraints, this could not be achieved. Tables 4-10 shows the results of the processing of the undisturbed samples from the three greenhouses.

Table 4-10 Undisturbed samples from Greenhouses (3, 13, 14)

Cylinder identity &	Mass in g	mass of cap	Dry mass in g	θ	Bulky(dry) density ρb	w	(ρt)Total (wet) Bulk density	Vol of water Vw	Vol of solid (Vs)	Vf	Degree of saturation (S)	Porosity f	Void Ratio e fract Vol. Of pores
Units		g		cm3*cm-3	g/cm3	g/g	g/cm3	cm3	cm3	cm3			
3 S	310	21	221	0.693	1.293	0.535	2.414	68	47.037	51.150	1.329	0.521	1.087
3M	307	20	231	0.570	1.405	0.406	2.383	56	51.111	47.076	1.190	0.479	0.921
3N	308	21	232	0.560	1.385	0.404	2.373	55	50.370	47.817	1.150	0.487	0.949
13 S	273		205	0.693	1.120	0.618	1.813	68	40.741	57.447	1.184	0.585	1.410
13 M	295		221	0.754	1.293	0.583	2.047	74	47.037	51.150	1.447	0.521	1.087
13 N	304		233	0.723	1.375	0.526	2.098	71	50.000	48.188	1.473	0.491	0.964
14 S	285		228	0.581	1.344	0.432	1.925	57	48.889	49.298	1.156	0.502	1.008
14 M	271		228	0.438	1.314	0.333	1.752	43	47.778	50.409	0.853	0.513	1.055
14N	276		231	0.458	1.365	0.336	1.823	45	49.629	48.558	0.926	0.495	0.978

4.4 Estimation of the soil parameters for leaching modeling using SWAP

To simulate the solute vertical transport, the SWAP model required other soil properties such as:

- Soil physical properties (type and the particle size distribution and organic matter content),
- Soil hydraulic properties.

4.4.1 Grain size distribution and organic matter content

The particle size distribution and the organic matter content were established in the ITC –laboratory using the soil samples from the SULMAC Farm based on the ISRIC/FAO procedures of soil analysis. Appendix 4.5 shows the analysis results.

The percentage of sand, silt and clay were compared on the USDA soil triangle from which the soil type was derived.

Diatomite material, which was prevalent at a depth of 2 m and below on being analysed, showed characteristics of silt loam soils.

The organic matter content was indirectly obtained by first obtaining the carbon content using the Walkley-Black procedure. The organic carbon content was found through the use of an empirical conversion factor of 2. The equation for the conversion is shown below as equation 4-4:

Equation 4-4

$$\%\boldsymbol{OM} = 2 * \%\boldsymbol{CarbonCont}$$

Where:

OM = Organic Matter

2 = empirical conversion factor

1.3 was used as a compensation factor for the incomplete combustion of organic matter in the calculation of the percentage carbon.

4.4.2 Moisture retention curves and the van Genuchten parameters

The moisture retention curve (pF curve) is normally derived from the undisturbed samples in a specialised laboratory. In the SWAP model, these curves are described by the van Genuchten shape parameters (van Dam et al., 1997). However, in view of the limitation in time, an alternative method was applied. The pedotransfer functions (PTF) were used to derive the pF curves and their van Genuchten parameters from the particle size distribution.

There are several methods for approximating the pF curve from particle sizes in the literature. Two of them were considered for the present work.

The method suggested by van Keulen and Wolf (1986) correlates the pore size distribution to the particle size distribution, and uses this information for the estimate of the pF curve. This method failed to describe the differences between the soil samples of the SULMAC Farm in detail, so it was not used in the further studies.

Another method was suggested by Saxton et al. (1986). They developed a set of equations from which soil-water characteristic equations for a number of soil textural classes can be derived. However, the equations published by Saxton et al. (1986) are not valid for soils with low and high clay content.

This method is based on the statistical correlation between soil texture and selected soil water potential using a large database, and also between selected soil textures and hydraulic conductivities. The method uses 3 mathematical equations for continuous estimates of the moisture characteristic curves over broad ranges of soil textures, water potentials (h or Ψ), and hydraulic conductivity. These terms are applicable in three pressure head ranges:

- 0 to air entry pressure (h_b or Ψ_e),
- h_b to 10 kPa
- 10 to above 1500 kPa.

Appendix 2.3 shows the above-mentioned mathematical terms while Appendix 4.15 shows the corresponding values. Figures 4-7 to 4-10 are the derived pF curves of the modelled soil layers.

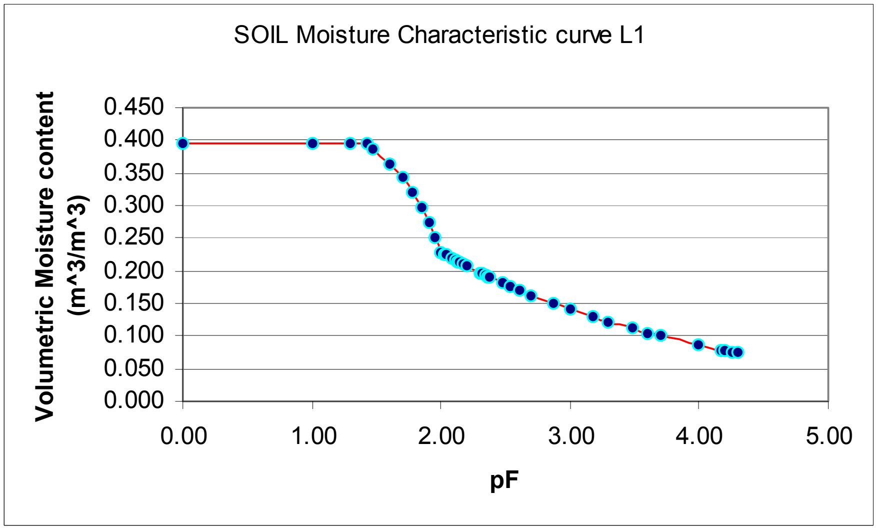


FIGURE 4-7 Moisture characteristic curve for Layer 1

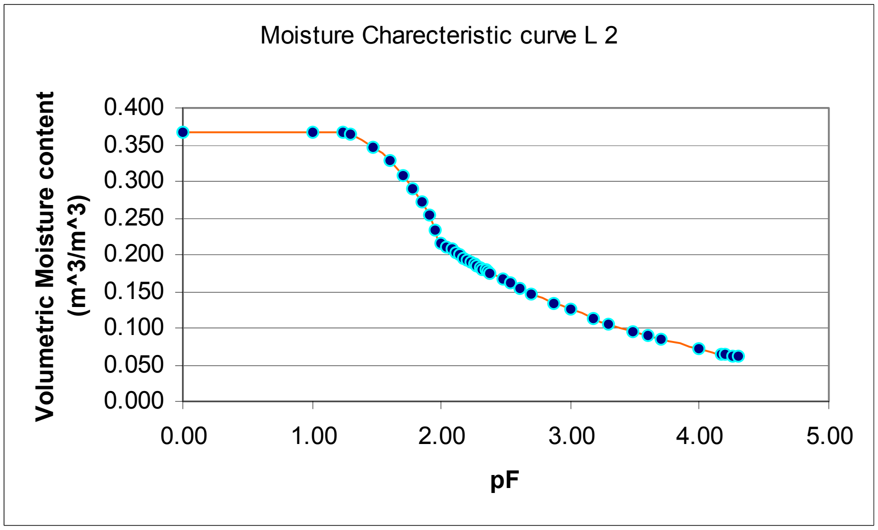


FIGURE 4-8 Soil Moisture characteristic curve for L2

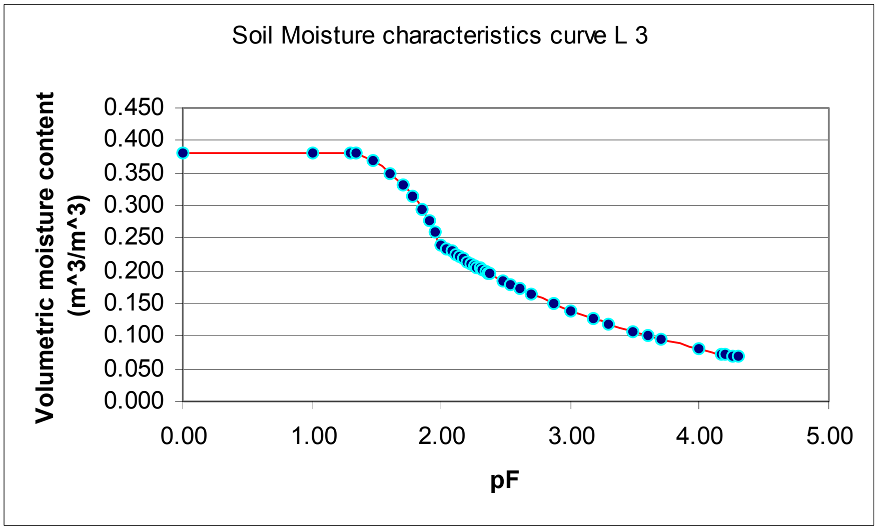


FIGURE 4-9 Soil Moisture characteristic curve for L3

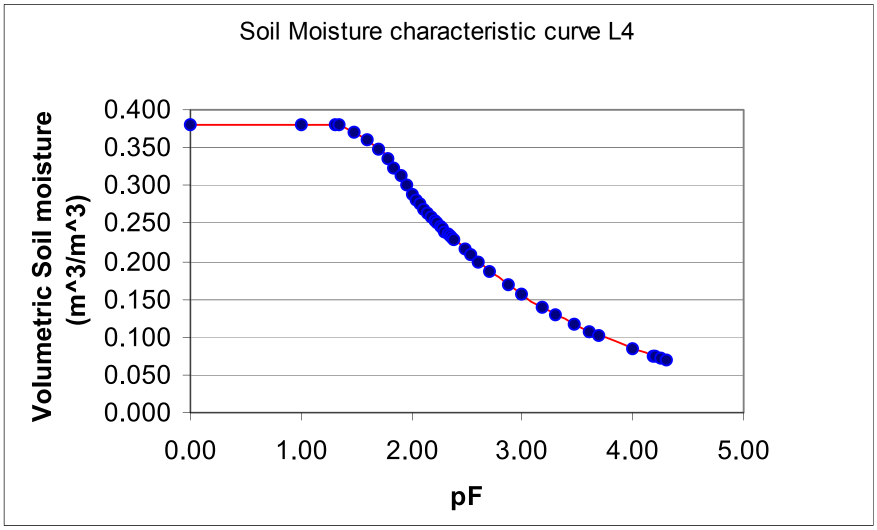


FIGURE 4-10 Soil Moisture characteristic curve L4

From the soil moisture characteristics curve, the following soil moisture values and van Genuchten parameters were derived:

Saturated soil moisture content (θ_{sat}), moisture content at field capacity (θ_{fc}), residual soil moisture (θ_{res}), soil moisture at air-entry pressure (θ_{hb}), α factor; m and n shape exponents in the van Genuchten approximation of the pF curve (Equation 4-4). The first approximation of the latter parameters was calculated with the Brooks and Corey method (Maidment, 1992) as shown in appendix 4.16.

Equation 4-3

$$\frac{\theta - \theta_{res}}{\theta_{sat} - \theta_{res}} = S = \left[1 + (\alpha \mid h \mid)^n\right]^{-m}$$

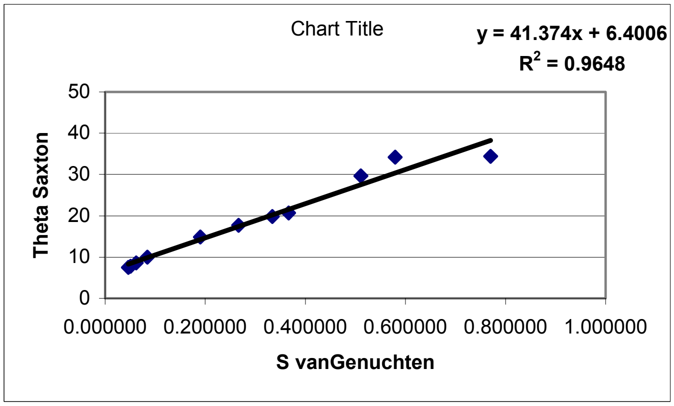
Where:

S is the reduced water content and the other parameters are as described above.

Using the values of this first approximation as a starting point, an optimisation was carried out to fit the curve calculated by the van Genuchten parameters (Equation4-4) onto the pF curves defined using the Saxton et al. (1986) method.

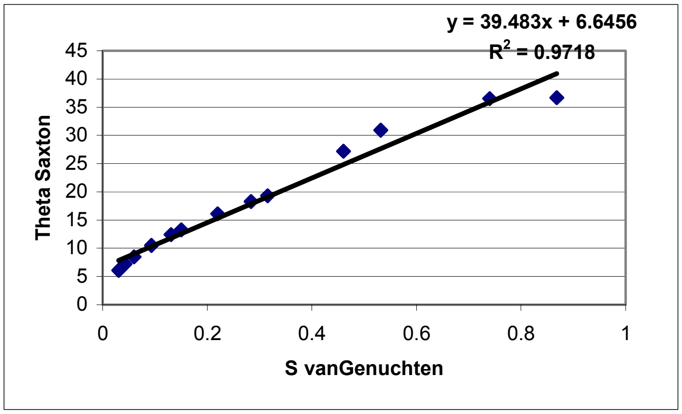
To verify the goodness of the fit between the two curves, the scatter plot of θ_{Saxton} against $S_{vanGenuchten}$ should give a straight line with θ_{res} as the intercept, and $\theta_{sat} - \theta_{res}$ as the gradient. The figures 4-14 to 4-17 give the resulting curves for Layer 1 to 4 of the soil pit.

However,it is important to note a kind of systematic discrepancy of the plotted points and the straight-line. This could be attributed to the approximation used in the pF- estimation. The largest inaccuracies are especially found at the extreme suction values such as the wilting point and the saturation point although fitting a straight line has acceptable accuracy.



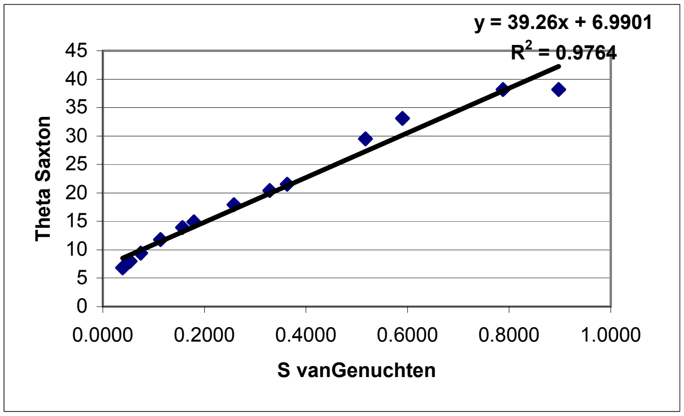
θr = 0.064

Figure 4-11 Curve fitting for Layer 1 (L1)



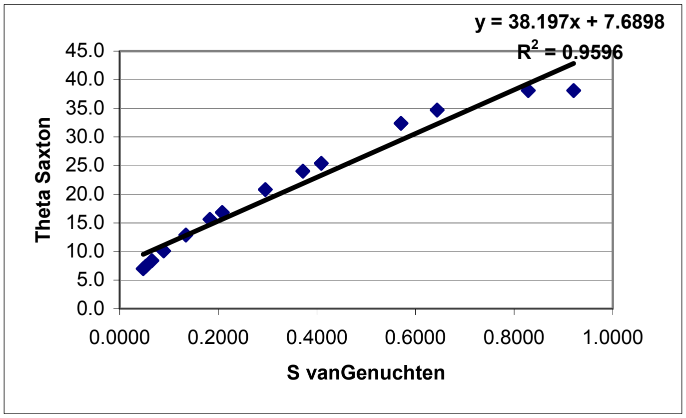
θr =0.066

Figure 4-12 Curve fitting for Layer 2 (L2☺



θr = 0.070

Figure 4-13 Curve fitting for Layer 3 (L3)



θr =0.077

Figure 4-14 Curve fitting for Layer 4 (L4)

The results of the parameter verification were satisfactory, so the optimised van Genuchten parameters were used as the starting values for the calibration of the model (Table 4-11).

Table 4-11 Soil property and van Genuchten parameters used in SWAP as a starting point for the model calibration

Layer	Grain size (%)			OM	θ_{sat}	θ_{hb}	θ_{fc}	θ_{res}	α	n	m
	Sand	Silt	Clay	%	%	%	%	cm³/cm³	cm⁻¹	-	-
L1	72	20	8	1.23	39.8	39.8	17.8	0.061	0.063	1.431	0.301
L2	75	20	5	0.62	36.8	36.8	16	0.050	0.066	1.486	0.327
L3	68	26	6	0.5	38.1	38.1	17.9	0.050	0.054	1.464	0.3168
L4	56	39	5	0.75	38.0	38.0	20.9	0.042	0.044	1.228	0.309

These parameters were the input to the SWAP model.

4.5 Crop data and other features

In this study only the rose flowers were considered as a crop for water and chemical balance evaluation, since roses occupy the largest proportion of the research area. The type of irrigation used is drip.

With the aid of satellite images (Aster 2000 and Landsat TM 2000), sampling sites were preliminary selected before fieldwork 2001. It was also possible to differentiate the land cover, including greenhouses, in the whole Naivasha Basin, prior to fieldwork. Crop data were obtained through interviews with the supervision staff, workers and site visits, site measurements and also from the literature. They include crop height, root depth, root density, and soil cover fraction. Crop feature data from Mekonnen (1999) was also used in this study to supplement missing details.

Crop development stages for the roses in this study were considered as being constant since roses their rooting depth does not change alot. The total growing cycle could be as long as 8 years, depending on the variety.

The details of crop feature measurements to be used in the model are shown in Table 4-12.

Table 4-12 Crop Features

ROSES				
Development Stage	Root depth (cm)	Root width (cm)	Height (cm)	Soil Cover (%)
DVS	50	60	115	80

4.6 DEPTH OF THE GROUNDWATER

The potential for ground water contamination depends highly depends on depth to ground water. The filtering of contaminated water primarily takes place in soil above the water table (the unsaturated zone of soil). A high water table results in a short travel time for water and contaminants to move through this unsaturated soil before reaching the ground water, therefore, there is little opportunity for the treatment of water to occur. Water table depths can fluctuate dramatically depending on the season of the year.

Figure 4-15 shows a map of ground water depth in the Naivasha Basin. According to the map, in the region of the SULMAC Farm the groundwater depth is more than 10 m.

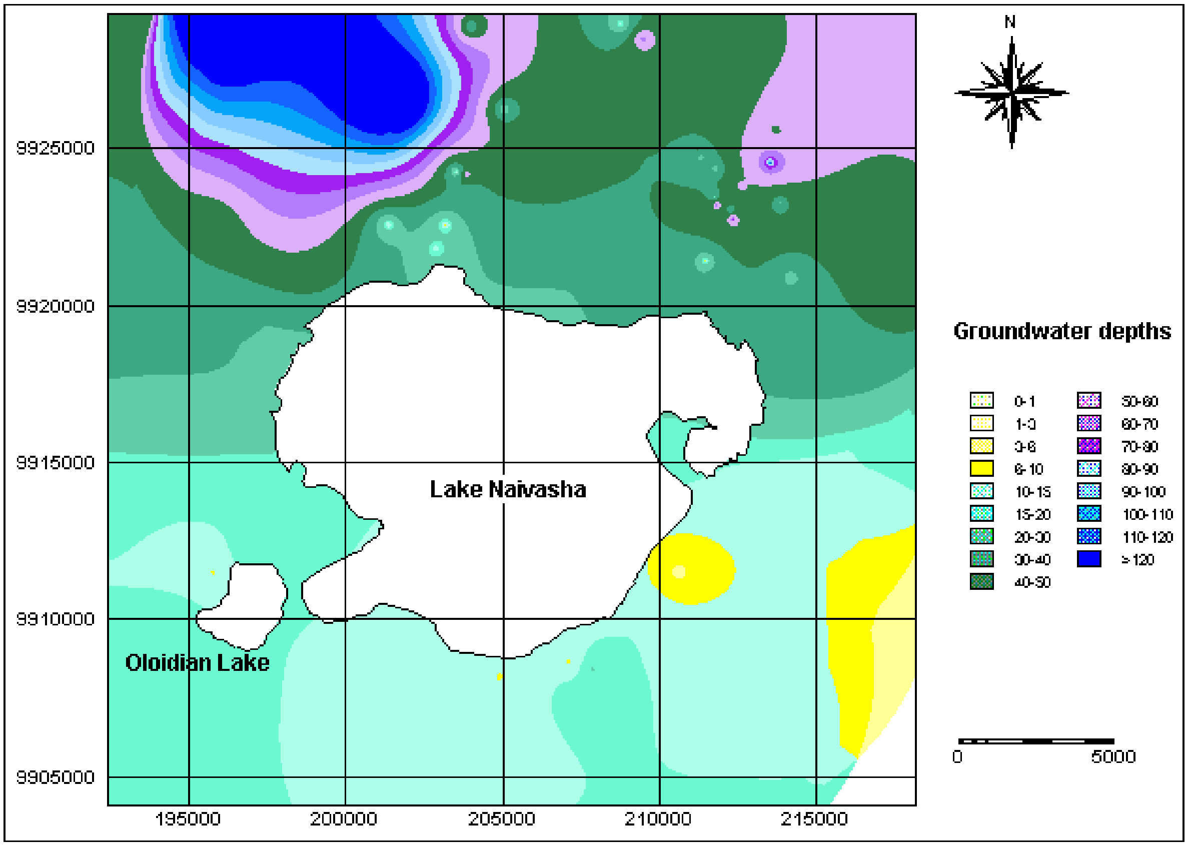


Figure 4-15 Groundwater depth in the study area in meters below ground level (Source: Oppong - Boateng, 2000).

4.7 CHEMICAL ANALYSIS

Water and and soil analyses were conducted in the ITC – laboratory according to the standard procedures. Information from the analyses where used in the simulation.

4.7.1 Water

Seven water samples where collected in 250 ml plastic containers from various points as shown by the Table 4-13:

Table 4-13 Water samples and their sources

sample No:	source	UTM X	UTM y	PRE-analysis	Value	Units	conservative used
S1	Drain_1	205424.7	9907571.6	pH	8		H_2SO_4
	Wooden_GH			EC	848	µS/cm	
	Rose4_DPS			NO_3^- N	OVER	mg/l	
				NH_3^- N	7.9	mg/l	
S2	Drain_2	205594.7	9907484.0	pH	7.5 – 8.0		H_2SO_4
	HYDROPONICS			EC	1327	µS/cm	
				NO_3^- N	OVER	mg/l	
				NH_3^- N	1.9	mg/l	
S3	Drain_3	205205.7	9907437.5	pH	7.0 - 7.5		H_2SO_4
	Wooden_GH			EC	1139	µS/cm	
				NO_3^- N	OVER	mg/l	
				NH_3^- N		mg/l	
S4	Drain_4	205300.6	9906986.0	pH	7.5 - 8.0		H_2SO_4
	Dripfilter_STN * 12stn			EC	332	µS/cm	
				NO_3^- N	0.6	mg/l	
				NH_3^- N	1.5	mg/l	
S5	Dripline_GH5	205296.8	9907202.5	pH	8		H_2SO_4
	IRRIGATION WTR_R4			EC	1620	µS/cm	
				NO_3^- N	OVER	mg/l	
				NH_3^- N	36.8	mg/l	
S6	Lagoon	205393.8	9907204.6	pH	7.5 - 8		H_2SO_4
	L NAIVASHA			EC	348	µS/cm	
				NO_3^- N	not done	mg/l	
				NH_3^- N	7.1	mg/l	
S7	Rain	205420.9	9907370.4	pH	6.6		H_2SO_4
				EC	148	µS/cm	
				Cl-	4.8	mg/l	

During the fieldwork, pre-analysis was carried out on the sample in the SULMAC farm’s laboratory, as shown by the column pre-analysis.

PRE-ANALYSIS TESTS

The cadmium reduction method using powder pillows and the Hach DR/2010 Spectrophotometer was used to assess the nitrate concentration in the water samples. The concentration of nitrate in the samples S1; S2; S3 and S5 was above the instrument’s range (0 – 30 mg/l). Due to lack of appropriate equipment, the nitrate test was therefore deferred for the Netherlands.

The Hach was used to measure the ammonium concentration of the samples. The initial concentrations were as shown in table 4-13.

Since the objective of the study is to assess leaching of nutrients, all the water samples were conserved with concentrated sulphuric acid (H_2SO_4). These samples where sealed in a metallic trunk while ice was spread on top.

CHEMICAL TESTS

This was conducted on all the seven samples in the ITC laboratory and involved some cation and anion test.

In order to carryout the electro-neutrality test, and assess the chemical loading of the water samples, several cation and anion tests were conducted on the water samples. The electro-neutrality test assesses the reliability of the water samples.

THE CHLORIDE TEST

The mercuric thiocyanate method was used to assess the chloride concentration in the seven samples using the Hach DR/2010 Spectrophotometer. The results of the analysis are displayed in table 4-14.

Table 4-14 Chemical Analysis of the water samples

Sample No:	**Source**	**UTM X**	**UTM y**	**NH_4^+**	**NO_3^-**	**PO_4^{-3}**	**Cl^-**	**K^+**	**Ca^{2+}**	**Na^+**	**Mg^{2+}**
S1	WD&R4	205424.7	9907572	2121.4	97.7	2.4	5.6	83.4	31.4	38.2	18.9
S2	HYDROPO	205594.7	9907484	414.7	326.4	4.0	5.7	101.7	63.5	56.9	25.4
S3	WD_GH	205205.7	9907437	502.6	297.3	95.2	1.2	60.7	48.4	37.5	41.5
S4	DripFilt_ST	205300.6	9906986	4.0	77.4	0.8	4.5	20.8	17.7	37.6	7.4

S5	Irrig_Water	205296.8	9907202	91.7	395.0	0.5	4.7	164.0	84.3	52.8	46.5
S6	Lake Naiva	205393.8	9907205	6.3	< 3	0.3	4.6	18.0	15.8	33.1	7.1
S7	Rain	205420.9	9907370	0.5	< 3	1.3	1.3	4.7	27.1	7.7	1.5

ACCURACY CHECK

The calibration curve equation (see Appendix 4.9) was used to verify the trend/response of the instrument to the different concentration of the chloride. The reproducibility of the measured standard solution by the instrument was assessed. According to the calibration curve, the trend was linear and in accordance with the Lambert – Bear law.

With the calibration curve, the measured values were corrected.

THE AMMONIUM TEST

The Ammonium test with the Nessler reagent was conducted with the Reflecto – Quant (LAB). According to the calibration line (Appendix 4.10), the instrument had a quadratic trend in accordance to the Lambert – Beer law. The reproducibility of the measurement was poor. From the above one can conclude that the accuracy of the reflecto-quant was rather poor. However, the measured results were corrected using the calibration curve equation.

NITRATE TEST

The Nitrate concentration test was done using the Reflecto – Quant (Lab). The Sulfanilic acid with Naphthalene method was used.

The Calibration line showed that the instrument had linear response to the measurements, which according to Lambert-Bear law was acceptable. The reproducibility of the result was rather poor. However, the final measurements were corrected with the equation of the curve.

PHOSPHATE TEST

The vanadomolybdo phosphoric acid calorimetric test was used. The test was carried out with the Hach DR/2010 Spectrophotometer.

The accuracy of the instrument was verified with the calibration curve. The response of the instruments to the measurements was linear. The reproducibility of the measurement was good.

CATION TEST

These tests were conducted with the Induction Coupled Plasma Atomic Absorption Spectrophotometer (ICP – AAS). The samples were tested for potassium; calcium; sodium; magnesium; aluminium; iron and manganese concentrations. The results of the ICP – analysis are appended as Appendix 4.13.

RESULT:

The concentration of potassium in the water samples from drains and from the irrigation water applied (S5) was very high This could have the result of fertilizers used (total amount of nutrients or strength/concentration of the liquid feed),. When roses reach maturity, they require more potassium (Nederhoff, 1998).

The water sample from the lagoon/reservoir originally from Lake Naivasha has a higher concentration of sodium.

4.7.2 Soil

Soils were collected from several sampling sites inside and outside the greenhouses, from 4 drain sites for further chemical analysis in the Netherlands. The soil samples were collected from 4 different depths as is indicated in the Appendix 4.6.

The soil samples after being air dried and sieved were subjected to the following tests:

- EC and pH
- Nitrate

The results from these tests are listed in Appendix 4.7.

CATION TEST RESULT

The ICP – results from the 1:5 (soil to water) extract showed distinctively higher values of Potassium concentration in the data sets from drain sites 1 and 2, while from drain sites 3 and 4 the sodium concentration was higher. A positive correlation between the Potassium and Sodium concentration in all data sets was evident, see Appendix 4.14d. The electric conductivity showed a positive correlation with the Sodium concentration (Appendix 4.14 c).

ANION TEST RESULT

Evident was the increase in Nitrate concentration with depth as shown in Figure 4-16. This can be explained an indication of the vertical movement of the nutrients below the root zone.

