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EVALUATION OF IRRIGATION PRACTICE AT FARM LEVEL USING GIS, RS DATA AND SWAP MODEL:

Case study at Lake Naivasha project, Kenya.

DAO VIET DUNG

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By

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Thesis submitted to the International Institute for Aerospace Survey and Earth Sciences in partial fulfilment of the requirements for the degree of Master of Science in Water Resources and Environment Management (WREM-2)

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ABSTRACT

In the development of human civilisation, food production is one of the most important activities for people survival in the world. To ensure the sustainable of food production, irrigation plays a very crucial role in modern agriculture development. It is especially important in the areas where water is a scare resource.

In the last few decades, researches in irrigation practices and management have been carried out by number of scientists and institutions. Many methods have also been applied in those researches in order to evaluate irrigation efficiency and identify ways to improve irrigation practices.

Formerly, most of the methods, when evaluating irrigation efficiency, were based on the field measurements and on physical data collection such as the level of irrigation supply for service area, volume of water supplied to the field versus crop water requirement obtained from experimental measurement, water loss in the supply system etc. Such those methods give reliable results if the measurements were carefully done but they were costly and time consuming.

One difficult mater in traditional methods is data collection. Due to large amount of data required for sophisticated model. Reliable quality and quantity of data are not always easy to get.

The GIS and RS can be used for data acquisition in continuation with the rapid development of computer aided modelling methods, the task of irrigation efficiency evaluation becomes more effective and less time consuming. It requires the researchers with skilful practice in data acquisition and analysis from RS, GIS and computer modelling.

Irrigation efficiency can be evaluated following different methods depends on the purpose of the study. One may evaluate irrigation efficiency with single criterion such as the percentage of design irrigated area to be ensured by irrigation or volume of water reach the field over the total volume supplied from the headwork. Other may use economic benefits in this evaluation such as the economic return over the expenditure in irrigation services or crop yield comparison of with and without irrigation. Other can apply multi-criteria in the evaluation by using two or more single criteria. Of course, more criteria to be used in evaluation require more reliable data that in many cases is difficult to be met.

In this research, the ratio between actual water supplied and crop water requirement generated from the computer model, is used to evaluate irrigation efficiency.

Main type of irrigation evaluation for this thesis is sprinkle (typically is central pivot) as it is dominantly used in vegetable production. Among many kinds of crop under irrigation, only some types of vegetable are chosen for irrigation evaluation at farm level in Naivasha area.

An agro-hydrologic model known as SWAP version 2.0, which is developed by Wageningen Agriculture University, the Netherlands, is used in irrigation evaluation. Data acquired from GIS, RS technique and data collected from the fieldwork September, 2000 are the input of the model.

The outputs of the model show in one hand the crop water requirement and in the other hand how irrigation practice to be in the research area.

Finally, some conclusions and recommendation for irrigation practice are given in order to improve irrigation activities around the Lake Naivasha.

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My gratitude is to the officers and drivers of WRAP, Rift land, Naivasha Kenya for their accompany and assistance during my field work.

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DEDICATION

The success of this thesis is dedicated to my parents and especially to my beloved wife, who had made a lot of affords in looking after my children while I was away for study at ITC and always encouraging me in my study. It is also a present to my new son, who was born during my stay in ITC and hasn't seen me until my graduation at ITC.

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LIST OF ABBREVIATIONS

GIS	Geographic Information System	
RS	Remote Sensing	
SWAP	Simulation of water flow, solute transport and plant growth in the Soil – Water – Air – Plant environment.	
WRAP	Water Resources Assessment Program	
DEM	Digital Elevation Mapping	
ET	**EvapoTranspiration**	
ET_c	Crop Potential EvapoTranspiration	
ET_{ref}	Grass Reference EvapoTranspiration	
FAO	Food and Agricultural Organization	
LAI	Leaf Area Index	
NDVI	Normalized Difference Vegetation Index	
LANDSAT	LAND remote sensing SATellite	
TM	Thematic Mapper	
USDA	US Department of Agriculture	
DVS	Crop development stage	
P	gross precipitation	(cm)
k	hydraulic conductivity	(cm/d)
S	soil water abstraction rate by plant root	(cm^3/cm^3/d)
C	water capacity (d θ/dh)	(1/cm)
T_p	potential transpiration rate	(cm/d)
Ta	actual transpiration rate	(cm/d)
W	the water capacity	$(d\theta / dh)$
ROU	Surface runoff	(cm)
Y	Yield	(cm)
RH	Relative humidity	[%]
q	soil water flux	(cm/day)
θ	volumetric water content	(cm^3/cm^3)
h	soil water pressure head	(cm)
θsat	the saturated water content	(cm^3/cm^3)
θres	the residual water content	(cm^3/cm^3)
α	air entry factor	(/cm)
n	empirical shape factor accounting for	(-)
m	the hysteresis of the soil	(-)
λ	shape constant factor	(-)
Kr	root uptake factor	(-)
Δt	the length of time step	(day)
ET	Evapotranspiration	(cm)
λE or LE	Latent heat flux	[W m^{-2}]
H	Sensible heat flux	[W m^{-2}]
G	Soil heat flux	[W m^{-2}]
n	**Bright sunshine hours in a day**	**[hours]**
Rn	**Net radiation flux**	**[W m-2/d]**
Ra	Incoming extraterrestrial short-wave radiation per day	[W m-2/d]
Rs	solar radiation	[MJ/m2/d]
Rso	clear-sky solar radiation	[MJ/m2/d]
Rns	net solar radiation	[MJ/m2/d]

Rnl	net long-way solar radiation	[MJ/m2/d]
T_o	Surface temperature	[K]
T_a	Air temperature at reference height	[K]
T_{mean}	Mean daily air temperature	[K]
T_{max}	Maximum daily air temperature	[K]
T_{min}	Minimum daily air temperature	[K]
σ	Stefan-Boltzmann Constant ($5.67*10^{-8}$)	[W m^{-2} K^{-4}]
I_{sc}	The solar constant (1367)	[W m^{-2}]
λ_v	Latent heat of vapourization	[MJ kg^{-1}]
P_a	Atmospheric vapour pressure	[k Pa]
ρ_a	Density of air	[Kg m^{-3}]
e_a	Atmospheric water vapour pressure at reference height	[k Pa]
$e_{a,sat}$	Saturation vapour pressure of air at reference height	[k Pa]
$e_{o,sat}$	Saturation vapour pressure near surface	[k Pa]
D	Vapour pressure deficit at reference height ($e_{a,sat}$ - e_a)	[k Pa]
r_{ah}	Aerodynamic resistance to heat transport	[s m^{-1}]
r_{av}	Aerodynamic resistance to water vapour transport	[s m^{-1}]
r_a	Aerodynamic resistance ($r_{ah} \approx r_{av}$)	[s m^{-1}]
Δ	Slope of saturation vapour pressure	[k Pa ^{0}C^{-1}]
u	Wind speed at reference height	[m s^{-1}]
γ	Psychrometric constant	[k Pa ^{0}C^{-1}]
θ_z	Solar zenith angle, incidence angle on a horizontal plane	[deg]
ϕ_z	Satellite zenith angle	[deg]

1 INTRODUCTION

Contents:

1.1 Problem recognition:

From the previous analysis of meteorological data, such as Kwacha C.P.H. Jonathan, 1998, Kamoni, 1998, clearly shows that the research area has less rainfall than evapotranspiration. That leads to the shortage of water for irrigation potential. Also from these researches, it is said that irrigation application for some main types of crops is much more than estimated water requirement (Huatuco, 1998 and Ahamad Salah,1999). The following research problems related to irrigation are identified:

- Water demand for main crop types such as flower, vegetables and grass in irrigated land is not fully studied (refer to “Water availability assessment using multi-objective decision support system (MODSS), a study around lake Naivasha, Rift Valey Province, Kenya. MSc thesis by Luisa Delfa Huaccho Huatuco, 1998).
- There are changes in cropping pattern follow the market orientation but the research on water requirement of those crops growing in the actual local climate condition has not been conducted.
- Level of over irrigation (from Huatuco MSc thesis, 1998, Ahmah Salah MSc thesis, 1999)
- The competitive use of water of different sectors led to the shortage of irrigation in some part of study area.
- The use of chemicals in irrigation might cause the pollution of surface and ground water resources.

1.2 Research objectives

The overall objective of this research is to calculate crop water requirement of the main crop type being cultivated and to evaluate the present irrigation water use and its efficiency in the Lake Navasha project area.

Some typical objectives can be defined as follow:

- To define the area in which irrigation and drainage take place and present an overview of irrigation practice.
- To demonstrate the use of GIS and RS in data acquisition, analysis and presentation.
- To assess the usefulness of hydrological model for crop water demand computation and evaluating irrigation efficiency.
- To evaluate irrigation for some main types of crops based on irrigation practices
- To give recommendations for irrigation practice in research area.

1.3 ***Research approach***

1.3.1 ***Research issues***

Irrigation efficiency is always a big issue in many irrigation systems throughout the world, especially in those of developing countries where irrigation management is remained at low level. The problem may become serious when water resources are scared, over-exploitation takes place or poor allocation.

In the study area, no irrigation efficiency evaluation has previously been made. It is unknown whether the irrigation practices in the agriculture land are well performed.

1.3.2 ***Research questions***

The aim of this study is to answer the following questions:

- What is the actual irrigation practice happening in the area?
- Does the irrigation practice have high efficiency?
- Can recommendations for irrigation activities be given?
- How GIS, RS and modelling can be used in irrigation evaluation studies?

This specific study will contribute to a better understanding of water resources management issues at the whole.

1.4 ***Data and materials***

- Maps of study area (topographic map, irrigated area, land use maps …)
- Long term data of meteorology (rainfall, temperature, humidity, evapotranspiration, wind speed, sunshine hours, radiation)
- Crop types and cropping calendar.
- Soil property-testing results such as soil type, soil texture, soil structure and hydraulic conductivity.
- On farm irrigation practice records and interviews.
- Irrigation measurement data from field work.
- Remotely sensed data (air photos, satellite images taken in May 2000) for identifying land cover, cropping patterns.
- Computer and necessary software for data processing and analysis.

Data need for this research are listed in the table below:

Figure 1.1: Table of data required for crop water requirement and irrigation efficiency evaluation:

Input data:	**Dimension**	**Used for**	**Obtained from**
Meteo	• Rainfall stations • Daily, monthly… • Radiation • Sunshine hours • Evaporation • Win speed	• Water balance • Running SWAP model • Running CROPWAT model	Meteorological records
Soil physic	• Soil type • Infiltration rate • Soil depth	• Soil water storage computation • Water loss from seepage	Laboratory tests Field check GIS, RS Available tables from previous research.
Cropping area	• Detailed crop map	• Irrigation calculation	RS,GIS and fieldwork
Crop type	• Name of crop • Planting season • Root depth	• Crop water req.,	RS,GIS, land use map, fielwork
Crop water requirement	• Water demand for specific crop type • Water demand for the whole area	• Water demand computation	CROPWAT/SWAP Crop type requirement index (FAO)
Physical condition of the system	• Infrastructure • Losses from irrigation system. (due to leakage, uncontrolled structures, seepage) • Availability of water resource for irrigation	• System capacity to meet water demand	• Filed visit • Field management • Computation
Irrigation practice:	• Irrigation schedule • Water volume irrigated in the field • Time and duration • Area ensured with irrigation.(ratio to the command area) • Habit of farmers in irrigation supply	• Reliability of water supply • Estimation of irrigation efficiency	• Field records • Field interviews • Calculation • Analysis
Topographic	Boundary, contour map	• Presentation	(DEM), topo-sheets
RS data	Satellite images Air photos	• Cover interpretation, land use • Presentation	Images TM 2000 from USDS database, air photos 1998

1.5 Research methods

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

Data acquisition from previous research and from locally available resources

Field work for additional necessary data to be used in the research.

Data processing using GIS,RS and modelling.

Evaluate the actual irrigation water use and its efficiency.

Methods used:

- Research literature review to help the problem identification
- Pre-fieldwork data processing (Satellite image geo-referencing, resampling)
- Organising the available data from previous researches
- Field visit to check available data and compare and reclassifying RS data
- Measure the typical physical on-farm data (soil related, crop, irrigation features …)
- Meeting and interview with farmers if necessary.
- Data manipulation and database formation for modelling.
- Data adjustment and analysis.
- Computer modelling
- Result analysis
- Result presentation

1.6 Flow chart of the research:

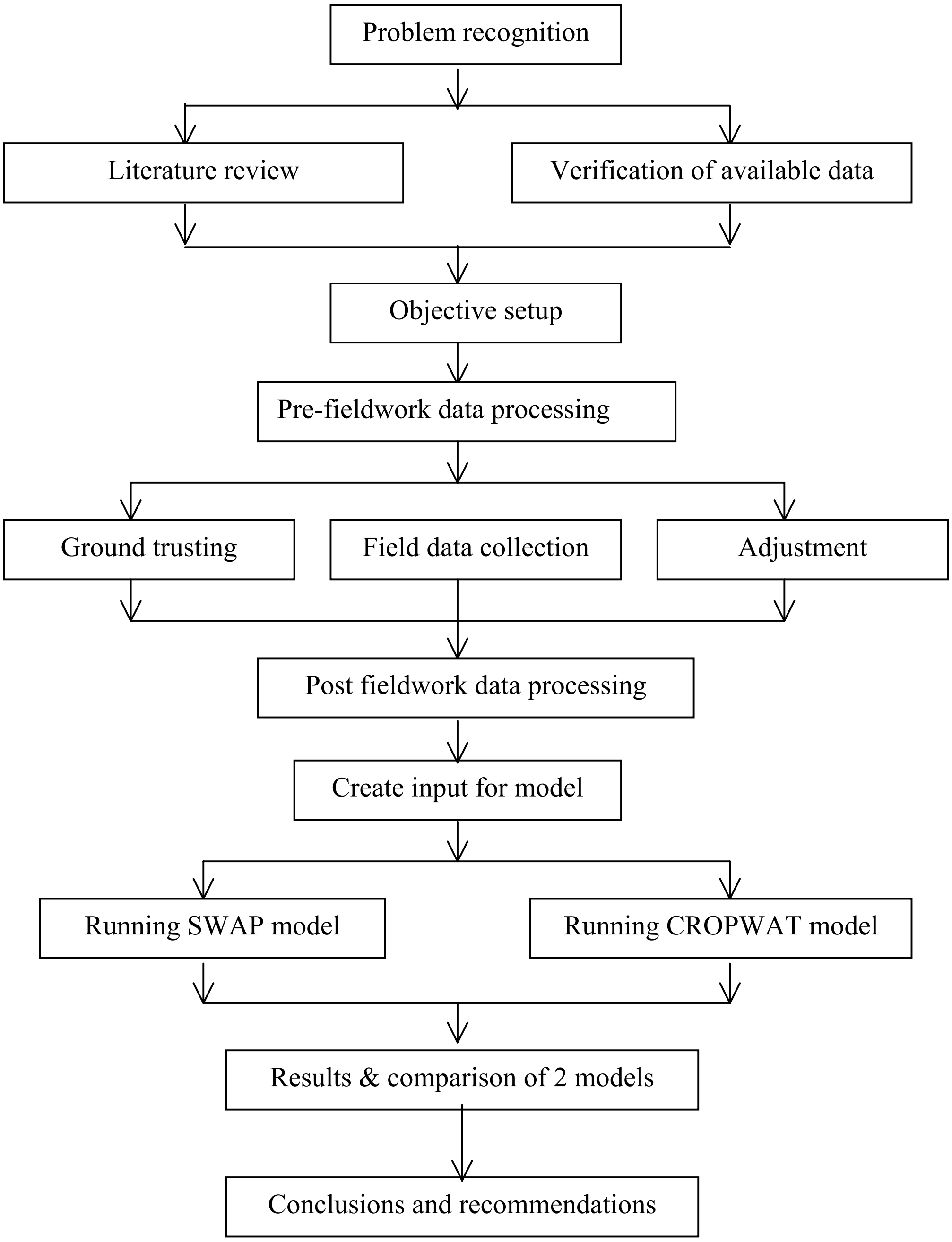

Figure 1.2: Flow chart of the research

2 LITERATURE REVIEW

Contents:

Start with the problem recognition and the purpose of this research, three main subjects will be reviewed:

2.1 Irrigation efficiency study in study area.

2.2 The application of GIS and remote sensing in water resources studies and in irrigation efficiency evaluation.

2.3 The application of SWAP and CROPWAT models.

2.1 Irrigation efficiency study in study area

Irrigation efficiency is difficult to evaluate as it concerns a lot of direct or indirect factors, such as physical properties of irrigation system, irrigation technique being applied, availability of water resources, water management skill, budget available as well as some social effects. Previous studies in Naivasha project show that no formal evaluation for irrigation practices has been carried out. In some researches, water use for irrigation was mentioned. For example, the research of Huatuco 1998, indicated the differences between declared water use for irrigation by farmer for 5 main types of crops growing in the region and theoretical water demand, in most case, were unbalanced. The over use of water in irrigation was reported but the irrigation efficiency was not mentioned in her research.

Ahmah Salah (1999) showed that applied irrigation was almost double compared to the actual evapotranspiration (table 1-2 page 10 in his thesis). Theoretically, crop evapotranspiration is mainly used to evaluate crop water demand. Total crop water demand depends on additional 'demand' for soil evaporation and losses due to irrigation management.

By the fact that actual evapotranspiration in the research area is very high compared to the precipitation, irrigation is the only way to develop agriculture in this area. In the scene of competing water use in this area as mentioned by Ahmad Salah (1999) there is still the gradual increase of land under irrigation. (See figure 2.1 bellow)

Figure 2.1: Table of area under irrigation from different years.

Year	Area under irrigation (ha)	% of total catchment area	Source from
1988	981.8*	0.298	Huaccho Huatuco, 1998
1997	3445 * 7353**	1.05	Huaccho Huatuco,1998
1998	4568**	1.37	Ahmad Salah, 1999
2000	5031**	1.53	Sayeed Ahamad, 2000
2000	4805**	1.46	Dao Viet Dung 2000

Note: * Area declared by farmers
** Area obtained from satellite image interpretation

- Total area of the Naivasha catchment is 329,211 ha (source from Ahmad Salah, 1999).

The differences are due to the different time of data collection and other factors. For example, interpretation from satellite image often aggregates non agriculture land (resident or office area) into surrounding agricultural land as they appear as very little pieces in the image or even disappeared due to the image resolution.

Over use of water in irrigation (although some modern techniques such as drip and sprinkle are considerably applied) have serious negative impacts sooner or later on the water resources (surface and groundwater) and as well on the lake water level.

2.2 The application of GIS and remote sensing in water resources studies and irrigation efficiency evaluation

“Remote Sensing has already been in use for more than a decade and many applications, trails and pilot experiences have been carried out in the field of irrigation and drainage”. That is the first sentence of the Preface of the Water Report 4 document titled: “Use of remote sensing techniques in irrigation and drainage”, FAO 1995. The summary and conclusions on the applicability of Remote Sensing in irrigation and drainage were drawn up.

Three main sections of irrigation and drainage for remote sensing application are 1) Planning and Identification of irrigation potential, 2) Management of irrigation systems and 3) Drainage and salinity monitoring and control. In more details, GIS and Remote sensing can be applicable in groundwater potential assessment, evaluation and planning of surface water resources, irrigation potential assessment and evaluation of economic impact of irrigation, mapping of irrigated surfaces (at national, regional and local levels), land use mapping, irrigation systems management, in hydrological models, flood modeling etc. In many specific cases, they can be used to detect the waterlog area and set dam site location

The advantages of GIS and remote sensing applications stated by many experts are the cost effective and less time consuming.

RS data can be used in one hand effectively to detect the irrigated land and in the other hand to evaluate water balance, evapotranspiration of cropping area. It is foreseeable that estimates of seasonal evapotranspiration for a region can be made using remotely sensed data (Bastiaanssen et al, 1999)

These days, in many countries, crop type inventories are based on a combination field observation and remote sensing. Normalized Difference Vegetation Index (NDVI) is most likely used in crop classification, as it is a sensitive indicator of reflectance from different crop type and their growing conditions.

Effective water resources management increasingly calls for integration of these technologies with hydrologic modeling (Tim, 1996). Bastiaanssen et al. (1998) provides an example of integrating satellite remote sensing and GIS with hydrologic models. That was the case study for performance assessment in Sirsa Irrigation Circle, India, where multi-temporal satellite images supplied by Indian Remote sensing Satellite (IRS-1B) were use to identify the agricultural conditions in research area during 1995/1996. NDVI was computed to obtain vegetation density and crop yield in comparing between crop cuts and NDVI values for different crops. The Hydrologic model applied in this research was model package FRAME in order to compute water balance, ground water, surface water allocation and drainage. Finally, GIS was employed to integrate remote sensed data, output from hydrologic model and field data. GIS was used in analysis of results. (Refer to report 27, IWMI)

GIS and Remote sensing are being used effectively to acquire data input (such as landuse map, area of interest, DEM, land surface temperature,…) for many computer models like SWAP, WMS-Watershed Modelling System, AHAS, DUFLOW, AGNPS.

Multiyear satellite data have been analysed to provide spatially distributed information on irrigated area, cropping pattern. This spatial and temporal information has helped analysts evaluate the performance of the agricultural system over several years and across the irrigation scheme. With improvements in remote sensing technology, even more detailed analyses will be possible. Currently, water consumption from irrigated areas can be estimated for single days (e.g., Roerink et al. 1997).

Space-borne remote sensing measurements can provide regular information on agricultural and hydrological conditions of the land surface for vast areas.

"However, even though considerable progress has been made over the past 20 years in research applications, remotely sensed data remain underutilized by practicing water resources managers". The reasons for under-utility of remote sensed information in irrigated agriculture are: first, the researchers have influence on sensor design and flight characteristics and second, water managers and policy makers are quite often unaware of new technical possibilities[1].

2.3 Application of SWAP model.

SWAP module is the software developed by DLO Winand Staring Centre and Wageningen Agricultural University in 1997-1998. SWAP has been developed from the agro-hydrological models SWATRE (Feddes et al., 1978; Belmans et al., 1983) and SWACROP (Wesseling et al., 1991; Kabat et al., 1992) and some of its numerous derivations, e.g. SWASALT for salt transport (Van den Broek et al., 1994) and FLOCR for shrinking and swelling clay soils (Oostindie and Bronswijk, 1992). For years the need was felt for a new model base version, which took advantage of the experiences gained with the existing SWATRE versions. This model integrates water flow, solute transport and crop growth according to current modeling concepts and simulation techniques.

It includes a more versatile numerical solution of the Richards' equation, incorporation of solute and heat transport, attention for soil heterogeneity, shrinking and swelling of clay soils and water repellency, coupling to the detailed WOFOST crop growth model, extension with regional drainage at various levels, and interaction with surface water management. In this way SWAP offers its users a whole range of new possibilities to address both research and practical applications in the field of agriculture, water management and environmental problems. Examples include design and monitoring of field irrigation and drainage systems, surface water management, soil and groundwater pollution by salts and pesticides and crop water use and crop production studies.

SWAP or its predecessor SWATRE model has been widely applied in the world with different purposes as mentioned in table 2.2:

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[1] Refer to the paper: "Remote sensing for irrigated agriculture: examples from research and possible applications". (W. Bastiaaansen et al, 2000)

Source	Country of study	Purpose
Boers et al. (1986)	Israel	Water harvesting
Ragab et al (1990)	Germany	Crop water consumption
Feddes and Bastiaanssen(1992)	Egypt	Sprinkle irrigation scheduling
Kabal et al. (1992)	The Netherlands	Crop production
Kumar and Bastiaanssen(1993)	India	Irrigation efficiency
Bastiaanssen et al.(1994)	India	Irrigation and drainage
Huygen et al. (1995)	Southern Europe	Irrigation scheduling
Menneti (1995)	Argentina	Rainfall runoff
Beekma et al. (1995)	Pakistan	Water logging and salinity
Singh (1995)	India	Groundwater recharge from irrigation
Kumar (1995)	India	Reuse of drainage water
Van Dam and Feddes (1996)	Pakistan	Irrigation and drainage improvement
Bastiaanssen(1996)	Argentina/ Egypt	Calibration of soil physical characteristics
Groen et al (1996)	The Netherlands	Pesticide fate

Figure 2.2: Table of SWAP worldwide application (after Bastiaanssen et al. 1996)

Some recently applications of SWAP are:

- Estimating actual evapotranspiration using a detailed agro-hydrological model, by P. Droogers, 2000. The research was carried out in Gediz basin in western Turkey.
- Exploring field scale salinity using simulation model, example for Rudesht area, Esfahan Province, Iran- by P. Droogers et al, 2000.

With the integrated output of the model, in the scope of this research, the most important output are evapotranspiration, soil water flux and irrigation requirement, it can be used for evaluating the irrigation efficiency in the research area when comparing with actual irrigation application of farmers.

From the output generated with different options or input scenarios, the model user can give suggestions on effective water use in the field. For example, with certain type of soil and certain type of crop, how much water the farmer should supply and at what time. Or the suggestion on what kind of crop more suitable to the soil condition is possibly given.

One constraint for the model is that a lot of detailed data are needed. For instant, daily meteorological data for the model are compulsorily required while we know that in many cases they are hard to get.

One of very good example of the use of SWAP is the: “Analysis and recommendations for integrated on-farm water management in Haryana, India: a model approach”, where the SWAP model application coupling with GIS, Management Decision Support System tools was used to give the recommendations for future on-farm water management.

In the research area at Lake Naivasha, SWAP model was used in the study of Jolicouer (1999) for groundwater quality study.

2.4 *Application of CROPWAT model.*

CROPWAT for Windows is a program that uses the FAO (1992) Penman-Monteith method for calculating reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations.

The program uses the same Penman-Monteith methodology as used in CROPWAT versions 5.7 and 7.0 and uses the same data such as the CLIMWAT climate and rainfall data files.

In CROPWAT the monthly ETo is converted into daily values. CROPWAT for Windows accepts monthly average climate/ETo data only. For crop water requirements (CWR) and irrigation scheduling purposes, the monthly ETo has to be distributed into equivalent daily values. This is maybe sometimes unreasonable, as the rainfall is not uniformly distributed throughout the month. But it may give the more simple way to calculate evapotranspiration and it require less detailed rainfall data. As meteo data for CROPWAT are based on monthly basic that can accept some data missing in daily records which is the case in SWAP.

Review previous researches in Lake Naivasha project, CROPWAT model has not yet been applied in any study.

In this thesis, CROPWAT is used to compare the results of crop water requirement generated from SWAP model.

3 STUDY AREA

The contents:

3.1 Location

Lake Naivasha is located 100 km Northwest of Nairobi in the Naivasha Division of Nakuru District, Rift Valley Province, Kenya (Map 2.1). The centre of the lake is at latitude $00^0$46'S and longitude $36^0$22'E. It is within the UTM zone 37. Its boundary coordinates are X_{min} 190000, Y_{min} 9907000; X_{max} 221000, Y_{max} 9934000. Altitude is around 1900m. (see map 3.1)

The target area for research is the agriculture area surrounding the lake, where irrigation takes place. (Xmin, Ymin: 183000, 9903000; Mmax, Ymax: 2202000, 9934000)

The water surface of the lake covers the area of about 130 km2 with the average depth of 4m. The lake receives 90% of its discharge from Malewa, Gigil rivers and some seasonal streams as well as the recharge from ground water flow.

By the fact of topographic condition, the lake itself is as the bottom of the pan that collects almost surface and groundwater in the catchment of study area. It becomes the most important water sources for all social and economic activities in the area. The wildlife, flora and fauna in the area also depend on the lake-water.

3.2 Climate conditions

The climate is humid to sub-humid in the highlands and semi-arid in the rift valley. The mean monthly maximum temperature range between 24.6°C to 28.3°C, and mean monthly minimum temperature between 6.8°C and 8.0°C. The average monthly temperature ranges between 15.9°C and 17.8°C. The lowest and highest temperatures during a day happen at 6.00 to 7.00hrs and 14.00 to 17.00hrs, respectively.

Rainfall has spatially an unequal distribution with average annual rainfall ranges from about 1300mm in Kinangop plateau (South Kinangop Njambini) to about 600mm around Lake Naivasha. The rainy seasons are typically from March to May (sometimes June) and October to November. From March to May it is the main rainy period, while short rains occur during October-November. Generally, rainfall is measured. Dry season happens from December to February.

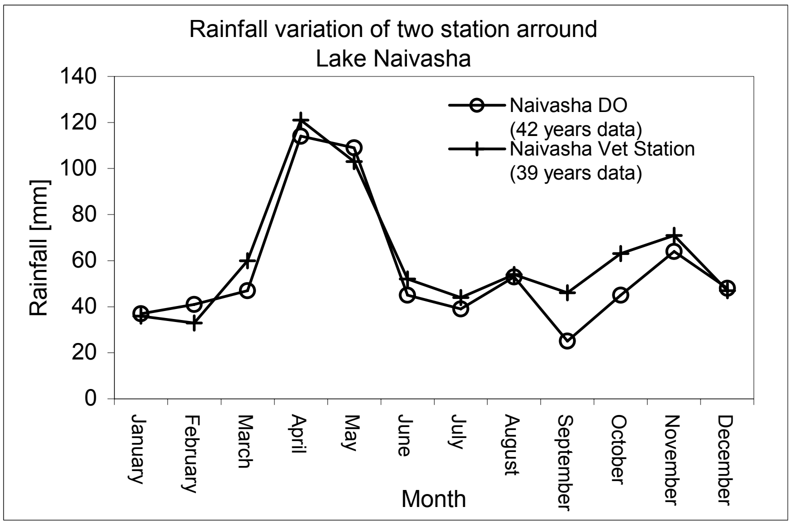

Figure 3.2: Rainfall variation of two stations around Lake Naivasha (source: Ashfaque,1999)

The evapotranspiration around the lake is about 1360mm a year which clearly far exceeds the rainfall and create some deficit for plant growing. (From Hamadudu, 1998).

The climate data collected from some weather stations located around the lake shows that the area is strongly effected with strong wind, long sunshine hours (5-6 hours a day in average) and low humidity during the day (40%-60%). That causes the main reason of high evapotranspiration in the research area.

3.3 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 about surrounding the lake shore which gain from the location advantage to be close to the water resources and available of groundwater.

3.4 Soil, land use and irrigated crop types

3.4.1 Soil

In the past, some soil surveys have been carried out in the area, with different level of detail. According to Siderius (1980) the distribution of soils in the area is 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 two: soils developed on the Lacustrine plain and those developed on the volcanic plain.

Soils developed on the Lacustrine plain are moderately well drained to well drained, very deep, very dark greyish brown to pale brown, clay - clay loam to loam. This type of soil is found in the north-Northeast part of the lake.

Soils developed on the volcanic plain are well drained, moderately deep to very deep, dark brown to pale brown, 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, Ocerian farms)

The testing results from soil samples collected from the fieldwork show that soil type in the Northern part of the lake is mainly silty clay to silty clay loam while in the southern part, where main farms for rose growing are found, 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 they have rather high infiltration. Refer to the infiltration tests conducted during the fieldwork in the different location around the lake presented in the table 4.5:

Figure 3.1: Map of the research area location.
(source: http://www.blissites.com/kenya/map.html and False colour composite TM2000 band 432)

3.4.2 Landuse

The following landuse types can be identified in the research area:

1) Resident area
2) Agriculture land (horticulture, vegetable and flower growing),
3) Range land (dairy)
4) Natural vegetation (include forest),
5) The lake and
6) Out crop rock.

The map of land use around the lake is acquired from satellite image TM May 2000 by visually interpretation from false colour composite raster map band 4,3 and 2 in corporate with field check. Comparison of land uses with previous study shows some extension of agriculture land around the lake. (See the map below).

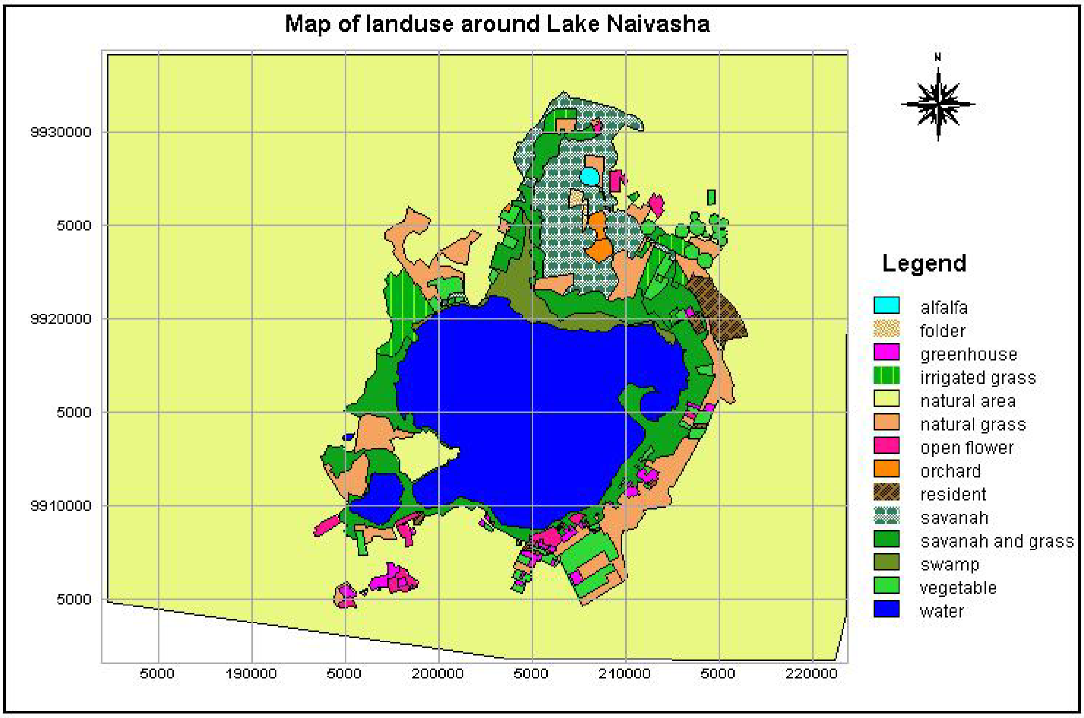

Figure 3.3: Map of Land use around Lake Naivasha interpreted from TM2000 and field check

A comparison was made between the image taken in 1995 and the image 2000. It shows that there are many changes during that period, especially regarding the agriculture land. There is the considerable expansion of flower and vegetable-growing area due to the change in market oriented production. The clearest changes between 2 images are the appearances of ThreePoint Farm for vegetable cultivation and Sher farm for roses growing in image TM 2000 but not in the image TM 1995.

There is a considerable large area around the lake for natural reservation and recreation. Many kind of wide life have been protected in this area such as Hippo, Giraffe, Zebra, deer, elephant, monkey and many types of bird. This area has the main land cover of Savanah forest, grass and bushes. Tourist activities take place in this area.

The lake itself with the water surface of more than 130 km^2, beside the role of supplying water for agriculture and domestic purposes, is the resource for fishery industry, wildlife reservation and environmental regulator.

Settlement is mainly concentrated in Naivasha town but homes and villages are scatteredly found on estates within the study area. Horticulture and flower growing is concentrated around the Lake. Vegetable and dairy farming is practised on large estates mainly in the Northeast shores of the Lake. The natural vegetation surrounding the Lake is mainly papyrus swamp vegetation and grass. Natural vegetation outside of the Lake surroundings is shrub, acacia and cactus trees.

Craster Lake, a natural reserve area

Wide life in reserve area around the Lake

Figure 3.4: Nature around Lake Naivasha

3.4.3 Crop cultivated around the lake

As partly mentioned in the Landuse paragraph, some main crop types can be taken into account such as flower (mainly roses) grown inside and outside the greenhouses, vegetable (cabbage, French bean, baby corn, garden peas…), alfalfa, wheat and grass.

Flower is one of high benefit crop type that attracts farmers to change their landuse from other type of crop to flower cultivation. Most of those farmers are rich. They can afford to grow flower (mostly are roses for European market) in greenhouses. These area of flower are found mainly in the southern part of the lake shore where the farmers can obtain available water for irrigation directly pumped from the lake Naivasha. Some typical big flower farms are Sulmac, Oserian, Sher, Flamingo farms.

The areas under irrigated vegetable are mainly located on the northern part of the lakeshore and some small fields in the southern part as well. They are also the big farms with cultivated land of some hundreds to a thousand ha. Vegetable in these farms is irrigated by either sprinkle or drip irrigation. In some farms (for example Three-Points, Delamere) the central pivot sprinkles have been applied for the last couple of years. The advantage of the farms in this area is that they can get water for irrigation from boreholes with very high discharge (up to 240 m3/hr-stated by Three Points Farm owner).

Beside the big farms for flower and vegetable, there is a diversity of landuse around the lake. Some crops with small portion have been seen around the lake as onion, sunflower, alfalfa, tomato, broccoli, Brussels sprouts, carrot, chili, egg plant…

A big farm for wheat growing is found in the western part of the lake, which obtain water from some springs in this hilly area. There are also some farms for dairy and cattle meat production with large grasslands (for instant the Delamere farm).

The area of landuse have been obtained from landuse map (shown in figure 3.3) by histogram calculation of polygon map landuse. The results are presented in the following table:

Land use	**Area (ha)**
Alfalfa (irrigated)	85.0
Flower (irrigated)	1169.9
Grass (irrigated)	1290.8
Lake	13247.9
Natural grass	4486.4
Orchard (irrigated)	242.9
Resident area	763.3
Savanah	3619.3
Savanah and grass	5696.1
Swamp	1186.5
Vegetable (irrigated)	1911.2
Wheat (irrigated)	105.9
Irrigated land:	***4805.8***

Figure 3.5: Table of landuse from the satellite image TM 2000 interpretation and fieldwork 9/2000.

The areas of landuse presented in above table are particularly based on field observations. Some differences of actual landuse and those obtained from the satellite image TM May 2000 can be found due to different time of data acquisition. For example, some new greenhouses have just recently built that were not appeared in the satellite image. Or some parts of land were in land preparation, which appeared as bare soil in the image, now are under agricultural production.

In irrigated agricultural land, many kinds of crop are growing but due to the market orientation, the large portion of main crops are flower and vegetable which most of their products are sold to European market and small portion for local consumption.

3.5 Water use in irrigation around the lake:

As mentioned above that water resource for irrigation around the lake is either from the Lake Naivasha or from boreholes.

Due the fact that farm owners can extract water for irrigation as much as they want, so in many case the farmers do not care much about how much water to be used or in the other word, they don't know exactly how much water is delivered on their field (or they do not want to show their real extraction volume!!!). In those cases, irrigation efficiency is hard to evaluate.

Some big farms where central pivot or drip irrigation are applied, the irrigation seems having a better control as the operators simply set the irrigation rate in the computerised control system or control box of the pivot.

Some following pictures show the main type of irrigation in agriculture production in research area.

Drip irrigation for roses in green house at Oserian Farm

Central pivot for cabbage irrigation at Three Points Farm

Sprinkle Irrigation for grass at Delamere farm

Sprinkle Irrigation for onion

Figure 3.6: Main irrigation type for vegetable and grass around the Lake.

Following the research objectives and methods used using modelling, data collection, crop water requirement and evaluation of irrigation practice around the Lake will be carried out in the following chapters.

4 DATA COLLECTION AND ANALYSIS

Contents:

4.1 Introduction

Primary data:

This is related to the data that have been collected from the fieldwork at Lake Naivasha project, in September 2000.

The primary data collection consist of:

- Ground check of land cover for satellite image
- Acquisition of meteorological data
- Preparation of landuse maps of some main farms
- Identification of crop type, crop feature and crop calendar.
- Soil information around the Lake
- Infiltration tests
- Soil samples collection
- Drainage system in the field
- Irrigation practice for some main types of crop of some main farms around the Lake
- Evident pictures.

Secondary data:

Those are the data collected from literature, from previous researches, from the other MSc students going on the fieldwork at the same time and in the same research area.

They are:

- Topographic maps of East Africa (Kenya) scale 1/50 000 and published in 1975 by Kenya Government, which cover the whole research area.
- Satellite image TM 2000 taken on the 18th May 2000, it includes of 7 bands in digital format.
- Landuse map for fieldwork was taken from Luisa thesis as a reference.
- Soil information is taken from previous studies (Joliceour, 1999 and Siderius,1998)

4.2 ***Meteorological data***

According to SWAP model data requirement, daily base meteo-data have to be collected.

The components of meteo-data set on daily bases must include radiation, minimum and maximum temperature, relative air humidity, wind speed at 2 m above ground surface and rainfall.

Unfortunately, no weather station around the Lake has a complete data set as required. The possible collection of meteo-data was from Sulmac automatic weather station and from manually recorded data from weather station of Ocerian Farm, which are located about the Lakeshore in the southern part of the Lake. There are also some other weather stations around the catchment of the Lake Naivasha that can provide some sort of meteo-data, but in most of the case, only rainfall and temperature data are available.

The data collected from Sulmac farm in digital format provide temperature (^{0}C), humidity (%), wind speed (mile/h) every 10 minutes from 10th October 1999 to 19th September 2000. While the data supplied by Ocerian farm are rainfall (mm/day), Pan evaporation (mm/day), humidity (%) and temperature (^{0}C) on daily basis from 1997 to September 2000.

No radiation data are available for the same period with data from Sulmac and Ocerian farm.

Judgements and corrections for meteo-data set:

In order to complete a full data set for SWAP model, all data available were verified and necessary combination of data from different sources into one was made.

Geographically, Sulmac and Ocerian farms are located in the southern lakeshore about 7 km apart. So, meteo-data from these 2 farms are combined into one complete set for SWAP model data input file. This file includes of temperature, humidity, wind speed from Sulmac data set and rainfall from Ocerian.

Some adjustments and corrections have been made in data processing. For example, in data collected from automatic weather station of Sulmac farm, some data were missing at different hours of the day or even in a couple of days.

For the missing data in different hours of a single day, data components are corrected following the trend of each component during a day. For instant, temperature would be minimum from 6.00 hrs to 7.00 hrs in the morning and reach the maximum about 14.00 to 15.30 hrs. While in opposite, air humidity get maximum in early in the morning and minimum during 14.00 to 16.00 hrs in the afternoon. The graphs in annex 4.3, 4.4, 4.5 show the typical trend of temperature, humidity and win speed during the day of the research area.

In the data set from Sulmac farm, no rainfall data are recorded but they are available from Ocerian farm.

Humidity data are available in both data set, but the one from Ocerian seems a bit high in contrast with very dry condition of the research area. This may be explainable that the weather station is located in the area with good coverage of grass and usually irrigated during the daytime or because of the effect from Pan A evaporator as the humidity recorder is installed very close to it.

The solution for lacking radiation data is to calculate it using temperature (Tmax and Tmin), geographic features (latitude, longitude, altitude), humidity, Julian day and some equations from “Crop Evapotranspiration”, FAO paper 56. (See annex 4.1, 4.2: Spreadsheet of daily solar radiation- only one part of calculation is presented).

Note that the period October 1999 to September 2000 was a very dry. The rainfall records from Ocerian farm result 394.7 mm compared to the average year rainfall of 667 mm (after Ashfaque,1999)

4.3 Soil properties from fieldwork

Input of SWAP model requires some soil properties for its computation. They are soil type, hydraulic conductivity, soil texture, soil structure and soil moisture contents.

Procedure:

In order to measure the hydraulic conductivity of the topsoil layer, double-ring infiltration method was used. This method converts the depletion rate of water to be filled inside the rings versus time of measurement into infiltration rate (hydraulic conductivity, cm/day). Those tests were carried out on different field of vegetable growing in some main soils around the lake.

The infiltration tests were conducted in the field until the infiltration rate reached the steady state (that value will be used in SWAP model).

As the root system of the most vegetable types appear in the soil depth of less than 50 cm so the layer lower than that depth is considered homogenous and invert auger method was applied for that layer.

For the hydraulic conductivity of the sub soil layers, the inverse auger method was used. Refer to the method instruction in the (Booker tropical soil manual, 1991).

In order to estimate the soil type and soil texture at the location where infiltration tests were conducted, un-disturbed soil samples were taken at different depths (15, 30 and 50 cm).

Figure 4.1: Picture of soil infiltration test and soil sample collections were conducted during the fieldwork in the vegetable field, September 2000.

The location of infiltration test, invert auger test and soil sample taken are presented in the table and the map below:

Farm	Type of landuse	X	Y	Type of measurement
3 points	Cabbage	213490	9924978	Infiltration, Invert auger, Soil sample
	French bean	214825	9925518	Soil sample
Delamere	baby corn	214568	9922948	Infiltration, Invert auger, Soil sample
	grass	211959	9923323	Infiltration, Invert auger, Soil sample
Sher	Roses	205091	9908531	Infiltration, Invert auger, Soil sample
Oserian	Open flower	197520	9905742	Infiltration, Invert auger, Soil sample
Sulmac	Grass land	207718	9906308	Infiltration,

Figure 4.2: Table of measurements taken from the fieldwork September 2000.

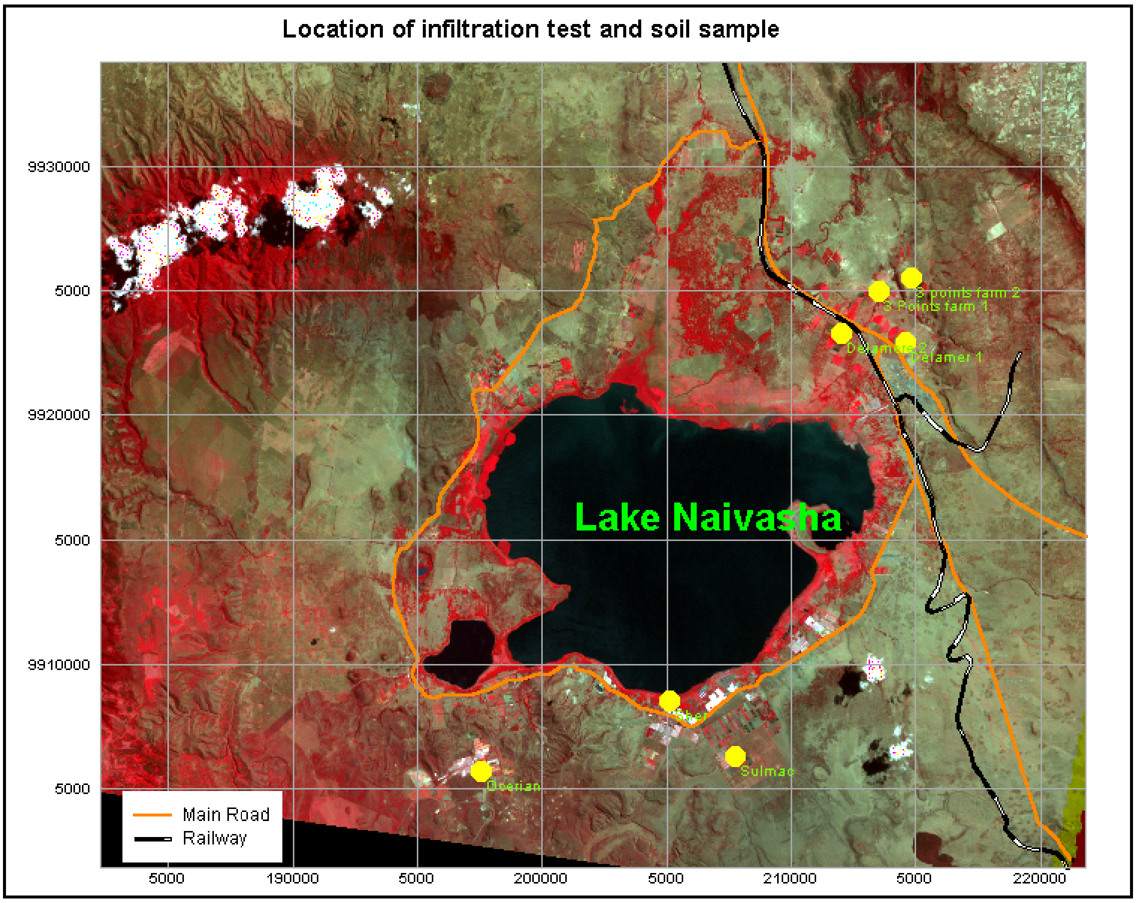

Figure 4.3: Map of the location where infiltration tests, soil samples were taken (background colour composite map, May 2000)

Soil moisture content was measured in-situ instantly before and after infiltration test by theta meter to evaluate instant and saturated moisture contents.

Soil structure was obtained by observing soil profile using auger with the depth about 1m.

Results:

The results show that the infiltration rates of soils around the Lake are much higher than the same soil type defined in the SWAP theory manual. See the graph below:

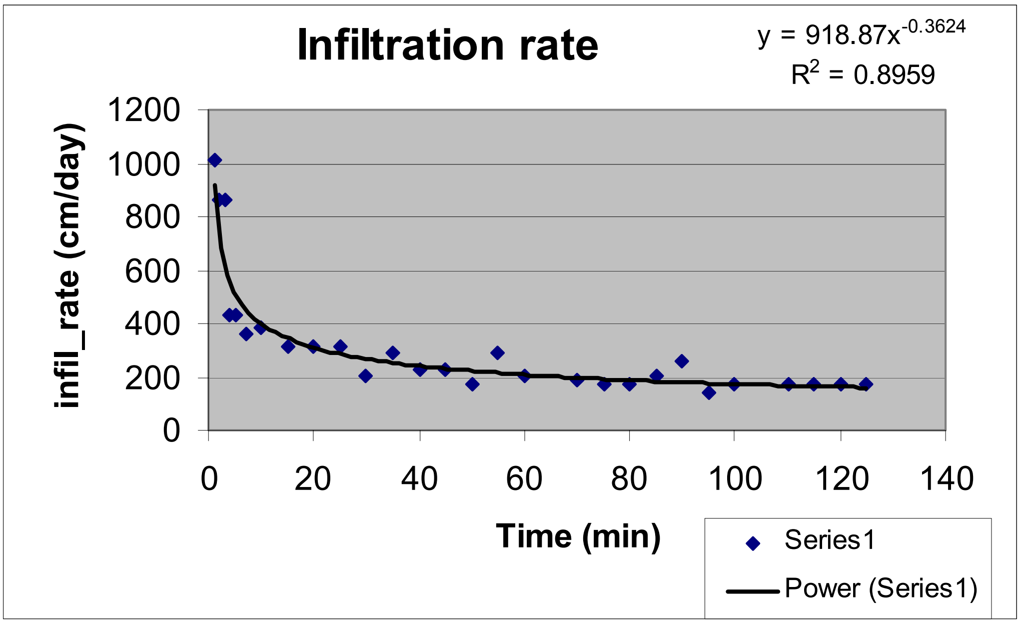

Figure 4.4: Infiltration test for top soil layer conducted at Baby corn field of Delamere Farm

The results from invert auger test also show high values of hydraulic conductivity of sub soil around the lake.

The soil types were estimated from soil samples taken from the field by feeling method. The processing for soil classification by feeling method is presented in Annex 4.6.

Soil texture can be obtained from soil sample analysis from the laboratory. Unfortunately, the soil samples could not be analysed in time. To solve this problem, soil data analysis from Joliceour (1999) for the soil in Threepoint Farm and from Soil survey conducted in 1998 by W. Siderius, are taken for data input of the model. The percentages of sand, silt and clay are then compared to the USDA soil triangle and estimated for the soil group.

Note that, soil residual moisture of each soil type can not measure directly from the field. It is then taken from SWAP manual.