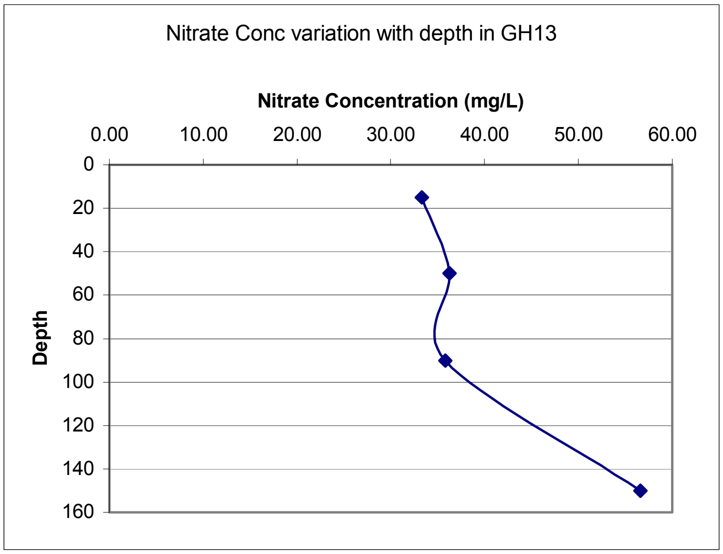


Figure 4-16 Variation of nitrate with depth

ORGANIC MATTER

There was a distinctive decline in the organic matter content with depth shown by the figure 4-17. This is an indication of the fluvial nature of the soil (young in the pedological context) in the sampling area.

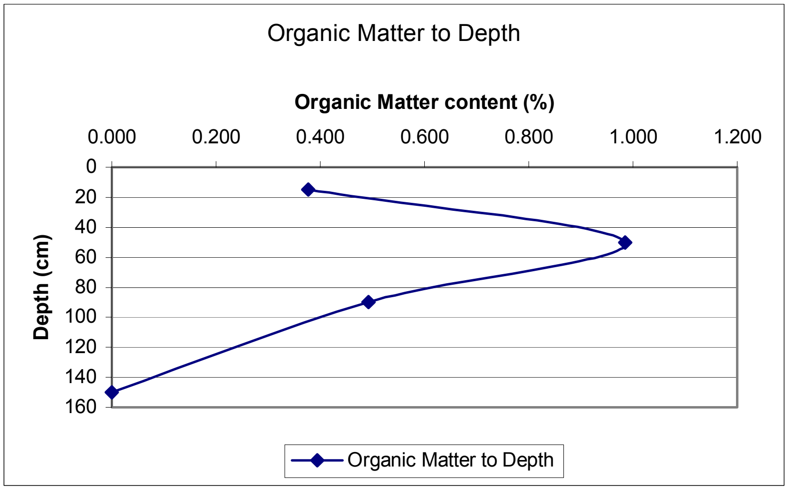


Figure 4-17 Variation of the organic matter to depth

5 WATER AND CHEMICAL BALANCES

Dissolved constituents in water move through the soil, with the water acting as carrier of the contaminants. Hornsby (1999). The possibility of surface water or groundwater contamination depends primarily on whether heavy rains or irrigation occur soon after chemical application. Without water to move them downward, fertilizer is more likely to remain within the biologically active crop root zone and may not be taken up by plants.

Through water and budgets chemical the gains (sources) and losses (sinks) of the water in a system is established.

5.1 WATER BALANCE

According to the mass balance principle, the simplest form of the water balance of any water system can be written as:

Inflow (I) – Outflow (Q) = change in Storage (S)

$I - Q = S1 - S2$

$i\Delta t - q\Delta t = \Delta S$

Writing it in a differential form we get Equation 5-1

Equation 5-1

$$i - q = \frac{dS}{dt}$$

For setting up the water balance of the greenhouses, all the variables of this equation have to be defined.

5.1.1 Water budget for the irrigation in the greenhouse system

The water balance components considered were: the inflow to the greenhouse consisting of the total water supplied through irrigation; while the outflow consisting of water leaving the fields through evapotranspiration, seepage and percolation (Figure 5-1). In this irrigated environment, the water budget can be written as Equation 5-2

Equation 5-2

$$W(t+\Delta t) = W(t) - ET(t,t+\Delta t) - I(t,t+\Delta t) - S_1(t,t+\Delta t) + IR(t,t+\Delta t)$$

Where:

$W(t + \Delta t)$ – the soil moisture content at time $t + \Delta t$,

$W(t)$ – the soil moisture content at time t,

$ET(t, t + \Delta t)$ – the loss through evapotranspiration between t and $t+\Delta t$,

$I(t, t + \Delta t)$ – the percolation loss to groundwater between t and $t + \Delta t$,

$S_1(t, t + \Delta t)$ – the seepage loss between t and $t + \Delta t$ and

$IR(t, t + \Delta t)$ – irrigation supplied between t and $t + \Delta t$

Runoff is negligible

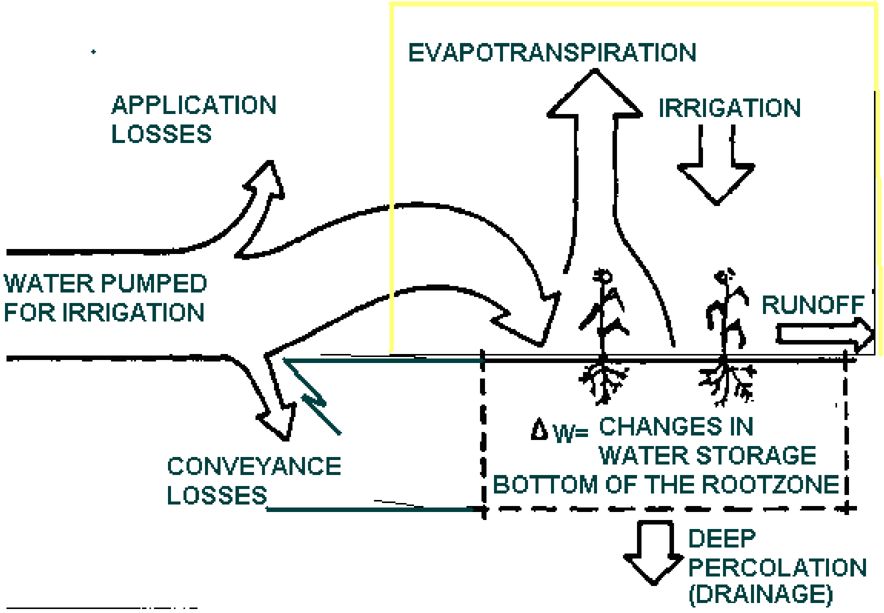


Figure 5-1 Water balance of a greenhouse

5.1.2 Quantifying the water budget of the greenhouse: incoming components

SULMAC farm gets all its irrigation water from the Lake Naivasha. The irrigation water supplied to each greenhouse per day was usually 7 mm. Less water is applied generally a day after a substantial rain. At the SULMAC Farm, the irrigation depth to apply after the rains is the responsibility of the section manager.

Quantifying the water budget of the greenhouse: outgoing components

EVAPOTRANSPIRATION

The FAO-Penman Monteith equation (Equation 5-3) is considered to calculate this component as it also takes into consideration the influence of vegetation features on the evapotranspiration regime (Monteith, 1965; FAO, 1998; Hazrat A. et al., 2000).

Equation 5-3

$$ET_o = \frac{0.408 * \Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

Where:

ET_o = Evapotranspiration (mm/day)

Δ - the gradient of the saturation vapour- pressure- temperature function (kPa0C-1)

R_n – net radiation (MJm^{-2} per day)

G – the soil heat flux (MJm^{-2} per day)

e_s– saturated vapour pressure of air (kPa), a function of air temperature measured at height z

e_a– mean actual vapour pressure of the air measured at height z (kPa)

u_2 – wind speed at 2 m height (m/s)

γ - the psychrometric constant (kPa 0 C- 1)

T – air temperature at 2 m height (C)

NOTE:

Equation 5-3 requires at least the following:

Air temperature

Wind speed

Solar radiation

The saturation -vapour -pressure deficit (e_s –e_a)

The net radiation R_n obtained from R_s (Doorenbos and Pruit, 1977) and R_{nl} (Penman, 1948) as Equation 5-4.

Equation 5-4

$$R_n = (1-\alpha)R_s - R_{nl}$$

$$R_n = (1-\alpha)(0.29 + 0.45\frac{n}{N})R_a - \sigma * T^4[0.34 - 0.044\sqrt{e_a}](0.1 + 0.9\frac{n}{N})$$

Where:

R_s – short-wave solar radiation (MJ m^{-2} per day)

R_{nl} – net long-wave outgoing radiation (MJ m^{-2} per day)

T – air temperature (K)

$\propto$ - albedo (0.08 for open water surface and 0.25 for most Kenyan crop covered surfaces (Kalders, 1988)

σ - Stefan Boltzmann constant = 4.903 x 10^{-9} $MJm^{-2}K^{-4}$ per day

NOTE: Since in this study the greenhouse environment was considered, the greenhouse climate was taken into consideration during the calculation of the evapotranspiration. It was however important to note that the transmissivity of the greenhouse cladding (single sheet PVC) according to Zhang et al (1996), was between 60 to 65 %. This implied that only about 62 % of the outside radiation was actually transmitted into the green house. From the transmitted shortwave radiation about 24 % was lost as outgoing shortwave radiation (Mekonnen, 1999). Which resulted into about 45 % of incoming (solar) radiation outside the greenhouse being transformed into latent heat within the greenhouse. (Stangellini C., 2001, personal communication).

Mekonen (1999) in his study compared the incoming shortwave radiation inside and outside the greenhouse. Mekonnen put the incoming shortwave radiation into the greenhouse as being 64 % of the incoming radiation outside the greenhouse.

In this study for the calculation of evapotranspiration inside the greenhouse the following methods were considered:

- Mekonnen, 1999 study which resulted in a daily evapotranspiration of

  3.18 mm/d,
- Stanghellini approach (personal communication) with which 3.09 mm/d was attained and
- FAO-Penman Montheith whose daily evapotranspiration was 1.26 mm/d.

In this study an average evapotranspiration rate of 2.50 mm/d will be adopted in the greenhouse water budgeting. This amount is close to Salah (1999)'s value of 2.1mm/d. In Appendices 5.6A to 5.6D, the spreadsheets of the radiation and evapotranspiration calculations using the methods discussed above are shown.

RUNOFF

In the greenhouses, because of the application of drip irrigation, which is localized and precise in the water application to the surface, runoff is negligible. As such it will not be considered in this study.

INFILTRATION

For the greenhouse condition, this can be described by the following expression (van Keulen et al, 1986):

Equation 5-5

$$IM = I_e - E_a$$

Where:

IM = actual infiltration rate (cm/d),

I_e = effective irrigation rate (cm/d)

E_a = the actual evapotranspiration rate (cm/d).

Actual Infiltration rate (IM) is determined by the total water supply at the soil surface and by the maximum possible infiltration (IM_{max}).

Equation 5-6

$$IM_{\max} = So * (1 - \frac{SM_{\psi}}{SM_0} * (\Delta t)^{-0.5} + A$$

Where:

So = Standard sorptivity (cm/d$^{0.5}$)

SM_{Ψ} = the soil moisture content (cm^3/cm^3)

SM_0 = soil moisture at zero matric suction (saturation) or total pore space (cm^3/cm^3)

A = Transmission zone (cm/d)

Δt = time in days

Appendix 5.3A shows the sorptivity and the maximum infiltration rate calculations possible in the loamy sandy soils of the SULMAC Farm, while Appendix 5.3B shows the variation of sorption and infiltration with soil moisture.

From the irrigation practices during the fieldwork period and using the above equations, the infiltration rate of 23.89 cm/d was calculated for the loamy sand soils.

SOIL WATER AVAILABILITY

Total available water (TAW)

To establish the soil moisture content of the soil at particular time knowledge of the moisture parameters such as the soil moisture content at saturation, at field capacity and at permanent wilting point are necessary. It only when that and the sink terms are known that the moisture condition (w(t)) can be established.

Equation 5-7

$$TAW = 1000(\theta_{FC} - \theta_{WP})Z_r$$

where:

TAW = the total available soil in the root zone (mm)

θ_{FC} = water content at field capacity (cm^3/cm^3)

θ_{WP} = water content at wilting point (cm^3/cm^3)

Z_r = rooting depth (m)

Readily Available water (RAW)

This is the moisture content condition, which a plant can access without suffering drought stress.

See Appendix 5.3 for detail illustration.

For the Green houses the following are the TAW and RAW values based on the textural class classification:

Table 5-1 Available Moisture for the Greenhouses

	TAW (mm)	RAW (mm)
GH 3	304	258.4
GH 13	361.5	307.3
GH 14	246	209.1

The difference between the total available water and the readily available water is maintained rather small because of the sensitivity of the flowers towards drought.

During the fieldwork 2001, and average volumetric moisture content for the greenhouse 3 was 0.61 cm^3/cm^3 and 13 was 0.72 cm^3/cm^3 while that of GH 14 was 0.49 cm^3/cm^3 The observed average moisture content values during the fieldwork looked relatively high.

In this context, it would appear as if the large proportion of the irrigation water applied percolates while the crop takes up only a smaller proportion. The water, which percolates, takes with it most solutes.

This can be illustrated in form in a water budget as follows:

Assumption: Run off is negligible:

Percolation ≈ Irrigation water – ETcr = **7**mm/day – **2.5** mm/day = **4.5** mm/day

If 365 days are considered on annual basis, then water not lost through evapotranspiration is = **1642.5** mm.

For the rose production at the SULMAC Farm with an area of **43.32** hectares,

This is **711531** m^3 /year.

SOIL WATER BUDGET FOR THE ROOT ZONE

The root zone system could be considered as a reservoir, which is subjected to the gains and losses of the moisture content as a result artificial or natural action, the presence of plant roots and the soil moisture gradient present, protective cover in form of glass can deter the moisture losses. Equation 5.9 describe the root zone moisture budget in detail:

Equation 5-8

$$D_{r,i} = D_{r,i-1} - I_i - CR_i + ET_{c,i} + DP_i$$

Where:

$D_{r,i}$ = root zone depletion at the end of day i (mm),

$D_{r,i-1}$ = water content in the root zone at the end of the previous day, i-1 (mm),

I_i = net irrigation depth on the day i that infiltrates the soil (mm),

CR_i = capillary rise from the groundwater table on day i (mm)

$ET_{c,i}$ = crop evapotranspiration on day i (mm),

DP_i = water loss out of the root zone by deep percolation on the day i (mm).

In the context of the SULMAC Farm, due to the fixed irrigation depth (I) of 7mm, the ETc,i of about 2.5 mm and also that the capillary rise does not reach the root zone, the root zone depletion at the end of each day could be considered negative. This is an indication of the excess water application in the root zone.

5.1.3 Water budget for the drain system

The major purpose of the drains at the SULMAC Farm is to divert runoff during and after precipitation events and to discharge flush water from the 12 drip stations. Flushing of the drains is done on hourly basis. The duration of flushing is about 2 minutes and a volume of 0.8 m^3 of water is used.

During the dry season most lengths of the drains are dry except near discharge points. These sections of the drains are associated with ponding. The water at this section only seems to flow when the drip stations are being flushed or when it rains.

INPUT COMPONENT

1) Flush water (*FD*) from drip-station

2) Rain (*P*):

P = 473 mm for the dry year,

P = 852 mm for the wet year,

P = 634 mm for the normal year according to Upendra (1998).

P (2001) = 716 mm can be considered as a normal or moderately wet year (Probability of exceedance = 27 % according to Upendra, 1998)

OUTPUT COMPONENT

Evaporation & transpiration from grass (*ET*) for 5.15 mm/day), (based on the observed drainage ditch length of 800 m and with of 2 m).

The losses from the drain is seepage through the drain (grassed) walls (*S*)

BUDGET

This is an accounting procedure, which is based on the conservation of mass principle

Equation 5-9

$$P + FD = ET + S$$

Where:

P = Precipitation,

FD = Flush water from the drip stations

S = Seepage

Situation 1: Iff P = 0, S = FD – ET (no rain)

DAILY BUDGET:

S = 72mm/day – 5.15 mm/day = 66.85mm/day

Situation 2: Iff $P \neq 0$, $P + FD = ET + S + Q_{lake\ Naivasha}$

ANNUAL BUDGET:

$P + FD - ET = S + Q_{Lake\ Naivasha}$

Where:

S – seepage,

Q – flow to Lake Naivasha

P = 716 mm/day

FD = 115.2 m^3/day = 42048 m^3/year (evaporates over an area of 2 m by 800 m)

Note: This figure (*FD*) could not be verified during the fieldwork

ET = 5.15 mm/day (based on the average reference grass *ET* for Naivasha (Kalders, 1988)

716 mm/yr + 26280 mm/year – 1879.75 mm/year = 24400.25 + $Q_{Lake\ Naivasha}$

26996 mm/yr – 26280 mm/yr = 716 mm/yr

The flow to Lake Naivasha will need to be verified,

Seepage will be influence by the soil type, the vertical and horizontal hydraulic conductivity.

5.1.4 Quantifying the flow into the drains

Number of drip station (*St*) = 12

Volume (*V*) = 0.8 m^3/2 minute/hr

Duration of Flushing (*tfl*)= 2 minutes

Frequency of Flushing (*zfl*) = 12 times/day

Total Volume of Flush water per Day:

$V_{tot} = V * St * zfl$

V_{tot} = 0.8 m^3/ St* 12 St * 12/day

=115.2 m^3

Rate of flow per drip station per day (*Rfl*):

$Rfl = 0.8\ m^3 * 12/24$ minutes

$= 0.4\ m^3/\text{minute}/St$

Rate of flow for the 12 station (Qfl):

$= 12 * 0.4m3/\text{minute}$

$Qfl = 4.8$ m3/min

$Qfl = 0.08$m3/s

The water flows only at the times of discharge and only for a short distance (in the cases of no precipitation), from the point of discharge (800 m). The Drain's water budget can also be described with the following expression:

Equation 5-10

$$I(t) - Q(t) = \frac{d(S(t))}{dt}$$

Where:

$I(t)$ is the inflow rate,

$Q(t)$ is the outflow rate,

$S(t)$ is the storage at time t

The outflow $Q(t)$ is made up of the following components:

Evapotranspiration; Seepage; percolation.

If the Outflow ($Q(t)$) is directly proportional to the storage:

Equation 5-11

$$S = k * Q$$

Where: k is the coefficient of proportionality or the average residence time (t_r).

Equation 5-12

$$t_r = \frac{S}{Q}$$

Tr = 27.2 minutes

Combining the equations 5.11 and 5.12 above gives us:

Equation 5-13

$$I(t) = Q(t) + k\frac{dQ}{dt}$$

Equation 5-14

$$Q = Q_o * e^{-\frac{t}{k}}$$

The flow will be dependent on the initial flow in the drain.

and

Equation 5-15

$$S = S_o * e^{-\frac{t}{k}}$$

The storage in the drain will depend on the initial storage.

5.2 CHEMICAL BALANCES

Groundwater pollution by nutrients, nitrate in particular, is a typical non-point source pollution in agricultural areas. In order to assess the impact of this pollution on water resources, the different mechanisms involved in nitrate transfer must be understood and quantified. Quantifying these mechanisms is especially important as pollution-prevention measures in an attempt to optimise the use of fertilizers, which are nutrients before becoming contaminants.

Nitrate transfer in a groundwater system involves two steps:

- the nitrogen cycle and nitrate leaching in soils and
- nitrate migration in aquifers.

5.2.1 The nitrogen cycle in irrigated agriculture

Nitrogen exists in the soil system in many forms and changes (transforms) very easily from one form to another. The nitrogen cycle is biologically influenced. Biological processes, in turn, are influenced by prevailing climatic conditions along with the physical and chemical properties of a particular soil.

Nitrates in soils are transported through the *advection* and *dispersion* and *diffusion* mechanisms through the soils. *Advection* refers to contaminant flow due to groundwater flow. The contaminant merely "goes along for the drive". But as water flows through the intergranular spaces its flow is deflected by the grains encountered away from the main contaminant mass. This spreading out of the contaminant mass by the matrix is called *dispersion*. *Diffusion*, the third mechanism is based on molecular movements. Here, the velocities caused by *diffusion* are much slower than those caused by *advection* and *dispersion*, so in case of fast water movement diffusion can be neglected. Equation 5-17, taking into account the two major mechanisms, describes the contaminant transport.

Equation 5-16

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left[D\left(\frac{\partial C}{\partial x}\right)\right] - v\left(\frac{\partial C}{\partial x}\right)$$

Where:

$\frac{\partial C}{\partial t}$ is the rate of change of the contaminant concentration.

D is the dispersion coefficient,

$\frac{\partial C}{\partial x}$ is the change in contaminant along the X-direction (vertical in this study).

5.2.2 CHEMICAL BALANCES FOR THE GREENHOUSE SYTEM

The fertigation practice at the SULMAC Farm entails pre-mixing of fertilisers in two 1000 litre water tanks to make the stock solution. The stock solution is injected into irrigation water at a regulated rate according to the crop nutrient requirement.

NITRATE-NITROGEN BUDGET

During the fieldwork period, 12 soluble fertilizers were being applied (table 4.1 for the rose production on daily basis) and 3 foliar fertilisers according to the spraying schedule at the SULMAC farm.

In this study only the nitrate – nitrogen will be considered.

QUANTIFYING THE CHEMICAL BUDGET COMPONENTS

This is based on the conservation of mass principle:

Equation 5-17

$$C_{in} - C_{out} = \frac{dC}{dt}$$

Where: C_{in} – Incoming component

C_{out} – Outgoing components

INCOME COMPONENT

- This consists of the (inorganic) fertilizer application (fertigation) in the irrigation water (169.4 kg/GH/year (SULMAC fertilizer schedule, September/October 2001);
- The nitrate - nitrogen from the mineralisation of organic matter

  (22.6 kg/GH/year);
- The natural nitrate - nitrogen in the soils (15 kg/GH/year)
- The nitrate - nitrogen in irrigation water (about 21.9 kg/GH/year) (Garcia R, 1999);

This will give a total annual nitrate - nitrogen of 228.91 kg/GH. The Appendix 5.7 & 5.8 shows how the above has been computed.

OUTGOING COMPONENT

Nitrogen is lost from the soil system in several ways:

- Crop uptake, which for roses is 42 g/m^2 annually (Kordes W, 1997);
- Denitrification
- Volatilization
- Leaching
- Decomposition.
- Crop removal
- Soil erosion and runoff

Denitrification can be a major loss mechanism of NO_3^- when soils are saturated with water for 2 or 3 days. Nitrogen in the NH_4^+ form is not subject to this loss.

Significant losses from some surface-applied N sources can occur through the process of **volatilisation.** In this process, N is lost as the ammonia (NH_3) gas. Nitrogen can be lost in this way from manure and fertilizer products containing urea. Loss of N from volatilisation is greater when soil pH is higher than 7.3, the air temperature is high, the soil surface is moist, and there is a lot of residue on the soil.

LEACHING:

In contrast to the biological transformations previously described, loss of nitrate by leaching is a physical event. Leaching is the loss of soluble NO_3^- as it moves with soil water, generally excess water, below the root zone. Nitrate that moves below the root zone has potential to enter either the groundwater or the surface water.

Coarse-textured soils such as sandy soils have a lower water-holding capacity and, therefore, a higher potential to lose nitrate from leaching when compared with fine-textured soils. Nitrate can be leached from any soil if rainfall or irrigation moves water through the root zone.

Groundwater is more prone to pollution from the fertiliser leaching below the root zone. Leaching is more pronounced in highly permeable soils with low adsorption capacities (low organic contents), or with high degrees of saturation with regard to a particular chemical. Furthermore, leaching is favoured by high fractions of dissolved species of certain chemical and by high infiltration rates of water (Harmsen, 2001). About 30 % of the total available Nitrogen maybe lost through leaching.

Crop removal: Substantial amounts of N are lost from the soil system through **crop removal.** Crop removal accounts for a majority of the N that leaves the soil system. This also applies to the Rose production despite the long growing period (up to 8 years.). Moreover, fertiliser application is continuous and plants do not seem to have a mechanism to turn off nitrogen uptake.

SOIL EROSION AND RUNOFF

As earlier mentioned, the soil erosion and runoff processes can be considered insignificant in as far as drip irrigation and the greenhouse environment is concerned.

Table 5-2 below shows a complete nitrogen budget for a greenhouse at the SULMAC Farm.

An average number of rose stems harvested per unit area is 300/m^2. The more flowers harvested the more fertiliser is required.

Table 5-2 Nitrogen *B*udget

IN	ITEM		QUANTITY	UNITS Per Year
1	Inorganic fertiliser		169.4	kg/GH
2	Mineralisation	2% * ON = (5% OM = ON)	22.6	kg/GH
3	Natural Nitrogen in the soils	10 ppm in Soils	15	kg/GH
4	Nitrogen in Natural irrigation water	2 mg/L	21.91	kg/GH
		SUBTOTAL	228.91	kg/GH
OUT				
1	Crop uptake	$42 g/m^2$	210	kg/GH
2	Denitrification			
3	Volitization			
4	Leaching	30% of IN	68.7	kg/GH
5	Immobilazation			
7	Soil Erosion and Runoff		-	-
		SUBTOTAL	278.7	kg/GH

6 THE LEACHING PROCESS

To simulate the nitrate-nitrogen leaching through the unsaturated soil matrix in rose production under the greenhouses of the SULMAC Farm, the SWAP model was used. The process was carried out to assess the possibility of contaminating the ground water with the nutrients; to assess the depth Through the simulation with SWAP, the temporal and spatial (vertical) variability of the water volumes and concentrations were estimated.

6.1 THE SWAP MODEL

This software simulates water flow, solute and heat transport through the soil simultaneously with crop growth.

From the output (e.g. balances generated with different scenarios), answers can be deduced to questions related to the vertical movement of water and chemical in a soil column, e.g. the efficiency of the water and nutrient application practices in drip irrigation can be assessed. Through the advection, dispersion and decomposition processes, the solutes are transported by water through the soils.

By using several scenarios with varying soil layer thickness, varying loads of nutrients and different water quantities and flow through the different types of soils with different hydraulic properties, the leaching process is thoroughly visualised, and therefore preventive measures can be undertaken to prevent groundwater contamination.

6.2 SOIL WATER FLOW

6.2.1 Soil water flow

Spatial differences of the soil water potential cause flow of soil water in any soil type. The well-known Richards' equation is used in simulation of soil water flow. See equation 2-7.

SOIL HYDRAULIC FUNCTION

The soil hydraulic function presents the relationship between water content θ, the pressure head h or Ψ and the unsaturated hydraulic conductivity $K(\theta)$ for each distinct soil layer. In SWAP the modeller has two options for soil hydraulic function: one can be obtained directly from field measurements and the other is the use of an analytical function. In this thesis, the analytical *θ(h)* function proposed by Van Genuchten (1993) is applied. See equation 4.3.

In order to calculate the unsaturated hydraulic conductivity *K(θ)*, the predictive equation of Mualem (1976), has been used (Equation 6-1).

Equation 6-1

$$K = K_{sat} S_e^{\lambda} \left[1 - \left(1 - S_e^{\frac{1}{m}} \right)^m \right]^2$$

Where K_{sat} is saturated conductivity (cm/day), λ is a shape parameter (-) depending on $\partial K/\partial h$, and S_e is relative saturation defined in Equation 6-3.

Equation 6-2

$$S_e = \frac{\theta - \theta_{res}}{\theta_{sat} - \theta_{res}}$$

The pedotransfer functions were used in estimating of the parameter values for this model. These parameters developed by Van Genuchten et al.(1991), Corel and Brooks (1964) and Saxton et al (1986) have been used in the estimation of the soil hydraulic parameters shown in Table 6-1. The developers of SWAP also supply a list of model parameters derived from soil samples from the Netherlands known as Staring Series.

SOIL WATER EXTRACTION BY ROOTS AND EVAPOTRANSPIRATION

A two-step approach of the Penman–Monteith equation is adopted in SWAP. This entails calculating the potential evapotranspiration first then the actual evapotranspiration is deduced based on the root water uptake reduction caused by the water stress or salinity.

The model computes the potential transpiration rate T_p (cm/d) that is governed by atmospheric conditions. The potential root water extraction rate at certain depth, $S_p(z)$ (1/day), may be determined by the root length density, $l_{root}(z)$ (cm/cm^3). The root distribution is the function of root depth; SWAP calculates root length density distribution with Equation 6-4.

Equation 6-3

$$S_p(z) = \frac{l_{root}(z)}{\int_{-D}^{0} l_{root}(z)dz} T_p$$

Where: D is the root layer thickness (cm).

Swap takes into account the water stress and this is described by the function proposed by Feddes et al. (1978).

Equation 6-4

$$S_a(z) = \alpha_{rw}\alpha_{rs}S_P(z)$$

Where: α_{rw} and α_{rs} are dimensionless reduction factors due to water and salinity stress, respectively.

α_{rw} as function of soil water pressure head h and potential transpiration rate T_p (after Feddes et al., 1978).

6.2.2 Top boundary

The top boundary condition governs the simulation of water fluxes through the soil surface. The model generates surface runoff if more intensive rain shower or flood occurs then the infiltration capacity of the soil. SWAP applies the procedure to select between flux and pressure head controlled top boundary according to the saturation level of the topsoil layer.

In this study, evapotranspiration induced by the root water uptake will be used as the top boundary. Moreover, surface runoff does not prevail in context of this study.

6.2.3 Bottom boundary

The bottom boundary conditions define the fluxes through the lower boundary of the modelled soil column. SWAP offers eight options to describe the lower boundary condition. In this study, as the water table is deep at the SULMAC Farm (18 – 43 m) and no evidence of any impervious layer below, the option of 'Free drain at the bottom of the profile was selected.

6.2.4 Soil heterogeneity

Media scaling method proposed by Miller and Miller (1956) is used in SWAP. This method investigates the effect of field spatial heterogeneity of soil hydraulic properties. For scaling method, the Mualem-Van Genuchten parameters those describe the reference curve and a set of scaling factors have to be inserted.

6.2.5 Daily evapotranspiration

The Penman-Monteith equation is used to estimate evapotranspiration. In SWAP, the reference evapotranspiration (ET_{ref}) is either specified or calculated. In this study ET_{ref} is specified.

SWAP separates potential evaporation and transpiration for partly covered soils using Leaf Area Index (LAI) or Soil Cover Fraction (SCF).

Actual soil evaporation is determined by atmospheric demand. SWAP calculates potential soil evaporation rate E_p (cm/day) in case of wet soil and actual soil evaporation E_a (cm/day) when the soil is drying out. Darcy's law is applied to calculate maximum evaporation rate E_{max}. SWAP will determine E_a by taking the minimum value of E_p, E_{max} and empirical evaporation functions (either by Black et al, 1969 or Boesten and Stroosnijder, 1986) may be used.

In this study because of the greenhouse conditions, rainfall is excluded and as such interception will be considered neither.

6.3 CROP GROWTH

SWAP uses WOFOST 6.0 to simulate crop grow. It contains maximum three crop growth routines: a detailed model, grass growth and a simple crop model. In this Naivasha case study a simple crop model is applied.

For details of this part the reader can refer to the part 7 of SWAP 2.0 theory manual (*V*an Dam et al., 1997).

6.4 FIELD IRRIGATION

The field irrigation and drainage part of the model simulates irrigation and drainage in order to develop optimal irrigation schedules. It is an essential component where a scarcity of water prevails.

The prime objective is to prevent crop water stress throughout the growing season. In case of limited irrigation water supply, the irrigation schedule can be optimised in order to obtain the maximum economic return.

Irrigation schedule applied in SWAP can be either fixed or scheduled irrigation as well as a mix of both. In this study, 365 fixed irrigation applications were adopted as practiced in the SULMAC farm (7 mm/day).

6.5 PARAMETER ESTIMATION AND DATA INPUT FOR THE SWAP MODEL.

The following are the data required for model inputs:

- Meteorological data
- Irrigation
- Crops

- Soil
- Solute concentration
- Drainage
- Bottom boundary condition
- Depth to the ground water

6.5.1 METEOROLOGICAL DATA INPUT

The daily meteorological data set were obtained from SULMAC weather station located within the research area. The meteorological data input includes the name of the station, time in daily format (from January, 2001 to December, 2001), radiation (kJ/m$^{2/}$day), daily maximum and minimum temperature (*C*), relative air humidity RH (decimal), daily rainfall (cm), wind speed (m/s), reference evapotranspiration ET_{ref} (cm). The missing value is filled with –99.9.

Unfortunately, meteorological data input for the model are only available for the period from 1*st* January 2001 to 3*rd* December 2001. That means meteo-data set is not completed for one-year period (28 days data missing). This data set was obtained after the fieldwork.

In order to run the model for different scenarios such as, different water input rates or different Concentration of fertilisers; the two data sets 2000 and 2001 were used. This means that the leaching process simulations were only carried out for the period January 2000 to December 2000 and January 2001 to December 2001.

6.5.2 IRRIGATION INPUT:

For the Rose flower growing at the SULMAC farm a fixed irrigation schedule is adopted. The daily water application rate of 7 mm is set according to the general rose production recommendations (Pertwee J, 1992).

In this thesis, drip is the type of localized surface irrigation considered and will be used for the leaching process simulation.

In the cases of a precipitation event, the fixed irrigation schedule application for the following day was reduced according to the rainfall amount based on the rule that ensured the pre-set irrigation amount for that day and the following day were maintained. In this study a fixed irrigation schedule of 7 mm per day has been adopted. And since irrigation is applied everyday, 365 fixed irrigation were input in the model.

6.5.3 CROP INPUT

The rose simple single crop model was selected as it depicted a homogeneously growing crop in one plot. With LAI of between 7 and 8, maximum rooting depth

60 cm. These parameters are given as function of the development stage. These parameters were taken from Mekonnen, 1999 work.

6.5.4 SOIL INPUT:

This describes the physical soil condition to be used in soil evaporation computation for SWAP. SWAP calculates actual soil evaporation using the soil hydraulic functions or empirical functions.

To attain accurate results and time of calculations, the number of soil layers of the soil profile and the number of compartments in each layer were defined.

From the examination of the horizon of the soil pit, the soil structure at SULMAC farm was considered as comprising 4 layers. Therefore the unsaturated soil zone was descretized into 4 layers. These 4 layers were further subdivided into 40 compartments or nodes. The descretization followed the particle size distribution.

The top layer with the depth of 30 cm contained more organic matter than the lower layers.

The second layer had a thickness of 50 cm, the third layer considered at the depth of 80 cm downward to 150 cm and a 4*th* layer considered from 150 to 200 cm. The Soil compartments according to the recommendation from SWAP model user guide are selected with the top 10 compartments of the top layer being 1 cm thick.

6.5.5 SOLUTE TRANSPORT.

As mentioned in this study only Nitrate – nitrogen was considered for the simulation due to its impact on the health of both human and animals.

The initial solute concentration of each compartment was given as follows:

Compartment Number range	Concentration (mg/cm^3)
1 to 30	0.019
31 to 35	0.016
36 to 37	0.017
38 to 40	0.001

Table 6-1 Initial Concentration in the Compartments

The above values were estimated from the nitrate-nitrogen test on the soil samples obtained outside the greenhouses and not being subjected to any fertigation (as a control). The solute concentration in the precipitation was taken as 0.002 mg/cm^3

based on fieldwork measurement. Nitrate-nitrogen concentration in the irrigation water of 0.000649 mg/cm^3 was based on the concentration of nitrogen in the fertilizer as shown in the Appendices 5.7, 6.1A and 6.1B, the nitrate-nitrogen concentration of 394.95 mg/l was based on the irrigation water nitrate test carried out as shown in appendix 6.2.

SWAP considers three main solute transport mechanisms in soil water:

Diffusion, convection and dispersion.

Diffusion: caused by a solute gradient.

The solute transport processes are expressed in terms of their fluxes.

The diffusive solute flux (g/cm^2/day) is described by Fick's first law :

Equation 6-1

$$J_{dif} = -\theta D_{dif} \frac{\partial C}{\partial x}$$

Where: D_{dif} = diffusion coefficient (cm^2/d)

C = solute concentration in soil water (g/cm^3)

The relation proposed by Millington and Quirk (1961) describes the diffusion process in SWAP:

Equation 6-2

$$D_{dif} = D_w \frac{\theta^{7/3}}{\phi_{por}^2}$$

Where: D_w = the solute diffusion coefficient in free water (cm^2/d) and

ϕ_{por} = the soil porosity (cm^3/cm^3).

The convective process transports most solutes, where solutes are carried along by moving water. This is calculated from the average soil water flux (g/cm^2/day) represented by equation 6-3

Equation 6-3

$$J_{con} = qC$$

Where q = the Darcy flux (cm/d)

The dispersion flux is proportional to the solute gradient by the following relation:

Equation 6-4

$$J_{dis} = -\theta D_{dis} \frac{\partial C}{\partial x}$$

Where J_{dis} is the dispersion coefficient (g/cm^2/d)

Considering all the above fluxes from the different processes, the total flux can therefore be written as:

Equation 6-5

$$J = J_{dif} + J_{con} + J_{dis} = qC - \left(D_{dif} + D_{dis}\right)\frac{\partial C}{\partial x}$$

The general transport equation applied in SWAP including the first order decay rate and the root uptake is written as followed:

Equation 6-6

$$\frac{\partial(\theta C + \rho bS)}{\partial t} = -\frac{\partial qC}{\partial x} + \frac{\partial}{\partial x}\left(\theta\left(D_{dif} + D_{dis}\right)\frac{\partial C}{\partial x}\right) - K1(\theta c + \rho bS) - k_r rC$$

Where: K_r is the root uptake factor (-) and r is the root water extraction rate (-).

To solve the above equation a numerical finite difference scheme is used. For more detail refer to the SWAP manual (Technical document 45, Van Dam et al., 1997)

In this study no adsorption was considered.

CHEMICAL PARAMETERS

The following fertisers where considered in the simulation. The choice was based on the Nitrate- nitrogen content, which is shown in the table 6.5-3.

Fertiliser Name	Chemical formular	Application rate in kg/1000 litre	% N
Calcium nitrate	$Ca\ (NO_3)_2$	43.1	17.07
Urea	$CO(NH_2)_2$	3.5	46.65
Ammonium sulphate	$(NH4)_2SO_4$	11.3	21.20
Potassium nitrate	KNO_3	26	13.85

Table 6-2 Fertilisers and nitrogen content considered in the simulation

These were derived from personal communication with experts, the literature and the Internet. The parameters that could not be found where assumed within the model suggested ranges. Table gives the adopted chemical parameters for the simulation.

Parameter	**Symbol**	**value**	**units**	**Sources**
Pore water velocity	v	1.823	cm/d	See appendix 6.4
Dispersion length	L_{dis}	5	cm	SWAP Manual
Dispersion coefficient	D_{dis}	9.115	cm^2/d	See Appendix 6.6
Diffusion coefficient	D_{dif}	0.186	cm^2/d	See Appendix 6.5
Dinitrification rate (Decay)	k	0.05 - 0.15	1/day	http://WWW.coe.uncc.edu/~jdbowen/eget 3000/1997/con-kin.html

Table 6-3 Chemical parameters used in solute transport

6.6 CALIBRATION OF THE SWAP MODEL

The purpose of the calibration was to represent the unsaturated soil system and the movement of the soil water, which carries the solutes (nutrients) in a manner similar to that of the natural system. The basis of the calibration was the soil moisture measurements carried out during the fieldwork. A trial-and-error procedure was used to improve the fit between modelled and observed soil moisture content (figure 6.1). Because of limited measurement and accuracy of the soil moisture measurement with moisture meter especially for the soil Layer 2, the strict fit of the observed and modelled soil moisture content values was not achieved even if a correlation coefficient of 0.9853 (R^2 = 0.9709) between the measured and modelled value was achieved (Figure 6.2 and 6.3). A qualitative calibration of the overall soil moisture profile was targeted and achieved.

The modelled soil water content of the uncalibrated model runs was in the top layer lower (L1) than the observed values; in the second (L2) and in the third layer (L3) the modelled values were higher than observed. Therefore values of Ksat were lowered to 60 cm/d in the first layer, in the second layer it was raised to 1000 cm/d, in the third to raised to 133.23 cm/d in the fourth layer the saturation hydraulic conductivity was lowered to 75 cm/d as shown in the table 6.4. Table 6.4 shows the adjusted parameter values for the calibration.

Table 6-4 The adjusted Hydraulic Conductivities values

VGM PARAMETER	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**
Layer Thickness (cm)	50	79	36	40
Texture Class	LS	LS	SL	SL
Residual moisture content (cm^3/cm^3)	0.0610	0.0500	0.0500	0.0420
Saturated moisture content (cm^3/cm^3)	0.3980	0.3680	0.3810	0.3800
Saturated hydraulic conductivity (cm/d)	60	1000	133.23	75.00
Alpha main drying curve drying (1 /cm)	0.0630	0.0660	0.0540	0.0440
Parameter m (-)	0.3010	0.3270	0.3170	0.3090
Exponent in hydr.cond.function (n)	1.4310	1.4860	1.4640	1.4480
Alpha main wetting curve (1 /cm)	0.0630	0.0660	0.0540	0.0440

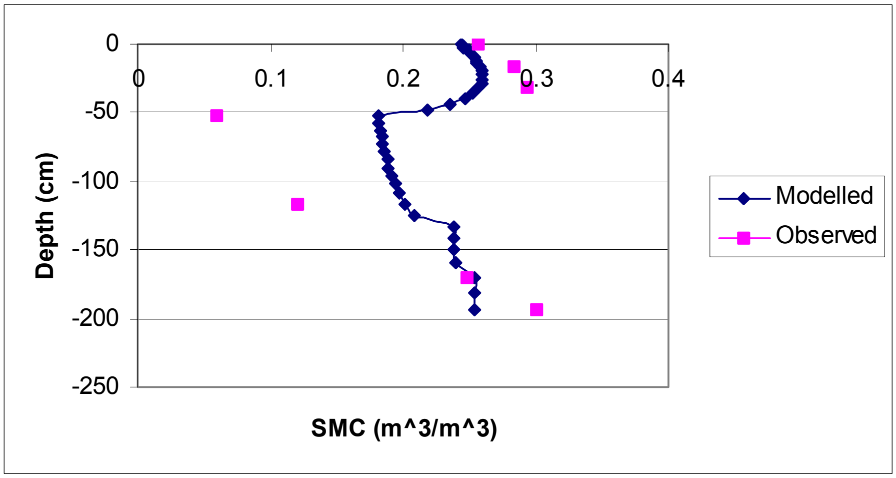


FIGURE 6-1 Hydraulically calibrated Model showing the observed to the Modelled soil moisture

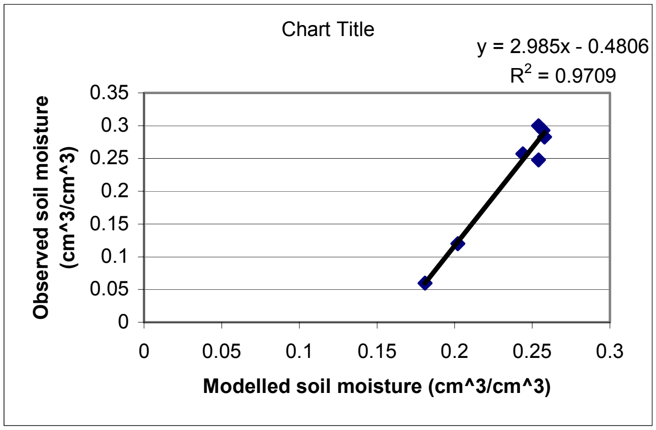


FIGURE 6-2 Correlation between the Measured and Modelled soil moisture content

6.6.1 VALIDATION OF THE HYDRAULICALLY CALIBRATED MODEL

To validate the Calibrated modeled, SWAP was run for a 7-day period to simulate vertical soil movement with only a single irrigation event on the first day. The resulting curves are shown as appendix 6.

The Graphs (Appendix 6.3 i to iv), shows a similar trend in the Modelled values to that of the measured values. From the graphs it is evident that if irrigation was absent for a period of six days, the difference in the moisture content will be 0.188 cm^3/cm^3 or (0.299 – 0.111) cm^3/cm^3 on the soil surface of the layer. This soil depletion could be attributed to the crop water up take and redistribution. At and below 50 cm the moisture content remains almost constant. The deviation between the modelled and the Measured in the second layer L2 (below 50 cm) could be attributed to inaccuracies in field measurement. Since all attempts at adjusting the Model towards the measured values proved futile, thorough field investigations are hereby called for to re- assess the physical and hydraulic properties of this layer.

To examine the model performance quantitatively, the coefficient of determination R^2 was used (*figure* 6-3) which in this case was 0.9709. This must approach unity for an accurate simulation of the observed dynamics.

To measure the magnitude of error (deviation of the simulated from the observed values), the root mean square error (RMSE) was also used.

Equation 6-7

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Mi - Si)^2}{N}}$$

Where:

Si = Simulated

Mi = Measured

RMSE = 0.060483 or 6.05%.

Finally the Nash – Sutcliffe modelling efficiency (*ME*) was used to measure how well the measured values are in agreement with the simulated values.

Equation 6-8

$$ME = 1 - \frac{\sum_{i=1}^{N}\left(Mi - Si\right)^2}{\sum_{i=1}^{N}\left(Mi - \overline{M}\right)^2}$$

ME = 0.52036

= 52%

Where:

Mi = Measured

$\overline{M}$ = mean of the measured values

The Modelling Efficiency (*ME*) quantifies the relative improvement of the model compared with the nominal situation (mean of measured value). Positive values are an indication of an improvement. Negative values imply that simply using the Measured mean is better than using the simulated values. As Modelled (simulated) tend to the measured value, the *ME* tends towards 1 (Zierl B, 2001).

7 DISCUSSIONS AND ANALYSIS OF RESULTS

Model simulations were conducted for a one-year period from 1st January 2001 to 31st December 2001. Nitrate leaching through the unsaturated soil zone was simulated during this period. The moisture and solute concentration distribution in the soil profile as well as the water and mass balance at the bottom of the modeled soil column were simulated by SWAP. The initial soil layer compartment concentrations were derived from the soil nitrate tests. The soil nitrate-nitrogen tests for the soil samples at the different depth were the basis of the comparison between the modeled values and the measured. However this was not easy as most chemical parameters for the nitrate nitrogen were not so readily available in the literature. In order to simulate realistic concentration values, the root uptake rate was adjusted so that the crop was at least able to take in the annual recommended rate of the nitrogen per unit area (42 g/m^2 per year). Through the comparison, the leaching depth and concentration of the nitrate leaching in the soil profile was assessed. The application of the SWAP model for monitoring and evaluating specific environmental degradation phenomenon occurring in space and time was also identified.

The hydraulic calibration of the model ensured that the simulations described the water movement with a reasonable accuracy (Chapter 6). The model was calibrated with data measured in one characteristic location of the region (soil pit).

A chemical calibration of SWAP was attempted. Due to limited time and limited availability of reliable chemical data, no direct chemical calibration was possible, therefore the chemical and physical properties of the nutrients were taken from literature, while those, which could not be found where taken from SWAP's recommended range. The sensitivity of SWAP to some of the most important parameters was analysed to assess where possible inaccuracies in the determination of the parameter values may arise.

By creating four different scenarios with the calibrated model, the ground water pollution potential was assessed under different management circumstances. These latter steps are discussed in detail in the following.

7.1 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis was to assess the response of the model to a range of parameters. By carrying out the sensitivity analysis, uncertainties in the fate and transport assumptions of the model were assessed. Through the sensitivity analysis, the model outputs (soil moisture and nitrate concentration distribution, water and chemical balances) were evaluated. The model response was analysed to the change in the van Genuchten parameters, the saturated hydraulic conductivity and the chemical parameters. These parameters where selected because of their influence on the soil moisture profile and the solute concentration.

To do the sensitivity analysis, multiplier factor was used to increase or decrease the parameters by a specific magnitude (+/- 10 % and +/- 25 %) around the calibrated value, which was assumed as the base value. Tables 7-1 – 7-2 show the effect of these changes. The change in the simulated bottom flux of water and solutes as well as the nitrogen concentration in the bottom compartment of the model (depth = 194 cm) were analyzed.

7.1.1 Sensitivity to the saturated hydraulic conductivity and van Genuchten parameters

Table 7-1 sensitivity analysis for the soil hydraulic parameter L1

	Parameter valu (soil hydraulic and vGP)	Multiplier Range	Depth (cm)	Concentration (mg/L)	Recharge	
					Water (cm)	Solute (mg/cm^2)
	75	+25 %	194	654	136.20	85.22
	66	+10 %	194	653	136.20	85.19
1	K_{sat} = 60 cm/d	Base value	194	653	136.20	85.16
	54	-10 %	194	653	136.20	85.13
	45	-25 %	194	651	136.59	85.12
	0.07875	+25 %	194	631	142.95	85.83
	0.0693	+10 %	194	653	136.22	85.17
2	Alfa = 0.063	Base value	194	653	136.20	85.16
	0.0567	-10%	194	653	136.20	85.15
	0.0473	-25%	194	653	136.20	85.13
	0.3763	+25 %	194	653	136.20	85.15
	0.3311	+10 %	194	653	136.20	85.16
3	m = 0.301	Base value	194	653	136.20	85.16
	0.2709	-10 %	194	653	136.20	85.16
	0.2258	-25 %	194	653	136.20	85.17
	1.7888	+25%	194	662	136.20	85.85
4	1.5741	+10%	194	657	136.20	85.48
	n = 1.431	Base value	194	653	136.20	85.16
	1.288	-10 %	194	637	139.41	85.08
	1.0733	-25 %	194	388	239.83	91.39

Where:

vGP = van Genuchten parameters

The change of the saturated hydraulic conductivity within the ±25 % range has no significant influence neither on the bottom flux (recharge) nor on the nitrogen concentration at the 194 cm depth. The slight changes indicate that the model may react more if larger inaccuracies occur in the determination of the saturated hydraulic conductivities.

Alfa has a positive correlation with recharge (bottom flux) and the solute flux. The changes of these modelling results are slight in the range of ±10 % change of alpha, but beyond10 % increase, the bottom flux increases non-linearly.

The shape factor *m* seems to have no influence on any parameters in the analysed range.

The shape factor *n* has positive correlation with the concentration distribution and negative correlation with the water bottom flux (recharge) and the solute flux. The model seems to be most sensitive to this parameter from the examined group.

7.1.2 Sensitivity to the chemical parameters

Table 7-2 sensitivity analysis for the chemical parameters

	Sensitivity value Chemical Parameter	Multiplier Range	Penetration (cm)	Concentration (mg/L)	Recharge	
					Water (cm)	Solute (mg/cm^2
	Dispersion Length 6.25	+25 %	194	651	136.20	85.10
	5.50	+10 %	194	652	136.20	85.14
1	5.00	Base value	194	653	136.20	85.16
	4.50	-10 %	194	654	136.20	85.19
	3.75	-25 %	194	656	136.20	85.23
	Diffusion 0.2325	+25 %	194	653	136.20	85.16
	coefficient 0.2046	+10 %	194	653	136.20	85.16
2	0.1860	Base value	194	653	136.20	85.16
	0.1674	-10 %	194	653	136.20	85.16
	0.1395	-25 %	194	653	136.20	85.16
	Relative 0.120	+25 %	194	636	136.20	83.11
	Root 0.088	+10 %	194	650	136.20	84.75
3	Uptake 0.080	Base value	194	653	136.20	85.16
	0.072	-10 %	194	657	136.20	85.58
	0.060	-25 %	194	662	136.20	86.21
	Decomposition rate	+25 %	194	638	136.20	83.19
		+10 %	194	647	136.20	84.37
4		Base value	194	653	136.20	85.16
		-10 %	194	659	136.20	85.96
		-25 %	194	669	136.20	87.18

The model is most sensitive to the relative root uptake and the decomposition rate. This focuses the attention on the accurate determination of these coefficients.

The final chemical parameters source was from reliable (traceable) sources while those, which could not be found, were taken from within the recommended range of the model. How the initial Nitrate – nitrogen concentration, needs to be verified on site.

In reality, the effect of diffusion is minor compared to the other distribution processes of chemicals. This is reflected in the fact that the model is not sensitive to the change of the diffusion coefficient in the discussed range.

Graphs in Appendices 7.5 to 7.7 illustrate the above.

7.2 LEACHING SIMULATION

Using the calibrated model the leaching of nitrate-nitrogen through the unsaturated zone was simulated. The objective of the simulation was to evaluate qualitatively and quantitatively the leaching of the nitrate under different hydrological, geological and agronomical conditions.

The following scenarios where taken into consideration:

- **Scenario 1**, Continuous supply of nitrate at an initial concentration of 394.85mg/l with 7 mm of irrigation water while varying the layer thickness of Layer 1 (L1) and Layer 2 (L2).
- **Scenario 2**, intermittent supply of nitrate at an initial concentration of 394.85 mg/l with 7 mm of irrigation water while varying the layer thickness of Layer 1 (L1) and Layer 2 (L2).
- **Scenario 3**, Reduced irrigation water of 4mm and continuous supply of Nitrate at an initial concentration of 394.85 mg/l with 7 mm of irrigation water while varying the layer thickness of Layer 1 (L1) and Layer 2 (L2).
- **Scenario 4**, Reduced irrigation water of 4mm and intermittent supply of Nitrate at an initial concentration of 394.85 mg/l with 7 mm of irrigation water while varying the layer thickness of Layer 1 (L1) and Layer 2 (L2).

7.2.1 SCENARIO 1: Continuous supply of Nitrate at an initial concentration of 394.85mg/l with 7 mm of irrigation water while varying the layer thickness of Layer 1 (L1) and Layer 2 (L2).

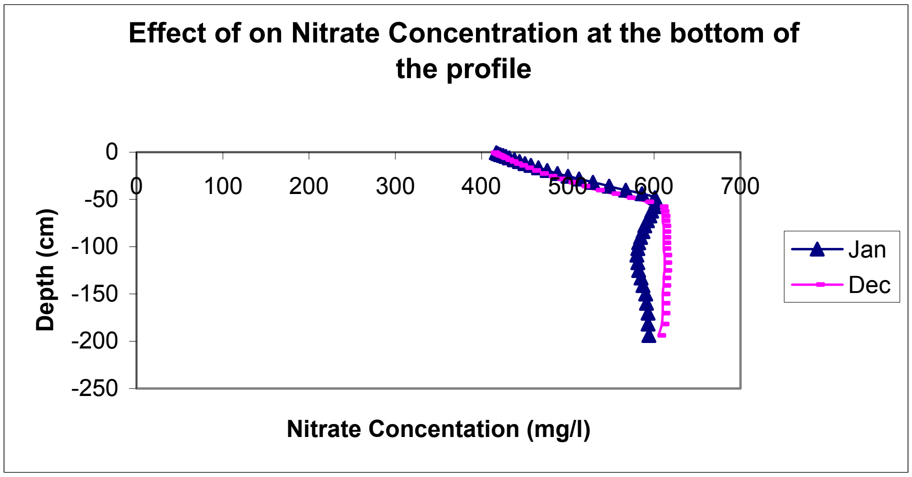
This concentration is based on the nitrate-nitrogen analysis of the irrigation water sample (S5), see table 4.13. The application frequency of fertilizer with the irrigation applied on either a continuous basis (as is the current practice) In this scenario the effect of variation in soil horizon on leaching when subjected to the nutrient load/regime will be analyzed. Two-layer arrangement will be analyzed.

Table 7-3 Soil layer thickness

RUN	Layer 1	Layer 2	Layer 3	Layer 4	Total thickness (cm)
1	15	130	20	35	200
1b	105	24	36	35	200

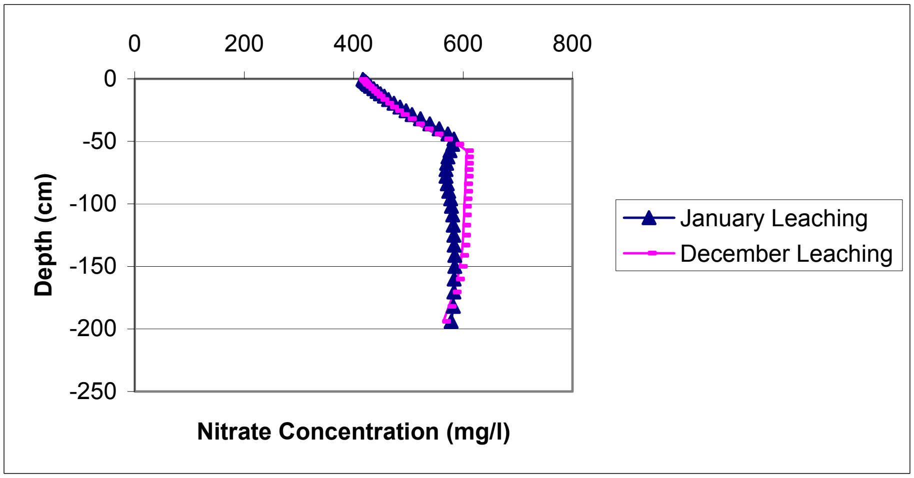
A) RUN 1:

FIGURE 7-1 Temporal variability of the nitrate concentration



B) RUN 1B:

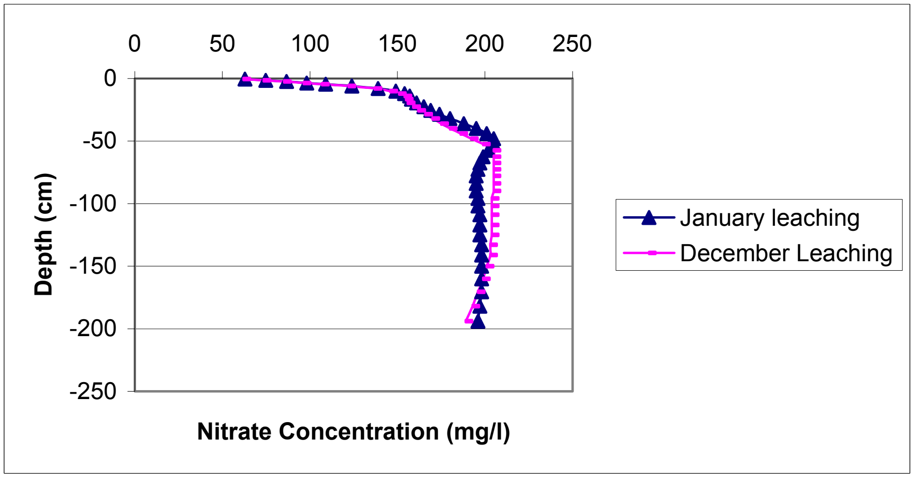
FIGURE 7-2 Effect of varying layer thickness on the nitrate concentration distribution in soil profile



7.2.2 SCENARIO 2: Intermittent supply of nitrate at an initial concentration of 394.85mg/l with 7 mm of irrigation water while varying the layer thickness of Layer 1 (L1) and Layer 2 (L2).