The results of soil property measurements are shown in the following tables:

Farm	Depth range (cm)	Saturated hydraulic conductivity (cm/day)	Soil types
Delamere	0-30	172.8	clay
(Baby corn field)	30-150	39.7	clay loam
Delamere	0-30	172.8	clay
(grass land)	30-150	238.5	clay loam
Three Points	0-30	144.0	clay
(cabbage field)	30-150	198.7	Clay loam
Oserian	0-30	172.8	Sandy loam
(open flower field)	30-150	159.0	Sandy loam
Sher	0-30	201.6	Sandy loam
(open rose field)	30-150	159.0	Sandy loam
Sulmac	0-30	345.6	
(dried grass land)	30-150	No measurement	

Figure 4.5: Results of saturated hydraulic conductivity and soil types from fieldwork measurements.

Farm	crop type	Soil type	depth of sample (cm)	% of sand	% of silt	% of clay	Org. cont.	θsat cm3/cm3
3 points	*Cabbage*	Clay	*40*	28	30	42	0.02	0.44
		Clay loam	*80*	35	34	31	0.006	0.42
		Loam	*150*	38	37	25	0.0045	0.42
Oserian	*flower*	Sandy loam	*40*	55	31	14	0.0042	0.42
		Sandy loam	*200*	70	25	5	0.0036	0.42
Sulmac	*Vegetable*	Sandy loam	*20*	64	24	12	0.0087	0.42
		Sandy loam	*50*	74	16	10	0.005	0.42
		Sandy loam	*120*	68	27	5	0.005	0.42

Figure 4.6: Table of soil texture (after Joliceour,1999 and W.Siderius,1998).

4.4 Crop data and crop features

Only some main types of crop have been chosen for irrigation evaluation. These are the crops having a big portion in total irrigated area of the research area. The crop types that were selected for this research are: baby corn, cabbage, French bean, garden peas, irrigated grass and the type of irrigation is sprinkle.

Crop types data are obtained from records, interviews with farm managers or related farm officers and field visits and field measurements.

The satellite image TM 2000 has been used to differentiate land cover and to choose sites during the fieldwork.

Crop features considered as crop parameters were measured directly from the field. They include crop height, root depth, root density, interception, soil cover fraction and root water uptake by crop in different development stages. These parameters are the function of the maturity stages and the function of depth.

Crop growing time is considered of 4 development stages. Each stage is about 3 and half weeks. Total length of crop cycle for vegetable is around 100 days and crop features have been measured according to crop development stages.

Grass is an annual crop and its height and root depth is considerably the same for the whole year round.

The results of crop feature measurements are presented in the following tables:

Cabbage				
Development Stage	Root depth (cm)	Root wide (cm)	Height (cm)	Soil Cover (%)
DVS 1	8	8	12	10
DVS 2	10	20	22	30
DVS 3	13	22	30	70
DVS 4	16	25	30	80

French Bean				
Development stage	Root depth (cm)	Root wide (cm)	Height (cm)	Soil Cover (%)
DVS 1	5	4	5	5
DVS 2	15	20	15	15
DVS 3	25	30	30	50
DVS 4	35	40	35	55

Garden Peas				
Development stage	Root depth (cm)	Root wide (cm)	Height (cm)	Soil Cover (%)
DVS 1	8	8	10	10
DVS 2	10	10	25	20
DVS 3	16	20	55	75
DVS 4	20	30	70	90

Grass				
Development Stage	Root depth (cm)	Root wide (cm)	Height (cm)	Soil Cover (%)
DVS 1	60		5	100
DVS 2	60		5	100
DVS 3	60		5	100
DVS 4	60		5	100

Baby Corn				
Development Stage	Root depth (cm)	Root wide (cm)	Height (cm)	Soil Cover (%)
DVS 1	8	15	6	0.5
DVS 2	20	32	40	40
DVS 3	30	35	160	90
DVS 4	35	40	250	80

Figure 4.7: Crop features for different crop types collected from fieldwork, September 2000.

4.5 Irrigation practices

As mentioned above, sprinkle irrigation has been chosen for evaluating irrigation efficiency. Although drip irrigation is also applied in this area but due to the limits of time, technique and equipment, it is only mentioned and not used in the model. Drip irrigation is applied in some big farms for roses and flowers except the case of Sulmac farm where drip irrigation is applied for vegetable as well.

In the dry area like Naivasha, drip irrigation may be the best solution of water supply for irrigated crop. But due to the high investment and high technological requirement in operation, maintenance and management it can only be afford in some rich and big farms where high value crops are grown.

Actual irrigation applications in some big farms were obtained by interviewing the farm owners or farm managers and operators.

Sprinkle irrigation is mainly applied for vegetable, grass, and alfalfa. Central pivots are now preferably use in big farms such as Three Points Farm, Delamere Farm, Marula Estate, Loldia Farm. Those farms are located in the northern part of the Lake where irrigation water can be sufficient from groundwater resource.

Central pivots take water from groundwater and operate under programmed schedule. In one pivot, some different program can be set for different angles where growing different type of crop or different development stages. In fact sprinkle irrigation schedule is often simply set at certain amount for the all types of crops under irrigation in the same field. For example, in Three Points

Farm, irrigation schedule of pivot was set at 10mm in every 2 days or 15 mm in every 3 days in case of Delamere Farm.

Following irrigation applications for some vegetable were obtained from farm managers and pivot operators:

Farm	Type of vegetable	Growing stage	Irrigation application
Three Point	Cabbage	Germination	12 mm/2day
		1 month	9-10 mm/2day
		2 month	7-8 mm/2day
		3 month	5 mm/2day
	French bean	Seed to germination	10-12 mm/2day
		1 month	8-9 mm/2day
		2 month	8-9 mm/2day
		3 month	6-7 mm/2day
	Garden peas	Seed to germination	10-12 mm/2day
		1 month	6-7 mm/2day
		2 month	5-6 mm/2day
		3 month	5-6 mm/2day
Delamere	Cabbage	Not mentioned	30 mm/3 time a week
	Baby corn	Not mentioned	30 mm/3 time a week
	French bean	Not mentioned	30 mm/3 time a week
	Grass		30 mm/1 time a week

Figure 4.8: Irrigation application applied for different vegetable in the northern part of the Lake

These are the 2 big farms, which apply sprinkle (central pivot) for vegetable irrigation. So their irrigation practice data are used for irrigation evaluation of this thesis.

Observation from the field shows that, in some places water was remained between rows after irrigation.

The runoff appeared on the land of outer ring of central pivot, where big drops of irrigation were applied. The cause could be either the clay soil texture or big drops of irrigation caused the soil surface blocked and water was hardly infiltrated into the soil. Consequently, the sub-soil layers, where the root system actives, have not enough moisture to supply water for crop. The symptom of this condition was the poor development condition of crops in such area compared to the crops planting in inner ring area of the pivots.

Less irrigation amount is applied whenever there is rain.

4.6 Other related data:

Additional data is needed for running SWAP model. They include the emergence time of vegetable seed, groundwater level round the Lake, irrigation water quality, and farm boundary. Those are corporately collected by other MSc students who have the same area of research and the same time. Richard Oppong Boateng provides data of groundwater level around the Lake, Sayeed Ahamad supplies his land use map base on GPS record for farm boundary and his total irrigated land area interpreted from satellite image and Janet Moncada provides data on crop type growing in some farms she had visited.

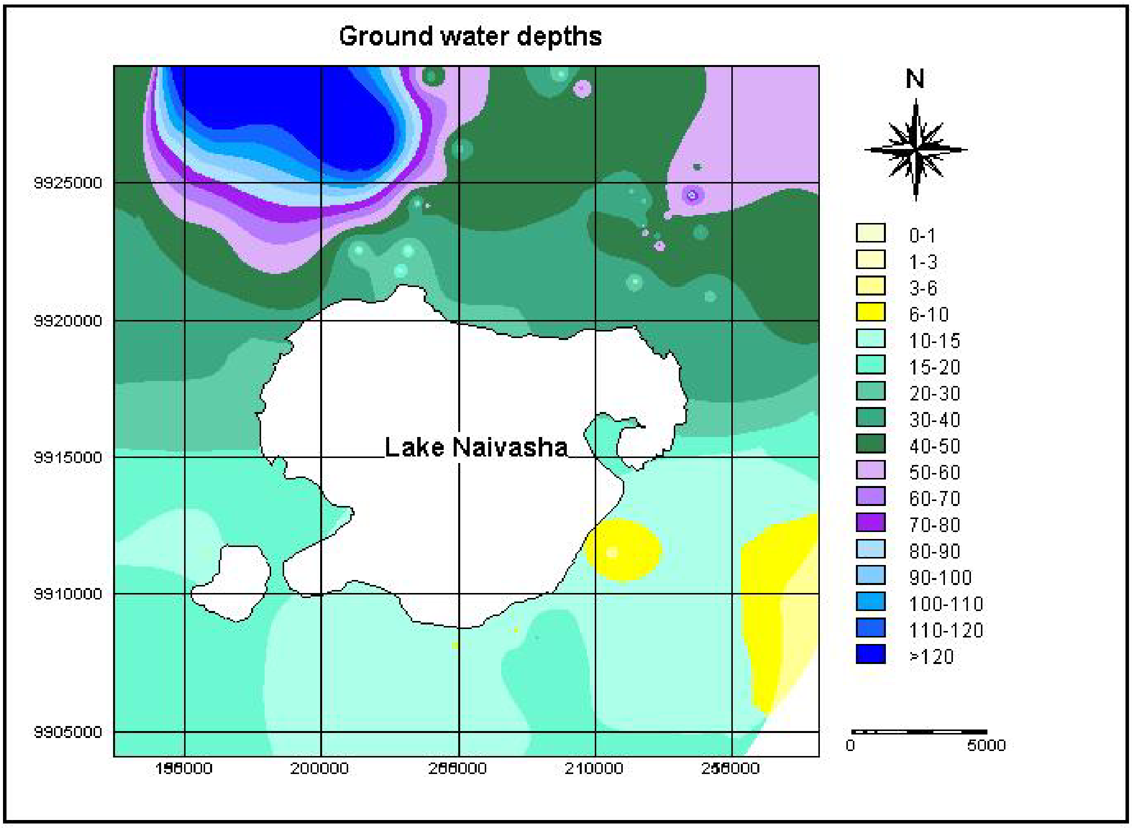

Figure 4.9: Map of ground water level in research area (Source: Oppong Boateng and Moncada, 2001)

Values in meters below surface.

4.7 Discussion on data accuracy

The unusual high values of infiltration rate for the most of soil types around the Lake Naivasha might be explained as due to the very dry condition of the sub soil layers and also because of soil properties.

The infiltration rate of Sulmac farm seems too high, perhaps, because of almost completely dry and bare soil.

Low water holding capacity of the soil can also be the cause of high infiltration rate. Beside that, low humidity during the day (40% to 60%) and strong effect of wind can speed up the evapotranspiration process in the field and quickly dry out the moisture of the top soil layer.

The appearance of runoff at the outer ring of the central pivot may lead to a question that how this problem can be solved? Pivot design improvement, perhaps?

5 Crop water requirement and irrigation evaluation

5.1 Swap model description and design

5.1.1 Introduction

As partly mentioned in the literature review of SWAP model application, this is the software developed by DLO Winand Staring Centre and Wageningen Agricultural University in 1997-1998. This model integrates water flow and crop growth according to current modeling concepts and simulation techniques. The modular program structure of SWAP offers its users a whole range of new possibilities to address both research and practical applications in the field of agriculture, water management and environmental problems.

SWAP is one-dimensional model, which can be used to compute soil water flux from climate data and irrigation data.

The interrelation between irrigation and evapotranspiration appears from the water balance, which for a one-dimensional unsaturated/saturated soil column can be written as:

$$\Delta W = P + I_{rr} + q_{bot} - T_{act} - E_{act} - E_I - E_w - R - D_r - S_t \quad (cm.d^{-1}) \quad (1)$$

Where:

W is the water storage change inside the soil with a specific depth

P is gross precipitation

I_{rr} is irrigation water supply

q_{bot} is the flux through the bottom of a vertical soil column (positive sign represents seepage, negative sign presents percolation, i.e. natural drainage)

T_{act} is actual crop transpiration rate

E_{act} is actual soil evaporation rate

E_i is evaporation of precipitation intercepted by foliage

E_w is evaporation of water eventually ponded at the land surface

R is runoff arising from delayed infiltration processes

D_r is man-induced drainage

$S_{t\ is}$ ponded layer at the land surface

Note: $P + I_{rr} - E_i - E_w - R - S_t$ equal to the amount of water being net infiltrated into soil.

The model is fully conducted for simulation of :

- Soil water flow
- Solute transport
- Soil heat flow
- Soil heterogeneity
- Daily evapotranspiration
- Crop grow
- Field irrigation and drainage
- Interaction with surface water management and regional drainage

In the scope of this thesis of simulating crop water requirement and irrigation evaluation, the solute transport and soil heat flow are excluded.

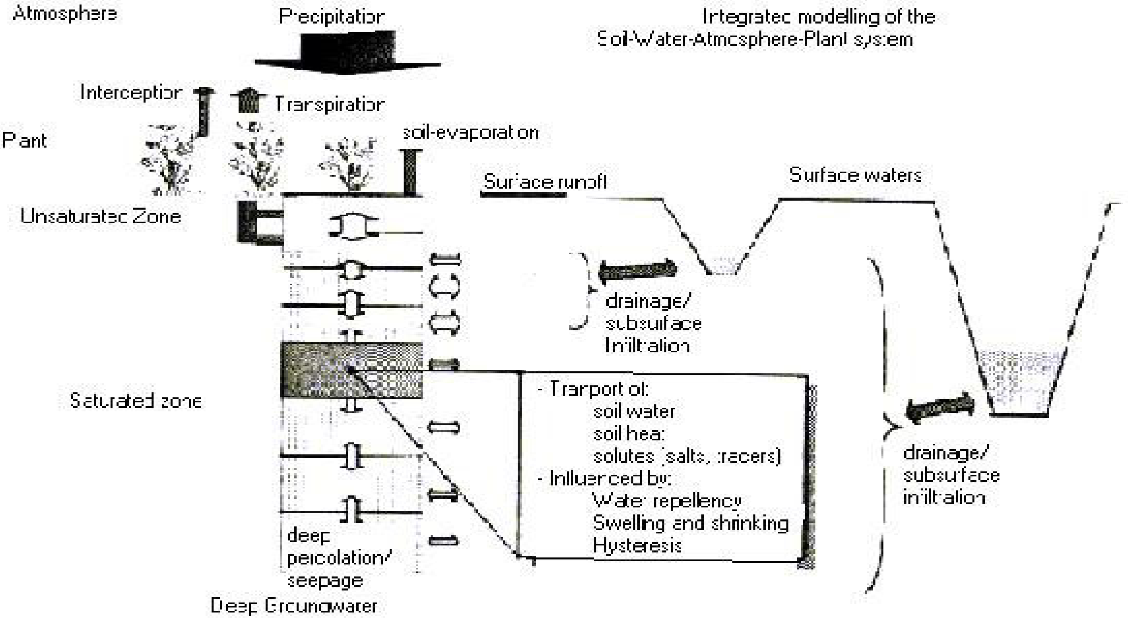

Figure 5.1: A schematised overview of the modelled system. (From User's Guide of SWAP model version 2.0)

5.1.2 Soil water flow

5.1.2.1 Soil water flow equation

Spatial differences of the soil water potential cause flow of soil water.

The well-known Richards' equation is used in simulation of soil water flow:

$$\frac{\partial\theta}{\partial t} = C(h)\frac{\partial h}{\partial t} = \frac{\partial[K(h)(\frac{\partial h}{\partial z}+1)]}{\partial z} - S(h) \qquad (2)$$

Where C is the water capacity $(d\theta/dh)$, K is hydraulic conductivity (cm/d), *h* is soil water pressure head (cm), S is soil water abstraction rate by plant root ($cm^3/cm^3/d$),

This is resulted by the combination from 2 equations: Darcy and Continuity:

One-dimensional vertical flow Darcy's equation is used to quantify this soil water:

$$\frac{\partial\theta}{\partial t} = -\frac{\partial q}{\partial z} - S(h) \qquad (3)$$

Continuity equation:

$$q = -K(h)\frac{\partial(h+z)}{\partial z} \qquad (4)$$

The Richards' equation is used for the unsaturated – Saturated zone.

5.1.2.2 Soil hydraulic function:

The soil hydraulic function presents the relationship between water content, the pressure head and the hydraulic conductivity for each distinct soil layer. There are 2 options for soil hydraulic function: one can be obtained directly from field measurement called tubular forms and the other is analytical function. In this thesis, the analytical θ(h) function proposed by Van Genuchten (1991) is applied

$$\theta = \theta_{res} + \frac{\theta_{sat} - \theta_{res}}{(1+|\alpha h|^{n})^{m}} \qquad (5)$$

Where θ_{sat} is saturated water content (cm3/cm3)

θ_{res} is residual water content in very dry range(cm3/cm3)

α (1/cm), n (-), m (-) are empirical shape factors obtained from Annex A of SWAP manual

Applying the theory on unsaturated hydraulic conductivity by Mualem (1976), K(θ) can be calculated following the equation:

$$K = K_{sat} S_e^{\lambda} \left[1 - \left(1 - S_e^{\frac{1}{m}} \right)^{m} \right]^{2} \qquad (6)$$

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 as:

$$S_e \frac{\theta - \theta_{res}}{\theta_{sat} - \theta_{res}} \qquad (7)$$

The program for estimating of the parameter values for this model was developed Van Genuchten et al.(1991). The developers of SWAP also supply a list of model parameters derived from soil samples from the Netherlands known as Staring Series. These data are to be applied in regional studies. Some limitations of Staring Series data are also mentioned.

Hysteresis is also taken into account when simulating different initial soil moisture condition.

5.1.2.3 Soil water extraction by roots

The model computes the potential transpiration rate T_p (cm/d) which 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 by:

$$S_p(z) = \frac{l_{root}(z)}{\int_{-D_{root}}^{0} l_{root}(z)dz} T_p \qquad (8)$$

Where: D_{root} is the root layer thickness (cm).

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

$$S_a(z) = \alpha_{rw}\alpha_{rs}S_p(z) \qquad (9)$$

Where: α_{rw} and α_{rs} are dimensionless reduction factors due to water and salinity stress, respectively. Water tress reduction is presented in the following figure:

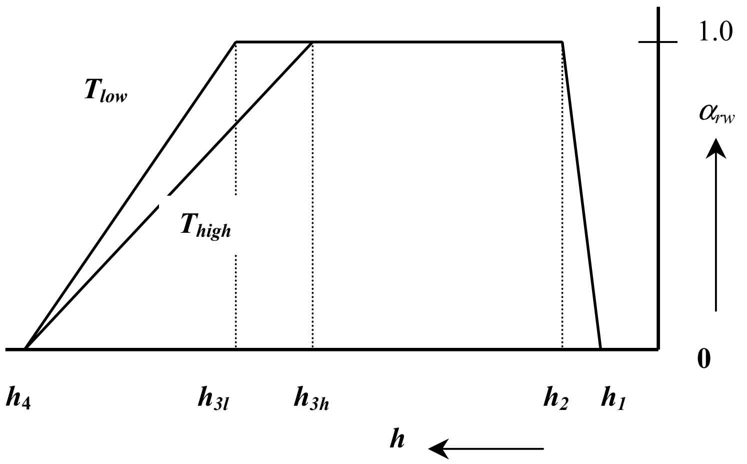

Figure 5.2: Reduction coefficient for root water uptake

α_{rw} as function of soil water pressure head h and potential transpiration rate Tp (after Feddes et al., 1978) (source: Theory of SWAP manual).

The actual transpiration rate T_a (cm/day) then can be obtained by integrated $S_a(z)$ over the root layer.

5.1.2.4 Top boundary

The top boundary condition is important for accurate simulation of changing soil water fluxes near the soil surface. The model will generate surface runoff in case of intensive rain shower or flood occurs. SWAP applies the procedure to select between flux and pressure head controlled top boundary according to the saturation level of topsoil layer.

5.1.2.5 Bottom boundary

This part of SWAP is applied to cumulate drainage possibility of the soil in unsaturated zone or in upper part of saturated zone. The bottom boundary defined by user will effect the local or region groundwater flow.

SWAP offers eight options to prescribe the lower boundary condition that users can apply them in the real condition. In this study, a free drainage to the deep groundwater level is assumed.

5.1.3 Soil heterogeneity

This part relates the spatial variability of soil hydraulic functions. Due to the huge amount of physical soil data required for an area, that is generally not feasible in practice, the similar 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 that describe the reference curve and a set of scaling factors have to be inserted.

5.1.4 Daily evapotranspiration

The well known Penman-Monteith equation is used to estimate evapotranspiration.

$$\lambda_w ET_P = \frac{10^{-4}\Delta_V(R_n - G) + 8.64*10^6 \rho_{air} C_{air}(\theta_{sat} - \theta_{act})\frac{1}{r_{air}}}{\Delta_V + \gamma_{air}(1 + \frac{r_{crop}}{r_{air}})} \qquad (10)$$

Where:

λ_w is the lateral heat of vaporisation (J g^{-1}), ET_p is the potential transpiration rate of the canopy (cm/d), R_n is the net radiation flux at the canopy surface (J m^{-2} d^{-1}), G is soil heat flux (J m^{-2} d^{-1}), ρ_{air} is air density (g/m^3), C_{air} is the heat capacity of moist air (J g^{-1} $^oC^{-1}$), θ_{sat} is air saturation vapour pressure (kPa), θ_{act} is actual vapour pressure (kPa), r_{crop} is the crop resistance (s/m), r_{air} is aerodynamic resistance (s/m), γ_{air} is the psychometric constant (kPa $^oC^{-1}$), Δ_v is the slope of the vapour pressure curve (kPa $^oC^{-1}$).

Net radiation is aggregated of net incoming short wave radiation flux R_{ns} (J m^{-2} d^{-1}) and net outgoing long wave radiation flux R_{nl} (J m^{-2} d^{-1}). Swap assumes G =0.

For the other parameters of equation (10) refer to the theory presented in part 6 Theory of SWAP.

SWAP can separate potential evaporation and transpiration for partly covered soils using Leaf Area Index (LAI) or Soil cover fraction (SCF).

In order to compute accurately irrigation requirement, interception of rainfall is simulated using LAI and the formula produced by Hoyningen - Hüne (1983) and Braden (1985):

$$P_i = a.LAI\left[1 - \frac{1}{1 + \frac{b.P_{gross}}{a.LAI}}\right] \qquad (11)$$

Where: P_I is intercepted precipitation (cm), P_{gross} is gross precipitation (cm), a is an empirical coefficient (cm) and b is soil cover fraction. In SWAP, for the case of ordinary agriculture crop, a is assumed =0.25.

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 Ea by taking the minimum value of Ep, Emax and empirical evaporation functions (either by Black, 1969 or Boesten and Stroosnijder, 1986) may be used.

5.1.5 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. The latest is applied in Naivasha case study.

Detail of this part can refer to the part 7 of SWAP 2.0 theory manual.

5.1.6 Field irrigation and drainage

5.1.6.1 Field irrigation

The field irrigation and drainage part of the model relates to the computation of irrigation schedule in order to develop optimal irrigation schedules. It is useful for those who has limited water resources for irrigation or who want to obtain better water management practice and maximise the crop production.

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

Irrigation schedule applied in SWAP can be either fixed or scheduled irrigation or a mix of both.

Normally, fixed irrigation schedule is applied in land preparation or for pre-transplanting date. The scheduled irrigation is planned during growing season.

The irrigation scheduling criteria applied in SWAP are similar to the criteria applied in CROPWAT (Smith, 1992) and IRSIS (Raes et al., 1988). The scheduling criteria define the time and depth of irrigation. They may be dynamic and are a function of crop development stages

The user can use specify 5 following different timing criteria to generate an irrigation schedule: 1) Allowable daily stress (fraction), 2) Allowable depletion of readily available water in the root zone (fraction), 3) Allowable depletion of total available water in the root zone (fraction), 4) allowable depletion amount of water in the root zone (mm) and 5) Critical pressure head or moisture content at sensor depth. In the case study, Allowable daily stress of 95% is applied.

And one of two application depth criteria can be selected: 1) back to field capacity and 2) fixed irrigation depth. The first is applied in this study.

5.1.6.2 Drainage:

The bottom boundary condition is considered in field drainage computation of the model. It calculates bottom flux q_{bot} (cm/day) and also the lateral field drainage flux to the local drainage system. Different methods can be used for this calculation. Four soil profiles are defined and the user can apply them according to the real case: 1) Homogenous profile, drain on top of impervious layer, 2) Homogenous profile, drain above impervious layer, 3) Heterogeneous soil profile, drain at interface between both soil layers and 4) Heterogeneous soil profile, drain in bottom layer. In the case study, free drainage is assumed, no lateral drainage takes place.

5.1.7 Interaction with surface water management and regional drainage

This part is dealing with surface water system. It simulates runoff, drainage/sub irrigation fluxes. SWAP can simulate drainage up to 4 levels of drainage system. Groundwater and surface water level are taken into account as they strongly affect drainage process and sub irrigation.

5.2 Data input for the SWAP model in this thesis.

Followings are the data required for model inputs:

- Meteorological data
- Irrigation
- Crops
- Soil
- Drainage
- Bottom boundary

5.2.1 Meteorological data input:

Daily meteo-data set obtained from Sulmac automatic weather station located within the research area. It includes of: name of the station, time in daily format (from October, 1999 to September, 2000), radiation (KJ/m^2), daily maximum and minimum temperature (^{0}C), relative air humidity RH (decimal), daily rainfall (cm), wind speed (m/s), referent evapotranspiration ET$_{ref}$ (cm). The missing value is filled with –99.9.

Unfortunately, meteo-data input for the model are only available for the period from 10th October 1999 to 19th September 2000. That means meteo-data set is not completed for one-year period (20 days data missing).

Due to the requirement from SWAP, 2 separated meteo-data files for year 1999 and 2000 are entered.