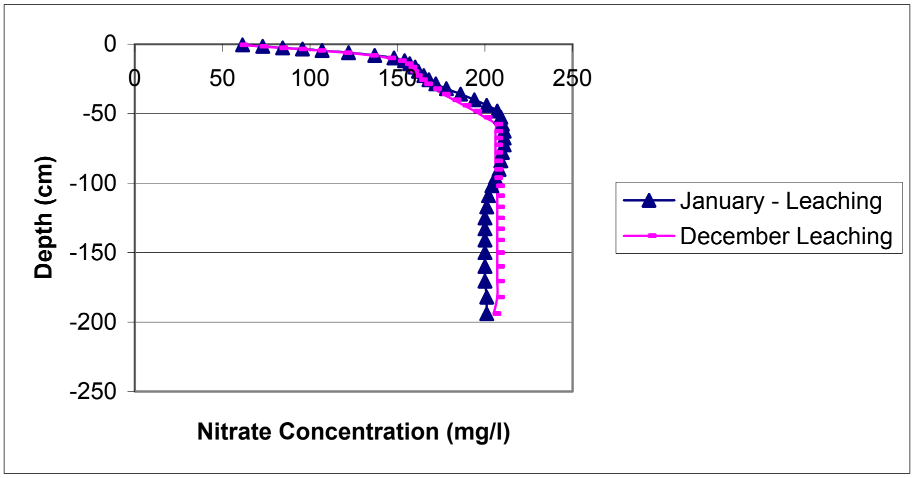
RUN 1:

FIGURE 7-3 The effect of intermittent supply of nitrate on the temporal variability of the nitrate concentration in the soil profile



RUN 2:

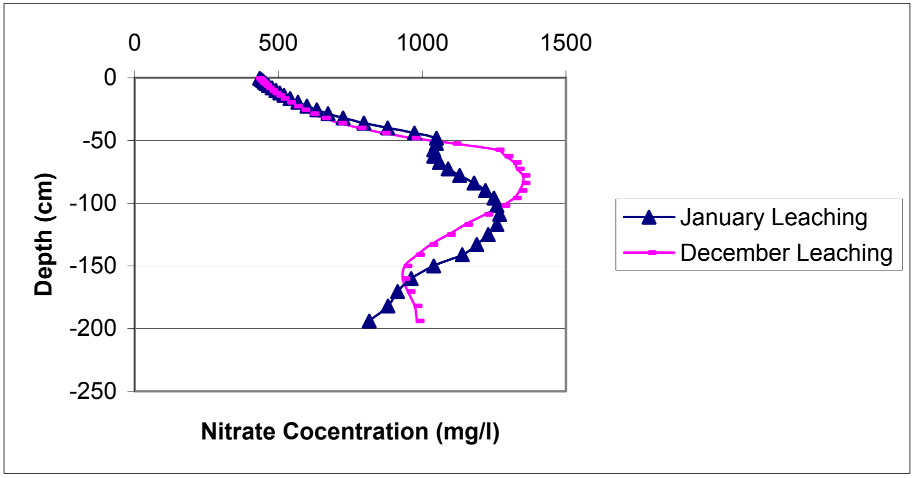
FIGURE 7-4 The effect intermittent supply, varying the layer thickness on temporal variability of the nitrate concentration in the soil profile



7.2.3 SCENARIO 3: Continuous supply of Nitrate at an initial concentration of 394.85mg/l with 4 mm of irrigation water while varying the layer thickness of Layer 1 (L1) and Layer 2 (L2).

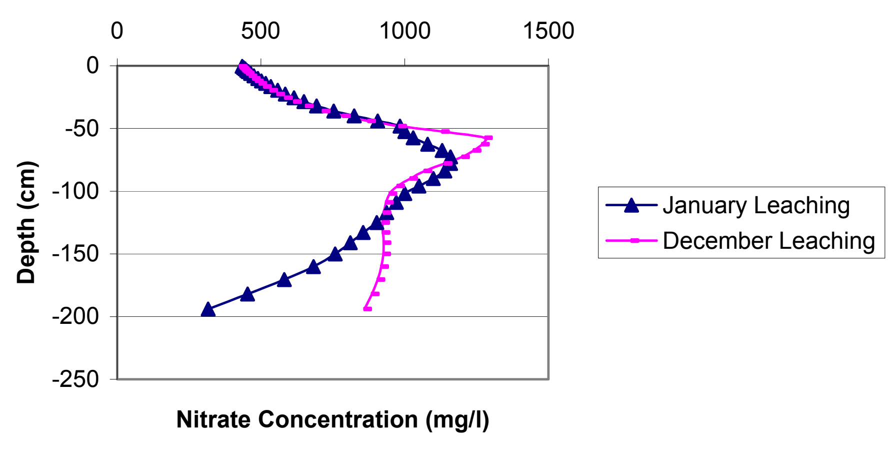
RUN1:

FIGURE 7-5 Effect of reduction of irrigation water and a continuous supply of fertilizer on the Temporal distribution of the Nitrate concentration in the soil profile



RUN 2:

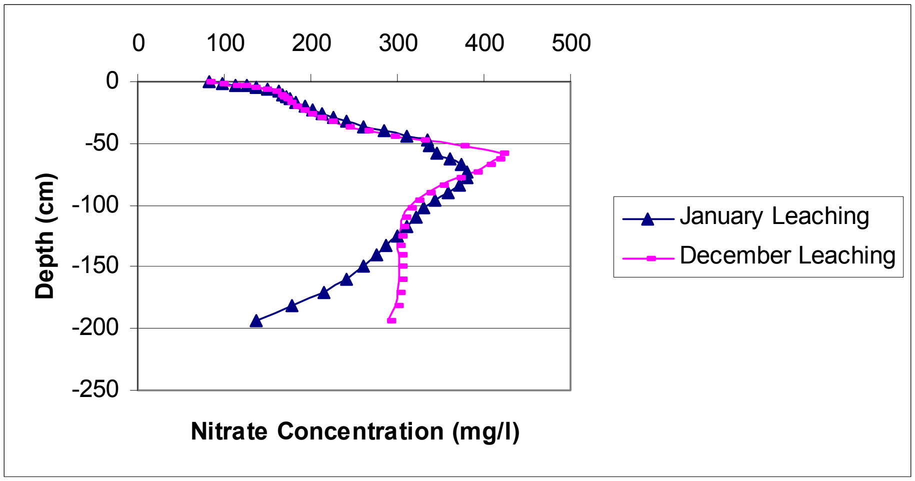
FIGURE 7-6 Effect of varying the layer thickness, reduction of irrigation water on the temporal distribution of the Nitrate concentration in the soil profile



7.2.4 SCENARIO 4: Intermittent supply of nitrate at an initial concentration of 394.85mg/L with 4 mm of irrigation water while varying the layer thickness of Layer 1 (L1) and Layer 2 (L2).

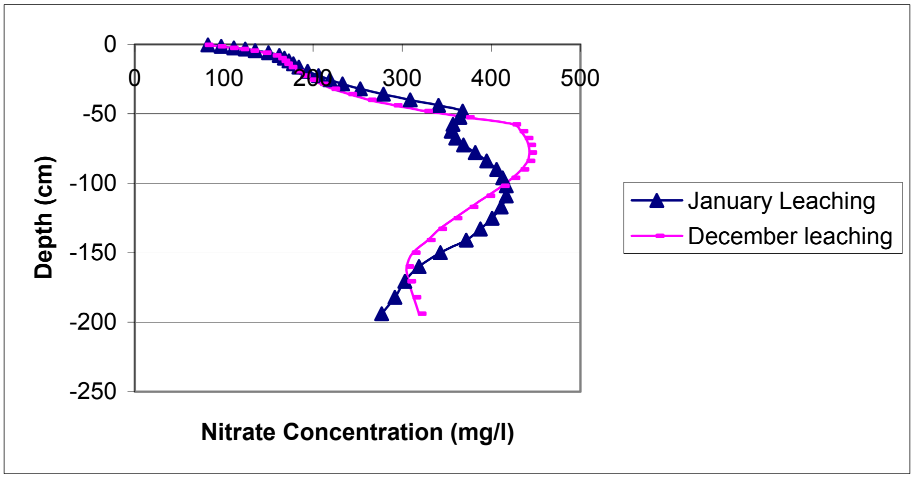
RUN1:

FIGURE 7-7 Intermittent supply and reduced water input on nitrate concentration distribution



RUN 2:

FIGURE 7-8 Effect of variation of the layer thickness, reduced irrigation water on nitrate concentration distribution



7.2.5 Analysis of the scenarios

From the above scenarios the table 7-3 summarizes the effects of varying the layer thickness, the regime of fertilization, the irrigation water depth on both the water and solute bottom flux, the root uptake, the decomposition rate and the nitrate concentration in the soil profile.

The effect of layer thickness can be clearly seen in the following:

- the solute flux,
- the decomposition rate,
- the final nitrate concentration at the bottom of the soil profile.

The layer thickness does not seem to affect the bottom flux for water,and has minor or no effect on the root uptake.

The fertilization regime only seemed to affect the root water uptake.

Table 7-4 codes representing layer arrangement

	Layer 1	Layer 2	Layer 3	Layer 4	Code
THICKNESS (cm)	15	130	20	35	A
THICKNESS (cm)	105	24	36	35	B

THE EFFECT OF REDUCTION OF IRRIGATION WATER (SCENARIO 3 AND 4):

When the irrigation water was reduced by 43% while maintaining the initial Nitrate concentration constant, the Nitrate accumulation rate showed general initial positive followed by negative growths below the root zone (figure 7.9). This therefore only resulted on a slight increase in the Nitrate concentration (mean monthly = 4.91 mg/l).

Table 7-5 SCENARIO ANALYSIS OUTPUT

SCENARIO	Layer arrangement Code (Table 7.1)	Irrigation depth (mm)	Initial Concentration (mg/l)	Nitrate Input regime	Concentration at depth of 194cm (mg/l)	Bottom Flux		Root uptake (mg/cm^2)	Decomposition (mg/cm^2)
						Water (cm)	Solute (mg/cm^2)		
1	A	7	394.85	cont	605	136.20	78.84	13.29	6.179
1b	B	7	394.85	cont	564	136.20	75.78	13.16	9.351
2	B	7	394.85	Interm	184	136.20	25.48	4.49	3.145
2b	A	7	394.85	Interm	205	136.20	26.51	4.49	2.078
3	A	4	394.85	cont	982	29.55	27.98	18.85	8.507
3b	B	4	394.85	cont	860	29.55	20.09	18.33	12.24
4	B	4	394.85	Interm	289	31.26	7.498	6.078	4.109
4b	A	4	394.85	Interm	319	31.26	9.895	6.235	2.832

Where:

Interm. – Intermittent.

Cont. - Continuous

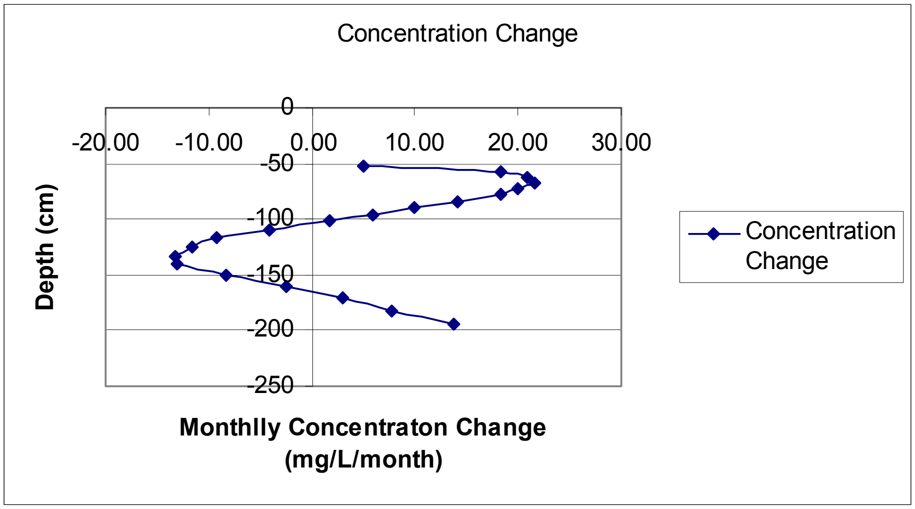


Figure 7-9 SCENARIO 3 showing the monthly accumulation rate of nitrates as a result of reduction of irrigation water (7 mm to 4 mm)

7.2.6 NITRATE – N CONCENTRATION DISTRIBUTION BELOW THE ROOT ZONE (Leaching)

While the objective was to know how deep a specific nutrient would leach below the rootzone, it was also important to know the concentration distribution of the nutrient in the soil profile that is either in the solid, liquid or vapor phases of the soil. Unfortunately SWAP does not have any provision to partition the leached nutrients into the forms mentioned above.

Nitrate- nitrogen as a nutrient is considered to be harmful when it is found in groundwater at a concentration higher than 10 ppm. This level is called the maximum contaminant level (MCL) and is the basis for investigation on whether nitrate-nitrogen is still a threat after a certain time at specific depths.

The concentrations of Nitrate-nitrogen at the end of the simulation from SWAP are given in tables 7.4. The values represent the concentration values at the lowest depths that the nutrient had reached at the end of the simulation year of each scenario.

Table 7-6 CONCENTRATION OF NITRATE- N AT THE END OF THE SIMULATION PERIOD AT LOWEST DEPTH

SCENARIO: Continuous Nutrient Input			Values	Nitrate Concentration in mg/l at 194cm depth
Initial Concentration (mg/L)			394.85	
Nutrient Application regime			Continuous	
SCENARIO1:	Layers			
Irrigation Depth (mm)			7	
Layer thickness (cm)	L1	L2		
GH1	30	99		669
GH3	75	99		648
GH6	105	24		631
GH13	50	79		658
GH14	113	16		626
GH20	60	69		663
SCENARIO 2:				
Irrigation Depth (mm)			4	
Layer thickness (mm)	L1	L2		
GH6	105	24		874

Table 7-7: CONCENTRATION DISTRIBUTION AT THE END OF THE SIMULATION PERIOD (1 year)

SCENARIO: Intermittent Nutrient Input			Values	Nitrate Concentration in mg/L at 194cm depth
Initial Concentration (mg/L)			394.85	
Nutrient Application regime			Intermittent	
SCENARIO:	Layers			
Irrigation Depth (mm)			7	
Layer thickness (cm)	L1	L2		
GH1	30	99		202
GH3	75	99		194
GH6	105	24		194
GH13	50	79		199
GH14	113	16		189
GH20	60	69		201
SCENARIO				
Irrigation Depth (mm)			4	
Layer thickness (mm)	L1	L2		
GH1	30	99		253
GH20	60	69		229

NOTE:

The Concentration of 0.649 mg/l did not produce any leaching regardless of the solute input regime.

SPATIAL (VERTICAL) VARIABILITY OF LEACHING

Through the varying of the layer thickness, the vertical variability of leaching was evaluated by observing the changes in the Nitrate concentration in the bottom layer. However, this did not produce any significant changes in the nitrate concentration at the bottom layer. This could be due to the shallow depth of only 200 cm, which was considered.

8 CONCLUSION AND RECOMMENDATION

8.1 CONCLUSION

In this study, a numerical model SWAP was used to simulate the vertical transport of water and nutrients in the unsaturated soils zone of the greenhouses of the SULMAC Farm in the Naivasha Basin, Kenya. As a result of the simulation, the water and chemical balances of the Sulmac farm were analyzed and quantified as part of the environmental monitoring and assessment. Prior to the simulation, the model was calibrated and validated using experimental field data combined with data from literature.

In the preparation phase a fieldwork was carried out, where several in situ field experiments were conducted up to the depth of 2 m. Water and soil samples were collected and analyzed in the ITC laboratory. From the analysis of the water samples the nutrient loading of the water was assessed. From the analysis of the soil samples, the particle size distribution, the organic carbon, the nitrate - nitrogen and some cations, the pH and EC were extracted. From the grain size distribution the moisture retention (pF) curves were obtained.

During the fieldwork the saturated hydraulic conductivity for each soil layer were measured. From the soil pit made on the periphery of the greenhouse the soil structure and the soil moisture were established. These observed (measured) soil moisture content values where used to calibrate the model.

Sensitivity analyses of the calibrated model where made to assess sensitive parameters in the model, which could be sources of inaccuracies in the output.

Four scenarios where created:

Scenario 1 consisted of a continuous supply of nutrient nitrate in irrigation water,

Scenario 2 consisted of the intermittent supply of nutrient in the same amount of irrigation water (7 mm).

Scenario 3 consisted of reduction in the water supply (to 4 mm) but continuous supply of nutrient

Scenario 4 consisted of reduction in the water supply (4 mm) and intermittent nutrient supply.

From the simulation, both the chemical and water balances for the soil profile were assessed. The bottom flux of both the water and solutes below the soil layer and the solute concentration in the soil profile were assessed to predict the environmental impact of the nutrients in flower farming on the groundwater.

The Result of this study is that there is an annual bottom flux (recharge) of 136.20 cm of water. The solute bottom flux is almost 4 fold of the combined root uptake and decomposition.

As the study area is dominated by one soil textural class (loamy sand), there is very low spatial variability (horizontal) of the concentration distribution in the soil profile.

When this annual flux is extrapolated over the entire area occupied by greenhouses in the Lake Naivasha basin (614 ha, Sayeed, 2001), assuming that the area has loamy sand soils and subjected to continuous nutrient input of 395.84mg/L, then a total of 5229 t of fertilizer will be lost through leaching on annual basis. Not only is this an environmental hazard but also an economical loss. In monetary terms this will cost the Lake Naivasha farming sector a total of US $1050000 per year.

The amount of water lost as bottom flux (136.20 cm) is more than 50 % of that applied (248.90 cm). As a matter of fact it is more than the total precipitation of an hydrological wet year (852 mm).

The result of the different scenarios show that there is potential threat to the groundwater pollution but this will depend on the initial solute concentration and the solute application regime (continuous or intermittent).

The reliability of the model can be further improved if it were to be chemically calibrated and validated. In this study chemical calibration could not be conclusively done, as the actual initial nutrient concentration was not so reliable and the Nutrient chemical parameters were not readily available.

The focus of this study was on analyzing the water and chemical balances of the drip irrigated greenhouse flowers with a view of ascertaining whether leaching prevailed. It is in this scope that the purpose of this study must be viewed.

The evaluation was based on a short–term field study (3 weeks). This means several assumptions had to be made.

8.2 RECOMMENDATION

Evapotranspiration in greenhouses was not easy to find from literature even if an average of 2.5 mm/day was used in this study based on personal communication and previous studies which had different objectives. I recommend that this be considered in the future studies in order to come up with a concrete evapotranspiration in the greenhouse conditions.

Large amount of agro-chemicals are used in the greenhouses, however, most of the previous studies restricted themselves to open fields. I suggest that this be considered in future studies in the greenhouse environment.

Several studies have been undertaken on the effect of agro – chemical in the Naivasha. However, most have restricted themselves to pesticides because of the readily available chemical properties in the literature. I recommend that in the future study more emphasis be paid to nutrients so as to make a rich future database.

In the absence of rains at the SULMAC farms, most lengths of drainage ditches are dry except at points where flush water is discharged. Substantial amount of flush water is released from the drip filter station (115.2 m^3/day). This amount of water flows for a short distance only. I recommend that more thoroughly temporal and spatial variability of the flow be investigated in the future studies in order to assess the possible groundwater contamination passage way.

I recommend the installation of Lysimeters to monitor solute movement in the unsaturated zone of the greenhouses. This maybe the basis for calibrating and validating numerical models such as SWAP. This may also be a way of monitoring the impact of the agro- chemicals on the environment.

Application of Remote sensing and GIS in mapping the leaching prone areas need to be further pursued especially in the situation where some greenhouses have been painted with other colours therefore the spectral information (tonal) on satellite images tend to vary from one location to the other, making the task of supervised classification rather long.

The soil type influences leaching, therefore crossing of the greenhouse maps with good soil maps will give indication of leaching prone areas. There is need to come up with a digital soil map showing the textural class of the Naivasha Basin.

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APPENDICES

The appendices are numbered according to the chapters to which they are appended.

APPENDIX 2.1 SOIL WATER RETENTION AND HYDRUALIC CONDUCTIVITY RELATIONSHIPS (Maidment,1993)

Hydaulic soil Characteristic	**Parameters**	**Parameter Correspondence**
Brooks and Corey		
Soil water retension $\frac{\theta-\theta_r}{\Phi-\theta_r}=\left(\frac{h_b}{h}\right)^{\lambda}$ Hydraulic conductivity $\frac{K(\theta)}{K_s}=\left(\frac{\theta-\theta_r}{\Phi-\theta_r}\right)^{n}=(Se)^{n}$	λ= pore-size index h_b = bubbling capillary pressure θ_r = residual water content Φ = porosity K_s= fully saturated conductivity (θ = Φ) $n=3+\frac{2}{\lambda}$	λ =λ $h_b = h_b$ $\theta_r = \theta_r$ Φ = Φ $K_s = K_s$
Campbell		
Soil water retension $\frac{\theta}{\Phi}=\left(\frac{H_b}{h}\right)^{1/b}$ Hydraulic conductivity $\frac{K(\theta)}{K_s}=\left(\frac{\theta}{\Phi}\right)^{n}$	Φ = porosity H_b = scaling parameter with Dimension of length B = constant n = 3+2b	Φ=Φ $H_b=h_b$ $b=\frac{1}{\lambda}$
Van Genuchten		
Soil water retension $\frac{\theta-\theta r}{\Phi-\theta r}=\left[\frac{1}{1+(\alpha h)^{n}}\right]^{m}$ Hydraulic conductivity $\frac{K(\theta)}{Ks}=\left(\frac{\theta-\theta_r}{\Phi-\theta_r}\right)^{1/2}\left\{1-\left[1-\left(\frac{\theta-\theta_r}{\Phi-\theta_r}\right)^{1/m}\right]^{m}\right\}^{2}$	Φ = Φ Θr = Θr α = $(h_b)^{-1}$ n = λ + 1 $m=\frac{\lambda}{\lambda+1}$	

Θ = water content; h = capillary suction (cm); K(θ) = hydraulic conductivity for given water content (cm/h)

APPENDIX 2.2 ESTIMATION EQUATION FOR BROOKS – COREY PARAMETERS:

h_b – Brooks – Corey bubbling pressure, cm

$$hb = \exp\begin{bmatrix} 5.3396738 + 0.1845038(C) - 2.48394546(\Phi) - 0.00213853(C)^2 - 0.04356349(S)(\Phi) - 0.61745089(C)(\Phi) + 0.00143598(S)^2(\Phi^2) \\ - 0.00855375(C^2)(\Phi^2) - 0.00001282(S^2)(C) + 0.00895359(C^2)(\Phi) - 0.00072472(S^2)(\Phi) + 0.0000054(C^2)(S) + 0.50028060(\Phi^2)(C) \end{bmatrix}$$

λ – Brooks – Corey pore – size distribution index

$$\lambda = \exp\begin{bmatrix} - 0.7842831 + 0.0177544(S) - 1.062498(\Phi) - 0.00005304(S^2) - 0.00273493(C^2) + 1.11134946(\Phi^2) - 0.03088295(S)(\Phi) + 0.00026587(S^2)(\Phi^2) - \\ 0.00610522(C^2)(\Phi^2) - 0.00000235(S^2)(C) + 0.00798746(C^2)(\Phi) - 0.00674491(\Phi^2)(C) \end{bmatrix}$$

θr – Brooks – Corey residual water content (volume fraction)

$$\theta r = \begin{bmatrix} - 0.0182482 + 0.00087269(S) + 0.00513488(C) + 0.02939286(\Phi) - 0.00015395(C^2) - 0.0010827(S)(\Phi) - 0.00018233(C^2)(\Phi^2) + 0.00030703(C^2)(\Phi) - \\ 0.0023584(\Phi^2)(C) \end{bmatrix}$$

Where:

C = percent clay (5< % < 60)

S = Percent sand (5 < % 70)

Φ = Porosity (volume fraction)

SOURCE: Maidment D. R, 1993. Handbook of Hydrology

APPENDIX 2.3: SUMMARY OF DERIVED SOIL – WATER CHARACTERISTIC EQUATION

Applied Tension range (kPa)	Equation
> 1500 to 10	$\Psi = A^*\theta B$ $A = \exp[\ a+b(\%C)+c(\%S)^2+d(\%S)^2]100.0$ $B = e + f(\%C)^2 + g(\%S)^2\ (\%C)$
10 to Ψe	$\Psi = 10.0 - (\theta - \theta_{10})(10.0 - \Psi e)/(\theta_s - \theta_{10})$ $\Theta 10 = \exp[(2.302 - \ln A)/B$ $\Psi e = 100.0\ [m + n(\theta_s)]$ $\Theta s = h + j(\%S) + k\log_{10}(\%C)$
Ψe to 0.0	$\Theta = \theta s$
> 1500 to 0.0	$K=2.778x10-6\{\exp[p +q(\%S) +[r+t(\%S)+u(\%C)+v(\%C)^2](1/\theta)]\}$

Where:

Coefficients:

$a = -4 .. 396$

$b = -0.0715$

$c = -4.880 \text{ X } 10^{-4}$

$d = -4.285 \text{ X } 10^{-5}$

$e = -3. 140$

$f = -2.22 \text{ X } 10^{-3}$

$g = -3.484\text{x } 10^{-5}$

$h = 0.332$

$j = -7.251 \text{ X } 10^{-4}$

$k = 0.01276$

$m = - 0.108$

$n = 0.341$

$p = 12.012$

$q = -7.55 \text{ x } 10\text{-}2$

$r = -3.8950$

$t = 3.671 \text{ X } 10^{-2}$

$u = -0.1103$

$v = 8.7546 \text{ X } 10^{-4}$

Definition:

Ψ = water potential (kPa)

Ψe = water potential at air entry (kPa)

Θ = water content (m3/m3)

θ_{10} = water content at 10 kPa

K = water conductivity (m/s)

(%S) = percent sand

Θs = water content at saturation, m3/m3 (%C = percent clay)

APPENDIX 2.4 THE BROOKS AND CORREL PARAMETER

Sample No:	Textural Class	hb (cm)	λ	θres	α	n	m
Standard	CL	38.5156	0.2635	0.1027	0.0260	1.2635	0.2085
SspL1	LS	11.3933	0.4312	0.0610	0.0878	1.4312	0.3013
SspL2	LS	13.5844	0.4858	0.0501	0.0736	1.4858	0.3270
SspL3	SL	15.8100	0.4637	0.0498	0.0633	1.4637	0.3168
SspL4	SL	23.3975	0.4480	0.0419	0.0427	1.4480	0.3094
SspL6	SiL	30.8387	0.3304	0.0751	0.0324	1.3304	0.2483
SGH3_1	LS	8.6762	0.4774	0.0593	0.1153	1.4774	0.3231
SGH3_2	LS	7.1437	0.4546	0.0644	0.1400	1.4546	0.3125
SsGH3_3	SL	10.7199	0.4511	0.0589	0.0933	1.4511	0.3109
SsGH3_4	LS	36.8743	0.7364	0.0408	0.0271	1.7364	0.4241
SGH13_1	SL	10.7245	0.4350	0.0606	0.0932	1.4350	0.3031
SGH13_2	SL	8.4984	0.4225	0.0664	0.1177	1.4225	0.2970
SsGH13_3	SIL	30.0224	0.3855	0.0510	0.0333	1.3855	0.2783
SsGH13_4	SL	13.0918	0.4286	0.0586	0.0764	1.4286	0.3000
SGH14_1	LS	8.3490	0.4563	0.0621	0.1198	1.4563	0.3133
SGH14_2	LS	7.3629	0.4391	0.0662	0.1358	1.4391	0.3051
SsGH14_3	L	25.2063	0.3735	0.0606	0.0397	1.3735	0.2719
SSGH14_4	LS	7.8707	0.4352	0.0655	0.1271	1.4352	0.3032
SGH14_4	LS	11.5483	0.4807	0.0536	0.0866	1.4807	0.3246
SDR4_1	LS	8.2996	0.4795	0.0594	0.1205	1.4795	0.3241
SDR4_2	SL	18.9445	0.4053	0.0568	0.0528	1.4053	0.2884
SDR4_3	L	30.6000	0.3246	0.0778	0.0327	1.3246	0.2451
SDR4_4	L	26.4665	0.3440	0.0716	0.0378	1.3440	0.2559
SoGH3_B3	SL	11.7459	0.4533	0.0567	0.0851	1.4533	0.3119

EXPLANATION TO THE CODES USED IN LABELLING THE SAMPLE

S_{GH3_1-1}	**S**	GH3	1-1	1-2	1-3	1-4
	Sample	Greenhouse Number 3	Depth = 15 cm	Depth = 50 cm	Depth = 90 cm	Depth = 150 cm

S_{OGH3_A1-1}	**S**	OGH3	A	A1-1	A1-2	A1-3
	Sample	Outside Greenhouse Number 3	Distance from GH = 50 cm	Depth = 30 cm	Depth = 60 cm	Depth = 100 cm

S_{OGH3_B1-1}	**S**	OGH3	B	B1-1	B1-2	B1-3
	Sample	Outside Greenhouse Number 3	Distance from GH = 200cm	Depth = 30 cm	Depth = 60 cm	Depth = 100 cm

S_{DR1_1-1}	**S**	DR1	1-1	1-2	1-3	1-4
	Sample	Drain Number 1	Depth = 50 cm	Depth = 100 cm	Depth = 150 cm	Depth = 200 cm

$S_{sp\ L1\_1}$	**S**	SPL	L1-1	L1-2	L1-3	L1-4	L1-5	L1-6
	Sample	Soil pit Layer	Layer 1 Depth = 15 cm	Layer 2 Depth = 50 cm	Layer 3 Depth= 110 cm	Layer 4 Depth = 167 cm	Layer 5 Depth = 200 cm	Below Layer 5 Depth = 250 cm

APPENDIX 4.1: IRRIGATION WATER APPLICATION

Irrigation application cycle number	Time		Irrigation application depth (in mm)
	Minutes	Hours	
1	14	0.23333	2.33
2	7	0.11667	1.167
3	7	0.11667	1.167
4	7	0.11667	1.167
5	7	0.11667	1.167
Total	42	0.70001	7.00

Table: Irrigation Cycles and Depth

Application depth:

$Q = A*v = V/t = 0.8333 m^3/min$

$d = V/A$

$A = Lbed * Wbed = 48m * 1.0m = 48\ m^2 * 2 = 96.0 m^2$/full ridge or bed

Where:

Lbed = Length of bed (ridge)

Wbed = Width of bed

d = Depth of application

V = Volume of water

v = Velocity of flow

A = Cross section area

t = Time

Total Area = Number of beds per GH * Area of one Full bed

= 38beds/GH * 96.0 m^2/bed

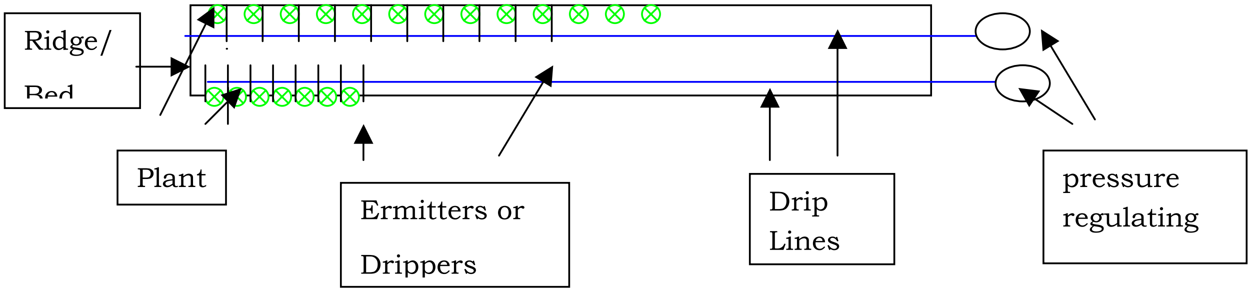
= 3648 m^2/GH

Depth of applications = $V/A = 35m^3 / 3648\ m^2 * 1000mm/m$

d = 9.59956mm

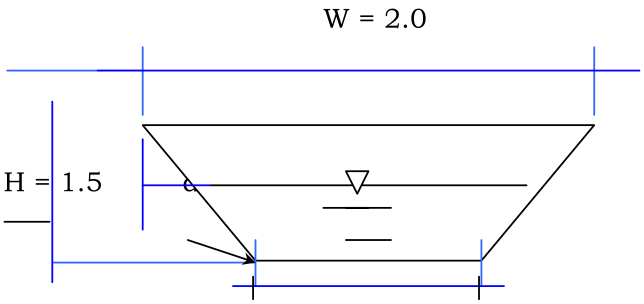
d = 9.6 mm

Figure : Dripline outlay on the Ridge



APPENDIX 4.2: DRAINAGE DITCHES

Figure : Cross- section of the Drain (all dimensions in m and not to scale)



Where:

W = Width of drain = 2m

w = Width of water = 1.03376m

H = Total depth of the drain = 1.5

d = height of water = 0.25

b = base of (trapezoidal section) drain = 0.27

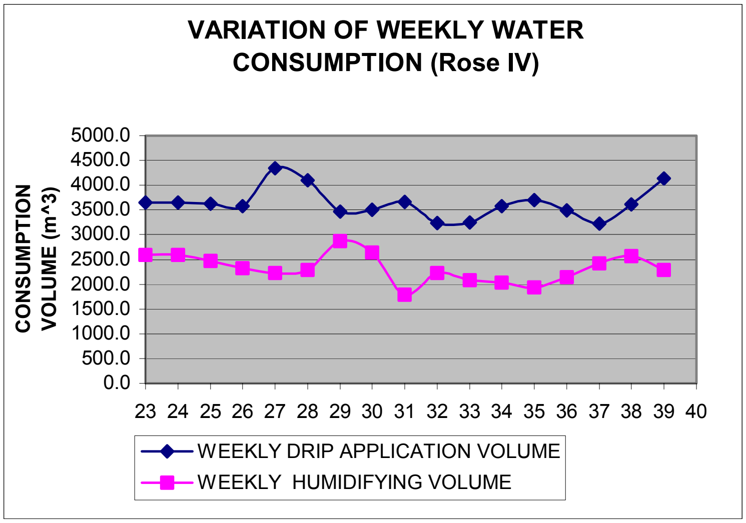
APPENDIX 4.3A: WEEKLY WATER CONSUMPTION (Roses IV)

MONTH:		JUN 2001			JUL 2001				AUG 2001					SEP 2001			
Days/month		30				31				31					30		
ROSES IV A = 10 ha	WK NO:23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Volume drip m3/wk	3649.5	3649.5	3621.7	3570.7	4346.6	4097.6	3465.2	3506.2	3659.0	3239.0	3242.4	3572.1	3698.3	3493.4	3220.0	3614.5	4141.7
Volume humidity m3/wk	2585.8	2585.8	2464.1	2326.3	2223.3	2291.0	2875.0	2643.8	1791.8	2227.4	2078.0	2029.8	1937.0	2140.5	2424.4	2564.6	2284.9
Volume Total m3/wk	6235.3	6235.3	6085.8	5897.0	6569.8	6388.6	6340.2	6150.0	5450.7	5466.4	5320.4	5601.8	5635.3	5634.0	5644.4	6179.1	6426.6
Application drip/day ltr/m2	5.2	5.2	5.2	5.1	6.2	5.9	5.0	5.0	5.2	4.6	4.6	5.1	5.3	5.0	4.6	5.2	5.9
Appl. Humidity/day ltr/m2	3.7	3.7	3.5	3.3	3.2	3.3	4.1	3.8	2.6	3.2	3.0	2.9	2.8	3.1	3.5	3.7	3.3
Application Total/day ltr/m2	8.9	8.9	8.7	8.4	9.4	9.1	9.1	8.8	7.8	7.8	7.6	8.0	8.1	8.0	8.1	8.8	9.2
	14491.4 9962.0				15415.5 10033.1				17410.7 10063.9					14469.7 9414.4			

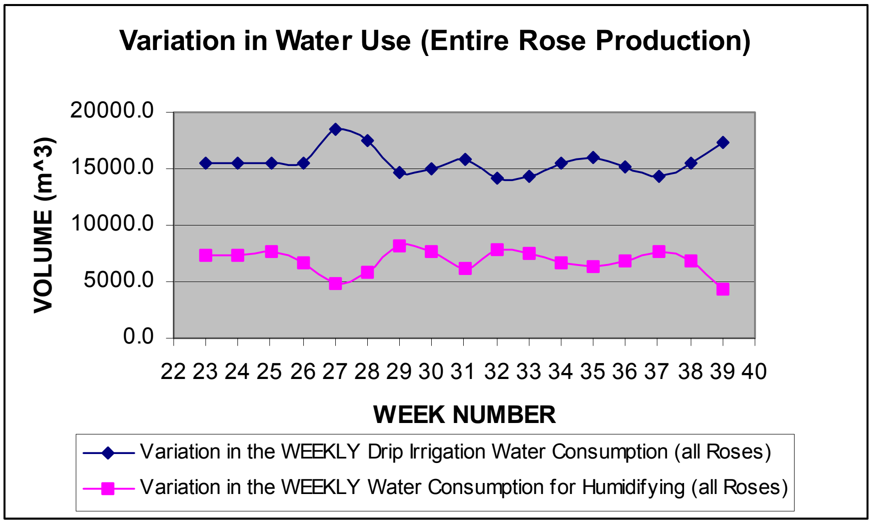
APPENDIX 4.3B TOTAL WATER CONSUMPTION FOR ALL ROSES

	JUN				JUL					AUG								
ROSES TOTAL A=43.32 ha	WK NO: 23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0
Volume drip m3/wk	15494.0	15494.0	15546.7	15543.0	18571.6	17515.9	14744.2	14936.9	15853.3	14088.6	14327.4	15567.1	15980.6	15165.1	14282.7	15545.1	17346.7	9024.2
Volume humidity m3/wk	7364.8	7364.8	7727.5	6688.2	4820.8	5752.6	8243.9	7690.6	6153.5	7794.7	7520.4	6640.0	6335.4	6846.4	7679.3	6769.3	4410.4	12395.5
Volume Total m3/wk	22858.7	22858.7	23274.2	22231.2	23392.4	23268.5	22988.1	22627.5	22006.8	21883.3	21847.8	22207.1	22316.0	22011.6	21961.9	22314.4	21757.2	21419.7
Application drip/day ltr/m2	5.1	5.1	5.1	5.1	6.1	5.8	4.9	4.9	5.2	4.6	4.7	5.1	5.3	5.0	4.7	5.1	5.7	3.0
Appl. Humidity/day ltr/m2	2.4	2.4	2.5	2.2	1.6	1.9	2.7	2.5	2.0	2.6	2.5	2.2	2.1	2.3	2.5	2.2	1.5	4.1
Application Total/day ltr/m2	7.5	7.5	7.7	7.3	7.7	7.7	7.6	7.5	7.3	7.2	7.2	7.3	7.4	7.3	7.2	7.4	7.2	7.1
	62077.7 29145.2				65768.5 26507.9				75817.0 34444.0					62339.7 25705.4				

a) Graphical representation of weekly water consumption at Rose IV



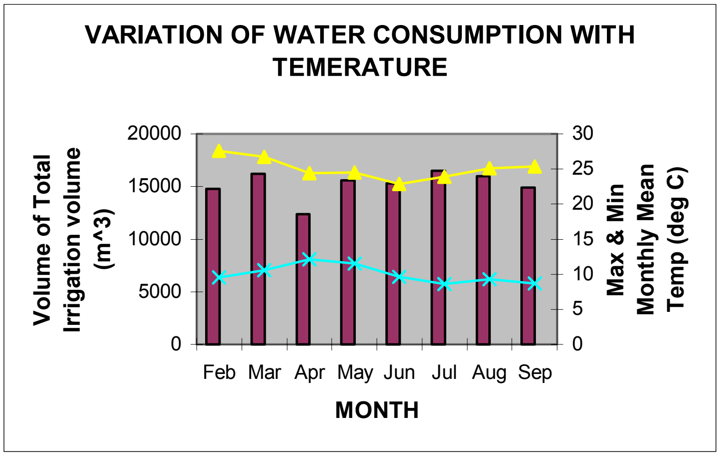
b) Graphical representation of weekly water consumption for the Entire Rose production

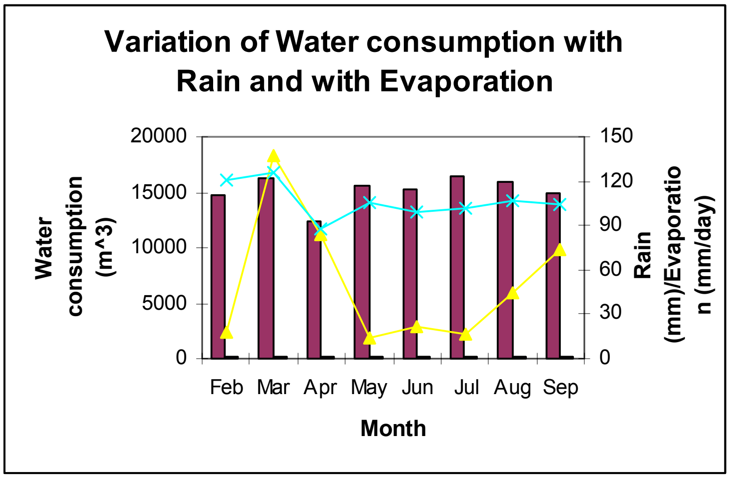


APPENDIX 4.3C RELATIONSHIP BETWEEN WATER CONSUMPTION AND CLIMATIC FACTORS

		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Water	m3	14779.74	16210.63	12373.46	15586.8	15277.87	16490.2	16001.44	14888.23
Temp_min	deg C	9.5	10.61	12.15	11.55	9.67	8.58	9.32	8.67
Temp_max	deg C	27.59	26.7	24.45	24.5	22.87	23.9	25.13	25.4
Rain	mm	18.06	136.74	83.78	14.38	21.12	17.02	44.42	73.53
Evaporation	mm/day	120.5	126.4	88.3	106	98.6	102.1	107.2	104.06
Humidity	%	60	63	72	65	64	63	62	62

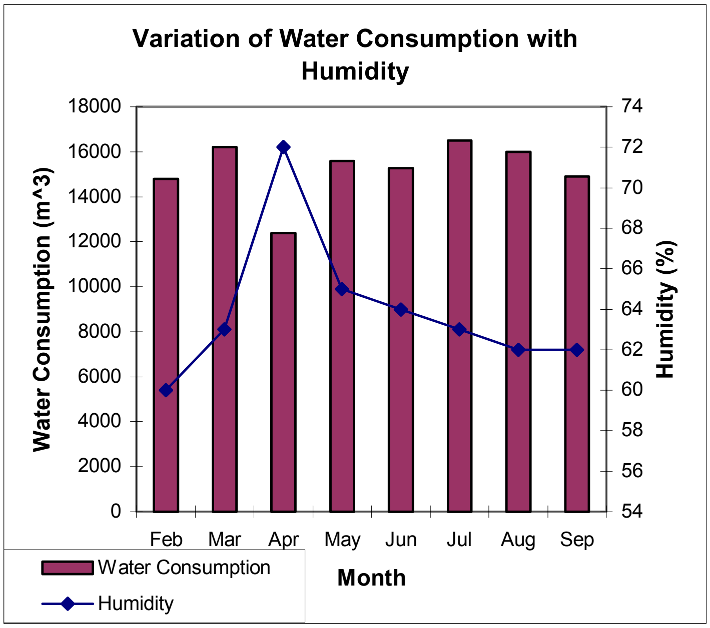
a) Graphical representation of Variation of the water Consumption with Temperature (max & Min)





b) Graphical representation of Variation of the water Consumption with Rainfall and Evaporation

c) Graphical representation of the water consumption with Humidity



APPENDIX 4.4: CARBON & ORGANIC MATTER CONTENT

ORGANIC CARBON ANALYSIS:The Walkley - Black procedure (Back Titration)

$$\%C = M_{FeSO_4} * \frac{V_{Blank} - V_{Sample}}{s} * 0.39 * mcf$$

%ORG Matter2* %
= Carbon

M_{RFeSO4} =
10/blan

1.61290323

Sequency	Sample No:	Code of Sample	m_{soil} (in g)	Vol of Titration (in ml)	%C	% ORG Matter
	I	Stand'd	0.5	6.2	2.63718	5.274
	II	Blank	empty	4.1		
1	S_{DR4_1-1}	1	0.505	5.85	0.435	0.870
2	S_{DR4_1-2}	2	0.504	5.95	0.311	0.623
3	S_{DR4_1-3}	3	0.503	6.1	0.125	0.250
4	S_{DR4_1-4}	4	0.504	6.05	0.187	0.374
5	S_{GH3_1-1}	5	0.504	5.75	0.561	1.121
6	S_{GH3_1-2}	6	0.504	5.9	0.374	0.748
7	S_{GH3_1-3}	7	0.502	6	0.250	0.500
8	S_{GH3_1-4}	8	0.507	5.85	0.433	0.867
9	S_{GH13_1-1}	9	0.5	6.05	0.188	0.377
10	S_{GH13_1-2}	10	0.51	5.8	0.492	0.985
11	S_{GH13_1-3}	11	0.51	6	0.246	0.492
12	S_{GH13_1-4}	12	0.501	6.2	0.000	0.000
13	S_{GH14_1-1}	13	0.503	5.75	0.562	1.123
14	S_{GH14_1-2}	14	0.499	5.8	0.503	1.007
15	S_{GH14_1-3}	15	0.504	5.95	0.311	0.623
16	S_{GH14_1-4}	16	0.504	6.1	0.125	0.249

17	S_{OGH3_B1-1}	17	0.514	5.8	0.489	0.977
18	S_{OGH3_B1-2}	18	0.505	5.9	0.373	0.746
19	S_{OGH3_B1-3}	19	0.518	5.95	0.303	0.606
20	S_{SP_L1-1}	20	0.51	5.7	0.616	1.231
21	S_{SP_L1-2}	21	0.505	5.95	0.311	0.622
22	S_{SP_L1-3}	22	0.503	6	0.250	0.499
23	S_{SP_L1-4}	23	0.506	5.9	0.372	0.745
24	S_{SP_L1-6}	24	0.501	6	0.251	0.501

APPENDIX 4.5: PARTICLE SIZE DISTRIBUTION AND TEXTURAL CLASS

	Sample No:	Sand Content (%)	Silt Content (%)	Clay Content (%)	Total (%)		Textural Class
	Standard	24	44	32	100.00		CL
	SspL1	72	20	8	100.00		LS
	SspL2	75	20	5	100.00		LS
	SspL3	68	26	6	100.00		SL
	SspL4	56	39	5	100.00		SL
	SspL6	33	49	18	100.00		SiL
	SGH3_1	84	9	6	100.00		LS
	SGH3_2	86	7	7	100.00		LS
	SsGH3_3	76	15	7	100.00		SL
	SsGH3_4	76	21	3	100.00		LS
	SGH13_1	73	18	8	100.00		SL
	SGH13_2	77	14	9	100.00		SL
	SsGH13_3	40	51	9	100.00		SiL
	SsGH13_4	68	24	8	100.00		SL
	SGH14_1	82	10	7	100.00		LS
	SGH14_2	83	9	8	100.00		LS
	SsGH14_3	44	44	12	100.00		L
	SSGH14_4	81	11	8	100.00		LS
	SGH14_4	78	16	5	100.00		LS
	SDR4_1	86	8	6	100.00		LS
	SDR4_2	55	35	9	100.00		SL
	SDR4_3	33	48	19	100.00		L
	SDR4_4	39	45	16	100.00		L
	SoGH3_B3	74	19	7	100.00		SL
	Blank	0.00	15.	84	100.00		

APPENDIX 4.6 : SOIL SAMPLE ANALYSIS

	Sample NO:	SOURCE	UTM X	UTM Y	DEPTH cm	DRYING (AIR)	pH	EC (in icroS/cm)	%C	ORGANIC MATTER CONTENT	N -N	
A1	SDR1_1	Drain 1	205423.5	9907567.6	50	*	7.4	676.48			1 5	
	SDR1_2	Drain 1	205423.5	9907567.6	100	*	7.6	736.64			1 4	
	SDR1_3	Drain 1	205423.5	9907567.6	150	*	7.2	1011.84			5 4	
	SDR1_4	Drain 1	205423.5	9907567.6	200	*	7.6	724.48			3 7	
A2	SDR2_1	Drain 2	205594.1	9907486.5	50	*	7.3	663.68				
	SDR2_-2	Drain 2	205594.1	9907486.5	100	*	7.6	736.64			2 9	
	SDR2_3	Drain 2	205594.1	9907486.5	150	*	7.2	785.92			1 8	
	SDR2_4	Drain 2	205594.1	9907486.5	200	*	7	906.24			3 7	
A3	SDR3_1	Drain 3	205205.4	9907439.0	50	*	6.8	451.2			8	
	SDR3_2	Drain 3	205205.4	9907439.0	100	*	6.9	436.48			1 3	
	SDR3_3	Drain 3	205205.4	9907439.0	150	*	7	263.68			1 2	
	SDR3_4	Drain 3	205205.4	9907439.0	200	*	8.2	395.52			2 2	
A4	SDR4_1	Drain 4	205300.5	9906986.0	50	*	6.8	376.96	0.435	0.870	1 3	
	SDR4_2	Drain 4	205300.5	9906986.0	100	*	7.2	297.6	0.311	0.623	1 6	
	SDR4_3	Drain 4	205300.	9906986.	150	*	7.9	686.72	0.12	0.250	1	

			5	0					5		4	
	SDR4_4	Drain 4	205300.5	9906986.0	200	*	7.5	488.96	0.187	0.374	15.86	
B	GREEN HOUSE											
B1	SGH3_1	GH3	205353.6	9907320	15	*	7.8	819.2	0.561	1.121	26.25	
	SGH3_2	GH3	205353.6	9907320	50	*	7.6	751.36	0.374	0.748	34.57	
	SGH3_3	GH3	205353.6	9907320	90	*	7.3	558.72	0.250	0.500	37.89	
	SGH3_4	GH3	205353.6	9907320	150	*	7.8	903.04	0.433	0.867	40.80	
	Sample NO:	SOURCE	UTM X	UTM Y	DEPTH cm	DRYING (AIR)	pH	EC (in microS/cm)	%C	ORGANIC MATTER CONTENT		
B2	SGH13-1	GH13	205356.4	9907095.1	15	*	6.8	870.4	0.188	0.377	33.32	
	SGH13-2	GH13	205356.4	9907095.1	50	*	7.2	608.64	0.492	0.985	36.23	
	SGH13-3	GH13	205356.4	9907095.1	90	*	7.1	560	0.246	0.492	35.81	
	SGH13-4	GH13	205356.4	9907095.1	150	*	9.7	1785.6	0.000	0.000	56.60	
B3	SGH14-1	GH14	205624.8	9907427.8	15	*	7.5	909.44	0.562	1.123	24.59	
	SGH14-2	GH14	205624.8	9907427.8	50	*	7.3	680.96	0.503	1.007	15.86	
	SGH14-3	GH14	205624.8	9907427.8	90	*	7.8	564.48	0.311	0.623	25.84	
	SGH14-4	GH14	205624.8	9907427.8	150	*	7.2	598.4	0.125	0.249	26.67	
	OUTSIDE Greenhouse											
C1	SOGH3_A1-1	OS_GH3	205377	9907349.4	30	*	7.6	751.36				

	SOGH3_A1-2	OS_GH3	205377	9907349.4	60	*	7.6	683.52				
	SOGH3_A1-3	OS_GH3	205377	9907349.4	100	*	7.8	540.16				
C2	SOGH3_B1-1	OS_GH3	205349.5	9907356	30	*	7.1	761.6	0.489	0.977	1 8	
	SOGH3_B1-2	OS_GH3	205349.5	9907356	60	*	7.4	501.12	0.373	0.746	1 7	
	SOGH3_B1-3	OS_GH3	205349.5	9907356	100	*	7.7	352	0.303	0.606	1 1	
D	SOIL PIT											
	SSP_L1-1	Soil Pit	205431.9	9907100.7	Top (15)	*	6.9	544.64	0.616	1.231		
	SSP_L1-2	Soil Pit	205431.9	9907100.7	50	*	7.1	534.4	0.311	0.622		
	SSP_L1-3	Soil Pit	205431.9	9907100.7	110	*	9.8	1151.36	0.250	0.499		
	SSP_L1-4	Soil Pit	205431.9	9907100.7	167	*	10	1504	0.372	0.745		
	SSP_L1-5	Soil Pit	205431.9	9907100.7	200	*	-					
	SSP_L1-6	Soil Pit	205431.9	9907100.7	250	*	10	1638.4	0.251	0.501		

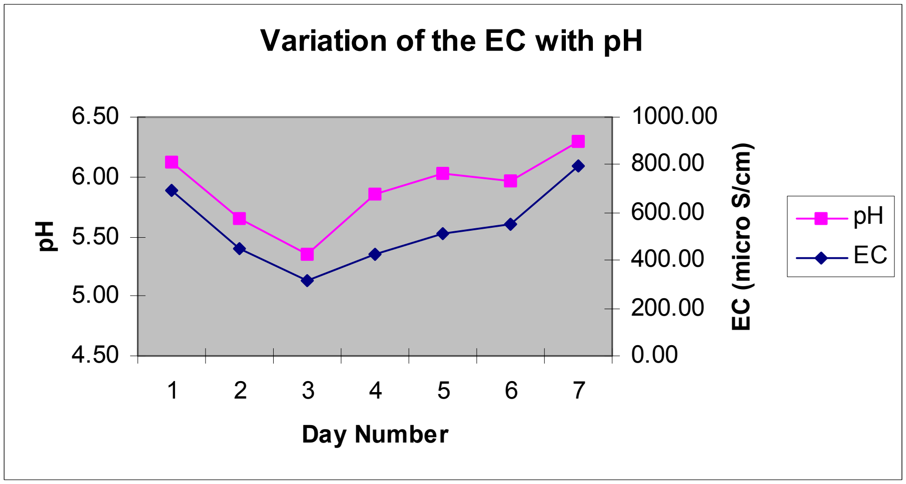
APPENDIX 4.7: SOIL CHEMICAL ANALYSIS

Sample NO:	Cl^- (mg/L)	NO_3^- -N	Ca^{2+}	K^+	Mg^{2+}	Na^+
S_{DR1_1-1}		18.35	3.09	3.87	0.8	2.75
S_{DR1_1-2}		17.94	3.51	3.87	0.76	3.27
S_{DR1_1-3}		52.44	3.82	6.13	1.06	3.43
S_{DR1_1-4}		32.07	2.92	4.39	0.79	2.95
S_{DR2_1-1}			1.06	6.57	0.37	6.34

S_{DR2_1-2}		22.09	2.46	6.02	0.67	4.24
S_{DR2_1-3}		19.18	1.25	5.54	0.37	4.04
S_{DR2_1-4}		34.57	0.2	0.39	0.08	0.94
S_{DR3_1-1}		8.38	0.73	2.52	0.5	2.88
S_{DR3_1-2}		15.03	0.69	2.25	0.31	3.7
S_{DR3_1-3}		17.52	0.42	1.49	0.2	2.2
S_{DR3_1-4}		20.02	0.6	2.17	0.2	3.01
S_{DR4_1-1}		15.03	0.65	2.34	0.31	2.81
S_{DR4_1-2}		13.36	0.45	1.54	0.21	2.73
S_{DR4_1-3}		10.04	2.46	3.46	0.39	4.51
S_{DR4_1-4}		15.86	0.93	2.03	0.26	4.18
GREEN HOUSE						
S_{GH3_1-1}		26.25	3.97	3.93	0.72	4.45
S_{GH3_1-2}		34.57	1.38	5.87	0.56	3.82
S_{GH3_1-3}		37.89	0.91	3.95	0.39	3.2
S_{GH3_1-4}		40.80	4.32	6.56	0.84	3.42
S_{GH13_1-1}		33.32	1.75	5.72	0.6	5.03
S_{GH13_1-2}		36.23	0.98	5.36	0.38	2.93
S_{GH13_1-3}		35.81	1.64	4.12	0.39	3.19
S_{GH13_1-4}		56.60	0.9	6.61	0.22	22.2
S_{GH14_1-1}		24.59	1.74	4.53	0.79	3.22
S_{GH14_1-2}		15.86	2.28	5.91	0.68	2.95
S_{GH14_1-3}		25.84	1.87	4.05	0.64	2.5
S_{GH14_1-4}		26.67	2.53	3.21	0.64	3.09
OUTSIDE Greenhouse						
S_{OGH3_A1-1}			2.93	6.02	0.76	2.97
S_{OGH3_A1-2}			3.28	3.66	0.88	3.16
S_{OGH3_A1-3}			2.19	7.22	0.77	5.03
S_{OGH3_B1-1}		19.18	4.31	6.16	0.8	3.94
S_{OGH3_B1-2}		16.27	1.12	3.44	0.4	3.96
S_{OGH3_B1-3}		17.11	0.53	2.03	0.21	3.37
SOIL PIT						
S_{SP_L1-1}	4.63		0.94	4.24	0.32	4.17

S_{SP_L1-2}	3.61		1.29	4.66	0.38	4.07
S_{SP_L1-3}	5.14		2.52	6.7	0.51	11.79
S_{SP_L1-4}	3.10		2.23	9.56	0.26	16.16
S_{SP_L1-5}						
S_{SP_L1-6}	1.06		1.4	8.82	0.43	19.75

APPENDIX 4.8: VARIATION OF THE SOIL PH WITH THE EC



APPENDIX 4.8B: variation of EC with soil pH

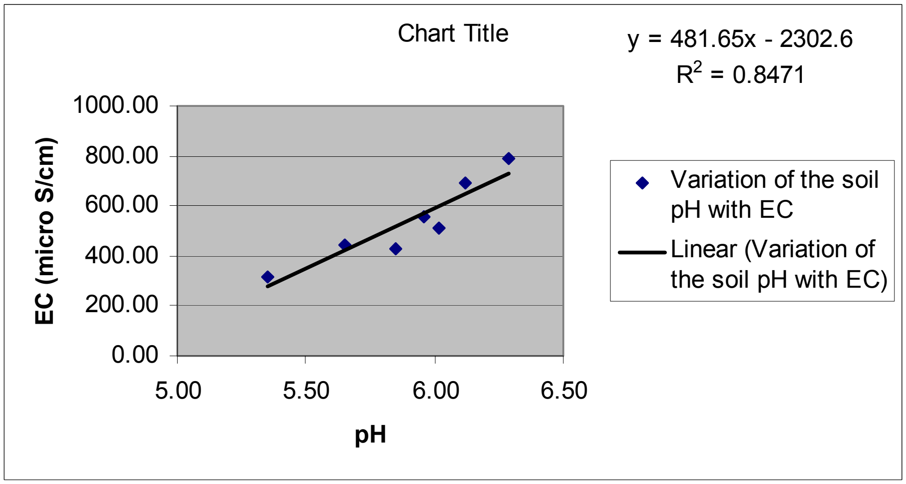
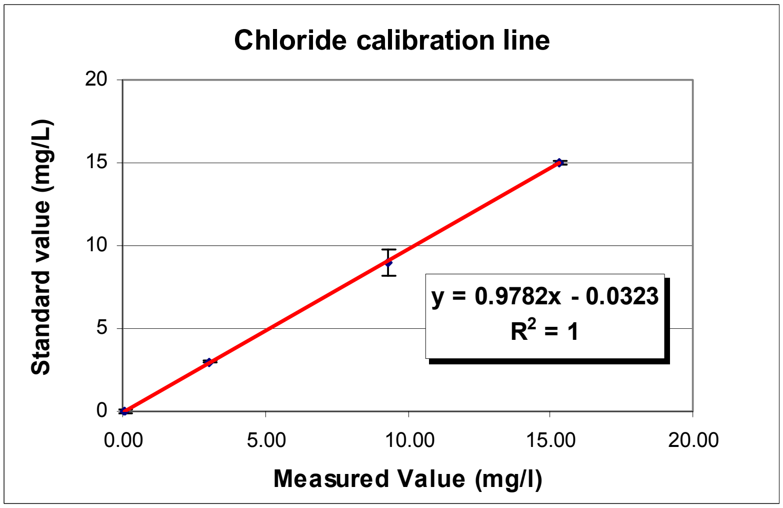


Table to Appendix 4.8B

APPENDIX 4.9: CHLORIDE ANALYSIS HACH 2010 SPECTROPHOTOMETER (Mercuric Thiocyanate method) CALIBRATION CURVE