In case the model runs for different scenarios of climate conditions, another meteorological years will be inputted. For example, when water demand computation for dry year, average year and wet year are conducted. But it is difficult to find complete data set for those years in the literature. So, the simulation model is only done for the period 0ctober 1999 to September 2000.

5.2.2 Irrigation input:

5.2.2.1 Fixed irrigation:

This input defines the starting time of irrigation with a fixed amount of water, normally before crop emergence in order to ensure certain soil moisture for seed emergence. The irrigation manager sets the depth of water applied. The time of fixed irrigation changes in accordant with starting time of crop cycle.

Due to the seed emergence in the time of one week, 7 days of fixed irrigation are set for model run and scheduled irrigation then starts just after crop emergence. From the interview during the fieldwork with farm managers, 10 mm/2day of fixed irrigation are used.

Different fixed irrigation files are inputted according to crop calendar proposed for the model. Following the available of meteo-data, 6 irrigation files (starting date of 1st November 1999, 1st December 1999, 1st January 2000, …1st June 2000) are produced.

Later on, fixed irrigation is set following the actual irrigation applied by irrigation manager. For example, 10mm/2 days or following the pre-set amount of irrigation applied in accordance with crop development stage[2]. Annex 5.1 and 5.1a is an example is fixed irrigation input for cabbage in Threepoint and Delamere farms. The results from this application demonstrate how good the irrigation could be in the practice when compared to the real irrigation needs.

5.2.2.2 Scheduled irrigation:

Input of this file requires the user to define the type of irrigation, timing criteria following crop development stage as well as depth criteria. In the scope of this thesis, sprinkle is considered the main type of irrigation to be evaluated and it has been chosen for model simulation. The contents of input criteria are following part 5.1.6 of this thesis.

The timing criterion of *Allowable daily stress* with fraction of 0.95 is selected for irrigation schedule computation. The reason for this selection is to ensure the optimal soil water condition for crop growing (without any serious shortage of water storage in the root zone). Of course, with this fraction, crop water requirement will be higher than the case of lower fraction.

Application depth criterion of *Back to field capacity* equal to 0 is applied for scheduling irrigation. That ensures the scheduled irrigation to meet exact crop water requirement.

For the case of irrigated grass, the fraction of 0.75 for timing criterion of *Allowable daily stress* is chosen because the grass land cover a very big area and irrigation application is being applied once a week.

5.2.3 Crop input

5.2.3.1 Crop calendar:

The crop input required is the number of crop growing in the system, crop model, the starting time of each crop, date of crop emergence, time of harvest (if fixed length of crop cycle is applied) and time of starting scheduled irrigation.

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[2] Refer to table 4.7

The simple crop model is selected as each type of crop is homogeneously growing in one plot. Beside that, the grass model is chosen for irrigated grass.

From the interviews with farm managers, all vegetable chosen for irrigation evaluation have the same crop cycle from 3-4 month. Hence, 100 days of crop cycle is considered the fixed length of crop cycle.

Due the fact that crop is rotationally grown during a year. For each crop type, different starting dates were chosen for model computation. But available meteo-data for only about 1 year as mention above allow only 6 starting - month to be produced. (This is a simplified assumption that a crop is started at the first day of a month and harvested after more than 3 months. The field then is prepared for the next crop, which will start at the first day of the following month).

Grass is an annual crop, so the computation for grass irrigation is taken for the whole time that meteo-data is available.

5.2.3.2 Crop data:

The input file describes the crop model (detailed, grass or simple one) and crop features, which will be applied in the model computation. In this thesis the following crop types are considered as the main crop of the research area: Cabbage, baby corn, French bean, garden peas and irrigated grass. Crop heights, root depth, root distribution and soil coverage by crop were measured for different crop development stages of each type of crop. Crop data are then entered in separated files for different crops together with the length of crop cycle. Table 4.5 is used for crop data input.

Yield response is equal to 1 as irrigation is fully supplied during each development stage.

Pressure heads for water and salt stress response function are taken from experimental values introduced in annex C and D of SWAP manual.

Due to detail grass factors could not be able measure during the fieldwork except grass height and root depth, the other grass factors are taken from SWAP model available data.

5.2.4 Soil input:

5.2.4.1 Profile description:

This describes the physical soil condition to be used in soil evaporation computation from SWAP. SWAP calculates actual soil evaporation using the soil hydraulic functions or empirical functions. Number of soil layers participating in to the process as well as the soil compartments are defined by user in order to ensure the accurate results and time of calculation.

Observations from the locations where soil samples were taken, soil structure in Naivasha can be considered comprising 3 layers and they are used for model input.

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

The second layer with the depth from 30 to 50 cm where root system is more active and widely spread in development stage 3 and 4.

The third layer considered at the depth of 50 cm downward to 150 cm.

Soil compartments are followed the recommendation from SWAP model user guide for the top layer of 1 cm thick.

SWAP calculates actual soil evaporation using the soil hydraulic functions in case of a dry soil. In case of a wet soil, actual evaporation equals potential evaporation.

Annex 5A, 5B, 5C, 5D, 5E present hydraulic properties of soil in research area.

5.2.4.2 Soil hydraulic properties

Due to the soil evaporation could be overestimated using the soil hydraulic functions, SWAP allows the use of two additional, empirical functions, which can be selected under this option. Since the functions are empirical, the parameters are soil and location specific and will need to be determined by the user. SWAP will determine the actual evaporation rate by taking the minimum value of Emax (from soil hydraulic functions), Ep (potential from air humidity) and the evaporation rates according to the empirical functions (if selected by the user). Some criteria are defined for the model such as: maximum thickness of ponding layer when runoff starts, minimum rainfall for model reset, time steps, soil texture, maximum rooting depth allowed by soil.

Some parameters of soil hydraulic function, which can not be measured from the fieldwork due to limitations of equipment and time, are taken from SWAP manual.

The following table contents the soil parameters to be the input of SWAP model.

For the soil type on vegetable field in the northern part of the Lake (include Threepoint and Delamere farms):

Layer	Soil depth (cm)	θres (cm/cm)	θsat cm/cm	α (1/cm)	n (-)	λ (-)	Ksat (cm/d)	% sand	% silt	% clay	% OM	Soil type
1	40	0.001	0.44	0.243	1.111	-5.395	172.8	28	30	42	2	Clay
2	80	0.001	0.42	0.0191	1.152	-1.384	39.7	35	34	25	0.6	Clay loam
3	150	0.001	0.42	0.0191	1.152	-1.384	39.7	38	37	25	0.45	loam

For the soil type on vegetable field in the southern part of the Lake:

Layer	Soil depth (cm)	θres (cm/cm)	θsat cm/cm	α (1/cm)	n (-)	λ (-)	Ksat (cm/d)	% sand	% silt	% clay	% OM	Soil type
1	20	0.01	0.42	0.0163	1.559	0.177	201.6	64	24	12	0.9	Sandy loam
2	50	0.01	0.42	0.0211	1.564	-0.522	159	74	16	10	0.5	Sandy loam
3	120	0.01	0.42	0.0211	1.564	-0.522	159	68	27	5	0.45	Sandy loam

Figure 5.3: Table of soil parameter input for SWAP model

Note that, θsat, Ksat is taken from fieldwork measurements, soil texture from Joliceour's (1999) soil analysis and Siderius (1998).

In this research, no hysteresis and no swelling/shrinkage are selected as the soil in irrigated land is often maintained at moisture levels much higher than residual moisture and it seems never be left at extreme dry condition that may lead the soil to be crack.

5.2.4.3 Layer hydraulic properties:

Because of time limitation and technical support during the fieldwork, soil parameters of hydraulic functions for soil types in Naivasha were not measured. So, analytical function is then chosen and the parameters for the model can be taken from Staring series, which was described earlier. The results from infiltration tests conducted in the fieldwork 9/2000 were taken into account as they presented the real soil condition at the research area.

Initial soil moisture status when starting simulation is set up following the instant moisture measured from the field and nodal pressure heads option is selected. The input for initial soil moisture and nodal pressure heads is entered as shown in Annex 5E.

5.2.5 Drainage

The basic drainage routine has been selected for the case of research area as no surface water or multi- drainage levels exist.

The method to establish the drainage flux of 'Calculated drainage with the formulas of Hooghoudt and Ernst' is selected among three options produced by the model because no impervious layer close to the soil top layers has been found in the soil survey (observed by auger holes and pits).

5.2.6 Bottom boundary

As no impervious layer exist, the option of 'Free drain at the bottom of the profile ' is selected and no detailed data is required by the model.

5.2.7 Some assumptions for model data input.

Simplification in soil property input (considering soils in Threepoint and Delamere farm are the same) was made.

Unfortunately no day to day records of irrigation practice are available. Some general irrigation practices were obtained via interviews with farm managers In practical fixed irrigation schedule input, irrigation applied for the day of rainfall is reduced according to the rainfall amount base on the rule that ensure the pre-set irrigation amount for that day and the following day. For example, proposed irrigation rate for a specific day was 10mm but rainfall in that day was 4 mm, then irrigation rate of 6mm will be the input of irrigation applied for the model. In fact it may be different with actual irrigation activities, as the irrigation application amount should be slightly higher. For example, the irrigation for one plot of crop starts and complete in the morning but the rainfall appear in the afternoon or evening, then the irrigation applied is actually loss.

Soil residual moistures of different layers were not fully measured except that for the soil layer from 0 to 50cm.Then, the residual moisture of soil layer deeper than 50cm is assumed close to field capacity as irrigation is actually applied once in every 2 days.

5.3 Results from SWAP model for crop irrigation requirement and irrigation evaluation.

5.3.1 Crop irrigation requirement

The model is run for different vegetable types and different starting times as mentioned in the part 5.2.

Vegetables growing in 2 farms, Threepoint and Delamere, are selected for this research.

Note that:

- Irrigation applications for vegetable in Threepoint and Delamere Farms are following the schedule presented in table 4.8 (two different irrigation schedules).
- In the output of the model, rainfall has been taken into account and irrigation requirement (with and without actual irrigation application) is generated based on the input (rainfall and irrigation applied).

- Irrigation requirement is computed to ensure the crop growing with very little water stress (when actual crop transpiration dropped under 95% of potential transpiration, irrigation then is required).
- For grass irrigation computation, the option of 75% Allowable Daily Stress is selected as it is not very important crop and water stress can be allowed. This is also taking into account the irrigation schedule for grass being once a week.

Due to the large amount (hundreds) of model output files for the crops selected for irrigation evaluation which can not all be presented in this thesis, 1 representative crop, irrigation practice and soil are discussed. Cabbage growing in Threepoint with starting date in 1st November 1999 and 1st February 2000 and 1st May 2000[3] are discussed here.

The model output for other crops and other starting months are used only for irrigation evaluation. The other output table for different starting date of crop can be found in annex 5.2.

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[3] The reason for choosing these 3 months is that, November is in short rainy season, March is the main rainy period and May is in dry period of the year.

Figure 5.4: Table of SWAP output (accumulation) for cabbage of Threepoint Farm with starting date 1st November for irrigation requirement

DATE	DAY	RAIN	[cm]	IRR	[cm]	RUO	TRA	[cm]	EVS	[cm]	FLUX [cm]		DSTOR	GWL	QDIF
d/m/y	nr	gro	net	gro	net	cm	pot	act	pot	act	lat	.bot	cm	cm	cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
2/11/99	2	1.75	1.75	0.5	0.5	0	0	0	0.98	0.7	0	-0.02	1.53	999	0
4/11/99	4	1.75	1.75	0.5	0.5	0	0.01	0.01	1.93	0.96	0	-0.04	1.25	999	0
6/11/99	6	2.45	2.44	0.5	0.5	0	0.03	0.03	2.94	1.4	0	-0.05	1.46	999	0
8/11/99	8	2.55	2.54	0.5	0.5	0	0.06	0.06	3.89	1.66	0	-0.07	1.25	999	0
10/11/99	10	2.95	2.93	0.5	0.5	0	0.09	0.09	4.9	2.1	0	-0.09	1.15	999	0
12/11/99	12	5.8	5.76	0.5	0.5	0	0.14	0.14	5.85	2.8	0	-0.11	3.22	999	0
14/11/99	14	9.98	9.92	0.5	0.5	0	0.18	0.17	6.58	3.5	0	-0.13	6.62	999	0
16/11/99	16	10.08	10.02	0.5	0.5	0	0.25	0.23	7.56	3.76	0	-0.15	6.38	999	0
18/11/99	18	10.93	10.84	0.5	0.5	0	0.31	0.3	8.41	4.46	0	-0.17	6.42	999	0
20/11/99	20	11.78	11.68	0.5	0.5	0	0.39	0.37	9.25	4.95	0	-0.21	6.65	999	0
24/11/99	24	12.19	12.06	0.5	0.5	0	0.58	0.56	11.03	5.91	0	-0.34	5.75	999	0
26/11/99	26	12.59	12.44	0.5	0.5	0	0.68	0.67	11.91	6.4	0	-0.45	5.42	999	0
28/11/99	28	13.49	13.3	0.5	0.5	0	0.8	0.78	12.73	7.1	0	-0.56	5.36	999	0
30/11/99	30	14.99	14.76	0.5	0.5	0	0.92	0.9	13.49	7.8	0	-0.68	5.88	999	0
2/12/99	32	16.29	16.02	0.5	0.5	0	1.07	1.05	14.19	8.47	0	-0.8	6.2	999	0
4/12/99	34	16.29	16.02	0.5	0.5	0	1.22	1.2	14.86	8.73	0	-0.92	5.67	999	0
6/12/99	36	16.29	16.02	0.5	0.5	0	1.42	1.4	15.65	8.9	0	-1.04	5.18	999	0
8/12/99	38	16.44	16.14	0.5	0.5	0	1.64	1.62	16.43	9.33	0	-1.16	4.54	999	0
10/12/99	40	17.14	16.8	0.5	0.5	0	1.85	1.82	17.13	9.82	0	-1.29	4.38	999	0
12/12/99	42	17.84	17.46	0.5	0.5	0	2.06	2.03	17.81	10.3	0	-1.4	4.22	999	0
14/12/99	44	17.84	17.46	0.5	0.5	0	2.35	2.31	18.55	10.51	0	-1.51	3.62	999	0
16/12/99	46	17.84	17.46	0.5	0.5	0	2.7	2.67	19.37	10.67	0	-1.62	3.01	999	0
18/12/99	48	17.84	17.46	0.5	0.5	0	3.02	2.98	20.09	10.8	0	-1.71	2.47	999	0
20/12/99	50	17.84	17.46	0.5	0.5	0	3.36	3.31	20.8	10.92	0	-1.8	1.93	999	0
24/12/99	54	18.49	18.04	0.5	0.5	0	4.04	3.97	22	11.37	0	-1.96	1.25	999	0
26/12/99	56	18.54	18.08	0.5	0.5	0	4.48	4.38	22.61	11.63	0	-2.03	0.54	999	0
28/12/99	58	20.54	20.02	1.4	1.4	0	4.92	4.81	23.14	12.05	0	-2.1	2.46	999	0
30/12/99	60	20.54	20.02	1.4	1.4	0	5.43	5.31	23.69	12.26	0	-2.16	1.7	999	0
1/1/00	62	20.54	20.02	1.4	1.4	0	5.98	5.84	24.22	12.41	0	-2.21	0.96	999	0
3/1/00	64	21.94	21.37	1.4	1.4	0	6.55	6.39	24.7	12.8	0	-2.26	1.32	999	0
5/1/00	66	21.94	21.37	1.4	1.4	0	7.16	6.96	25.14	13	0	-2.31	0.49	999	0
7/1/00	68	21.94	21.37	2.3	2.3	0	7.84	7.6	25.56	13.35	0	-2.36	0.32	999	0
9/1/00	70	21.94	21.37	3.2	3.1	0	8.57	8.27	25.95	13.67	0	-2.4	0.14	999	0
11/1/00	72	21.94	21.37	4.2	4	0	9.4	9.03	26.33	14.01	0	-2.44	-0.11	999	0
13/01/00	74	21.94	21.37	5.2	4.9	0	10.28	9.82	26.68	14.33	0	-2.48	-0.32	999	0
15/01/00	76	22.04	21.44	6.2	5.9	0	11.12	10.57	26.97	14.62	0	-2.52	-0.37	999	0
17/01/00	78	22.04	21.44	7.2	6.8	0	12.05	11.39	27.27	14.91	0	-2.55	-0.57	999	0
19/01/00	80	22.12	21.48	8.3	7.9	0	12.91	12.15	27.55	15.18	0	-2.59	-0.59	999	0
21/01/00	82	22.12	21.48	9.3	8.8	0	13.72	12.88	27.8	15.43	0	-2.62	-0.62	999	0
23/01/00	84	22.12	21.48	10.3	9.8	0	14.72	13.76	28.09	15.72	0	-2.65	-0.84	999	0
25/01/00	86	22.12	21.48	11.4	11	0	15.65	14.58	28.35	15.97	0	-2.68	-0.9	999	0
27/01/00	88	22.12	21.48	12.6	12	0	16.53	15.36	28.59	16.22	0	-2.71	-0.9	999	0
29/01/00	90	22.37	21.68	13.6	13	0	17.43	16.17	28.82	16.45	0	-2.73	-0.75	999	0
31/01/00	92	22.37	21.68	14.6	14	0	18.39	17.04	29.05	16.68	0	-2.76	-0.96	999	0
2/2/00	94	22.37	21.68	15.7	15	0	19.3	17.87	29.28	16.9	0	-2.78	-0.98	999	0
4/2/00	96	22.37	21.68	16.9	16	0	20.37	18.85	29.51	17.13	0	-2.81	-1.18	999	0
6/2/00	98	22.37	21.68	18.1	17	0	21.63	20	29.75	17.38	0	-2.83	-1.46	999	0
8/2/00	100	22.37	21.68	19.4	18	0	22.68	20.95	29.96	17.59	0	-2.85	-1.38	999	0

Figure 5.5: Table of SWAP output (accumulation) under actual irrigation application for cabbage in Threepoint Farm with starting date 1st November.

DATE	DAY	RAIN	[cm]	IRR	[cm]	RUO	TRA	[cm]	EVS	[cm]	FLUX [cm]		DSTOR	GWL	QDIF
d/m/y	nr	gro	net	gro	net	cm	pot	act	pot	act	lat	.bot	cm	cm	cm
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*	*(15)*	*(16)*
2/11/99	2	1.75	1.75	0.3	0.3	0	0	0	0.98	0.7	0	-0	1.33	999	0
4/11/99	4	1.75	1.75	1	1	0	0.01	0.01	1.92	1.19	0	-0	1.51	999	0
6/11/99	6	2.45	2.44	2.2	2.2	0	0.03	0.03	2.94	1.89	0	-0.1	2.66	999	0
8/11/99	8	2.55	2.54	2.8	2.8	0	0.06	0.06	3.89	2.39	0	-0.1	2.82	999	0
10/11/99	10	2.95	2.94	4	4	0	0.09	0.09	4.89	3.09	0	-0.1	3.65	999	0
12/11/99	12	5.8	5.77	4.9	4.9	0	0.14	0.14	5.84	3.79	0	-0.1	6.62	999	0
14/11/99	14	9.98	9.93	4.9	4.9	0	0.18	0.17	6.57	4.49	0	-0.1	10.02	999	0
16/11/99	16	10.08	10	4.9	4.9	0	0.24	0.23	7.55	4.75	0	-0.2	9.77	999	0
18/11/99	18	10.93	10.9	6.1	6.1	0	0.31	0.3	8.4	5.45	0	-0.4	10.84	999	0
20/11/99	20	11.78	11.7	6.8	6.8	0	0.38	0.37	9.23	6.15	0	-0.8	11.12	999	0
24/11/99	24	12.19	12.1	8.6	8.5	0	0.57	0.56	11	7.34	0	-2.2	10.57	999	0
26/11/99	26	12.59	12.5	9.5	9.4	0	0.68	0.66	11.9	7.84	0	-2.8	10.59	999	0
27/11/99	27	13.24	13.1	9.7	9.6	0	0.74	0.72	12.3	8.19	0	-3.1	10.69	999	0
29/11/99	29	14.79	14.6	9.7	9.6	0	0.85	0.83	13	8.88	0	-3.7	10.78	999	0
30/11/99	30	14.99	14.8	9.7	9.6	0	0.92	0.9	13.5	9.23	0	-4	10.24	999	0
2/12/99	32	16.29	16.1	10	9.9	0	1.06	1.04	14.2	9.9	0	-4.6	10.41	999	0
4/12/99	34	16.29	16.1	10.9	10.8	0	1.22	1.19	14.8	10.4	0	-5.2	10.09	999	0
6/12/99	36	16.29	16.1	11.8	11.7	0	1.41	1.39	15.6	10.9	0	-5.7	9.73	999	0
8/12/99	38	16.44	16.2	12.7	12.5	0	1.63	1.6	16.4	11.6	0	-6.3	9.28	999	0
10/12/99	40	17.14	16.9	13.2	13	0	1.83	1.8	17.1	12.1	0	-6.7	9.27	999	0
12/12/99	42	17.84	17.5	13.7	13.5	0	2.05	2.02	17.7	12.5	0	-7.2	9.29	999	0
14/12/99	44	17.84	17.5	14.6	14.4	0	2.33	2.29	18.5	13	0	-7.6	8.97	999	0
16/12/99	46	17.84	17.5	15.5	15.2	0	2.68	2.64	19.3	13.5	0	-8	8.6	999	0
18/12/99	48	17.84	17.5	16.4	16.1	0	2.98	2.94	20	14	0	-8.4	8.29	999	0
20/12/99	50	17.84	17.5	17.3	17	0	3.31	3.27	20.6	14.5	0	-8.7	8.02	999	0
24/12/99	54	18.49	18.1	18.7	18.3	0	3.98	3.93	21.8	15.5	0	-9.3	7.68	999	0
26/12/99	56	18.54	18.2	19.1	18.6	0	4.41	4.36	22.4	15.9	0	-9.6	6.96	999	0
28/12/99	58	20.54	20.1	19.1	18.6	0	4.85	4.79	22.9	16.4	0	-9.8	7.78	999	0
30/12/99	60	20.54	20.1	19.8	19.3	0	5.34	5.27	23.5	16.8	0	-10	7.32	999	0
1/1/00	62	20.54	20.1	20.5	19.9	0	5.87	5.79	24	17.1	0	-10	6.84	999	0
3/1/00	64	21.94	21.5	20.5	19.9	0	6.45	6.34	24.5	17.5	0	-11	7.03	999	0
5/1/00	66	21.94	21.5	21.2	20.6	0	7.04	6.9	24.9	17.9	0	-11	6.56	999	0
7/1/00	68	21.94	21.5	22.1	21.4	0	7.7	7.53	25.3	18.3	0	-11	6.14	999	0
9/1/00	70	21.94	21.5	22.8	22.1	0	8.43	8.21	25.7	18.6	0	-11	5.59	999	0
11/1/00	72	21.94	21.5	23.9	23	0	9.23	8.96	26.1	19	0	-11	5.24	999	0
13/01/00	74	21.94	21.5	24.6	23.7	0	10.1	9.77	26.4	19.3	0	-11	4.59	999	0
15/01/00	76	22.04	21.6	25.7	24.7	0	11	10.5	26.7	19.6	0	-12	4.55	999	0
17/01/00	78	22.04	21.6	26.4	25.4	0	11.9	11.4	27	19.9	0	-12	3.94	999	0
19/01/00	80	22.12	21.6	27.6	26.5	0	12.7	12.1	27.3	20.2	0	-12	3.96	999	0
21/01/00	82	22.12	21.6	28.1	26.9	0	13.5	12.9	27.5	20.4	0	-12	3.3	999	0
23/01/00	84	22.12	21.6	29.4	28	0	14.5	13.7	27.8	20.7	0	-12	3.14	999	0
25/01/00	86	22.12	21.6	29.9	28.4	0	15.4	14.6	28.1	20.9	0	-12	2.39	999	0
27/01/00	88	22.12	21.6	31.2	29.7	0	16.3	15.3	28.3	21.2	0	-12	2.54	999	0
29/01/00	90	22.37	21.8	31.7	30.1	0	17.2	16.1	28.5	21.4	0	-12	2.05	999	0
31/01/00	92	22.37	21.8	33	31.3	0	18.1	17	28.8	21.6	0	-12	2.09	999	0
2/2/00	94	22.37	21.8	33.5	31.7	0	19	17.8	29	21.9	0	-12	1.4	999	0
4/2/00	96	22.37	21.8	35	33.1	0	20.1	18.8	29.2	22.1	0	-13	1.5	999	0
6/2/00	98	22.37	21.8	35.5	33.5	0	21.3	19.9	29.4	22.3	0	-13	0.47	999	0
8/2/00	100	22.37	21.8	37.2	35.1	0	22.3	20.8	29.6	22.5	0	-13	0.93	999	0

Output of model on WATER BALANCE for irrigation requirement of Cabbage growing in Threepoint farm are shown in the following text boxes:

Figure 5.6: Output on water balance from SWAP model for Cabbage in Threepoint farm (from irrigation requirement computation)

```
Period           : 1/11/1999 until   8/02/2000
Depth soil profile :  150.00 cm

        Water storage
Final   :       45.75 cm
Initial :       47.13 cm
        ============
Change          -1.38 cm

                         Water balance components (cm)

  In                                  Out
  ====================              ==========================
  Rain       :   22.37                Interception     :    1.75
  Irrigation  :   19.38               Runoff           :    0.00
  Bottom flux :    -2.85              Transpiration    :   20.95
                                      Soil evaporation  :   17.59
                                      Crack flux       :    0.00
  ====================              ==========================
  Sum        :   38.90                Sum              :   40.29
```

```
Period           : 1/02/2000 until  10/05/2000
Depth soil profile :  150.00 cm

        Water storage
Final   :       44.83 cm
Initial :       47.13 cm
        ============
Change          -2.30 cm


                         Water balance components (cm)

  In                                   Out
  ====================              ==========================
  Rain       :   7.38                 Interception     :    2.15
  Irrigation  :   33.62               Runoff           :    0.00
  Bottom flux :    -0.65              Transpiration    :   24.37
                                      Soil evaporation  :   16.13
                                      Crack flux       :    0.00
  ====================              ==========================
  Sum        :   40.35                Sum              :   42.65
```

```
Period          : 1/05/2000 until   8/08/2000
Depth soil profile :  150.00 cm

          Water storage
Final   :        44.98 cm
Initial :        47.13 cm
          =============
Change           -2.15 cm


                              Water balance components (cm)

  In                                        Out
  =====================                     ============================
  Rain        :    6.83                     Interception     :    1.88
  Irrigation  :   29.82                     Runoff           :    0.00
  Bottom flux :   -0.72                     Transpiration    :   21.34
                                            Soil evaporation :   14.85
                                            Crack flux       :    0.00
  =====================                     ============================
  Sum         :   35.92                     Sum              :   38.07
```

And output of WATER BALANCE for irrigation requirement under irrigation practice are presented in the following text boxes:

Figure 5.7: Output on water balance from SWAP model for Cabbage in Threepoint farm (from irrigation requirement under irrigation practice computation)

```
Period          : 1/11/1999 until   8/02/2000
Depth soil profile :  150.00 cm

          Water storage
Final   :        48.06 cm
Initial :        47.13 cm
          =============
Change            0.93 cm


                              Water balance components (cm)

  In                                        Out
  =====================                     ============================
  Rain        :   22.37                     Interception     :    2.66
  Irrigation  :   37.22                     Runoff           :    0.00
  Bottom flux :  -12.66                     Transpiration    :   20.81
                                            Soil evaporation :   22.52
                                            Crack flux       :    0.00
  =====================                     ============================
  Sum         :   46.92                     Sum              :   45.99
```

```
Period           :  1/02/2000 until  10/05/2000
Depth soil profile :  150.00 cm

        Water storage
Final   :      46.22 cm
Initial :      47.13 cm
        ============
Change          -0.91 cm

                                  Water balance components (cm)
  In                                    Out
  =====================          ===========================
  Rain        :    7.38                Interception     :    2.57
  Irrigation  :   45.29                Runoff          :    0.00
  Bottom flux :    -4.78               Transpiration    :   24.76
                                       Soil evaporation  :   21.47
                                       Crack flux       :    0.00
  =====================          ===========================
  Sum         :   47.90                Sum             :   48.81
```

```
Period           :  1/05/2000 until   8/08/2000
Depth soil profile :  150.00 cm

        Water storage
Final   :      47.51 cm
Initial :      47.13 cm
        ============
Change           0.38 cm


                            Water balance components (cm)

  In                                   Out
  =====================          ===========================
  Rain        :    6.83                Interception     :    2.42
  Irrigation  :   44.07                Runoff          :    0.00
  Bottom flux :    -6.22               Transpiration    :   21.70
                                       Soil evaporation  :   20.18
                                       Crack flux       :    0.00
  =====================          ===========================
  Sum         :   44.68                Sum             :   44.30
```

The output of the water balance for other crops and other different starting times are placed in Annex 5.2. It comprises the output for irrigation requirement and irrigation requirement under irrigation practice.