Standard solution (mg/l)	Measured (mg/L) M1	M2	M3	Average	standard deviation	% relative error
0.00	0.00	0.00	0.10	0.03	0.06	-
3.00	3.00	3.10	3.10	3.07	0.06	1.88
9.00	9.90	9.60	8.40	9.30	0.79	8.53
15.00	15.30	15.50	15.20	15.33	0.15	1.00

Appendix 4.9B Chloride Calibration Curve

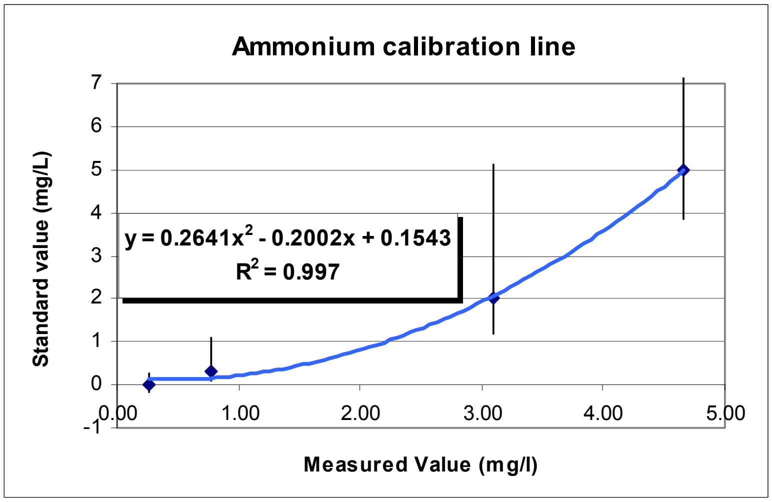


DAY NUM:	1	2	3	4	5	6	7
pH	6.12	5.65	5.35	5.85	6.02	5.96	6.29
EC(µ S/cm)	695.5	445.9	317.9	428.8	512.0	552.7	791.9

APPENDIX 4.10: AMMONIUM CALIBRATION CURVE ON FOR THE REFLECTO - QUANT (LAB); RANGE:0-5 mg/l (Nessler reagent Method)

Standard solution (in ppm)	M1	M2	M3	AVR Measured (in mg/L)	standard deviation	% relative Error	Accuracy
0.00	0.30	0.40	0.10	0.27	0.18	-	
0.32	0.70	0.80	0.80	0.77	0.23	29.77	-139.58
2.00	3.60	3.40	2.30	3.10	0.79	25.59	-55.00
5.00	5.70	3.10	5.20	4.67	1.14	24.40	6.67

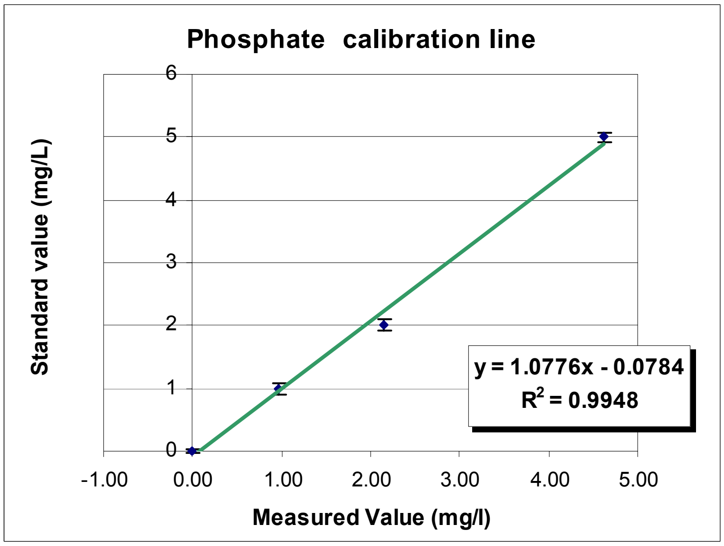
Appendix 4.10B: Ammonium Calibration Curve



APPENDIX 4.11: PHOSPHATE ANALYSIS HACH 2010 SPECTROPHOTOMETER (TEST'N TUBE METHOD) CALIBRATION CURVE

Standard solution (mg/l)	Measured (mg/L) M1	M2	M3	M4	Average	standard deviation	% relative error
0.00	0.04	0.00	-0.06	-0.01	-0.01	0.04	-
1.00	0.98	0.88	0.89	1.08	0.96	0.09	9.74
2.00	2.23	2.19	2.13	2.02	2.14	0.09	4.27
5.00	4.66	4.56	4.57	4.70	4.62	0.07	1.48

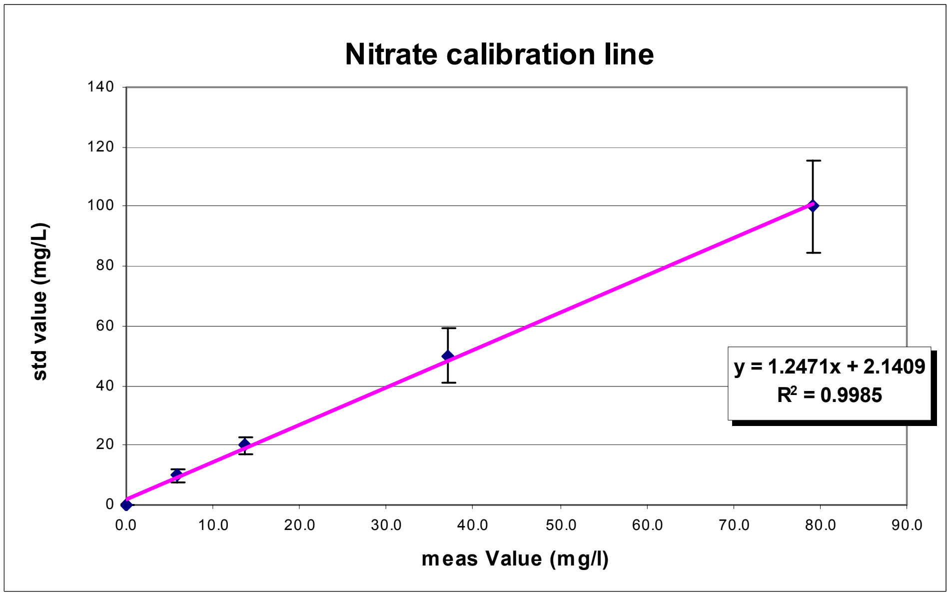
Appendix 4.11B Phosphate Calibration Curve



APPENDIX 4.12 CALIBRATION FOR THE REFLECTO - QUANT (LAB); RANGE: 3 - 90 MG/L (METHOD: NITRATE TEST WITH SULFANILIC ACID/ NAPHTALENE)

Standard solution (in ppm)	M1	M2	M3	M4	AVR Measured (in mg/L)	standard deviation	% relative error	Accuracy	Actual Conc. (in ppm)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	-		
10.00	6.00	7.00	4.00	6.00	5.75	2.19	38.10	42.50	9.31
20.00	15.00	14.00	13.00	13.00	13.75	2.92	21.20	31.25	19.29
50.00	44.00	44.00	30.00	30.00	37.00	9.10	24.59	26.00	48.28
100.00	91.00	92.00	65.00	69.00	79.25	15.44	19.48	20.75	100.97

Appendix 4.12B Nitrate Calibration Curve

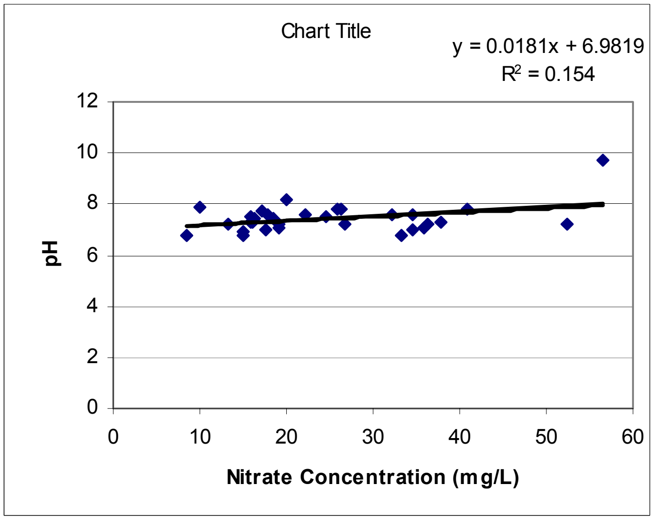


APPENDIX 4.13: ICP –RESULT FOR CATIONS IN WATER

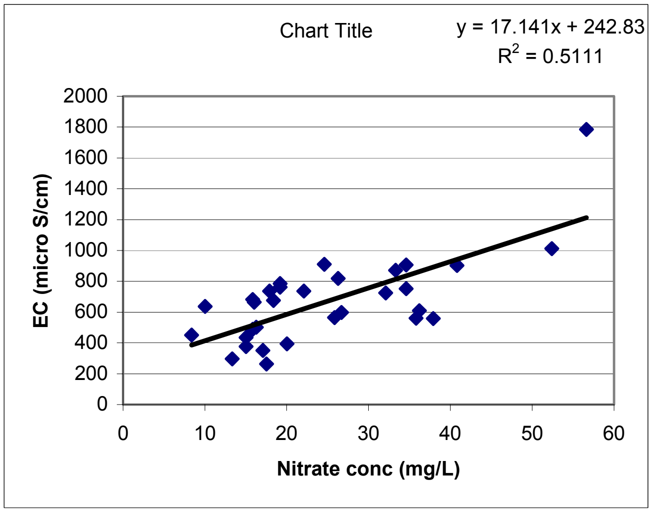
Sample number	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	Al (mg/L)	Fe (mg/L)	Li (mg/L)	Mn (mg/L)
S1	31.44	83.43	18.93	38.15	10.99	14.78	< LOD	5.65
S2	63.50	101.74	25.41	56.93	14.06	34.61	< LOD	3.54
S3	48.40	60.71	41.47	37.51	9.98	13.42	< LOD	2.71
S4	17.75	20.84	7.41	37.56	4.04	4.94	< LOD	0.86
S5	84.31	163.98	46.54	52.76	7.20	30.01	< LOD	9.48
S6	15.79	18.05	7.08	33.07	3.46	7.16	< LOD	2.53
S7	27.12	4.66	1.45	7.66				

APPENDIX 4.14 CORRELATION BETWEEN (pH, EC,Nitrate, Sodium, Potassium):

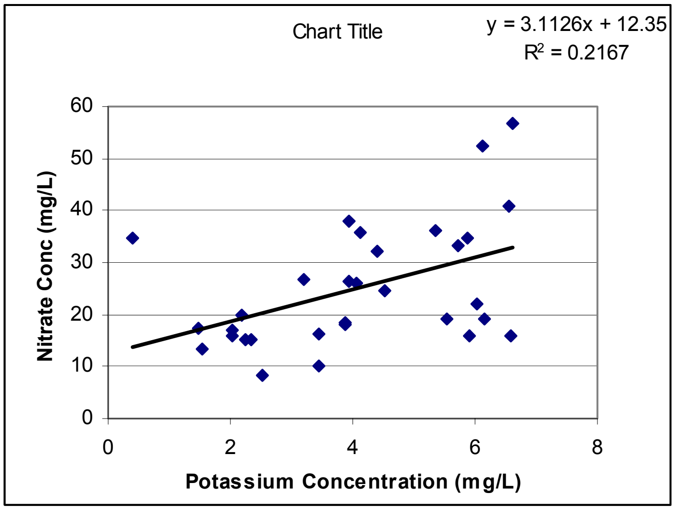
a) The pH and Nitrate (Entire analysized Data set)



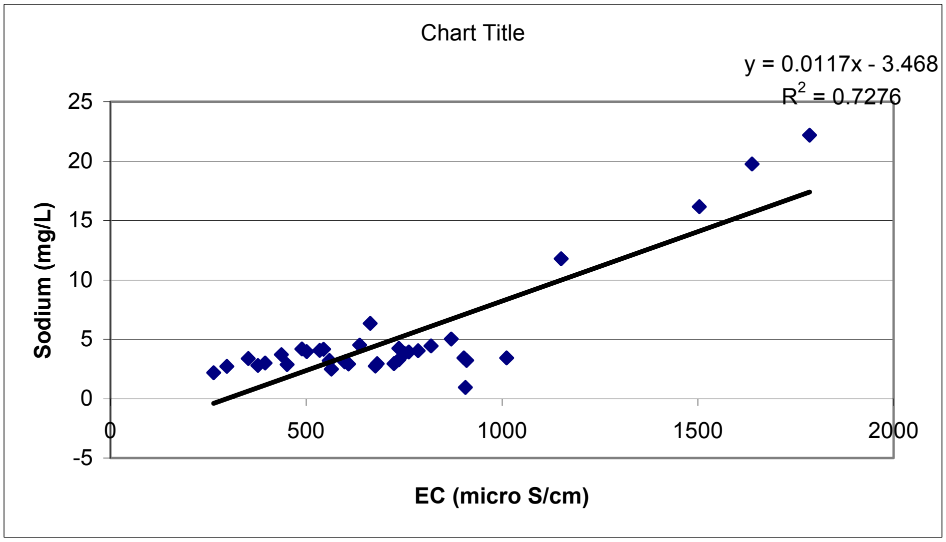
b) EC and Nitrate concentration (Entire analysized Data set)



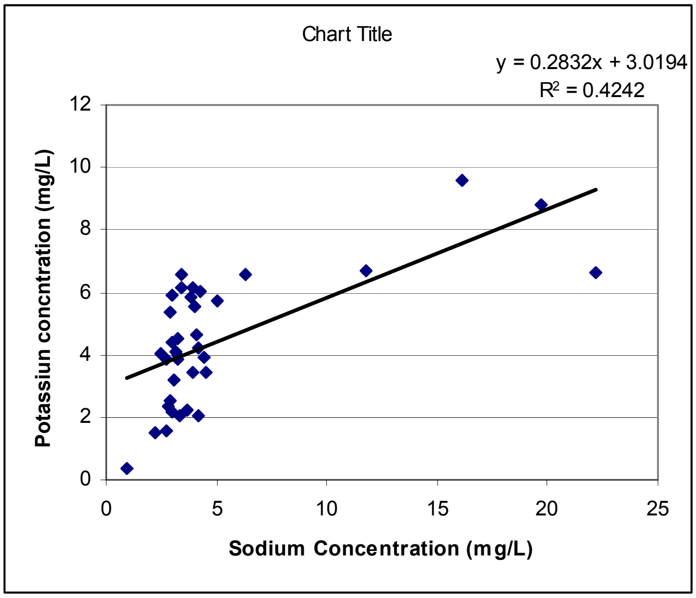
c) The Correlation between Nitrate and potassium concentration



d) EC and Sodium (Entire analysized Data set)



e) Sodium and Potassium



APPENDIX 4.15 ESTIMATION OF THE SOIL MOISTURE CHARACTERISTIC CURVE PARAMETERS USING the *Saxton W.J. et al, 1986* *Equations.*

h (kPa)	Theta (cm3/cm3)	h (cm)	log h (pF)	K (θ) cm/d
0	0.395	0.00	0.00	89.40
1	0.395	10.00	1.00	89.40
2	0.395	20.00	1.30	89.40
2.670424	0.395	26.70	1.43	89.40
3	0.388	30.00	1.48	80.77
4	0.365	40.00	1.60	57.88
5	0.342	50.00	1.70	39.68
6	0.320	60.00	1.78	25.79
7	0.297	70.00	1.85	15.69
8	0.274	80.00	1.90	8.79
9	0.251	90.00	1.95	4.44
10	0.229	100.00	2.00	1.96
10.5	0.226	105.00	2.02	1.78
11	0.224	110.00	2.04	1.62
12	0.220	120.00	2.08	1.37
13	0.216	130.00	2.11	1.16
13.584	0.214	135.84	2.13	1.06
14	0.213	140.00	2.15	1.00
15	0.210	150.00	2.18	0.87
15.81	0.208	158.10	2.20	0.78
16	0.207	160.00	2.20	0.76
20	0.198	200.00	2.30	0.47
21	0.196	210.00	2.32	0.42
22	0.194	220.00	2.34	0.38
23	0.192	230.00	2.36	0.34
23.397	0.191	233.97	2.37	0.33
24	0.190	240.00	2.38	0.31

h (kPa)	**Theta (cm3/cm3)**	**h (cm)**	**log h (pF)**	**K (θ) cm/d**
30	0.181	300.00	2.48	0.18
34	0.177	340.00	2.53	0.10
40	0.171	400.00	2.60	0.09
50	0.163	500.00	2.70	0.05
75	0.149	750.00	2.88	0.02
100	0.141	1000.00	3.00	0.01
150	0.129	1500.00	3.18	0.00
200	0.121	2000.00	3.30	0.00
300	0.111	3000.00	3.48	0.00
400	0.105	4000.00	3.60	0.00
500	0.100	5000.00	3.70	0.00
1000	0.086	10000.00	4.00	0.00
1500	0.079	15000.00	4.18	0.00
1600	0.078	16000.00	4.20	0.00
1800	0.076	18000.00	4.26	0.00
2000	0.075	20000.00	4.30	0.00

Layer 1 , Soil type LS; %C = 8 ; %S = 72; A = 9.38E-03 ; B = -4.73E+00

K(θ) = 2.778E-6{exp[p+q(%S)+[r+t(%S)+[u(%S)+v(%C)2](1/θ)]}

Where:

%C = Clay in percentage

%S = Sand content in percentage.

APPENDIX 4.16 BROOKS AND COREY PARAMETERS ESTIMATION:

Sample No:	Textural Class	λ	θres	α	n	m	b
Standard	CL	0.263	0.103	0.026	1.263	0.209	3.795
S_{spL1}	LS	0.431	0.061	0.088	1.431	0.301	2.319
S_{spL2}	LS	0.486	0.050	0.074	1.486	0.327	2.058
S_{spL3}	SL	0.464	0.050	0.063	1.464	0.317	2.156
S_{spL4}	SL	0.448	0.042	0.043	1.448	0.309	2.232
S_{spL6}	SiL	0.330	0.075	0.032	1.330	0.248	3.027
S_{GH3_1}	LS	0.477	0.059	0.115	1.477	0.323	2.095
S_{GH3_2}	LS	0.455	0.064	0.140	1.455	0.313	2.200
S_{sGH3_3}	SL	0.451	0.059	0.093	1.451	0.311	2.217
S_{sGH3_4}	LS	0.736	0.041	0.027	1.736	0.424	1.358
S_{GH13_1}	SL	0.435	0.061	0.093	1.435	0.303	2.299
S_{GH13_2}	SL	0.422	0.066	0.118	1.422	0.297	2.367
S_{sGH13_3}	SiL	0.386	0.051	0.033	1.386	0.278	2.594
S_{sGH13_4}	SL	0.429	0.059	0.076	1.429	0.300	2.333
S_{GH14_1}	LS	0.456	0.062	0.120	1.456	0.313	2.191
S_{GH14_2}	LS	0.439	0.066	0.136	1.439	0.305	2.277
S_{sGH14_3}	L	0.373	0.061	0.040	1.373	0.272	2.678
S_{SGH14_4}	LS	0.435	0.066	0.127	1.435	0.303	2.298
S_{GH14_4}	LS	0.481	0.054	0.087	1.481	0.325	2.080
S_{DR4_1}	LS	0.479	0.059	0.120	1.479	0.324	2.086
S_{DR4_2}	SL	0.405	0.057	0.053	1.405	0.288	2.467
S_{DR4_3}	L	0.325	0.078	0.033	1.325	0.245	3.080
S_{DR4_4}	L	0.344	0.072	0.038	1.344	0.256	2.907
S_{oGH3_B3}	SL	0.453	0.057	0.085	1.453	0.312	2.206

APPENDIX 5: WATER AND CHEMICAL BALANCES

IRRIGATION DEPTH

To obtain the true irrigation depth for the partially wetted surfaces as is the case in drip irrigation, the average infiltrated depth to be divided over the average fraction of the soil surface wetted by irrigation (fw).

$$I_w = \frac{I}{f_w}$$

Where:

Iw = True Irrigation depth for the partially wetted surface (mm)

fw = Fraction of surface wetted by irrigation, (for drip = **fw *(1-(2/3)fc**).

I = Irrigation depth in the field (mm) = 7 mm.

Fc = fraction occupied by the crop = 0.8

I w = 8.75 mm

APPENDIX 5.3 SORPTIVITY (S) AND MAXIMUM INFILTRATION RATE POSSIBLE AT SULMAC FARM IN LOAMY SAND SOIL.

Texture Class: Loamy Sand. Standard sorptivity (So) = 19.2 cm/d1/2

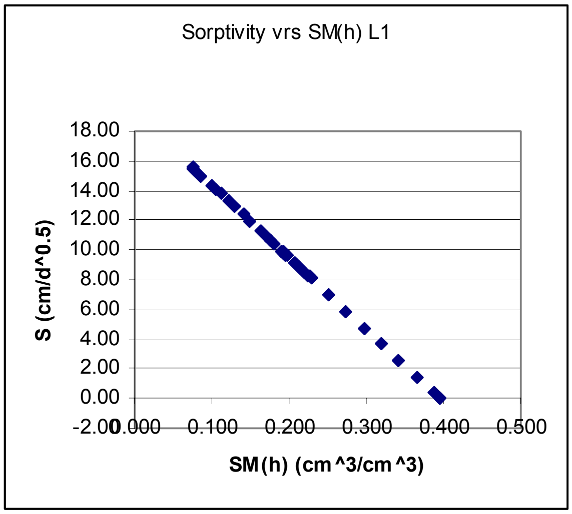
SMo = 0.395 cm3/cm3 Transmission zone (A) = 17.8 cm/d Δt = 0.029 d

h (cm)	Theta cm3/cm3	S ($cm/d^{1/2}$)	IMmax (cm/d)
0.0	0.395	0.00	17.792
10.0	0.395	0.00	17.792
20.0	0.395	0.00	17.792
26.7	0.395	0.00	17.792
30.0	0.388	0.36	19.926
40.0	0.365	1.46	26.399
50.0	0.342	2.57	32.872
60.0	0.320	3.67	39.345
70.0	0.297	4.77	45.818
80.0	0.274	5.87	52.291
90.0	0.251	6.98	58.764
100.0	0.229	8.08	65.237
105.0	0.226	8.19	65.916
110.0	0.224	8.30	66.549
120.0	0.220	8.50	67.716
130.0	0.216	8.68	68.771
135.8	0.214	8.78	69.343
140.0	0.213	8.84	69.732
150.0	0.210	8.99	70.613
158.1	0.208	9.11	71.276
160.0	0.207	9.13	71.426
200.0	0.198	9.60	74.152
210.0	0.196	9.69	74.731
220.0	0.194	9.79	75.278
230.0	0.192	9.88	75.795
234.0	0.191	9.91	75.993

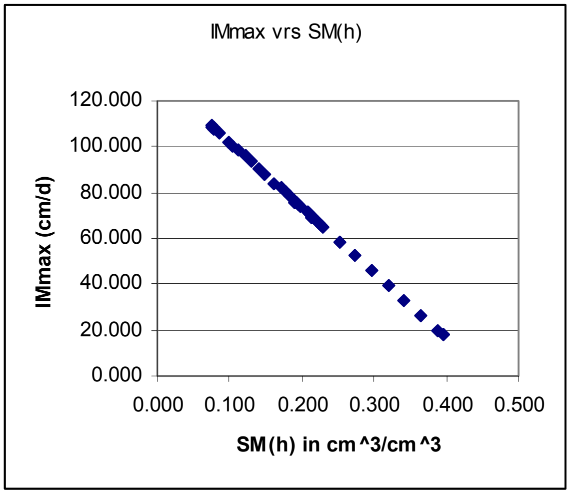
240.0	0.190	9.96	76.286
300.0	0.181	10.39	78.788
340.0	0.177	10.62	80.140
400.0	0.171	10.91	81.844
500.0	0.163	11.29	84.089
750.0	0.149	11.94	87.908
1000.0	0.141	12.37	90.426
1500.0	0.129	12.93	93.724
2000.0	0.121	13.30	95.898
3000.0	0.111	13.78	98.746
4000.0	0.105	14.10	100.624
5000.0	0.100	14.34	102.003
10000.0	0.086	15.00	105.896
15000.0	0.079	15.35	107.923

APPENDIX 5.3B GRAPHICAL REPRESENTATION:

i) Sorptivity variation with Soil Moisture



ii) Maximum possible Infiltration variation with Soil Moisture



APPENDIX 5.4 SORPTIVITY (S) and MAXIMUM INFILTRATION RATE POSSIBLE AT SULMAC FARM in Sandy Loam soil.

Texture Class: Sandy loam Standard sorptivity (So) = 17.57 $cm/d^{1/2}$

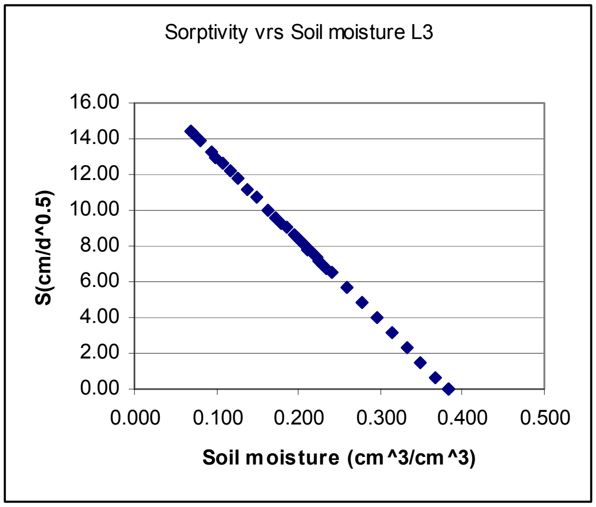
SMo = 0.382 cm3/cm3 Transmission zone (A) = 9.36 cm/d Δt = 0.029 d

h (cm)	Theta cm3/cm3	S ($cm/d^{1/2}$)	Immax (cm/d)
0	0.382	0.00	9.364
10	0.382	0.00	9.364
20	0.382	0.00	9.364
22.256987	0.382	0.00	9.364
30	0.368	0.65	13.172
40	0.350	1.49	18.090
50	0.331	2.32	23.008
60	0.313	3.16	27.925
70	0.295	4.00	32.843
80	0.277	4.84	37.761
90	0.259	5.67	42.679
100	0.240	6.51	47.597

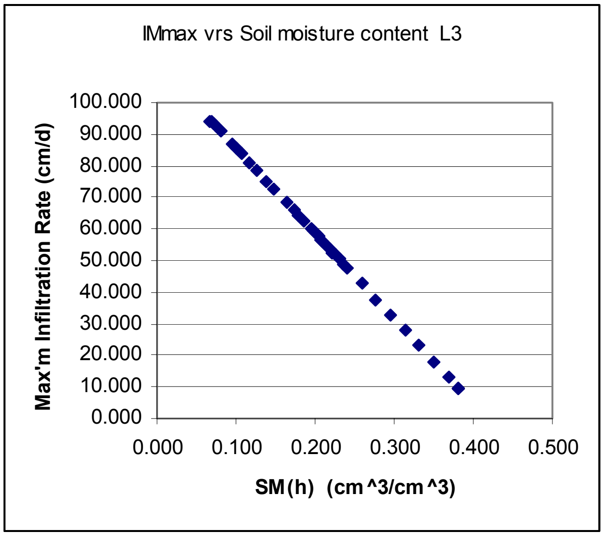
110	0.235	6.76	49.067
120	0.230	6.98	50.373
130	0.226	7.18	51.550
140	0.222	7.37	52.620
150	0.218	7.53	53.599
160	0.215	7.69	54.501
170	0.212	7.83	55.335
180	0.209	7.96	56.111
190	0.206	8.08	56.835
200	0.204	8.20	57.513
210	0.201	8.31	58.151
220	0.199	8.41	58.752
230	0.197	8.51	59.320
240	0.195	8.60	59.858
300	0.185	9.07	62.592
340	0.179	9.32	64.063
400	0.173	9.63	65.909
500	0.164	10.04	68.329
750	0.149	10.74	72.409
1000	0.139	11.19	75.074
1500	0.126	11.78	78.532
2000	0.118	12.16	80.790
3000	0.107	12.66	83.720
4000	0.100	12.99	85.634
5000	0.094	13.23	87.030
10000	0.080	13.89	90.922
15000	0.073	14.23	92.917
16000	0.072	14.28	93.217

APPENDIX 5.4B GRAPHICAL REPRESENTATION:

i) Sorptivity variation with Soil Moisture



iii) Maximum possible Infiltration variation with Soil Moisture



APPENDIX 5-5 SOIL WATER HOLDING CAPACITY

Rooting depth of the Rose plant (Zr) = 50 cm

TAW = Available water * Rooting depth (Zr)

RAW = TAW * Depletion coefficient (p)

P for flowers = 0.15

APPENDIX 5-7 Fertiliser Loading in Irrigation water

DAILY FERTILISER LOAD:				in 35000ltr		in 35000ltr
FERT.typ	**QTY kg/1000 ltr**	**Tank**	**Conc.in the Stock Solution in mg/l**	**Conc in Irrig Wtr (mg/l)**	**N- Conc. in Stock sol.n (mg/L)**	**N-Conc. in Irrig Water (mg/L)**
Ca(NO3)2	43.1	A	43100	1.23143	15085.00	0.431
Urea	2.1	A	2100	0.06000	979.65	0.028
Fe (11%)	1.8	A	1800	0.05143		
Urea	1.4	B	1400	0.04000	653.10	0.019
(NH4)2SO4	11.3	B	11300	0.32286	2395.60	0.068
K2SO4	6.7	B	6700	0.19143		
KNO3	26	B	26000	0.74286	3601.00	0.103
MgSO4	23.7	B	23700	0.67714		
CuSO4(25%)	0.024	B	24	0.00069		
Solubor (Bo) 20%	0.1105	B	110.5	0.00316		
Zn (15%)	0.0165	B	16.5	0.00047		
Mn(13%)	0.2	B	200	0.00571		
Sodium Molybdate	0.002	B	2	0.00006		
TOTAL			**116453**	**3.32723**	**22714.35**	**0.649**

ORGANIC MATTER

Per greenhouse with an Area of 5000 m^2 and Soils with Organic content of 1.12%.