Actual irrigation application is shown in Annex 5.1 and 5.1a

5.3.2 Irrigation evaluation.

5.3.2.1 Evaluation criteria:

The evaluation is applied in two ways:

1) Evaluating irrigation for the whole crop cycle and
2) Evaluating irrigation inside a crop cycle.

5.3.2.2 Evaluation for irrigation evaluation for the whole crop cycle[4]*:*

$$Losses = \frac{Total\ actual\ \ irrigation\ applied - Total\ \ irrigation\ requirement}{Total\ irrigation\ requirement} x100 \qquad (\%)$$

The evaluation of irrigation practice for different crop are presented in the following table:

Figure 5.6: Tables and charts present irrigation evaluation for whole crop cycle of some vegetables growing in research area:

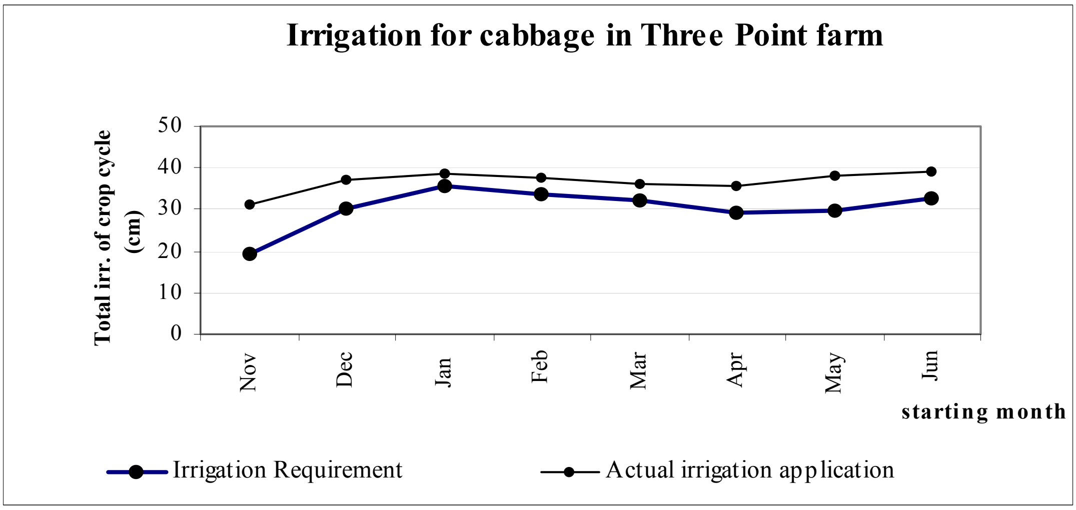
Threepoint Farm

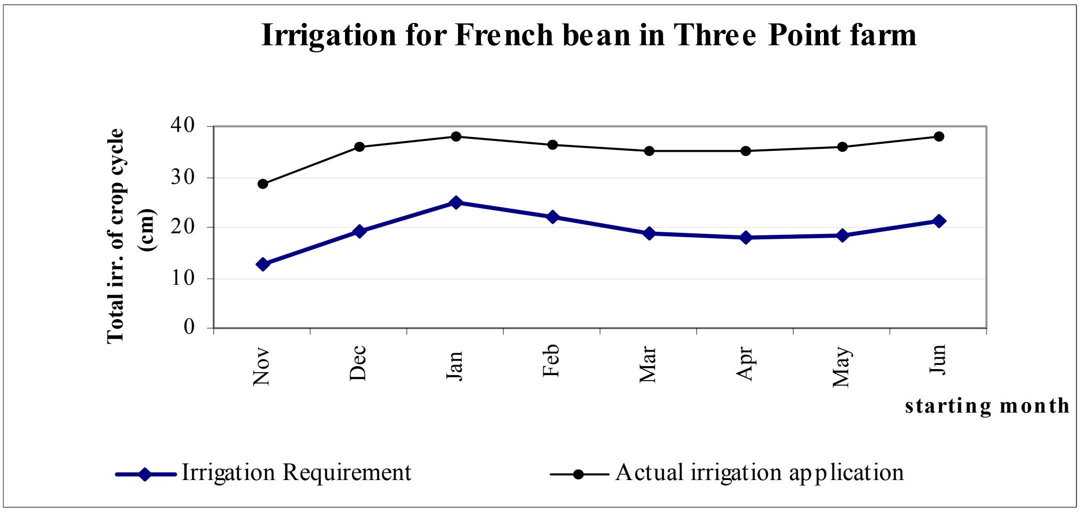
Crop type	Length of crop cycle	Staring date	Total irrigation requirement	Total actual irrigation[5] (cm)	Estimated losses	
	(day)	(d/m/y)	(cm)	(cm)	(cm)	(%)
Cabbage	100	1/11/1999	19.4	31.0	11.6	59.8
		1/12/1999	30.0	37.2	7.2	24.0
		1/1/2000	35.4	38.8	3.4	9.6
		1/2/2000	33.6	37.6	4.0	11.9
		1/3/2000	32.4	36.1	3.7	11.4
		1/4/2000	29.4	35.7	6.3	21.4
		1/5/2000	29.8	37.9	8.1	27.2
		1/6/2000	32.9	39.3	6.4	19.5
French bean	100	1/11/1999	12.8	28.6	15.8	123.4
		1/12/1999	19.2	36.0	16.8	87.5
		1/1/2000	24.9	38.0	14.0	52.6
		1/2/2000	22.1	36.5	14.4	65.2
		1/3/2000	18.6	35.1	16.5	88.7
		1/4/2000	18.0	35.0	17.0	94.4
		1/5/2000	18.5	36.0	16.5	94.6
		1/6/2000	21.2	37.8	16.6	78.3
Peas	100	1/11/1999	19.7	24.5	4.8	24.4
		1/12/1999	30.7	28.2	-2.5	-8.1
		1/1/2000	36.1	30.3	-5.8	-16.1
		1/2/2000	32.7	28.8	-3.9	-11.9
		1/3/2000	29.3	27.8	-1.5	-5.1
		1/4/2000	28.2	26.6	-1.6	-5.7
		1/5/2000	30.4	28.1	-2.3	-7.6
		1/6/2000	33.1	30.8	-2.3	-6.9

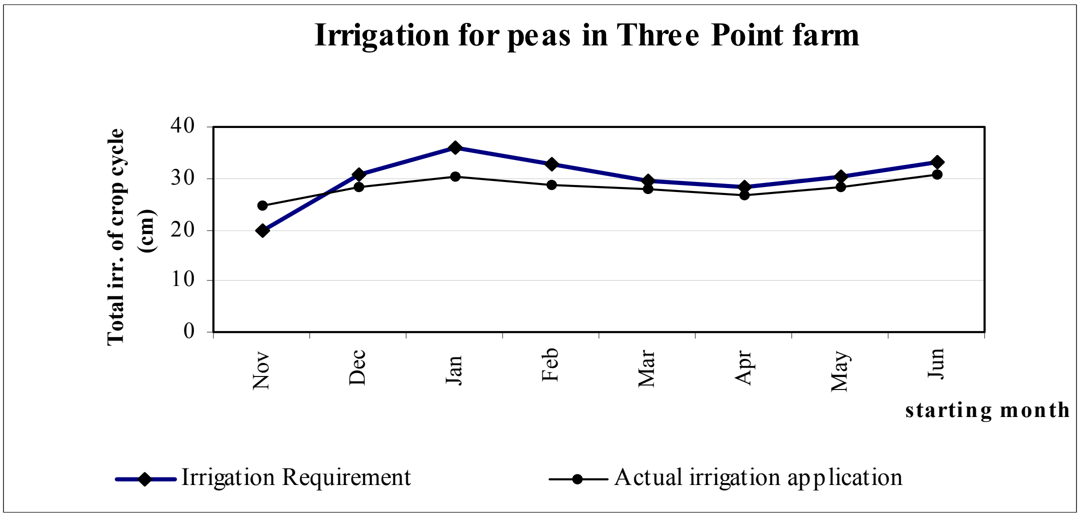
---

[4] This is the accumulated values of modelled irrigation requirement in the output table of the model.
[5] The detailed application can be found in Annex 5.1 and 5.1a

And followings are the charts conducted from the table above:

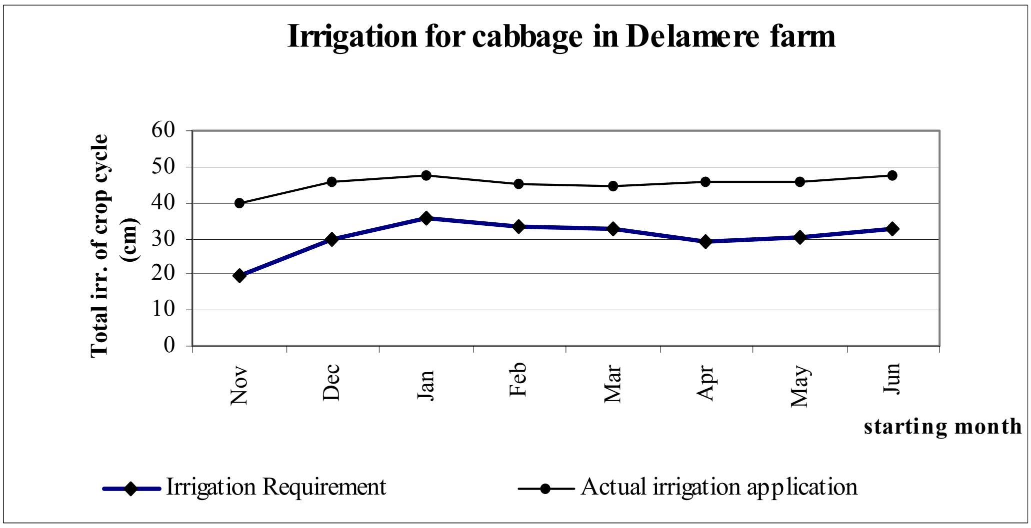


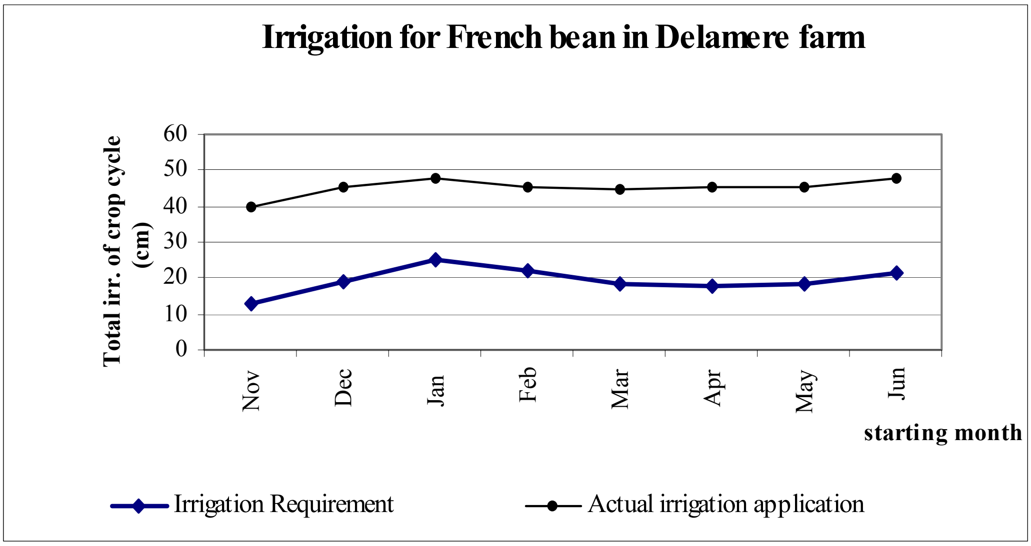


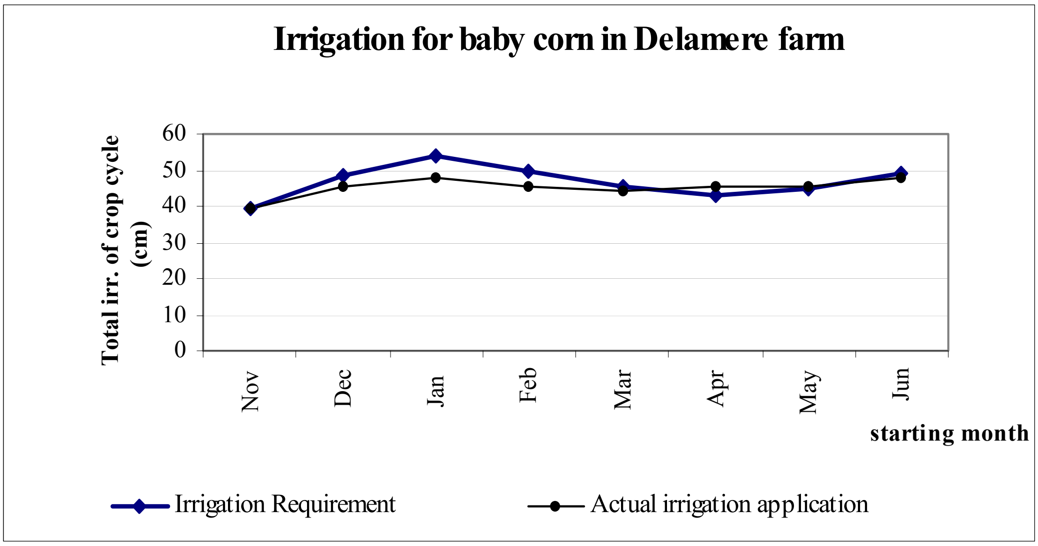


Delamere Farm

Crop type	Length of crop cycle (day)	Staring date (d/m/y)	Total irrigation requirement (cm)	Total actual irrigation (cm)	Estimated losses	
					(cm)	(%)
Cabbage	100	1/11/1999	19.6	39.6	20	102
		1/12/1999	30.0	45.6	15.6	52
		1/1/2000	35.4	47.8	12.4	35
		1/2/2000	33.4	45.3	11.9	36
		1/3/2000	32.4	44.5	12.1	37
		1/4/2000	29.4	45.5	16.1	55
		1/5/2000	30.2	45.5	15.3	51
		1/6/2000	32.9	47.6	14.7	45
French bean	100	1/11/1999	12.8	39.6	26.8	209
		1/12/1999	19.2	45.6	26.4	138
		1/1/2000	24.9	47.8	22.9	92
		1/2/2000	22.1	45.3	23.2	105
		1/3/2000	18.6	44.5	25.9	139
		1/4/2000	18.0	45.5	27.5	153
		1/5/2000	18.5	45.5	27	146
		1/6/2000	21.2	47.6	26.4	125
Baby corn	100	1/11/1999	39.2	39.6	0.4	1
		1/12/1999	48.3	45.6	-2.7	-6
		1/1/2000	54.2	47.8	-6.4	-12
		1/2/2000	50	45.3	-4.7	-9
		1/3/2000	45.4	44.5	-0.9	-2
		1/4/2000	42.8	45.5	2.7	6
		1/5/2000	44.8	45.5	0.7	2
		1/6/2000	48.8	47.6	-1.2	-2
Grass	Annual	10/10/1999	165.5	118.5	-47.0	-28.4

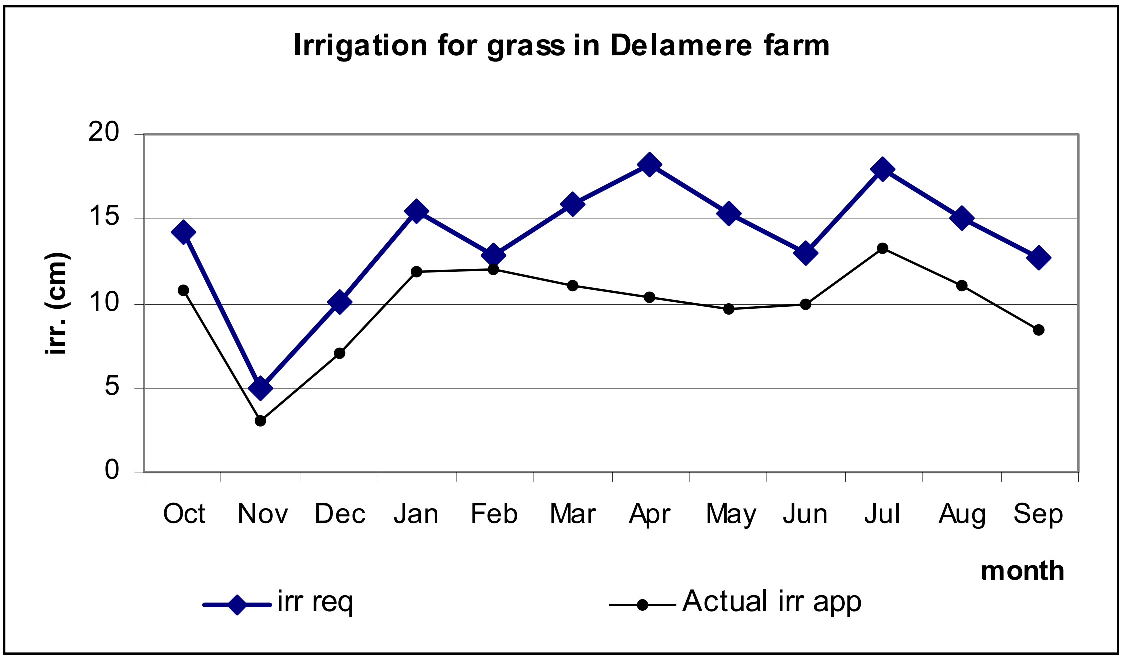

Irrigation for cabbage in Delamere farm
Total irr. of crop cycle (cm)
60
50
40
30
20
10
0
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
starting month
Irrigation Requirement
Actual irrigation application


Irrigation for French bean in Delamere farm
Total irr. of crop cycle (cm)
60
50
40
30
20
10
0
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
starting month
Irrigation Requirement
Actual irrigation application


Irrigation for baby corn in Delamere farm
Total irr. of crop cycle (cm)
60
50
40
30
20
10
0
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
starting month
Irrigation Requirement
Actual irrigation application

Delamere Farm

Crop type	Length of crop cycle (day)	Month	Total irrigation requirement (cm)	Total actual irrigation (cm)	Estimated losses	
					(cm)	(%)
Grass	Annual	Oct	14.2	10.8	-3.4	-24
		Nov	5.0	3.1	-1.9	-38
		Dec	10.1	7.1	-3	-30
		Jan	15.4	11.8	-3.6	-23
		Feb	12.8	12	-0.8	-6
		Mar	15.8	11.1	-4.7	-30
		Apr	18.2	10.3	-7.9	-43
		May	15.3	9.6	-5.7	-37
		Jun	12.9	10	-2.9	-22
		Jul	18.0	13.3	-4.7	-26
		Aug	15.1	11	-4.1	-27
		Sep	12.7	8.4	-4.3	-34



Based on the results from the comparison in the figure 5.6, it is clear that current irrigation practice for cabbage, French bean is much higher than crop requirement while it is slightly insufficient for peas and baby corn.

Observations from the fieldwork 2000 show that, some water still remains between rows of young crop after irrigation had finished. Is exceed irrigation given in the early stage of the crop cycle? This issue leads to the need of evaluating irrigation practice for inside crop cycle.

5.3.2.3 Evaluating irrigation practice for inside crop cycle:

The actual irrigation applications have been entered as irrigation input for model to compute the actual irrigation requirement under irrigation practice. The schedule of irrigation application is following those mentioned in the table 4.8.

The actual irrigation applied for the day when rainfall occurred was subtracted with the amount of rainfall. If rainfall was equal or higher than scheduled amount of irrigation, no irrigation is given. The effect of rainfall on the irrigation supply was also taken into account for the consecutive day and being reduced with a certain amount depending on the rainfall amount[6].

In order to evaluate irrigation practice, irrigation requirement generated from the model is compared to irrigation requirement under irrigation practice and actual irrigation applied.

Note that, modeled irrigation applied is the result from combining the actual irrigation practice with the option 95% allowable daily stress. SWAP model calculates irrigation needs to ensure this requirement. In case actual irrigation applied is not enough, SWAP will add a certain amount into irrigation requirement actual application. The result from the model in this case will be higher than the actual irrigation applied. Otherwise, modeled irrigation applied will be equal to real irrigation applied (a surplus is given in most cases).

The comparison of model outputs and actual irrigation application for cabbage growing in Threepoint and Delamere farm with starting date in November are presented in the following tables and graphs.

The comparison of model outputs and actual irrigation application for different crops and different starting time are also presented in tables and graph format and can be found in Annex 5.3a and Annex 5.3b.

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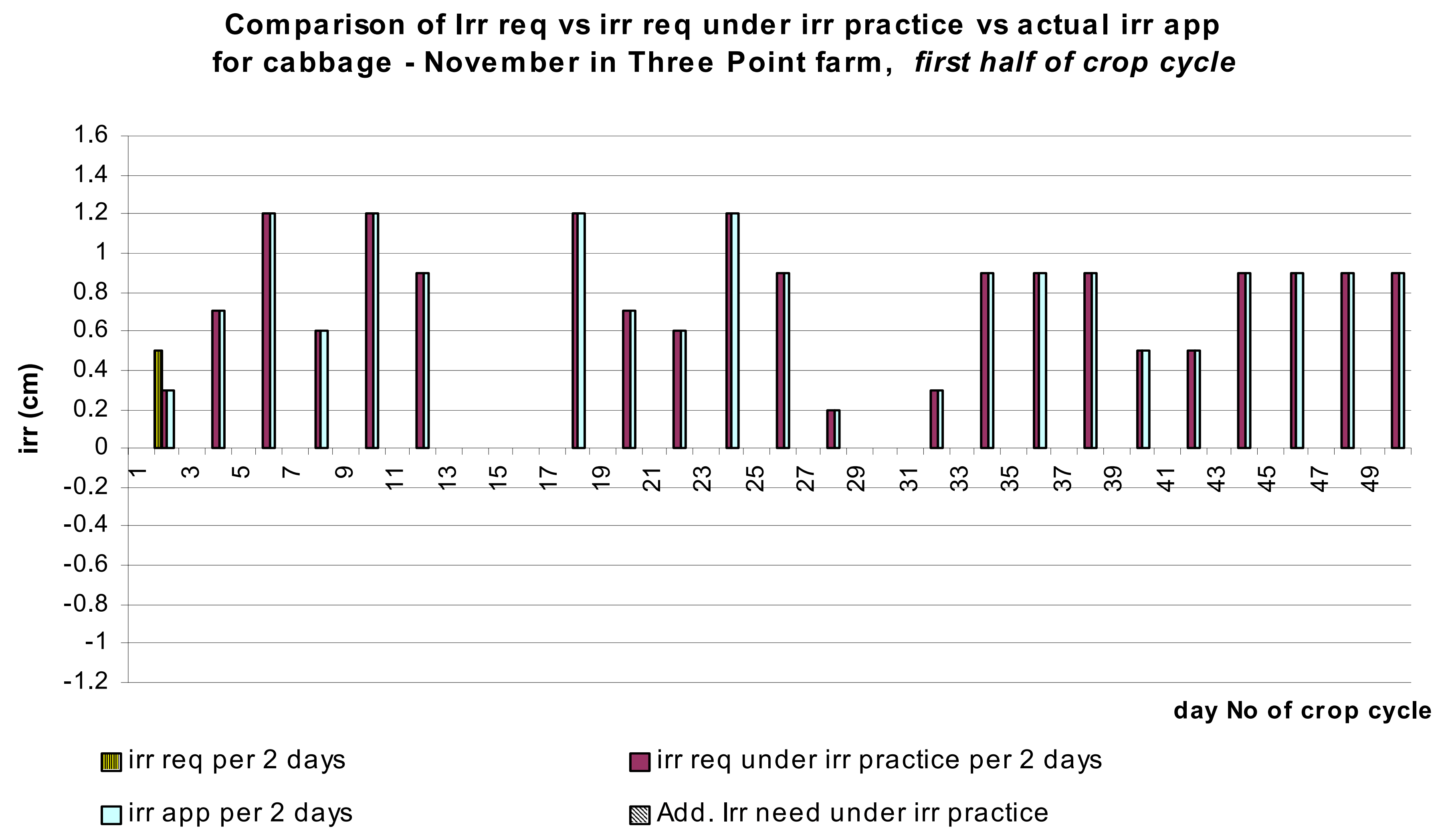
[6] It is considered as no rainfall effect if rainfall amount is less than 2mm and irrigation applied for that day had no deduction.