Humus contains about 5% organic nitrogen and approximately 2% of the Organic nitrogen is mineralised annually.

APPENDIX 5-8 Nitrogen Sources

1) Annual Mineralisation of Organic Matter Calculation:						
Garcia R:http://launionswcd.org/nitrogen1.htm						
A (m^2)	5000					
depth (m)	0.30					
V (m^3)	1500				5%OM=ON	2%ON
	Bulky Density (kg/m^3):	Mass of Soil (kg)	OM (%)	OM/GH (kg)	ON/GH (kg/GH)	Mineralisation (kg/GH)
GH_3	1361	2041500	1.121	22885.22	1144.26	**22.89**
GH_13	1263	1894500	0.377	7142.265	357.11	**7.14**
GH_14	1341	2011500	1.123	22589.15	1129.46	**22.59**

Where:

A = Area

GH = Greenhouse

V = Volume,

Mass of soil = BD * V_Soil profile

OM = Organic matter content

ON = Organic Nitrogen

b) Other sources of Nitrogen:

2) Soil Nitrate - Nitrogen (NO_3^- -N)		Units			
NO_3^- Content:	10	ppm	Res. N		
Cont. per GH	15000000	mg	N- cont*V		
	15	kg/GH			
3) Other sources:					
water	< 3	ml/L	Assume:	1mg/L	0.035kg/da

						y
	Annual:	**10.955**	kg/GH			
4) In organic: fertilisers		203.14	mg/L	**304.71**	kg/GH	
Total available NO_3^- -N:		from OM+ Soil + Others +In -organic fertiliser				
		22.6 + 15 + 10.955 + 304.71				
		345.31	kg/GH/yr			

NOTE:

In organic fertiliser (Nitrogen content) =

Total N content in the in-organic fertiliser per day * 313 days = 0.649 mg/L/day * 313 days

= **203.14** mg/L

Annual Load = 203.14 mg/L * V_ soil profile = 304.71 kg/ GH

APPENDIX 5.10 FLOW IN THE DRAINAGE DITCH

Equation

$$A = \frac{d}{2}(b + w)$$

A = 0.162970 m2

Equation

$$P = b + d\left(2 * \sqrt{d^2 + (W - w)^2}\right)$$

P = 0.4974 m

Equation

$$R = \frac{A}{P}$$

R = 0.327623 m

S = 0.000962

Equation

$$V = \frac{k}{n} R^{2/3} * S^{1/2}$$

n = 0.030 for weedy Earth Channels

v = 0.49136 m/s

Q = V*A

= 0.08m^3/s

Where:

Q = Discharge or flow rate

v = Velocity

n = Manning's coefficient

S = Channel Slope

R = Hydraulic radius

P = Wetted Perimeter

STORAGE VOLUME V:

V = A * L = 0.162970 m^2 * 800 m

= 130.4 m^3

The Mass Conservation for the Flow in the Drain

The continuity equation can be used to determine the water flow and the Agro - chemical transport. The General equation can be represented as follows:

Equation

$$\frac{\partial(A*\mu)}{\partial t}+\frac{\partial F}{\partial x}=Si,o$$

Where:

F, Flux (kg/s)

µ, density (kg/m3)

A, Cross-sectional area (m2)

S, source or sink (kg/s)

i – input; o - output

For the Flow, the unsteady flow equation can be used to determine the variation of flow in time and space domain:

Let µ = ρ

F = ρ * Q = ρ * A* v

Equation

$$w\frac{\partial h}{\partial t}+\frac{\partial Q}{\partial x}=0$$

Where: h – height or depth of water level

For the Agro - Chemical (fertilizer) transport in the Drain:

Equation

$$\frac{\partial(A*C)}{\partial t}+\frac{\partial(Q*C)}{\partial x}=0$$

If we have a steady state, Q = v * A, then,

Equation

$$A\left(\frac{\partial C}{\partial t}\right)+Q\left(\frac{\partial C}{\partial x}\right)=0$$

Equation

$$\frac{\partial C}{\partial t} = -v\frac{\partial C}{\partial x}$$

This can also be written as follows:

Equation

$$\frac{C_o - C}{\Delta t} = -v\frac{(C_o - C)}{\Delta x}$$

Where:

Co = initial Concentration

C = Concentration as a function of space and time

v = velocity of flow

Δx = change in distance = 800 m

For Nitrate - nitrogen, Dispersion, Reactions and decay are likely to take place

Flow in the Drain

If the Inflow is 0, then:

Equation

$$Q(t) + k\frac{dQ}{dt} = 0$$

Equation

$$\int \frac{dQ}{Q} = -\frac{1}{k}\int dt$$

Q = Qo*e (-t/k)

Where:

Qo = Initial flow rate (m^3/s)

Q = final flow rate (m^3/s)

k = Decay rate or dinitrification rate (0.05 - 0.105 /day

t = days

APPENDIX 5.6 EVAPOTRANSPIRATION CALCULATION

CALCULATING SHORTWAVE RADIATION:									
	$Rs = Ra\ (a + b * \frac{n}{N})$		Month	Year	Ra in MJ/m^2/day	N	n	Rs in MJ/m^2/day	Rns	Rso
	1	1	1	2001	36.062	12.043	11.750	26.291	19.718	26.686
	2	2	1	2001	36.082	12.043	11.750	26.306	19.729	26.701
	3	3	1	2001	36.104	12.043	11.750	26.322	19.741	26.717
	4	4	1	2001	36.127	12.043	11.750	26.338	19.754	26.734
	5	5	1	2001	36.151	12.043	11.750	26.356	19.767	26.751
	6	6	1	2001	36.176	12.042	11.750	26.375	19.781	26.770
	7	7	1	2001	36.202	12.042	11.750	26.394	19.796	26.790
	8	8	1	2001	36.230	12.042	11.750	26.415	19.811	26.810
	9	9	1	2001	36.258	12.042	11.750	26.436	19.827	26.831
	10	10	1	2001	36.288	12.041	11.750	26.458	19.843	26.853
	11	11	1	2001	36.318	12.041	11.750	26.481	19.860	26.876
	12	12	1	2001	36.350	12.041	11.750	26.504	19.878	26.899
	13	13	1	2001	36.382	12.040	11.750	26.528	19.896	26.923
	14	14	1	2001	36.416	12.040	11.750	26.553	19.915	26.948
	15	15	1	2001	36.450	12.040	11.750	26.578	19.934	26.973
	16	16	1	2001	36.485	12.039	11.750	26.604	19.953	26.999
	17	17	1	2001	36.521	12.039	11.750	26.631	19.973	27.025

CALCULATING SHORTWAVE RADIATION:

	$Rs = Ra\ (a + b * \frac{n}{N})$		Month	Year	Ra in MJ/m^2/day	N	n	Rs in MJ/m^2/day	Rns	Rso
	18	18	1	2001	36.557	12.039	11.750	26.658	19.993	27.052
	19	19	1	2001	36.594	12.038	11.750	26.685	20.014	27.080
	20	20	1	2001	36.632	12.038	11.750	26.713	20.035	27.107
	21	21	1	2001	36.670	12.037	11.750	26.742	20.056	27.136
	22	22	1	2001	36.708	12.037	11.750	26.770	20.078	27.164
	23	23	1	2001	36.747	12.037	11.750	26.799	20.100	27.193
	24	24	1	2001	36.787	12.036	11.750	26.829	20.122	27.222
	25	25	1	2001	36.826	12.036	11.750	26.858	20.144	27.252
	26	26	1	2001	36.866	12.035	11.750	26.888	20.166	27.281
	27	27	1	2001	36.906	12.035	11.750	26.918	20.188	27.311
	28	28	1	2001	36.947	12.034	11.750	26.948	20.211	27.341
	29	29	1	2001	36.987	12.034	11.750	26.978	20.234	27.370
	30	30	1	2001	37.027	12.033	11.750	27.008	20.256	27.400
	31	31	1	2001	37.068	12.033	11.750	27.038	20.279	27.430
	32	1	2	2001	37.108	12.032	12.000	27.415	20.561	27.460
	33	2	2	2001	37.148	12.032	12.000	27.445	20.584	27.489
	34	3	2	2001	37.187	12.031	12.000	27.476	20.607	27.519
	35	4	2	2001	37.227	12.030	12.000	27.505	20.629	27.548

CALCULATING SHORTWAVE RADIATION:

	$Rs = Ra\,(a + b * \frac{n}{N})$		Month	Year	Ra in MJ/m^2/day	N	n	Rs in MJ/m^2/day	Rns	Rso
	36	5	2	2001	37.266	12.030	12.000	27.535	20.651	27.577
	37	6	2	2001	37.305	12.029	12.000	27.564	20.673	27.605
	38	7	2	2001	37.343	12.029	12.000	27.593	20.695	27.634
	39	8	2	2001	37.380	12.028	12.000	27.622	20.717	27.661
	40	9	2	2001	37.417	12.028	12.000	27.650	20.738	27.689
	41	10	2	2001	37.454	12.027	12.000	27.678	20.758	27.716
	42	11	2	2001	37.489	12.026	12.000	27.705	20.779	27.742
	43	12	2	2001	37.524	12.026	12.000	27.732	20.799	27.768
	44	13	2	2001	37.558	12.025	12.000	27.758	20.818	27.793
	45	14	2	2001	37.591	12.025	12.000	27.783	20.837	27.818
	46	15	2	2001	37.623	12.024	12.000	27.808	20.856	27.841
	47	16	2	2001	37.654	12.023	12.000	27.831	20.874	27.864
	48	17	2	2001	37.684	12.023	12.000	27.854	20.891	27.887
	49	18	2	2001	37.713	12.022	12.000	27.877	20.908	27.908
	50	19	2	2001	37.741	12.021	12.000	27.898	20.924	27.928
	51	20	2	2001	37.768	12.021	12.000	27.919	20.939	27.948
	52	21	2	2001	37.793	12.020	12.000	27.938	20.954	27.967
	53	22	2	2001	37.817	12.019	12.000	27.957	20.968	27.984

CALCULATING SHORTWAVE RADIATION:										
	$Rs = Ra\ (a + b * \frac{n}{N})$		Month	Year	Ra in MJ/m^2/day	N	n	Rs in MJ/m^2/day	Rns	Rso
	54	23	2	2001	37.839	12.019	12.000	27.974	20.981	28.001
	55	24	2	2001	37.860	12.018	12.000	27.991	20.993	28.017
	56	25	2	2001	37.880	12.017	12.000	28.006	21.005	28.031
	57	26	2	2001	37.898	12.017	12.000	28.021	21.015	28.044
	58	27	2	2001	37.914	12.016	12.000	28.034	21.025	28.057

APPENDIX 5.6B: GREENHOUSE ET CALCULATION

Day in year	day_ Month	Month	year	**Tmin**	**Tmax**	**RH**	$e^o(Tmax)$ kPa	$e^o(Tmin)$ kPa	e_s kPa	Δ ($kPa/^oC$)	e_a kPa	**Rnl**	**Outside GH Rn (MJ/m2/day)**	**Rad into GH (kJ/day/m^2)**	**Rad From GH (kJ/day/m^2)**	Rnet GH (MJ/m2/day)	ETo (mm/day)
1	1	1	2001	9	31	66	4.493	1.148	2.820	0.145	1.861	3.064	16.654	10290.74	2495.50	7.795	3.180
2	2	1	2001	10	30	70	4.243	1.228	2.736	0.145	1.915	2.968	16.761	10356.58	2511.47	7.845	3.201
3	3	1	2001	10	29	65	4.006	1.228	2.617	0.141	1.701	3.153	16.589	10250.14	2485.66	7.764	3.168
4	4	1	2001	6	34	53	5.319	0.935	3.127	0.145	1.657	3.417	16.337	10094.69	2447.96	7.647	3.120
5	5	1	2001	6	29	56	4.006	0.935	2.470	0.126	1.383	3.512	16.256	10044.36	2435.76	7.609	3.104
6	6	1	2001	6	32	58	4.755	0.935	2.845	0.137	1.650	3.337	16.444	10160.82	2464.00	7.697	3.140
7	7	1	2001	9	34	57	5.319	1.148	3.234	0.157	1.843	3.207	16.589	10250.46	2485.74	7.765	3.168
8	8	1	2001	10	29	56	4.006	1.228	2.617	0.141	1.465	3.415	16.396	10130.90	2456.74	7.674	3.131
9	9	1	2001	10	32	56	4.755	1.228	2.991	0.153	1.675	3.309	16.518	10206.54	2475.09	7.731	3.154
10	10	1	2001	11	30	69	4.243	1.313	2.778	0.149	1.917	2.967	16.877	10428.08	2528.81	7.899	3.223
11	11	1	2001	10	34	38	5.319	1.228	3.274	0.161	1.244	3.932	15.928	9841.91	2386.66	7.455	3.042
12	12	1	2001	9	33	42	5.030	1.148	3.089	0.153	1.297	3.811	16.067	9927.51	2407.42	7.520	3.068
13	13	1	2001	8	33	56	5.030	1.073	3.051	0.149	1.709	3.314	16.582	10245.77	2484.60	7.761	3.167
14	14	1	2001	9	35	48	5.623	1.148	3.385	0.161	1.625	3.501	16.414	10142.29	2459.50	7.683	3.135
15	15	1	2001	8	32	56	4.755	1.073	2.914	0.145	1.632	3.359	16.575	10241.76	2483.63	7.758	3.165

Day in year	day_ Month	Month	year	**Tmin**	**Tmax**	**RH**	$e^o(T_{max})$ kPa	$e^o(T_{min})$ kPa	e_s kPa	Δ (kPa/^{o}C)	e_a kPa	**Rnl**	**Outside GH Rn (MJ/m2/day)**	**Rad into GH (kJ/day/m^2)**	**Rad From GH (kJ/day/m^2)**	Rnet GH (MJ/m2/day)	ETo (mm/day)
16	16	1	2001	9	32	58	4.755	1.148	2.951	0.149	1.712	3.268	16.685	10309.60	2500.08	7.810	3.186
17	17	1	2001	10	33	54	5.030	1.228	3.129	0.157	1.690	3.336	16.637	10279.74	2492.84	7.787	3.177
18	18	1	2001	11	32	58	4.755	1.313	3.034	0.157	1.760	3.216	16.778	10366.99	2514.00	7.853	3.204
19	19	1	2001	11	29	63	4.006	1.313	2.659	0.145	1.675	3.181	16.833	10400.96	2522.23	7.879	3.215
20	20	1	2001	8	35	63	5.623	1.073	3.348	0.157	2.109	2.962	17.073	10549.12	2558.16	7.991	3.260
21	21	1	2001	10	28	59	3.780	1.228	2.504	0.137	1.477	3.358	16.698	10317.94	2502.10	7.816	3.189
22	22	1	2001	10	32	61	4.755	1.228	2.991	0.153	1.825	3.145	16.933	10462.83	2537.24	7.926	3.234
23	23	1	2001	10	32	32	4.755	1.228	2.991	0.153	0.957	4.232	15.868	9804.68	2377.64	7.427	3.030
24	24	1	2001	11	32	53	4.755	1.313	3.034	0.157	1.611	3.384	16.738	10342.35	2508.02	7.834	3.196
25	25	1	2001	11	35	51	5.623	1.313	3.468	0.170	1.769	3.334	16.809	10386.52	2518.73	7.868	3.210
26	26	1	2001	7	32	52	4.755	1.002	2.878	0.141	1.497	3.517	16.649	10287.36	2494.68	7.793	3.179
27	27	1	2001	4	34	41	5.319	0.813	3.066	0.137	1.257	3.916	16.272	10054.48	2438.21	7.616	3.107
28	28	1	2001	5	34	43	5.319	0.872	3.096	0.141	1.331	3.819	16.392	10128.54	2456.17	7.672	3.130
29	29	1	2001	7	34	49	5.319	1.002	3.161	0.149	1.549	3.548	16.686	10310.27	2500.24	7.810	3.186
30	30	1	2001	8	33	51	5.030	1.073	3.051	0.149	1.556	3.493	16.763	10358.10	2511.84	7.846	3.201
31	31	1	2001	8	35	49	5.623	1.073	3.348	0.157	1.640	3.484	16.795	10377.43	2516.53	7.861	3.207

Day in year	day_ Month	Month	year	**Tmin**	**Tmax**	**RH**	e^o(Tmax) kPa	e^o(Tmin) kPa	e_s kPa	Δ (kPa/^{o}C)	e_a kPa	**Rnl**	**Outside GH Rn (MJ/m2/day)**	**Rad into GH (kJ/day/m^2)**	**Rad From GH (kJ/day/m^2)**	Rnet GH (MJ/m2/day)	ETo (mm/day)
32	1	2	2001	7	32	58	4.755	1.002	2.878	0.141	1.669	3.375	17.186	10619.37	2575.20	8.044	3.282
33	2	2	2001	8	31	58	4.493	1.073	2.783	0.141	1.614	3.395	17.189	10621.32	2575.67	8.046	3.283
34	3	2	2001	10	31	56	4.493	1.228	2.860	0.149	1.602	3.409	17.198	10626.48	2576.92	8.050	3.284
35	4	2	2001	14	32	56	4.755	1.599	3.177	0.170	1.779	3.252	17.377	10737.51	2603.85	8.134	3.319
36	5	2	2001	9	35	52	5.623	1.148	3.385	0.161	1.760	3.403	17.248	10657.69	2584.49	8.073	3.294
37	6	2	2001	12	36	29	5.941	1.403	3.672	0.179	1.065	4.370	16.303	10073.59	2442.85	7.631	3.113
38	7	2	2001	7	33	48	5.030	1.002	3.016	0.145	1.448	3.688	17.007	10508.78	2548.38	7.960	3.248
39	8	2	2001	8	33	51	5.030	1.073	3.051	0.149	1.556	3.555	17.162	10604.33	2571.55	8.033	3.277
40	9	2	2001	8	32	50	4.755	1.073	2.914	0.145	1.457	3.629	17.109	10571.55	2563.60	8.008	3.267
41	10	2	2001	9	33	56	5.030	1.148	3.089	0.153	1.730	3.351	17.407	10756.06	2608.34	8.148	3.324
42	11	2	2001	9	31	49	4.493	1.148	2.820	0.145	1.382	3.674	17.105	10569.05	2563.00	8.006	3.266
43	12	2	2001	7	31	49	4.493	1.002	2.747	0.137	1.346	3.719	17.080	10553.50	2559.22	7.994	3.262
44	13	2	2001	7	33	50	5.030	1.002	3.016	0.145	1.508	3.614	17.204	10630.46	2577.89	8.053	3.285
45	14	2	2001	9	37	46	6.275	1.148	3.711	0.170	1.707	3.558	17.280	10677.11	2589.20	8.088	3.300
46	15	2	2001	8	34	45	5.319	1.073	3.196	0.153	1.438	3.749	17.106	10569.90	2563.20	8.007	3.267
47	16	2	2001	8	35	45	5.623	1.073	3.348	0.157	1.506	3.712	17.162	10604.26	2571.53	8.033	3.277

Day in year	day_ Month	Month	year	**Tmin**	**Tmax**	**RH**	e^o(Tmax) kPa	e^o(Tmin) kPa	e_s kPa	Δ (kPa/^{o}C)	e_a kPa	**Rnl**	**Outside GH Rn (MJ/m2/day)**	**Rad into GH (kJ/day/m^2)**	**Rad From GH (kJ/day/m^2)**	Rnet GH (MJ/m2/day)	ETo (mm/day)
48	17	2	2001	7	35	47	5.623	1.002	3.312	0.153	1.557	3.649	17.242	10653.66	2583.51	8.070	3.293
49	18	2	2001	7	33	47	5.030	1.002	3.016	0.145	1.418	3.727	17.180	10615.60	2574.28	8.041	3.281
50	19	2	2001	9	31	48	4.493	1.148	2.820	0.145	1.354	3.711	17.213	10635.92	2579.21	8.057	3.287
51	20	2	2001	6	34	39	5.319	0.935	3.127	0.145	1.220	4.040	16.899	10442.01	2532.19	7.910	3.227
52	21	2	2001	6	35	34	5.623	0.935	3.279	0.149	1.115	4.243	16.711	10325.66	2503.97	7.822	3.191
53	22	2	2001	9	31	53	4.493	1.148	2.820	0.145	1.495	3.539	17.496	10489.98	2543.82	7.946	3.242
54	23	2	2001	10	32	48	4.755	1.228	2.991	0.153	1.436	3.658	17.384	10505.23	2547.52	7.958	3.247
55	24	2	2001	13	34	62	5.319	1.498	3.409	0.174	2.113	2.975	18.074	10676.07	2588.95	8.087	3.300
56	25	2	2001	10	38	58	6.625	1.228	3.926	0.179	2.277	2.956	18.100	10773.21	2612.50	8.161	3.330
57	26	2	2001	10	34	55	5.319	1.228	3.274	0.161	1.800	3.317	17.744	10718.03	2599.12	8.119	3.313
58	27	2	2001	12	33	65	5.030	1.403	3.216	0.165	2.091	2.961	18.105	10833.91	2627.22	8.207	3.348
59	28	2	2001	9	34	59	5.319	1.148	3.234	0.157	1.908	3.197	17.872	10810.58	2621.57	8.189	3.341
60	1	3	2001	10	35	55	5.623	1.228	3.425	0.165	1.884	3.266	17.805	10741.88	2604.91	8.137	3.320
61	2	3	2001	12	34	59	5.319	1.403	3.361	0.170	1.983	3.115	17.957	11168.10	2708.26	8.460	3.452
62	3	3	2001	11	31	57	4.493	1.313	2.903	0.153	1.655	3.353	17.719	11184.16	2712.16	8.472	3.457
63	4	3	2001	9	34	50	5.319	1.148	3.234	0.157	1.617	3.533	17.539	10964.02	2658.77	8.305	3.389

Day in year	day_ Month	Month	year	**Tmin**	**Tmax**	**RH**	$e^o(Tmax)$ kPa	$e^o(Tmin)$ kPa	e_s kPa	Δ (kPa/^{o}C)	e_a kPa	**Rnl**	**Outside GH Rn (MJ/m2/day)**	**Rad into GH (kJ/day/m^2)**	**Rad From GH (kJ/day/m^2)**	Rnet GH (MJ/m2/day)	ETo (mm/day)
64	5	3	2001	11	36	52	5.941	1.313	3.627	0.174	1.886	3.307	17.763	11186.91	2712.83	8.474	3.457
65	6	3	2001	11	32	57	4.755	1.313	3.034	0.157	1.729	3.313	17.754	11042.91	2677.90	8.365	3.413
66	7	3	2001	9	34	50	5.319	1.148	3.234	0.157	1.617	3.533	17.530	11001.77	2667.93	8.334	3.400
67	8	3	2001	9	32	49	4.755	1.148	2.951	0.149	1.446	3.647	17.411	11095.71	2690.71	8.405	3.429
68	9	3	2001	11	31	54	4.493	1.313	2.903	0.153	1.567	3.455	17.597	10948.78	2655.08	8.294	3.384
69	10	3	2001	11	31	56	4.493	1.313	2.903	0.153	1.625	3.388	17.657	10837.43	2628.08	8.209	3.349
70	11	3	2001	11	30	56	4.243	1.313	2.778	0.149	1.556	3.424	17.613	10975.81	2661.63	8.314	3.392
71	12	3	2001	10	36	50	5.941	1.228	3.584	0.170	1.792	3.416	17.611	10970.47	2660.34	8.310	3.391
72	13	3	2001	10	33	53	5.030	1.228	3.129	0.157	1.658	3.440	17.577	10831.71	2626.69	8.205	3.348
73	14	3	2001	10	33	54	5.030	1.228	3.129	0.157	1.690	3.403	17.602	10758.01	2608.82	8.149	3.325
74	15	3	2001	10	32	49	4.755	1.228	2.991	0.153	1.466	3.625	17.368	10873.12	2636.73	8.236	3.360
75	16	3	2001	9	35	46	5.623	1.148	3.385	0.161	1.557	3.654	17.324	10910.24	2645.73	8.265	3.372
76	17	3	2001	9	31	43	4.493	1.148	2.820	0.145	1.213	3.899	17.065	10882.79	2639.08	8.244	3.363
77	18	3	2001	11	33	54	5.030	1.313	3.171	0.161	1.713	3.377	17.570	10881.59	2638.79	8.243	3.363
78	19	3	2001	9	30	60	4.243	1.148	2.696	0.141	1.617	3.354	17.577	10860.83	2633.75	8.227	3.357
79	20	3	2001	9	34	53	5.319	1.148	3.234	0.157	1.714	3.421	17.492	10876.11	2637.46	8.239	3.361

Day in year	day_ Month	Month	year	**Tmin**	**Tmax**	**RH**	e^o(Tmax) kPa	e^o(Tmin) kPa	e_s kPa	Δ (kPa/^{o}C)	e_a kPa	**Rnl**	**Outside GH Rn (MJ/m2/day)**	**Rad into GH (kJ/day/m^2)**	**Rad From GH (kJ/day/m^2)**	Rnet GH (MJ/m2/day)	ETo (mm/day)
80	21	3	2001	9	34	52	5.319	1.148	3.234	0.157	1.682	3.459	17.435	10731.51	2602.39	8.129	3.317
81	22	3	2001	12	32	53	4.755	1.403	3.079	0.161	1.632	3.427	17.447	10704.71	2595.89	8.109	3.308
82	23	3	2001	11	34	54	5.319	1.313	3.316	0.165	1.791	3.333	17.520	10544.21	2556.97	7.987	3.259
83	24	3	2001	12	32	54	4.755	1.403	3.079	0.161	1.662	3.392	17.439	10856.78	2632.77	8.224	3.355
84	25	3	2001	9	32	51	4.755	0.611	2.683	0.116	1.368	3.748	17.059	10860.71	2633.72	8.227	3.357
85	26	3	2001	9	34	53	5.319	1.148	3.234	0.157	1.714	3.421	17.492	10808.53	2621.07	8.187	3.340
86	27	3	2001	9	34	52	5.319	1.148	3.234	0.157	1.682	3.459	17.435	10773.25	2612.51	8.161	3.330
87	28	3	2001	12	32	53	4.755	1.403	3.079	0.161	1.632	3.427	17.447	10780.29	2614.22	8.166	3.332
88	29	3	2001	11	34	54	5.319	1.313	3.316	0.165	1.791	3.333	17.520	10825.86	2625.27	8.201	3.346
89	30	3	2001	12	32	54	4.755	1.403	3.079	0.161	1.662	3.392	17.439	10775.52	2613.06	8.162	3.330
90	31	3	2001	9	32	51	4.755	1.148	2.951	0.149	1.505	3.578	17.230	10541.03	2556.20	7.985	3.258

APPENDIX 5.6 C: ETo – CALCULATION (FAO – PEN MAN MONTHEITH)

DAY	Month	Year	Rad KJ/day/m^2	Rad MJ/day/m^2	Tair[min] (deg C)	Tmax (deg C)	Tmean (deg C)	RH (%)	e^o(Tmax) kPa	e^o(Tmin) kPa	e_s kPa	Δ (kPa/^{o}C)	e_a kPa	e_s-e_a (kPa)	γ (kPa/^{o}C)	u_2 (m/s)	ETo (mm/d)
1	1	2001	7795.23	7.795	10.6	29.8	20.2	69.7	4.199	1.165	2.682	0.1465	1.870	0.812	0.053223	1.74	1.463
2	1	2001	7845.11	7.845	12.3	29.8	21.1	69.8	4.199	1.284	2.742	0.1532	1.914	0.828	0.053223	1.38	1.295
3	1	2001	7764.48	7.764	13.4	25.6	19.5	69.7	3.275	1.370	2.322	0.1407	1.618	0.704	0.053223	1.38	1.172
4	1	2001	7646.73	7.647	15.6	27.7	21.7	69.5	3.712	1.556	2.634	0.1583	1.832	0.802	0.053223	1.00	1.061
5	1	2001	7608.60	7.609	15.6	24.5	20.1	69.5	3.074	1.556	2.315	0.1453	1.608	0.706	0.053223	1.00	0.983
6	1	2001	7696.82	7.697	15.1	23.4	19.3	69.6	2.883	1.507	2.195	0.1390	1.528	0.667	0.053223	0.89	0.905
7	1	2001	7764.73	7.765	14.5	24.5	19.5	69.7	3.074	1.460	2.267	0.1409	1.580	0.687	0.053223	0.89	0.924
8	1	2001	7674.16	7.674	15.6	25.6	20.6	79.9	3.275	1.556	2.415	0.1495	1.929	0.486	0.053223	0.89	0.792
9	1	2001	7731.45	7.731	15.6	23.4	19.5	83.1	2.883	1.556	2.220	0.1411	1.844	0.376	0.053223	1.19	0.785
10	1	2001	7899.27	7.899	15.6	24.5	20.1	82.0	3.074	1.556	2.315	0.1453	1.898	0.417	0.053223	0.88	0.749
11	1	2001	7455.25	7.455	15.6	22.4	19.0	88.4	2.703	1.556	2.130	0.1371	1.882	0.247	0.053223	1.06	0.623
12	1	2001	7520.09	7.520	16.2	25.6	20.9	77.7	3.275	1.606	2.440	0.1518	1.897	0.543	0.053223	1.06	0.886
13	1	2001	7761.17	7.761	15.6	24.5	20.1	86.3	3.074	1.556	2.315	0.1453	1.997	0.318	0.053223	1.19	0.742
14	1	2001	7682.78	7.683	11.7	26.6	19.2	73.5	3.488	1.243	2.366	0.1384	1.738	0.627	0.053223	1.19	1.007
15	1	2001	7758.14	7.758	11.2	25.6	18.4	78.8	3.275	1.204	2.239	0.1324	1.765	0.475	0.053223	1.19	0.868
16	1	2001	7809.52	7.810	10.1	27.7	18.9	70.3	3.712	1.127	2.420	0.1361	1.701	0.719	0.053223	1.19	1.100
17	1	2001	7786.90	7.787	11.2	27.7	19.4	69.2	3.712	1.204	2.458	0.1403	1.702	0.756	0.053223	1.19	1.131