Figure 5.7: Tables and charts present irrigation evaluation for inside crop cycle of cabbage growing in Threepoint farm:

Irrigation for cabbage in Threepoint Farm, starting date at 1st of November, 1999,

first half								second half							
Date	day No	irr req	irr req per 2 days	irr req under irr practice	irr req under irr practice per 2 days	irr. app per 2 days	Add. Irr need under irr practice	Date	day No	irr req	irr req per 2 days	Irr req under irr practice	irr req under irr practice per 2 days	irr. app per 2 days	Add. Irr need under irr practice
		(cm)	(cm)	(cm)	(cm)	(cm)	(cm)			(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
1/11/99	1	0.5		0.3				21/12/99	51	0		0.7			
2/11/99	2	0	0.5	0	0.3	0.3	0	22/12/99	52	0	0	0	0.7	0.7	0
3/11/99	3	0		0.7				23/12/99	53	0		0.7			
4/11/99	4	0	0	0	0.7	0.7	0	24/12/99	54	0	0	0	0.7	0.7	0
5/11/99	5	0		1.2				25/12/99	55	0		0.4			
6/11/99	6	0	0	0	1.2	1.2	0	26/12/99	56	0	0	0	0.4	0.4	0
7/11/99	7	0		0.6				27/12/99	57	0.9		0			
8/11/99	8	0	0	0	0.6	0.6	0	28/12/99	58	0	0.9	0	0	0	0
9/11/99	9	0		1.2				29/12/99	59	0		0.7			
10/11/99	10	0	0	0	1.2	1.2	0	30/12/99	60	0	0	0	0.7	0.7	0
11/11/99	11	0		0.9				31/12/99	61	0		0.7			
12/11/99	12	0	0	0	0.9	0.9	0	1/1/00	62	0	0	0	0.7	0.7	0
13/11/99	13	0		0				2/1/00	63	0		0			
14/11/99	14	0	0	0	0	0	0	3/1/00	64	0	0	0	0	0	0
15/11/99	15	0		0				4/1/00	65	0		0.7			
16/11/99	16	0	0	0	0	0	0	5/1/00	66	0	0	0	0.7	0.7	0
17/11/99	17	0		1.2				6/1/00	67	0.9		0.7			
18/11/99	18	0	0	0	1.2	1.2	0	7/1/00	68	0	0.9	0.2	0.9	0.7	-0.2
19/11/99	19	0		0.7				8/1/00	69	0.9		0.7			
20/11/99	20	0	0	0	0.7	0.7	0	9/1/00	70	0	0.9	0	0.7	0.7	0
21/11/99	21	0		0.6				10/1/00	71	1		0.7			
22/11/99	22	0	0	0	0.6	0.6	0	11/1/00	72	0	1	0.4	1.1	0.7	-0.4
23/11/99	23	0		1.2				12/1/00	73	1		0.7			
24/11/99	24	0	0	0	1.2	1.2	0	13/01/00	74	0	1	0	0.7	0.7	0
25/11/99	25	0		0.9				14/01/00	75	1		0.7			
26/11/99	26	0	0	0	0.9	0.9	0	15/01/00	76	0	1	0.4	1.1	0.7	-0.4
27/11/99	27	0		0.2				16/01/00	77	1		0.7			
28/11/99	28	0	0	0	0.2	0.2	0	17/01/00	78	0	1	0	0.7	0.7	0
29/11/99	29	0		0				18/01/00	79	1.1		0.7			
30/11/99	30	0	0	0	0	0	0	19/01/00	80	0	1.1	0.5	1.2	0.7	-0.5
1/12/99	31	0		0.3				20/01/00	81	1		0.5			
2/12/99	32	0	0	0	0.3	0.3	0	21/01/00	82	0	1	0	0.5	0.5	0
3/12/99	33	0		0.9				22/01/00	83	1		0.5			
4/12/99	34	0	0	0	0.9	0.9	0	23/01/00	84	0	1	0.8	1.3	0.5	-0.8
5/12/99	35	0		0.9				24/01/00	85	1.1		0.5			
6/12/99	36	0	0	0	0.9	0.9	0	25/01/00	86	0	1.1	0	0.5	0.5	0
7/12/99	37	0		0.9				26/01/00	87	1.2		0.5			
8/12/99	38	0	0	0	0.9	0.9	0	27/01/00	88	0	1.2	0.8	1.3	0.5	-0.8
9/12/99	39	0		0.5				28/01/00	89	1		0.5			
10/12/99	40	0	0	0	0.5	0.5	0	29/01/00	90	0	1	0	0.5	0.5	0
11/12/99	41	0		0.5				30/01/00	91	1		0.4			
12/12/99	42	0	0	0	0.5	0.5	0	31/01/00	92	0	1	0.9	1.3	0.4	-0.9
13/12/99	43	0		0.9				1/2/00	93	1.1		0.5			
14/12/99	44	0	0	0	0.9	0.9	0	2/2/00	94	0	1.1	0	0.5	0.5	0
15/12/99	45	0		0.9				3/2/00	95	1.2		0.5			
16/12/99	46	0	0	0	0.9	0.9	0	4/2/00	96	0	1.2	1	1.5	0.5	-1
17/12/99	47	0		0.9				5/2/00	97	1.2		0.5			
18/12/99	48	0	0	0	0.9	0.9	0	6/2/00	98	0	1.2	0	0.5	0.5	0
19/12/99	49	0		0.9				7/2/00	99	1.3		0.5			
20/12/99	50	0	0	0	0.9	0.9	0	8/2/00	100	0	1.3	0	0.5	0.5	0

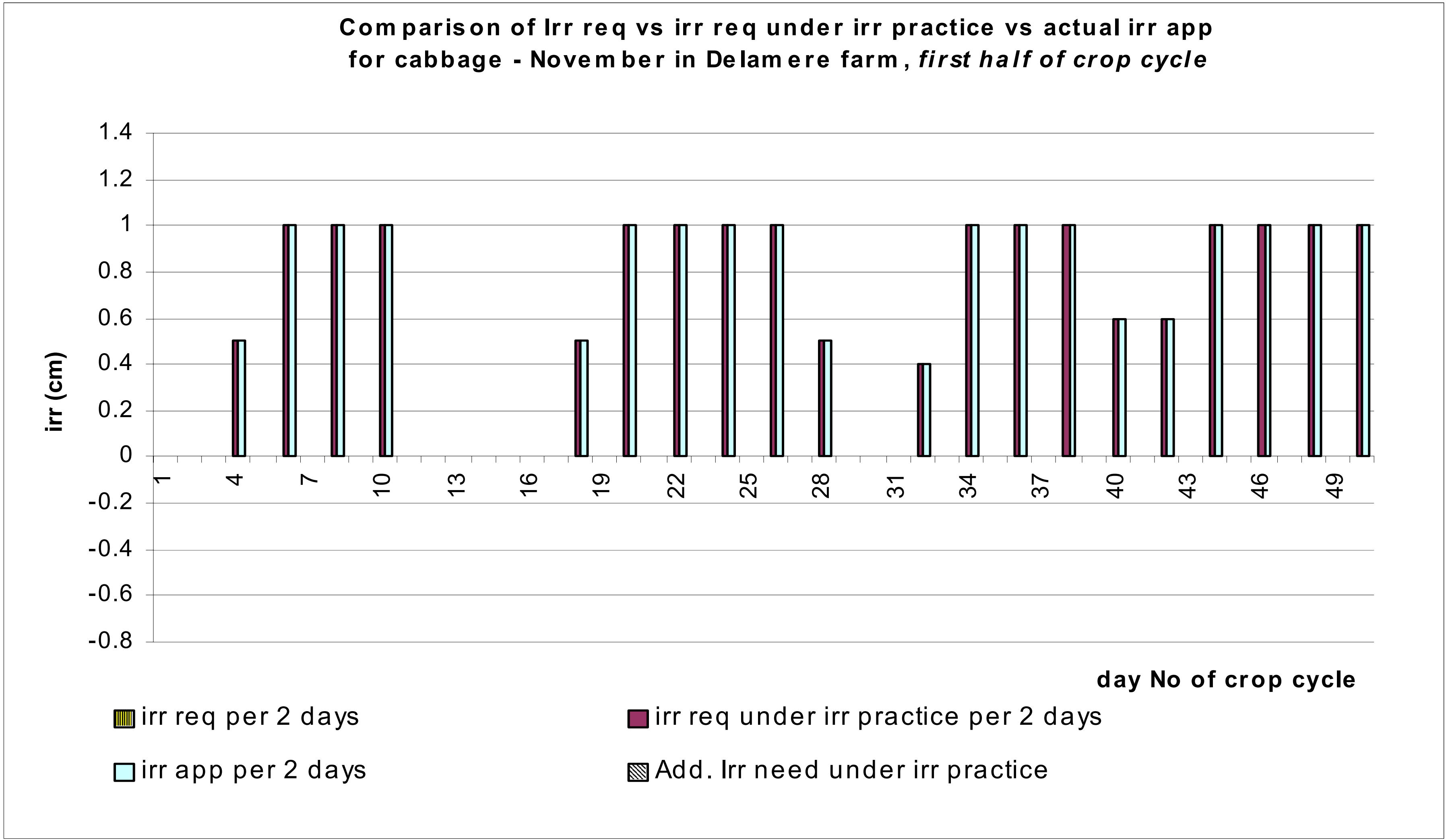

Comparison of Irr req vs irr req under irr practice vs actual irr app for cabbage - November in Three Point farm, ***first half of crop cycle***

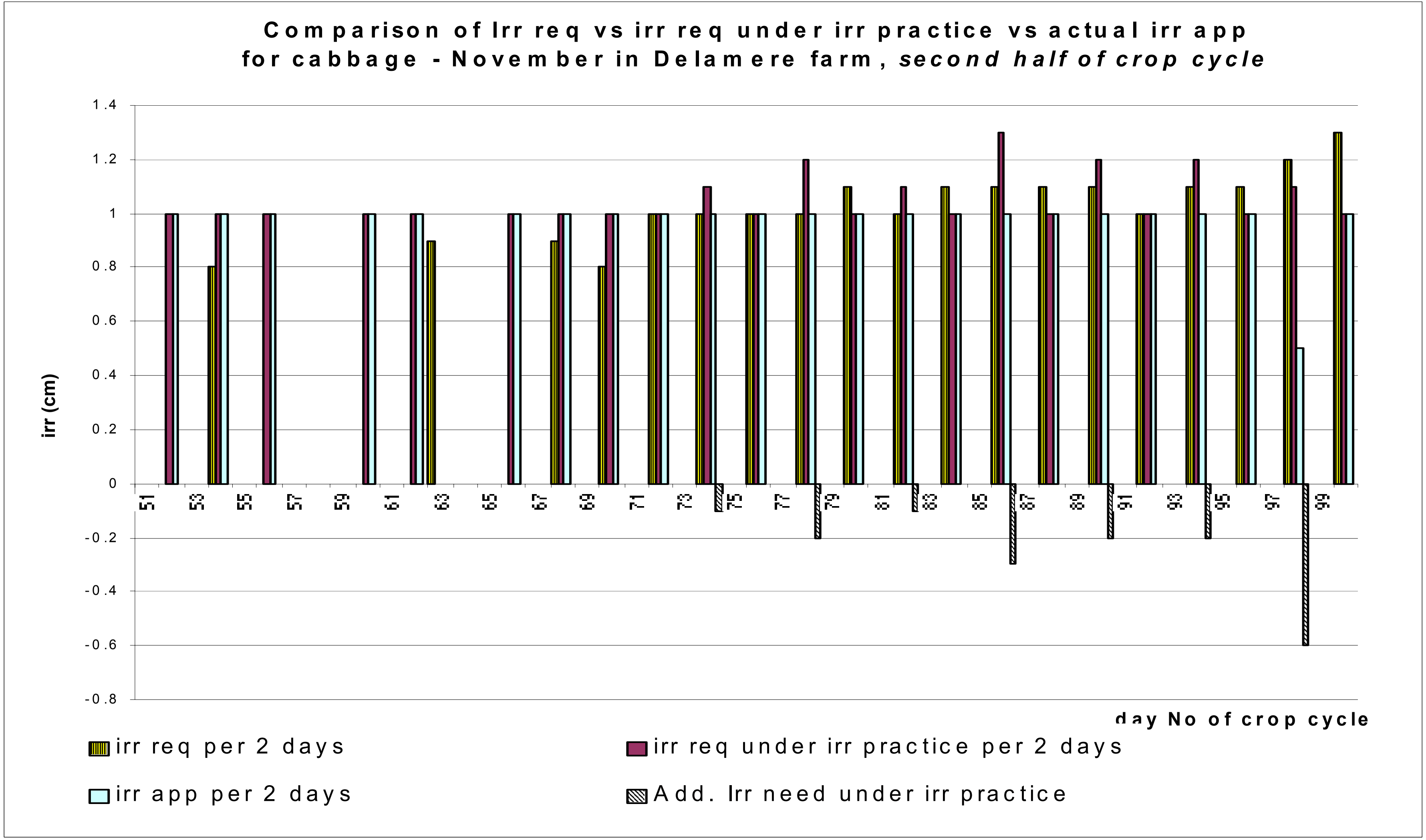

Comparison of Irr req vs irr req under irr practice vs actual irr app
for cabbage-November in Three Point farm, *second half of crop cycle*
irr (cm)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
51
53
55
57
59
61
63
65
67
69
71
73
75
77
79
81
83
85
87
89
91
93
95
97
99
day No of crop cycle
irr req per 2 days
irr req under irr practice per 2 days
irr app per 2 days
Add. Irr need under irr practice

Figure 5.8: Tables and charts present irrigation evaluation for inside crop cycle of cabbage growing in Delamere farm:

Irrigation for cabbage in Delamere Farm, starting date at 1st of November, 1999,

first half								second half							
Date	day No	irr req	irr req per 2 days	irr req under irr practice	irr req under irr practice per 2 days	irr. app per 2 days	Add. Irr need under irr practice	Date	day No	irr req	irr req per 2 days	irr req under irr practice	irr req under irr practice per 2 days	irr. app per 2 days	Add. Irr need under irr practice
		(cm)	(cm)	(cm)	(cm)	(cm)	(cm)			(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
1/11/99	1	0		0				21/12/99	51	0		1			
2/11/99	2	0	0	0	0	0	0	22/12/99	52	0	0	0	1	1	0
3/11/99	3	0		0.5				23/12/99	53	0		1			
4/11/99	4	0	0	0	0.5	0.5	0	24/12/99	54	0.8	0.8	0	1	1	0
5/11/99	5	0		1				25/12/99	55	0		1			
6/11/99	6	0	0	0	1	1	0	26/12/99	56	0	0	0	1	1	0
7/11/99	7	0		1				27/12/99	57	0		0			
8/11/99	8	0	0	0	1	1	0	28/12/99	58	0	0	0	0	0	0
9/11/99	9	0		1				29/12/99	59	0		1			
10/11/99	10	0	0	0	1	1	0	30/12/99	60	0	0	0	1	1	0
11/11/99	11	0		0				31/12/99	61	0		1			
12/11/99	12	0	0	0	0	0	0	1/1/00	62	0	0	0	1	1	0
13/11/99	13	0		0				2/1/00	63	0.9		0			
14/11/99	14	0	0	0	0	0	0	3/1/00	64	0	0.9	0	0	0	0
15/11/99	15	0		0				4/1/00	65	0		1			
16/11/99	16	0	0	0	0	0	0	5/1/00	66	0	0	0	1	1	0
17/11/99	17	0		0.5				6/1/00	67	0		1			
18/11/99	18	0	0	0	0.5	0.5	0	7/1/00	68	0.9	0.9	0	1	1	0
19/11/99	19	0		1				8/1/00	69	0		1			
20/11/99	20	0	0	0	1	1	0	9/1/00	70	0.8	0.8	0	1	1	0
21/11/99	21	0		1				10/1/00	71	0		1			
22/11/99	22	0	0	0	1	1	0	11/1/00	72	1	1	0	1	1	0
23/11/99	23	0		1				12/1/00	73	0		1			
24/11/99	24	0	0	0	1	1	0	13/01/00	74	1	1	0.1	1.1	1	-0.1
25/11/99	25	0		1				14/01/00	75	0		1			
26/11/99	26	0	0	0	1	1	0	15/01/00	76	1	1	0	1	1	0
27/11/99	27	0		0.5				16/01/00	77	0		1			
28/11/99	28	0	0	0	0.5	0.5	0	17/01/00	78	1	1	0.2	1.2	1	-0.2
29/11/99	29	0		0				18/01/00	79	0		1			
30/11/99	30	0	0	0	0	0	0	19/01/00	80	1.1	1.1	0	1	1	0
1/12/99	31	0		0.4				20/01/00	81	0		1			
2/12/99	32	0	0	0	0.4	0.4	0	21/01/00	82	1	1	0.1	1.1	1	-0.1
3/12/99	33	0		1				22/01/00	83	0		1			
4/12/99	34	0	0	0	1	1	0	23/01/00	84	1.1	1.1	0	1	1	0
5/12/99	35	0		1				24/01/00	85	0		1			
6/12/99	36	0	0	0	1	1	0	25/01/00	86	1.1	1.1	0.3	1.3	1	-0.3
7/12/99	37	0		1				26/01/00	87	0		1			
8/12/99	38	0	0	0	1	1	0	27/01/00	88	1.1	1.1	0	1	1	0
9/12/99	39	0		0.6				28/01/00	89	0		1			
10/12/99	40	0	0	0	0.6	0.6	0	29/01/00	90	1.1	1.1	0.2	1.2	1	-0.2
11/12/99	41	0		0.6				30/01/00	91	0		1			
12/12/99	42	0	0	0	0.6	0.6	0	31/01/00	92	1	1	0	1	1	0
13/12/99	43	0		1				1/2/00	93	0		1			
14/12/99	44	0	0	0	1	1	0	2/2/00	94	1.1	1.1	0.2	1.2	1	-0.2
15/12/99	45	0		1				3/2/00	95	0		1			
16/12/99	46	0	0	0	1	1	0	4/2/00	96	1.1	1.1	0	1	1	0
17/12/99	47	0		1				5/2/00	97	0		0.5			
18/12/99	48	0	0	0	1	1	0	6/2/00	98	1.2	1.2	0.6	1.1	0.5	-0.6
19/12/99	49	0		1				7/2/00	99	0		1			
20/12/99	50	0	0	0	1	1	0	8/2/00	100	1.3	1.3	0	1	1	0


Comparison of Irr req vs irr req under irr practice vs actual irr app for cabbage - November in Delamere farm, *first half of crop cycle*
irr (cm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
day No of crop cycle
irr req per 2 days
irr req under irr practice per 2 days
irr app per 2 days
Add. Irr need under irr practice



Comparison of Irr req vs irr req under irr practice vs actual irr app for cabbage - November in Delamere farm, *second half of crop cycle*

The comparison based on the difference between actual application subtract the irrigation requirement under irrigation practice presents the shortage of actual irrigation application

5.3.3 Conclusion for irrigation practice:

From the tables and graphs presented above, it is clear that for the whole crop cycle that most irrigation practice for most vegetables under sprinkle irrigation in the northern part of the Lake have used more water than crop requires if total irrigation application. Average losses (defined as the average value of estimated loss in figure 5.6) for the crops as follow:

Figure 5.9: estimated loss of irrigation application for crop in Threepoint and Delamere farms

Crop type	Farm	Average loss (cm)	Average loss (%)
Cabbage	Threepoint	6.3	23.1
	Delamere	14.8	51.6
French bean	Threepoint	16.0	85.6
	Delamere	25.8	138.4
Peas	Threepoint	-1.9	-4.6
Baby corn	Delamere	-1.5	-2.8
Grass	Delamere	-3.9	-28.3

This result shows that irrigation practice in Delamere farm for cabbage and French bean creates more losses than that of Threepoint farm.

But in the other hand, when looking into irrigation application along the crop development, the current irrigation practice creates some shortage of water for crop growing in later crop stages[7].

For cabbage, the shortage of irrigation occurred after day 67 of crop cycle and it presents a more serious shortage of irrigation in case of Threepoint farm than irrigation for the same crop in Delamere farm.

The results from the model show that actual irrigation application for French bean in Delamere has well captured the crop requirement as no shortage appeared along the crop-growing season for every different starting time. In this case the irrigation gift by far exceeds the irrigation needs, a lot of losses occur. But in contrast, French bean in Threepoint farm is under a better irrigation schedule and only a little shortage of irrigation happened by the end of crop cycle and the losses was also smaller than that of Delamere farm.

For Peas and baby corn in both farm are under-irrigated as the shortage appeared strongly in the last quarter of the crop cycle.

With 30mm of irrigation once a week for grass, it clearly shows that this application is under grass water requirement. In the table and graph that compare irrigation requirement generated from the model and actual irrigation application, the shortage of irrigation happened along the whole computing time. The average shortage of irrigation for grass is about 28% of current application as shown in the figure 5.9.

How the irrigation schedule should be for better crop production? A test for optimum irrigation schedule has been conducted in the following part:

---

[7] Those are presented in tables and graphs of figure 5.7, 5.8 and in Annex 5.3a and 5.3b

5.3.4 Test for optimum irrigation schedule

Cabbage growing in Threepoint farm has been selected for this test.

The model inputs of fixed irrigation for different starting month was changed following the crop water requirement.

The schedule was changed gradually until no irrigation shortage appears in the output of the model for irrigation requirement under irrigation practice.

Annex 5.5a presents the result of the test and new irrigation application for optimum irrigation practice for cabbage with starting time in November 1999, February and May 2000.

Hereafter is the table of old irrigation application and optimum irrigation for cabbage (figure 5.10 in the next page).

This result is really important and useful for irrigator in improving irrigation application in the field in order to meet crop water demand and reduce water losses in practice, hence reduce the operation cost of irrigation system.

It is clear that if the irrigation application can follow the optimum schedule, the irrigation depth can be considerably reduced, from 15 to 30% as shown in figure 5.10)

Figure 5.10: Comparison of current irrigation application and optimum irrigation application.

Day	Nov				Feb				May			
No	day	month	old depth	*optimum depth*	day	month	old depth	*optimum depth*	day	month	old depth	*optimum depth*
			mm	*mm*			mm	*mm*			mm	*mm*
1	1	11	3	*0*	1	2	12	*3*	1	5	12	*3*
3	3	11	7	*0*	3	2	12	*0*	3	5	0	*0*
5	5	11	12	*2*	5	2	12	*0*	5	5	12	*2*
7	7	11	6	*2*	7	2	12	*2*	7	5	12	*2*
9	9	11	12	*2*	9	2	12	*0*	9	5	12	*2*
11	11	11	9	*0*	11	2	12	*0*	11	5	12	*2*
13	13	11	0	*0*	13	2	12	*2*	13	5	12	*2*
15	15	11	0	*0*	15	2	12	*0*	15	5	12	*2*
17	17	11	12	*2*	17	2	12	*0*	17	5	12	*4*
19	19	11	7	*2*	19	2	12	*3*	19	5	12	*4*
21	21	11	6	*0*	21	2	12	*3*	21	5	12	*4*
23	23	11	12	*2*	23	2	12	*3*	23	5	12	*4*
25	25	11	9	*2*	25	2	9	*5*	25	5	5	*0*
27	27	11	2	*0*	27	2	9	*6*	27	5	5	*4*
29	29	11	0	*0*	29	2	9	*6*	29	5	4	*0*
31	1	12	3	*0*	2	3	9	*6*	31	5	9	*4*
33	3	12	9	*2*	4	3	9	*6*	2	6	9	*5*
35	5	12	9	*4*	6	3	4	*5*	4	6	9	*5*
37	7	12	9	*4*	8	3	9	*5*	6	6	9	*5*
39	9	12	5	*0*	10	3	3	*5*	8	6	9	*5*
41	11	12	5	*2*	12	3	9	*8*	10	6	9	*6*
43	13	12	9	*4*	14	3	9	*8*	12	6	9	*6*
45	15	12	9	*4*	16	3	9	*8*	14	6	9	*6*
47	17	12	9	*4*	18	3	9	*8*	16	6	9	*6*
49	19	12	9	*5*	20	3	9	*8*	18	6	9	*6*
51	21	12	7	*6*	22	3	7	*8*	20	6	9	*6*
53	23	12	7	*6*	24	3	7	*8*	22	6	2	*0*
55	25	12	4	*2*	26	3	7	*10*	24	6	7	*8*
57	27	12	0	*0*	28	3	7	*10*	26	6	7	*8*
59	29	12	7	*6*	30	3	7	*10*	28	6	7	*8*
61	31	12	7	*7*	1	4	7	*10*	30	6	7	*8*
63	2	1	0	*0*	3	4	3	*7*	2	7	7	*8*
65	4	1	7	*7*	5	4	7	*8*	4	7	3	*0*
67	6	1	7	*7*	7	4	3	*4*	6	7	7	*10*
69	8	1	7	*7*	9	4	4	*6*	8	7	7	*10*
71	10	1	7	*7*	11	4	7	*12*	10	7	7	*10*
73	12	1	7	*7*	13	4	7	*12*	12	7	7	*10*
75	14	1	7	*8*	15	4	7	*12*	14	7	7	*10*
77	16	1	7	*8*	17	4	2	*8*	16	7	7	*10*
79	18	1	7	*8*	19	4	7	*10*	18	7	7	*10*
81	20	1	5	*8*	21	4	5	*10*	20	7	5	*10*
83	22	1	5	*8*	23	4	2	*6*	22	7	0	*0*
85	24	1	5	*8*	25	4	0	*0*	24	7	5	*10*
87	26	1	5	*8*	27	4	5	*12*	26	7	5	*10*
89	28	1	5	*8*	29	4	5	*12*	28	7	5	*9*
91	30	1	4	*8*	1	5	5	*12*	30	7	5	*9*
93	1	2	5	*8*	3	5	0	*5*	1	8	5	*10*
95	3	2	5	*10*	5	5	5	*10*	3	8	5	*9*
97	5	2	5	*10*	7	5	5	*10*	5	8	5	*10*
99	7	2	5	*10*	9	5	5	*10*	7	8	5	*10*
Total (mm)			**310**	***215***			**376**	***322***			**379**	***292***

5.4 *Sensitive analysis of SWAP model*

In order to suggest the better irrigation practice, it is necessary to conduct model sensitive analysis where some model input parameters become variable and effect the output of the model on irrigation requirement. Suggestion on irrigation practice can be given based on this analysis.

Following parameters are used for this purpose:

- Soil type.
- Timing criteria of scheduled irrigation
- Initial soil moisture content (hence, be converted to the soil pressure head input)

Cabbage growing in Threepoint farm is used for this analysis

5.4.1 *Analysis procedures:*

5.4.1.1 *Change of soil properties:*

The first attempt is to change the soil type from clay loam (as mentioned in the earlier part) to silty clay loam[8], the percentage of sand, silt and clay are assumed at the middle of soil group in USDA soil triangle. The layer hydraulic properties are kept the same (as given in SWAP annex A). Other parameters are the same with previous computation.

The results from this option show that no change in irrigation requirement was made from the model.

Then the layer-hydraulic properties are assumed to be changed with Ksat from 172.8 cm/day to 144.0 cm/day for the top layer and from 39.7 to 198.7 cm/day for the sub-layers. With those change, the results from the model indicated that irrigation application of Threepoint farm for any starting time are far under irrigated. That seems not true when compared to irrigation observed from the field, but it can be said that model is sensitive to the change of soil type and it may have a strong effect on irrigation requirement computation.

5.4.1.2 *Change of timing criteria of scheduled irrigation*

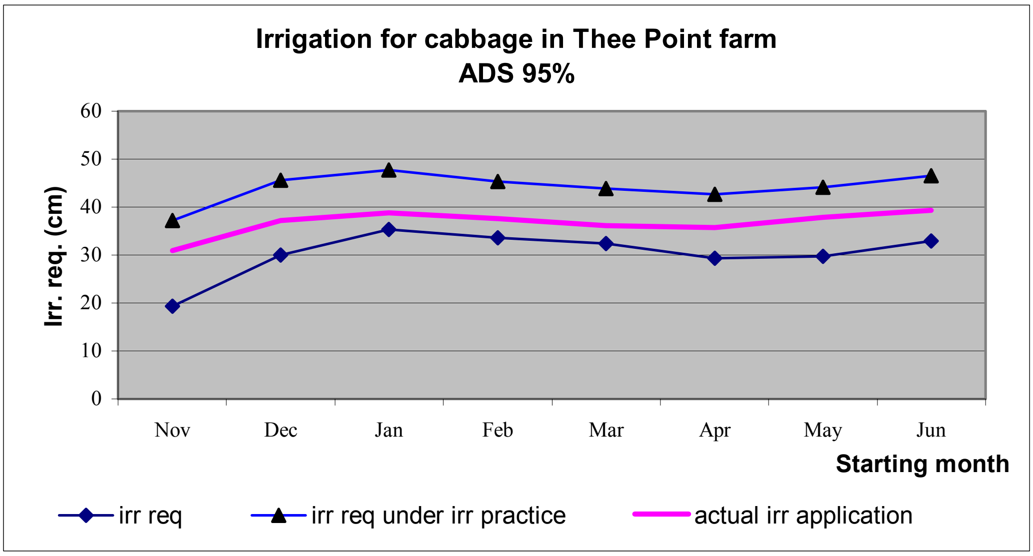
If the timing criteria of scheduled irrigation is set changed from ***0.95 ADS*** (Allowable Daily Stress) ***to 0,75 ADS*** then the model results are presented in following tables and graphs:

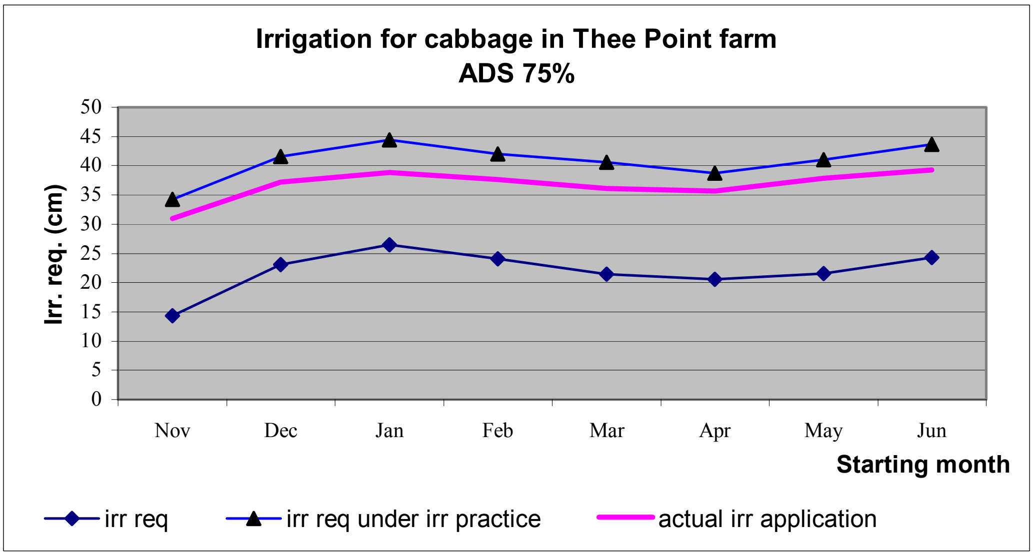
---

[8] The reason for this choice is due to one of soil samples taken from the field appeared as silty clay loam when classified by feeling method.

Figure 5.11: Tables and graphs present the comparison of irrigation requirement when timing criteria of scheduled irrigation changed from 0.95 to 0.75 of Allowable Daily Stress.

Staring month	ADS 95%		ADS 75%		Actual irrigation application
	Irr req	irr req under irr app	Irr req	irr req under irr app	
	cm	cm	cm	cm	cm
Nov	19.4	37.2	14.3	34.2	31.0
Dec	30	45.6	23.1	41.6	37.2
Jan	35.4	47.8	26.5	44.4	38.8
Feb	33.6	45.3	24.1	42	37.6
Mar	32.4	43.9	21.4	40.6	36.1
Apr	29.4	42.7	20.6	38.7	35.7
May	29.8	44.1	21.6	41	37.9
Jun	32.9	46.5	24.3	43.7	39.3



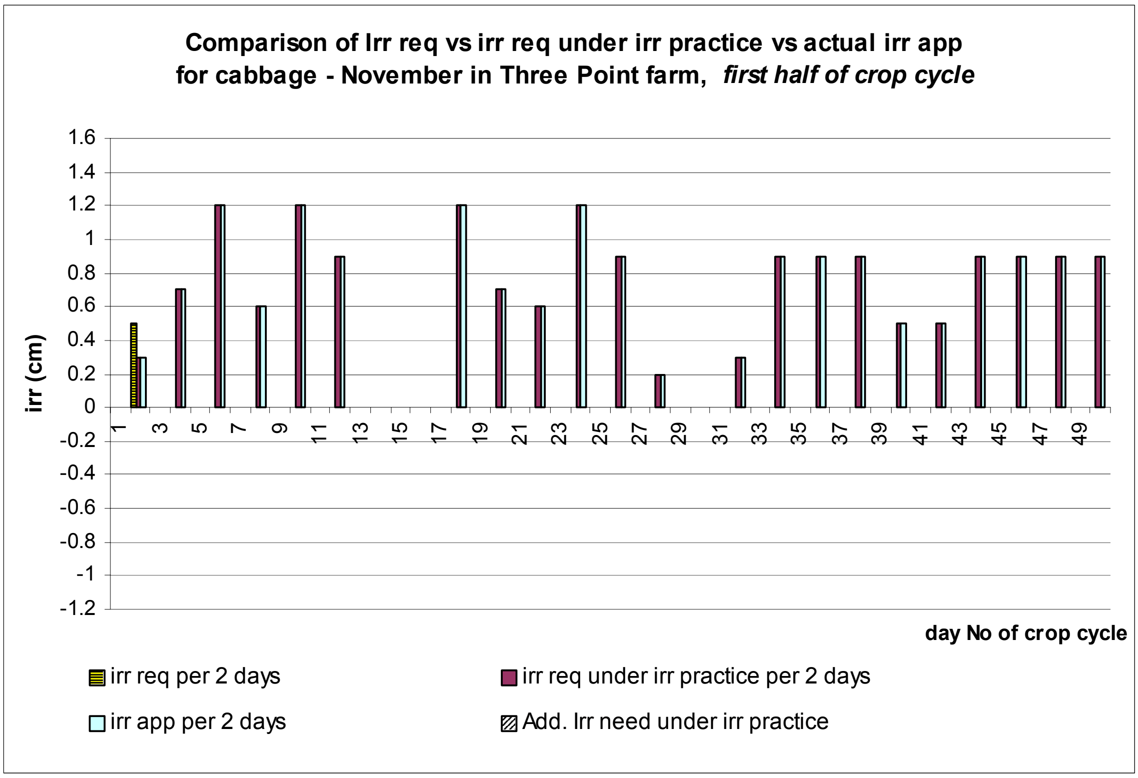


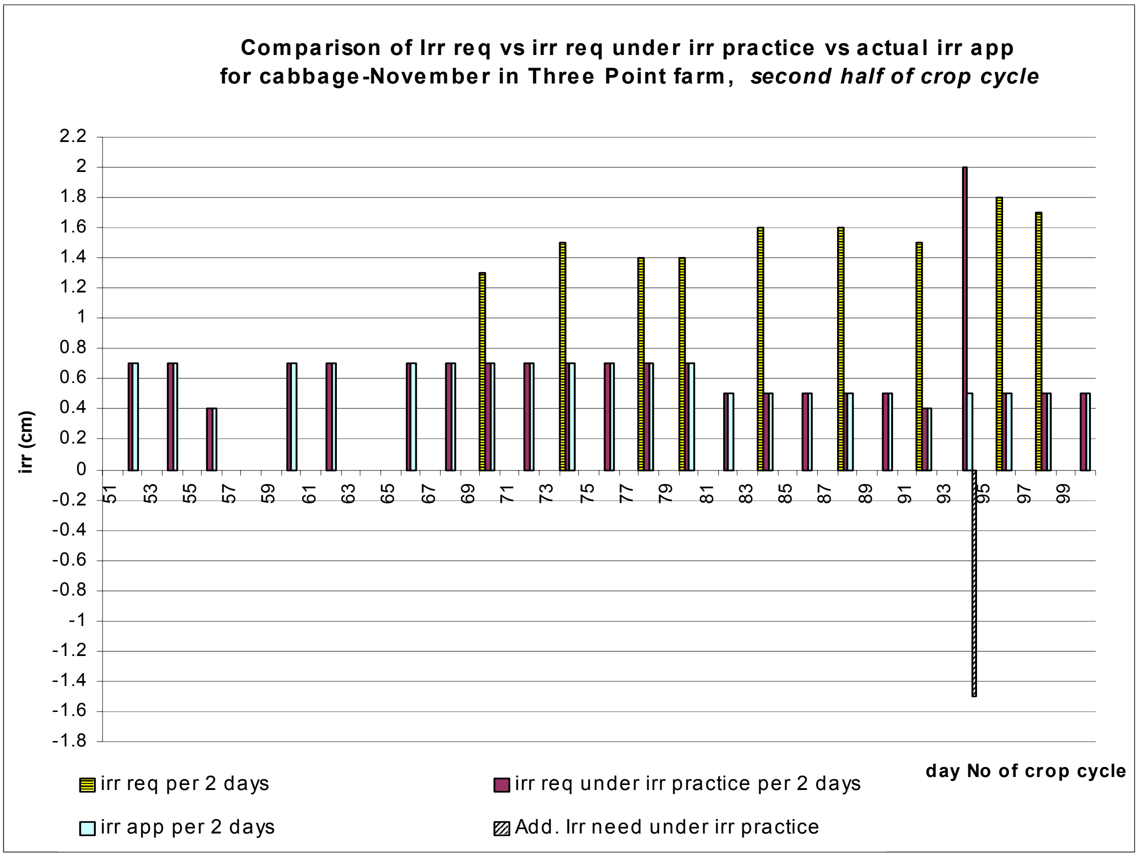
It is clear that irrigation requirement in the case of 0.75 ADS (Allowable Daily Stress) is much lower than that of 0.95 ADS. If the criterion is applied in the field then the irrigation application become more over irrigated as shown in the graph above.

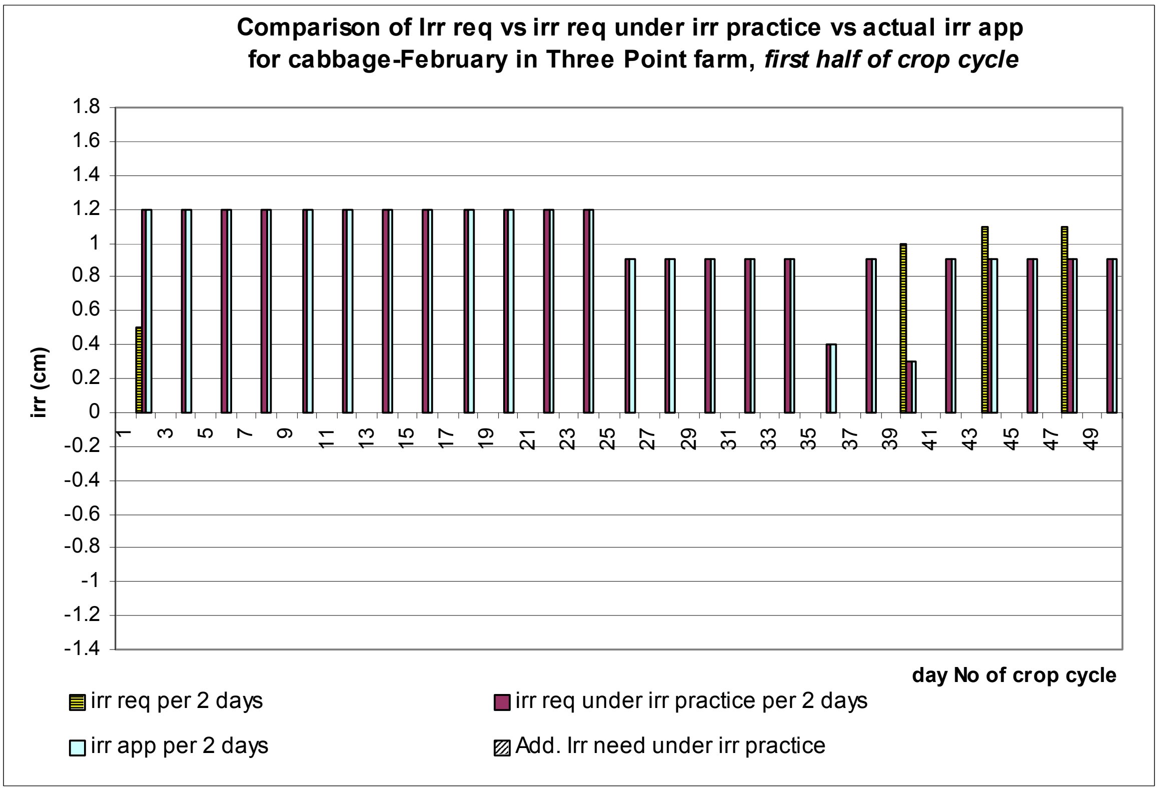
But when look into the following graphs (figure 5.12), we can see that less shortage of irrigation appear inside crop cycle than that of previous case although the losses of irrigation in the early stage are higher.

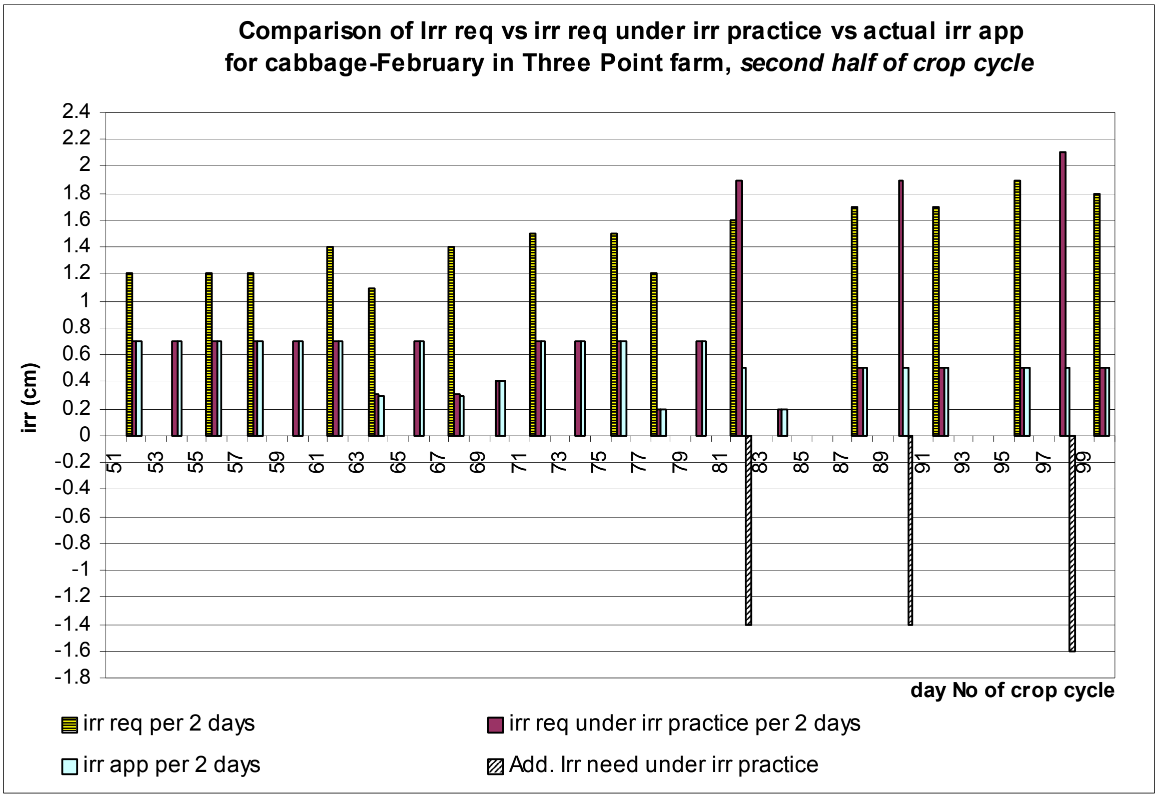
This may be an important point to irrigation manager when select a suitable schedule to meet his irrigation supply ability.

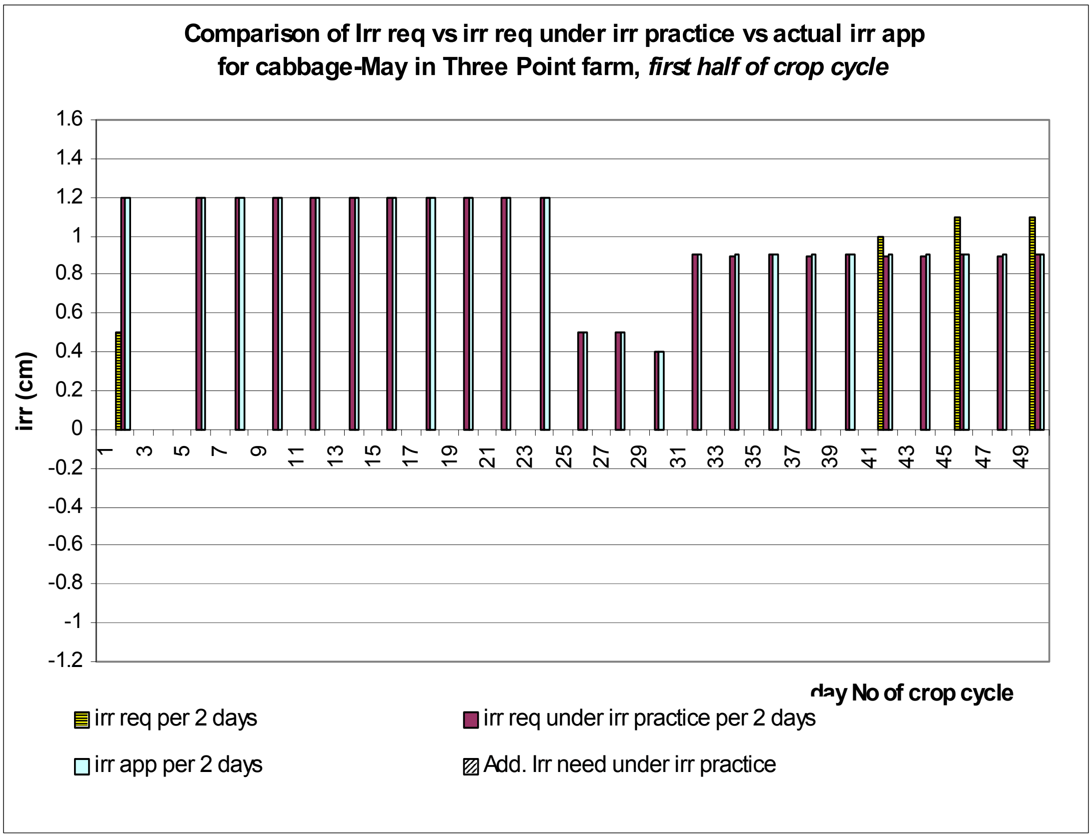
Figure 5.12: Comparison irrigation requirement of inside crop cycle for cabbage of Threepoint farm for the case of 0.75 Allowable daily strees.

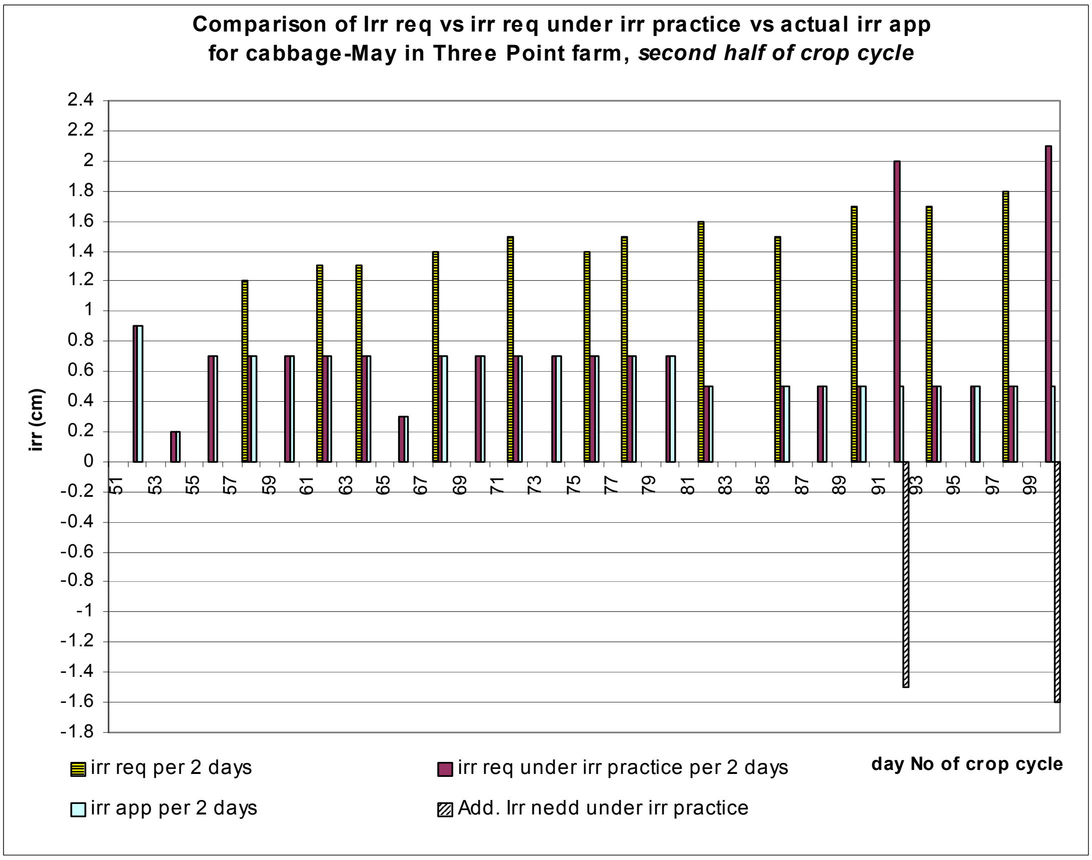





Comparison of Irr req vs irr req under irr practice vs actual irr app
for cabbage-February in Three Point farm, *first half of crop cycle*
irr (cm)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
day No of crop cycle
irr req per 2 days
irr req under irr practice per 2 days
irr app per 2 days
Add. Irr need under irr practice


Comparison of Irr req vs irr req under irr practice vs actual irr app
for cabbage-February in Three Point farm, *second half of crop cycle*
irr (cm)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
51
53
55
57
59
61
63
65
67
69
71
73
75
77
79
81
83
85
87
89
91
93
95
97
99
day No of crop cycle
irr req per 2 days
irr req under irr practice per 2 days
irr app per 2 days
Add. Irr need under irr practice


Comparison of Irr req vs irr req under irr practice vs actual irr app
for cabbage-May in Three Point farm, *first half of crop cycle*
irr (cm)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
day No of crop cycle
irr req per 2 days
irr req under irr practice per 2 days
irr app per 2 days
Add. Irr need under irr practice


Comparison of Irr req vs irr req under irr practice vs actual irr app
for cabbage-May in Three Point farm, *second half of crop cycle*
irr (cm)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
51
53
55
57
59
61
63
65
67
69
71
73
75
77
79
81
83
85
87
89
91
93
95
97
99
day No of crop cycle
irr req per 2 days
irr req under irr practice per 2 days
irr app per 2 days
Add. Irr nedd under irr practice

5.4.1.3 Change of initial soil moisture content

Soil moisture content would be the strongest effect on irrigation requirement computation. The following table is the assumed initial moisture[9]. This assumes that the top and lower layers are left drier than the soil moisture in the previous computed case. This soil condition is quite possible to be happened in the practice.