DAY	Month	Year	Rad KJ/day/m^2	Rad MJ/day/m^2	Tair[min] (deg C)	Tmax (deg C)	Tmean (deg C)	RH (%)	e^o(Tmax) kPa	e^o(Tmin) kPa	e_s kPa	Δ (kPa/^{o}C)	e_a kPa	e_s-e_a (kPa)	γ (kPa/^{o}C)	u_2 (m/s)	ETo (mm/d)
18	1	2001	7853.00	7.853	12.3	27.2	19.7	74.6	3.598	1.284	2.441	0.1426	1.820	0.621	0.053223	1.19	1.015
19	1	2001	7878.72	7.879	10.1	27.7	18.9	73.5	3.712	1.127	2.420	0.1361	1.778	0.642	0.053223	1.20	1.034
20	1	2001	7990.96	7.991	10.1	28.8	19.4	70.3	3.949	1.127	2.538	0.1401	1.784	0.754	0.053223	1.20	1.145
21	1	2001	7815.84	7.816	12.3	28.8	20.5	69.2	3.949	1.284	2.617	0.1489	1.812	0.805	0.053223	1.60	1.385
22	1	2001	7925.59	7.926	13.4	24.5	19.0	78.8	3.074	1.370	2.222	0.1367	1.751	0.471	0.053223	1.07	0.838
23	1	2001	7427.05	7.427	15.6	27.7	21.7	72.4	3.712	1.556	2.634	0.1583	1.908	0.726	0.053223	1.07	1.028
24	1	2001	7834.33	7.834	14.5	22.4	18.4	56.5	2.703	1.460	2.082	0.1330	1.177	0.905	0.053223	1.11	1.223
25	1	2001	7867.79	7.868	15.6	22.4	19.0	86.3	2.703	1.556	2.130	0.1371	1.837	0.292	0.053223	0.92	0.653
26	1	2001	7792.67	7.793	14.5	20.2	17.4	85.2	2.373	1.460	1.916	0.1254	1.633	0.284	0.053223	0.92	0.619
27	1	2001	7616.27	7.616	12.3	23.4	17.9	74.6	2.883	1.284	2.084	0.1288	1.554	0.530	0.053223	0.92	0.804
28	1	2001	7672.37	7.672	12.3	24.5	18.4	82.0	3.074	1.284	2.179	0.1326	1.787	0.392	0.053223	0.92	0.708
29	1	2001	7810.03	7.810	11.2	24.5	17.8	72.4	3.074	1.204	2.139	0.1286	1.549	0.590	0.053223	0.92	0.859
30	1	2001	7846.26	7.846	10.1	26.6	18.3	66.0	3.488	1.127	2.308	0.1322	1.524	0.784	0.053223	0.94	1.020
31	1	2001	7860.90	7.861	8.9	27.7	18.3	67.1	3.712	1.055	2.384	0.1320	1.599	0.784	0.053223	0.94	1.021

APPENDIX 5.6D: ETo – CALCULATION (according to Stanghellini C, 2001)

Day number in year	Radiation Outside GH Rn (MJ/m2/day)	Rad_in GH (0.7*Rn)	Latent H 0.65*Rad_in	mm/day Equiv.
1	16.654	11.658	7.578	3.09
2	16.761	11.733	7.626	3.11
3	16.589	11.612	7.548	3.08
4	16.337	11.436	7.433	3.03
5	16.256	11.379	7.396	3.02
6	16.444	11.511	7.482	3.05
7	16.589	11.612	7.548	3.08
8	16.396	11.477	7.460	3.04
9	16.518	11.563	7.516	3.07
10	16.877	11.814	7.679	3.13
11	15.928	11.150	7.247	2.96
12	16.067	11.247	7.310	2.98
13	16.582	11.607	7.545	3.08
14	16.414	11.490	7.468	3.05
15	16.575	11.603	7.542	3.08
16	16.685	11.679	7.592	3.10
17	16.637	11.646	7.570	3.09
18	16.778	11.744	7.634	3.11
19	16.833	11.783	7.659	3.12
20	17.073	11.951	7.768	3.17
21	16.698	11.689	7.598	3.10
22	16.933	11.853	7.704	3.14
23	15.868	11.107	7.220	2.95
24	16.738	11.717	7.616	3.11
25	16.809	11.767	7.648	3.12
26	16.649	11.654	7.575	3.09
27	16.272	11.390	7.404	3.02
28	16.392	11.474	7.458	3.04
29	16.686	11.680	7.592	3.10

30	16.763	11.734	7.627	3.11
31	16.795	11.756	7.642	3.12
32	17.186	12.030	7.820	3.19
33	17.189	12.033	7.821	3.19
34	17.198	12.038	7.825	3.19
35	17.377	12.164	7.907	3.23
36	17.248	12.074	7.848	3.20
37	16.303	11.412	7.418	3.03
38	17.007	11.905	7.738	3.16
39	17.162	12.013	7.809	3.19
40	17.109	11.976	7.785	3.18
41	17.407	12.185	7.920	3.23
42	17.105	11.973	7.783	3.18
43	17.080	11.956	7.771	3.17
44	17.204	12.043	7.828	3.19
45	17.280	12.096	7.862	3.21
46	17.106	11.974	7.783	3.18
47	17.162	12.013	7.809	3.19
48	17.242	12.069	7.845	3.20
49	17.180	12.026	7.817	3.19
50	17.213	12.049	7.832	3.20
51	16.899	11.829	7.689	3.14
52	16.711	11.698	7.603	3.10
53	16.977	11.884	7.724	3.15
54	17.002	11.901	7.736	3.16
55	17.278	12.095	7.861	3.21
56	17.435	12.205	7.933	3.24
57	17.346	12.142	7.892	3.22
58	17.533	12.273	7.978	3.25
59	17.496	12.247	7.961	3.25
60	17.384	12.169	7.910	3.23

APPENDIX 6.1A: ANNUAL MINERALISATION OF ORGANIC MATTER CALCULATION

1)							
Garcia R:http://launionswcd.org/nitrogen1.htm							
	A (m^2)	5000					
	depth (m)	0.3					
	V (m^3)	1500				5%OM=ON	2%ON
	Bulky Dens (kg/m^3):		Mass of Soil (kg)	OM (%)	OM/GH (kg)	ON/GH (kg/GH)	Mineralisation (kg/GH)
	GH_3	1361	2041500	1.121	22885.22	1144.26	**22.89**
	GH_13	1263	1894500	0.377	7142.265	357.11	**7.14**
	GH_14	1341	2011500	1.123	22589.15	1129.46	**22.59**
2) Soil Nitrate - Nitrogen (NO$_3^-$ -N							
	NO$_3^-$ Content:	10	ppm				
	Cont per GH	15000000	mg				
		15	kg/GH				
3) Other sources:							
	water	< 3	ml/L				
	Assume	1	mg/L	or	0.035	kg/d	
		10.96	kg/year/GH				
4)	In organic:	236.9	mg/L	**355.35**	kg/GH		
Total available NO$_3^-$ -N:		from OM+ Soil + Others +In -organic fertiliser					
		22.6 + 15 + 4.5 + 355.35					
		403.91	kg/GH				

APPENDIX 6.1B: NITROGEN CONCENTRATION IN THE FERTILISER

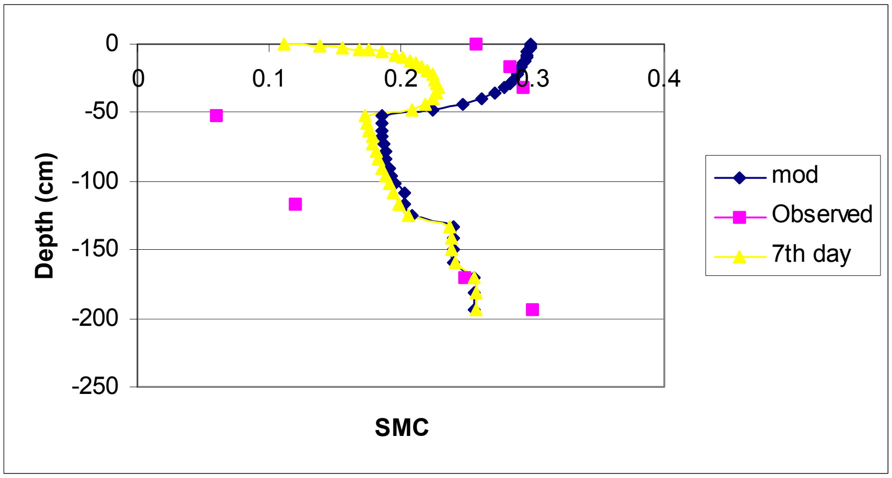
FERTILISER TYPE	QTY kg/1000 ltr	Tank	Concentration in the Stock Solution in mg/l	(in 35000ltr) Concentration in Irrigation Water (mg/l)	N- Conc. in Stock sol.n (mg/L)	N-Concentr. in Irrigation Water (mg/L)
$Ca(NO_3)_2$	43.1	A	43100	1.231428571	15085.00	0.431
Urea	2.1	A	2100	0.06	979.65	0.028
Fe (11%)	1.8	A	1800	0.051428571		
Urea	1.4	B	1400	0.04	653.10	0.019
$(NH_4)_2SO_4$	11.3	B	11300	0.322857143	2395.60	0.068
K_2SO_4	6.7	B	6700	0.191428571		
KNO_3	26	B	26000	0.742857143	3601.00	0.103
$MgSO_4$	23.7	B	23700	0.677142857		
$CuSO_4$(25%)	0.024	B	24	0.000685714		
Solubor (Bo) 20%	0.1105	B	110.5	0.003157143		
Zn (15%)	0.0165	B	16.5	0.000471429		
Mn(13%)	0.2	B	200	0.005714286		
Sodium Molybdate	0.002	B	2	5.71429E-05		
			116453	**3.327228571**	**22714.35**	**0.649**
This is mixed in 30 - 35m^3 of Water						

APPENDIX 6.2 NITRATE ANALYSIS ON THE WATER SAMPLE

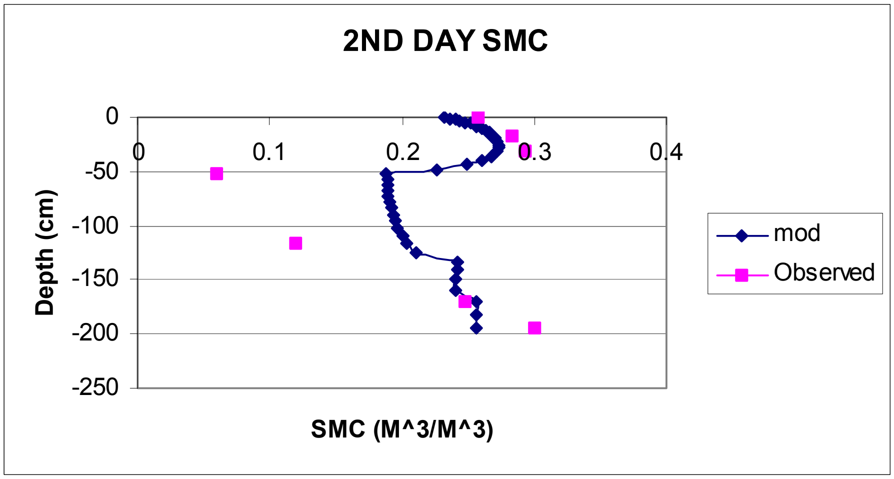
Sample No:	**T1 (mg/L)**	**T2 (mg/L)**	**T3 (mg/L)**	**mean (mg/L)**	Corrected Conc. (mg/L)
S1	80	80	70	76.67	97.74
S2	270	260	250	260.00	326.36
S3	270	220	220	236.67	297.26
S4	58	64	59	60.33	77.38
S5	320	310		315.00	394.95
S6				< 3	< 3
S7				< 3	< 3

APPENDIX 6.3 VALIDATION OF THE CALIBRATED SWAP MODEL WITH A 7- Day RUN

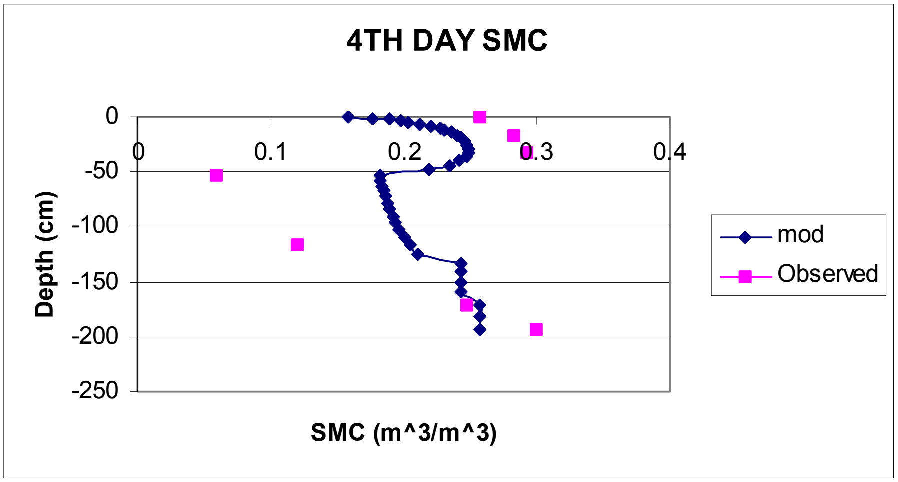
i) Day 1 and day 7



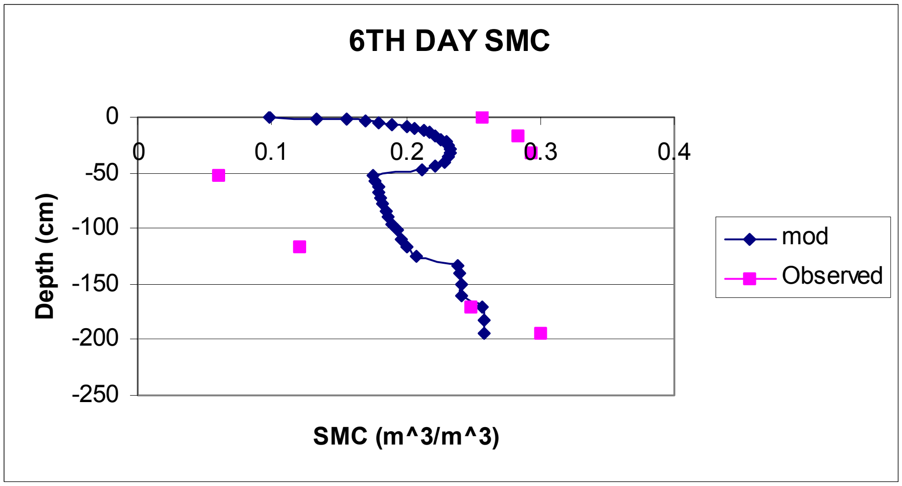
ii) Day 2



iii) Day 4



iv) Day 6



APPENDIX 6.4 CALCULATION ALGORITHM FOR THE PORE WATER VELOCITY

Pore water velocity v (*layer 1*):

Equation 1

$$v = \frac{r}{q}$$

where:

r = Recharge = 0.3732 cm/d or (136.20 cm/year)

q = 0.205cm^3/cm^3 (projected water content)

Equation 2 :

$$q = \theta = \theta_s * \left(\frac{r}{k_{sat}} \right)^{\frac{1}{2b+3}}$$

, where: b = 2.32 = 1/ λ (λ is Brooks Corey's pore size index = 0.4312)

K_{sat} = 60cm/d

Θ_{sat} = 0.395 cm^3/cm^3

v = 1.823 cm/d

(Algorithm source: Ravi V. et al.,)

APPENDIX 6.5 DIFFUSION COEFFICIENT:

The Law of Einstein for molecular diffusion of particles was used to determine the value for the molecular diffusion coefficient (Mannaerts, 2002).

The equation states that:

Equation 3

$$D = \frac{kT}{\Phi} = \frac{kT}{6\pi r \upsilon}$$

Where:

k = Boltzman constant or 1.38 E-17 erg (Dyne cm)

T = Temp in Kelvin

υ = Viscosity (dynamic) (micro poise)

r = radius of the particle (cm)

Assuming a Nitrate- Ion radius of 10^{-6} mm and a Temperature of 20 ^{o}C this would lead to:

D_m = 2.15E-6 cm^2/sec

= 0.186 cm^2/day

Mannaerts, 2002: Personal communication

APPENDIX 6.6 DISPERSION COEFFICIENT

Equation 3

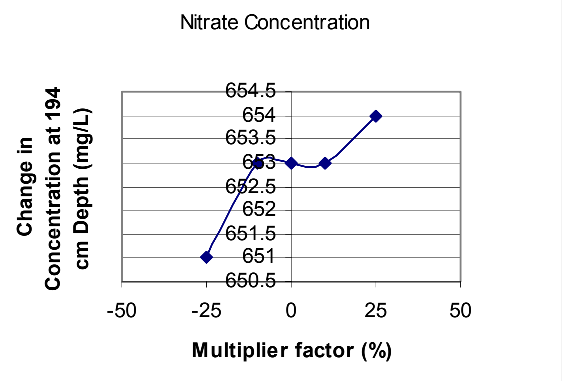
$$Ddis = L_{dis} * v$$

= 9.115 cm^2/day

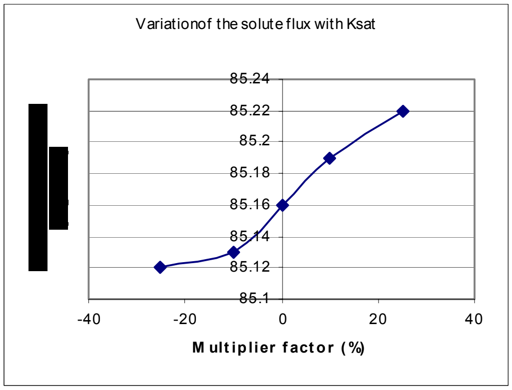
APPENDIX 7 SENSITIVITY ANALYSIS

Appendix 7.1 : EFFECT OF HYDRAULIC CONDUCTIVITY ON:

a) Concentration Distribution

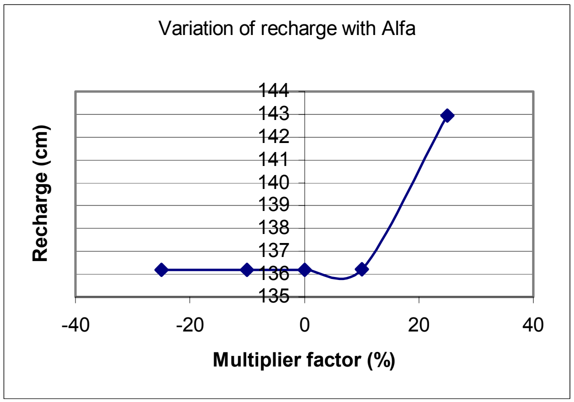


b) Solute Bottom flux

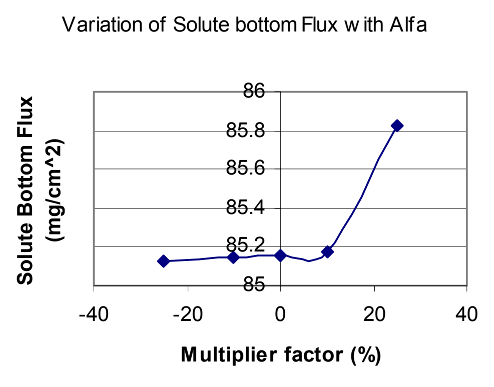


Appendix 7.2 EFFECT OF ALFA ON:

a) Recharge (Bottom flux)

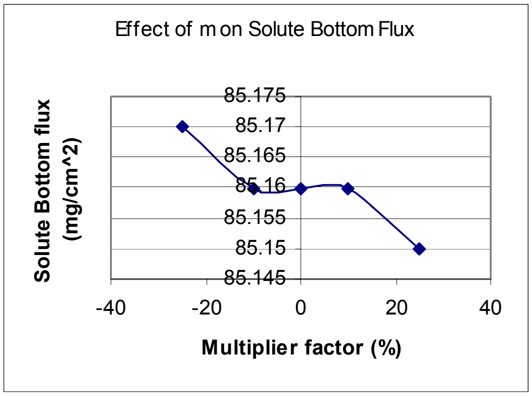


b) Solute Bottom flux



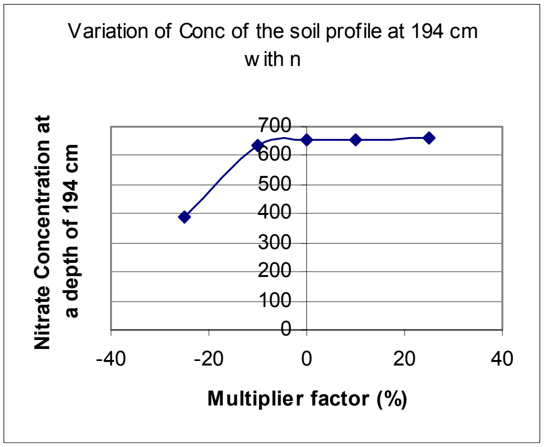
Appendix 7.3 EFFECT OF M – FACTOR (SHAPE) ON:

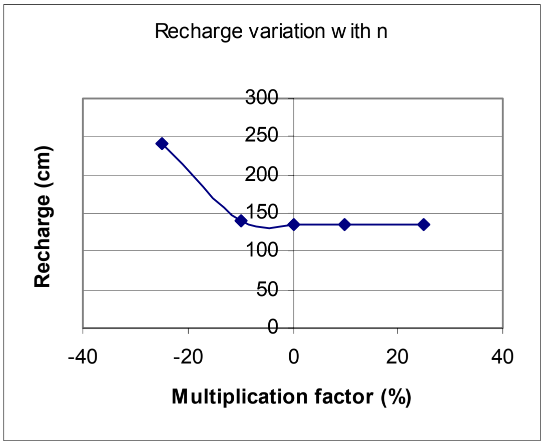
a) Solute Bottom Flux



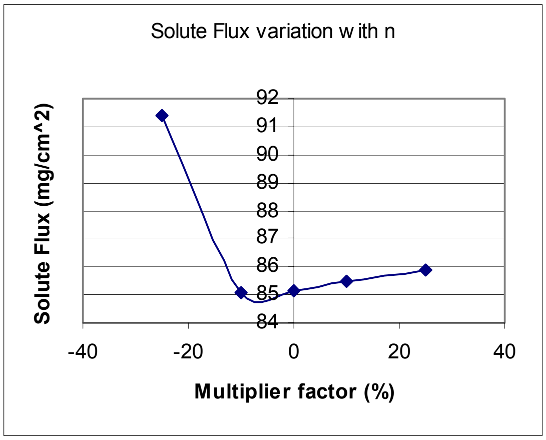
Appendix 7.4 EFFECT OF N – FACTOR (SHAPE) ON:

a) Nitrate concentration at 194 cm b) Recharge (Bottom Flux)





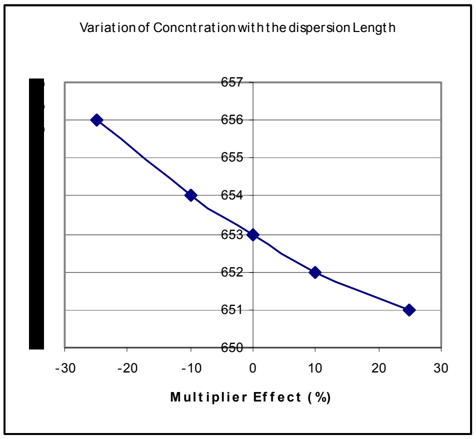
c) Solute flux

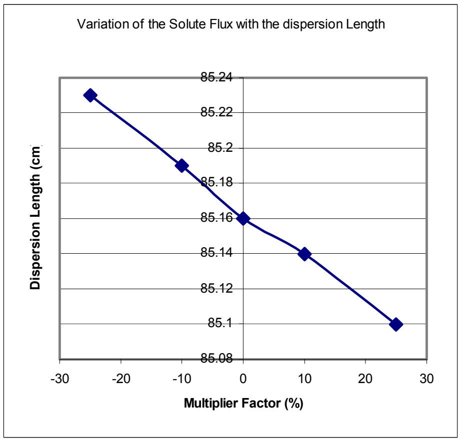


CHEMICAL PARAMETERS:

Appendix 7.5Effect of the Dispersion length on:

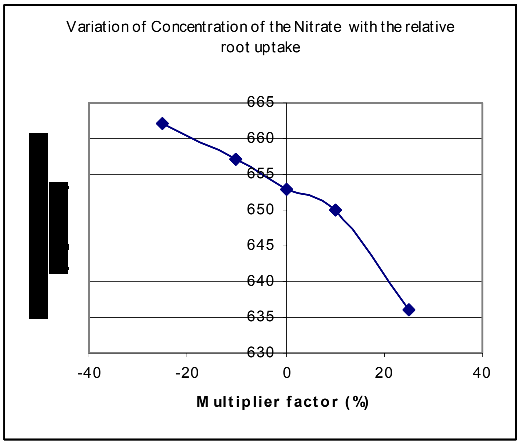
a) Concentration distribution at 194 cm b) the solute flux

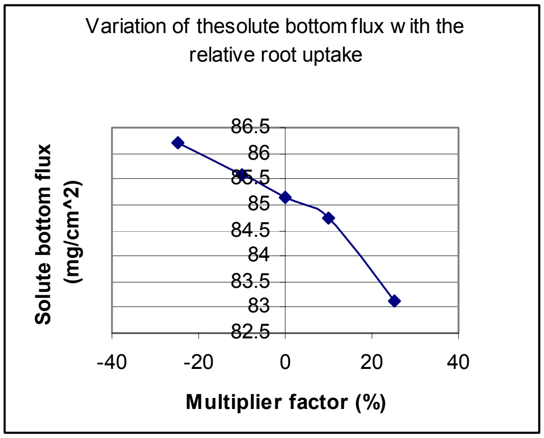




Appendix 7.6 Effect of the Root up take on:

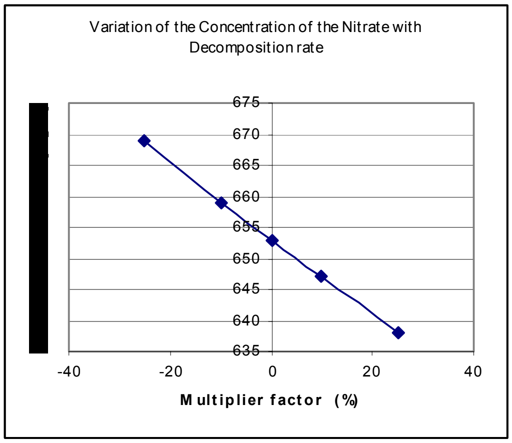
b) Nitrate concentration distribution at 194 cm c) Solute bottom flux

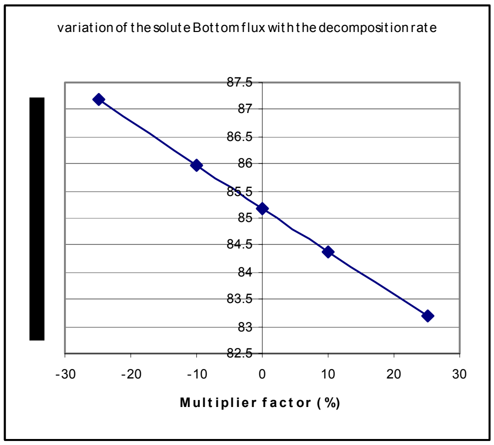




Appendix 7.7 Effect of Decomposition rate on:

a) Nitrate concentration distribution at 194 cm b) Solute Bottom flux


Variation of the Concentration of the Nitrate with Decomposition rate
[redacted]
675
670
665
660
655
650
645
640
635
-40
-20
0
20
40
Multiplier factor (%)


variation of the solute Bottom flux with the decomposition rate
[redacted]
87.5
87
86.5
86
85.5
85
84.5
84
83.5
83
82.5
-30
-20
-10
0
10
20
30
Multiplier factor (%)

FIELDWORK PHOTOGRAPHS

a) GH surroundings showing air vents

b) Inside a GH showing a thermal screen

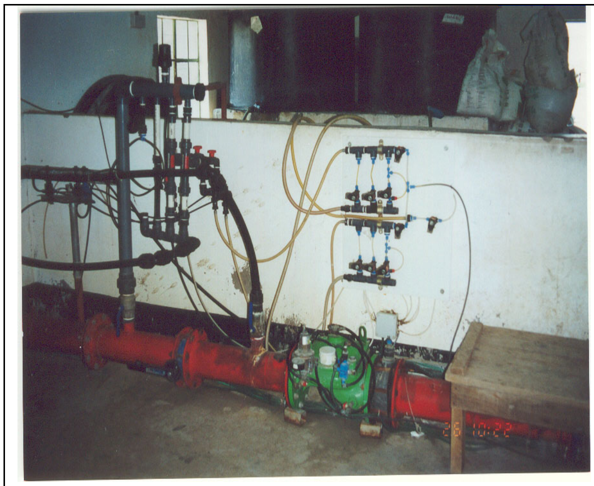
c)Wind blower (anti-humidity)

d) Water on the surface for humidity

e) Driplines on the ridge

f) Pumping unit showing the filter

g) Fertiliser injection unit



h) Fertiliser mixing tanks (stock solution)

i) Soil pit showing the layers

j) Soil pit showing the moisture profile

K) Naivasha North showing STRATIFICATION

L) Inside Njorowa Gorge showing Salts crystallisation