The results from the model computation are presented in the (figure 5.13)

Figure 5.13: Irrigation requirement with new initial soil moisture condition

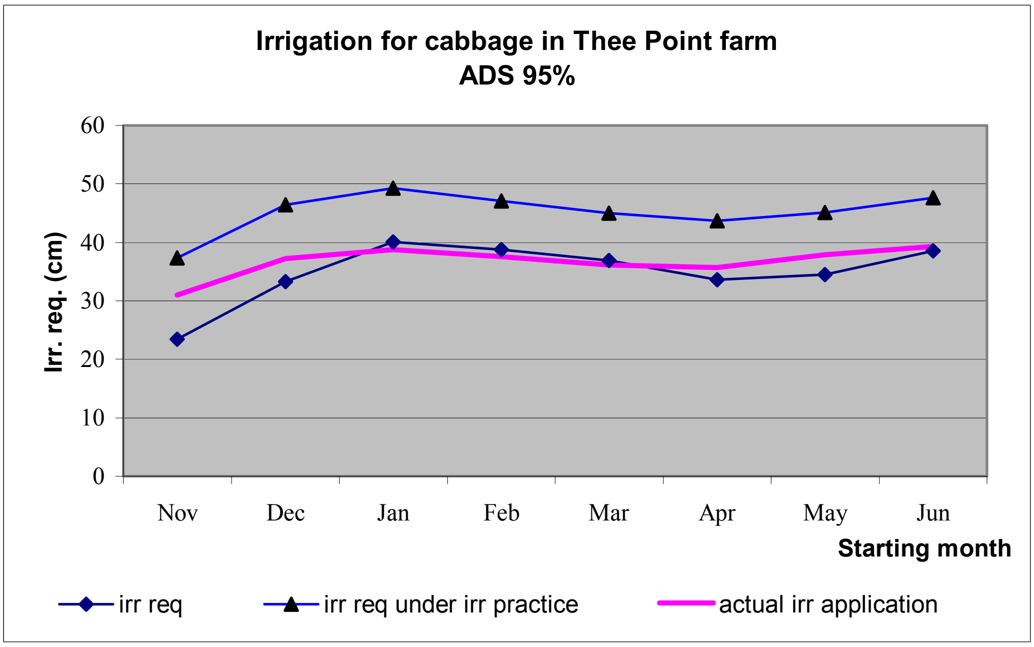


Figure 5.14: Table for comparing irrigation requirement for different initial soil moisture content

Staring month	Previous soil moisture content		New assumed soil moisture content	
	Irr req	irr req under irr app	Irr req	irr req under irr app
	cm	cm	cm	cm
Nov	19.4	37.2	23.4	37.3
Dec	30	45.6	33.3	46.4
Jan	35.4	47.8	40.1	49.3
Feb	33.6	45.3	38.8	47.1
Mar	32.4	43.9	36.9	45
Apr	29.4	42.7	33.6	43.7
May	29.8	44.1	34.5	45.1
Jun	32.9	46.5	38.5	47.6

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[9] To see the different between 2 soil moisture status, refer to the Annex 5E and 5F

It is clear that irrigation requirement has considerably increased while irrigation requirement under irrigation practice has a very little change. Then less loss can be expected.

5.4.2 Conclusion for sensitive analysis:

Irrigation requirement is strongly effected in the case of different soil hydraulic properties and scheduled irrigation timing criteria. The irrigation managers can base on these factors to schedule their irrigation practice.

5.5 Results from CROPWAT model

Next to SWAP also the CROPWAT model can calculate crop water requirements and the local water balance. Part of the research is to see if the CROPWAT model can be used for the same kind of evaluation.

5.5.1 Model input:

CROPWAT is used to calculate irrigation requirement of crops growing in the research area. The climate data are taken from meteo data set which were used for SWAP model, but with average value for each month. They includes mean maximum temperature, mean minimum temperature, air humidity, wind speed, daily sunshine hours. The values of sunshine hours are taken from research of Hamududu (1998).

Rainfall data are taken from the data set used for SWAP but with the sum value for each month of computing period.

Cabbage is chosen for irrigation requirements as a case study. The root depth of cabbage is following the crop input for SWAP model[10]. Kc values for different crop development stages are taken from CROPWAT pre-defined data set for cabbage.

Three different starting dates (November 1st, February 1st and May 1st) are chosen in accordance with those of SWAP computation.

The data for soil data are entered for model computation. But the limitation of soil maximum infiltration rate in 30cm/day while the actual infiltration rate measured from the field is 172.8 cm/day. Anyway, the max value of soil infiltration rate is used. Initial soil moisture when stating simulation is 95% of total available moisture as chosen in SWAP.

Irrigation criteria options are chosen with fixed irrigation for every 2 days and the moisture is to be brought back to field capacity. Planting date is November 1st.

Effective rainfall of the model is calculated by USDA soil conservation method.

Inputs of the model are placed in Annex 5.7

5.5.2 Model outputs:

The results from model execution included of crop water requirement and irrigation requirement and are presented in the following tables (figure 5.11) and in Annex 5.6.

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[10] Refer to the figure 4.8.

Figure 5.11: CROPWAT output for cabbage water requirement (starting at 1st Nov, 1st Feb and 1st May)

```
2/5/01 CROPWAT          4 Windows   Ver             4.2
*******************************************************************************
       Crop      Water    Requirements              Report
*******************************************************************************
-      Crop         #                   1 :         CABBAGE
-      Block        #           :         [All      blocks]
-      Planting     date        :            1-Nov-99
-      Calculation  time step   =                 2 Day(s)
-      Irrigation   Efficiency  =               70%
```

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
1-Nov	8.85	100	0.7	6.19	6.58	4.94	1.26	0.1
3-Nov	8.85	100	0.7	6.19	7.69	5.76	0.44	0.04
5-Nov	8.85	100	0.7	6.19	8.56	6.4	0	0
7-Nov	8.85	100	0.7	6.19	9.2	6.89	0	0
9-Nov	8.85	100	0.7	6.19	9.64	7.24	0	0
11-Nov	8.85	100	0.7	6.19	9.9	7.46	0	0
13-Nov	8.85	100	0.7	6.19	10	7.57	0	0
15-Nov	8.85	100	0.7	6.19	9.97	7.59	0	0
17-Nov	8.84	100	0.7	6.19	9.82	7.52	0	0
19-Nov	8.84	100	0.7	6.19	9.58	7.38	0	0
21-Nov	8.84	100	0.7	6.19	9.25	7.18	0	0
23-Nov	8.84	100	0.7	6.19	8.86	6.93	0	0
25-Nov	8.83	100	0.7	6.23	8.42	6.65	0	0
27-Nov	8.83	100	0.72	6.4	7.94	6.33	0.07	0.01
29-Nov	8.83	100	0.75	6.58	7.44	5.99	0.59	0.05
1-Dec	8.82	100	0.76	6.75	6.91	5.63	1.12	0.09
3-Dec	8.82	100	0.78	6.92	6.38	5.27	1.65	0.14
5-Dec	8.81	100	0.8	7.09	5.86	4.9	2.19	0.18
7-Dec	8.81	100	0.82	7.26	5.34	4.54	2.73	0.23
9-Dec	8.8	100	0.84	7.43	4.84	4.18	3.26	0.27
11-Dec	8.79	100	0.86	7.6	4.36	3.83	3.77	0.31
13-Dec	8.78	100	0.88	7.77	3.9	3.5	4.27	0.35
15-Dec	8.78	100	0.9	7.94	3.48	3.19	4.75	0.39
17-Dec	8.77	100	0.92	8.11	3.09	2.9	5.22	0.43
19-Dec	8.76	100	0.94	8.28	2.73	2.62	5.65	0.47
21-Dec	8.75	100	0.96	8.44	2.41	2.38	6.07	0.5
23-Dec	8.74	100	0.98	8.61	2.13	2.13	6.48	0.54
25-Dec	8.73	100	1	8.78	1.89	1.89	6.89	0.57
27-Dec	8.72	100	1.02	8.94	1.68	1.68	7.26	0.6
29-Dec	8.71	100	1.04	9.11	1.51	1.51	7.59	0.63
31-Dec	8.79	100	1.05	9.23	1.93	1.83	7.4	0.61
2-Jan	8.93	100	1.05	9.38	2.32	2.14	7.25	0.6
4-Jan	9.02	100	1.05	9.47	2.14	1.98	7.49	0.62
6-Jan	9.1	100	1.05	9.55	1.96	1.82	7.73	0.64
8-Jan	9.18	100	1.05	9.64	1.78	1.66	7.98	0.66
10-Jan	9.26	100	1.05	9.72	1.6	1.51	8.21	0.68
12-Jan	9.33	100	1.05	9.8	1.42	1.35	8.45	0.7
14-Jan	9.41	100	1.05	9.88	1.25	1.21	8.67	0.72
16-Jan	9.49	100	1.05	9.96	1.09	1.07	8.89	0.73
18-Jan	9.56	100	1.05	10.04	0.94	0.94	9.1	0.75
20-Jan	9.63	100	1.05	10.11	0.8	0.8	9.32	0.77
22-Jan	9.7	100	1.05	10.19	0.67	0.67	9.52	0.79
24-Jan	9.77	100	1.05	10.23	0.55	0.55	9.68	0.8
26-Jan	9.84	100	1.03	10.16	0.44	0.44	9.73	0.8
28-Jan	9.9	100	1.02	10.1	0.34	0.34	9.76	0.81
30-Jan	9.96	100	1.01	10.03	0.25	0.25	9.78	0.81
1-Feb	10.02	100	0.99	9.96	0.17	0.17	9.79	0.81
3-Feb	10.08	100	0.98	9.88	0.09	0.09	9.79	0.81
5-Feb	10.14	100	0.97	9.8	0.02	0.02	9.78	0.81
7-Feb	10.19	100	0.95	9.72	0	0	9.72	0.8
Total	455.55			409.41	209.12	170.78	**249.29**	[0.41]

- Crop # 1 : CABBAGE
- Block # : [All blocks]
- Planting date : 1-Feb-00
- Calculation time step = 2 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
1-Feb	10.02	100	0.7	7.02	0.17	0.17	6.85	0.57
3-Feb	10.08	100	0.7	7.06	0.09	0.09	6.97	0.58
5-Feb	10.14	100	0.7	7.1	0.02	0.02	7.08	0.59
7-Feb	10.19	100	0.7	7.13	0	0	7.13	0.59
9-Feb	10.24	100	0.7	7.17	0	0	7.17	0.59
11-Feb	10.29	100	0.7	7.21	0	0	7.21	0.6
13-Feb	10.34	100	0.7	7.24	0	0	7.24	0.6
15-Feb	10.39	100	0.7	7.27	0	0	7.27	0.6
17-Feb	10.43	100	0.7	7.3	0	0	7.3	0.6
19-Feb	10.47	100	0.7	7.33	0	0	7.33	0.61
21-Feb	10.5	100	0.7	7.35	0	0	7.35	0.61
23-Feb	10.54	100	0.7	7.38	0	0	7.38	0.61
25-Feb	10.57	100	0.7	7.45	0	0	7.45	0.62
27-Feb	10.6	100	0.72	7.69	0	0	7.69	0.64
1-Mar	10.63	100	0.75	7.92	0	0	7.92	0.65
3-Mar	10.66	100	0.76	8.15	0	0	8.15	0.67
5-Mar	10.68	100	0.78	8.38	0	0	8.38	0.69
7-Mar	10.7	100	0.8	8.61	0	0	8.61	0.71
9-Mar	10.72	100	0.82	8.84	0	0	8.84	0.73
11-Mar	10.73	100	0.84	9.07	0	0	9.07	0.75
13-Mar	10.75	100	0.86	9.3	0	0	9.3	0.77
15-Mar	10.76	100	0.88	9.52	0	0	9.52	0.79
17-Mar	10.77	100	0.9	9.75	0	0	9.75	0.81
19-Mar	10.78	100	0.92	9.97	0	0	9.97	0.82
21-Mar	10.78	100	0.94	10.19	0	0	10.19	0.84
23-Mar	10.78	100	0.96	10.41	0	0	10.41	0.86
25-Mar	10.79	100	0.98	10.62	0.35	0.34	10.28	0.85
27-Mar	10.78	100	1	10.84	1.02	0.98	9.86	0.82
29-Mar	10.78	100	1.02	11.05	1.42	1.34	9.71	0.8
31-Mar	10.78	100	1.04	11.26	1.78	1.66	9.6	0.79
2-Apr	10.77	100	1.05	11.31	2.11	1.95	9.35	0.77
4-Apr	10.76	100	1.05	11.3	2.39	2.21	9.09	0.75
6-Apr	10.75	100	1.05	11.29	2.64	2.44	8.85	0.73
8-Apr	10.74	100	1.05	11.28	2.85	2.63	8.65	0.72
10-Apr	10.73	100	1.05	11.26	3.02	2.79	8.47	0.7
12-Apr	10.71	100	1.05	11.25	3.17	2.92	8.33	0.69
14-Apr	10.69	100	1.05	11.23	3.28	3.02	8.21	0.68
16-Apr	10.68	100	1.05	11.21	3.36	3.09	8.12	0.67
18-Apr	10.66	100	1.05	11.19	3.4	3.14	8.05	0.67
20-Apr	10.64	100	1.05	11.17	3.42	3.16	8.01	0.66
22-Apr	10.61	100	1.05	11.14	3.42	3.15	7.99	0.66
24-Apr	10.59	100	1.05	11.12	3.39	3.13	7.99	0.66
26-Apr	10.57	100	1.05	11.06	3.33	3.08	7.98	0.66
28-Apr	10.54	100	1.03	10.89	3.26	3.02	7.87	0.65
30-Apr	10.51	100	1.02	10.72	3.16	2.93	7.79	0.64
2-May	10.48	100	1.01	10.55	3.05	2.83	7.72	0.64
4-May	10.46	100	0.99	10.39	2.92	2.72	7.67	0.63
6-May	10.43	100	0.98	10.22	2.78	2.59	7.62	0.63
8-May	10.40	100	0.97	10.05	2.63	2.46	7.59	0.63
10-May	10.37	100	0.95	9.88	2.47	2.32	7.56	0.63
Total				474.08	64.88	60.17	**413.91**	[0.68]

- Crop # 1 : CABBAGE
- Block # : [All blocks]
- Planting date : 1-May-00
- Calculation time step = 2 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
1-May	10.5	100	0.7	7.35	3.11	2.88	4.47	0.37
3-May	10.47	100	0.7	7.33	2.99	2.78	4.55	0.38
5-May	10.44	100	0.7	7.31	2.85	2.66	4.65	0.38
7-May	10.41	100	0.7	7.29	2.7	2.53	4.76	0.39
9-May	10.38	100	0.7	7.27	2.55	2.39	4.88	0.4
11-May	10.35	100	0.7	7.24	2.38	2.24	5	0.41
13-May	10.32	100	0.7	7.22	2.22	2.09	5.13	0.42
15-May	10.28	100	0.7	7.2	2.05	1.94	5.26	0.43
17-May	10.25	100	0.7	7.18	1.88	1.79	5.38	0.45
19-May	10.22	100	0.7	7.15	1.72	1.65	5.51	0.46
21-May	10.18	100	0.7	7.13	1.56	1.51	5.62	0.46
23-May	10.15	100	0.7	7.1	1.42	1.38	5.73	0.47
25-May	10.11	100	0.7	7.13	1.29	1.26	5.87	0.49
27-May	10.08	100	0.72	7.31	1.18	1.16	6.15	0.51
29-May	10.04	100	0.75	7.48	1.09	1.07	6.41	0.53
31-May	10.01	100	0.76	7.66	1.03	1.01	6.64	0.55
2-Jun	9.97	100	0.78	7.83	1	0.98	6.85	0.57
4-Jun	9.94	100	0.8	8	1	0.97	7.03	0.58
6-Jun	9.9	100	0.82	8.17	0	0	8.17	0.68
8-Jun	9.87	100	0.84	8.34	0	0	8.34	0.69
10-Jun	9.83	100	0.86	8.5	0	0	8.5	0.7
12-Jun	9.8	100	0.88	8.67	0	0	8.67	0.72
14-Jun	9.76	100	0.9	8.83	0	0	8.83	0.73
16-Jun	9.73	100	0.92	9	0	0	9	0.74
18-Jun	9.69	100	0.94	9.16	0	0	9.16	0.76
20-Jun	9.66	100	0.96	9.32	0	0	9.32	0.77
22-Jun	9.62	100	0.98	9.48	0	0	9.48	0.78
24-Jun	9.59	100	1	9.64	0.5	0.49	9.15	0.76
26-Jun	9.56	100	1.02	9.8	1.02	1	8.8	0.73
28-Jun	9.53	100	1.04	9.96	1.05	1.02	8.93	0.74
30-Jun	9.49	100	1.05	9.97	1.08	1.05	8.92	0.74
2-Jul	9.46	100	1.05	9.94	1.1	1.07	8.87	0.73
4-Jul	9.43	100	1.05	9.9	1.12	1.09	8.82	0.73
6-Jul	9.4	100	1.05	9.87	1.13	1.1	8.77	0.73
8-Jul	9.37	100	1.05	9.84	1.14	1.11	8.73	0.72
10-Jul	9.35	100	1.05	9.81	1.15	1.12	8.7	0.72
12-Jul	9.32	100	1.05	9.78	1.15	1.12	8.66	0.72
14-Jul	9.29	100	1.05	9.75	1.15	1.12	8.64	0.71
16-Jul	9.26	100	1.05	9.73	1.14	1.11	8.62	0.71
18-Jul	9.24	100	1.05	9.7	1.13	1.1	8.6	0.71
20-Jul	9.21	100	1.05	9.67	1.12	1.09	8.59	0.71
22-Jul	9.19	100	1.05	9.65	1.1	1.07	8.58	0.71
24-Jul	9.16	100	1.05	9.59	1.07	1.04	8.55	0.71
26-Jul	9.14	100	1.03	9.45	1.04	1.01	8.44	0.7
28-Jul	9.12	100	1.02	9.3	1	0.98	8.33	0.69
30-Jul	9.1	100	1.01	9.16	0.96	0.94	8.22	0.68
1-Aug	9.08	100	0.99	9.02	0.91	0.89	8.13	0.67
3-Aug	9.06	100	0.98	8.88	0.85	0.84	8.04	0.66
5-Aug	9.04	100	0.97	8.74	0.4	0.4	8.34	0.69
7-Aug	9.02	100	0.95	8.6	0	0	8.6	0.71
Total			485.4	431.41	56.31	54.01	377.4	[0.62]

5.6 ***Comparison between SWAP and CROPWAT outputs on irrigation requirement:***

The table bellow presents the comparison of results generated from the 2 models:

Figure 5.12: Comparison on irrigation requirement for cabbage between SWAP and CROPWAT model :

Starting month	Irrigation requirement of SWAP (cm)	Irrigation requirement of CROPWAT (cm)	Difference (%)
Nov	19.6	24.9	27.2
Dec	30.0	36.6	22.0
Jan	35.4	42.9	21.2
Feb	33.4	41.4	23.9
Mar	32.4	39.1	20.7
Apr	29.4	36.9	25.5
May	30.2	37.7	25.0
Jun	32.9	38.9	18.2
	Average difference		**23.0**

The difference is calculated as:

$$Difference = \frac{irr\ req\ (CROPWAT) - irr\ req\ (SWAP)}{irr\ req\ (SWAP)} * 100 \qquad (\%)$$

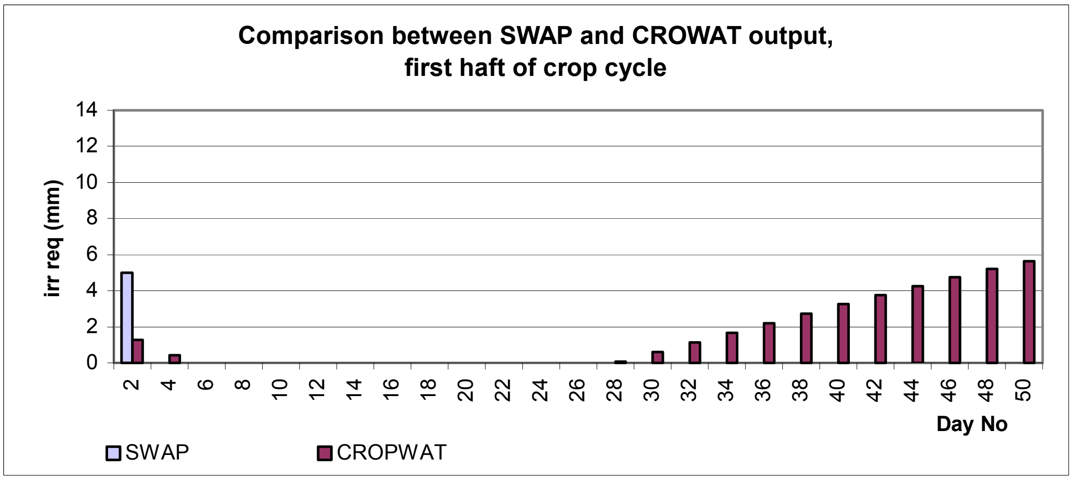
Some judgments on the results of comparison:

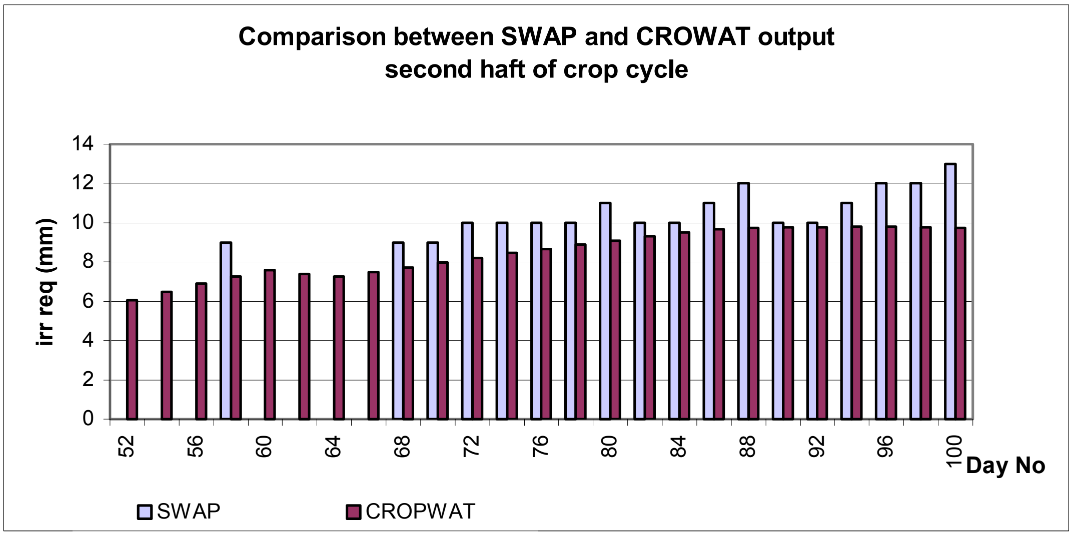
The average difference of the results from 2 models is about 23% as shown in above table can be due to some reasons as follow:

- CROPWAT uses average monthly climate data and then applies the results for the period defined by user (daily, monthly or specific period) while SWAP takes daily basic data.
- the limit of CROPWAT on soil infiltration rate (maximum at 300mm/day) is not true for the case study. Actual infiltration rate at research site is 1728 mm/day. A limited infiltration rate should lead to a lower irrigation requirement for CROPWAT, which in fact is the case in the second part of the crop cycle.
- CROPWAT does not consider the leaf year but always calculates irrigation requirement for 28 days of February. So in that case, irrigation requirement will be less as day 29th is not taken into account.

2 graphs bellow (figure 5.13) show the different trend of crop irrigation requirement computed by 2 models.

Figure 5.13: comparison of irrigation requirement generated from 2 models for cabbage following along the crop cycle





The commend on these graphs is that, irrigation requirement generated from CROPWAT is gradually increasing following crop mature while SWAP generated crop irrigation requirement follow not only crop development stage but also a real time climate condition. The difference is lying in the use of different climate conditions of 2 models[11].

In the beginning CROPWAT generates a demand but later on the demand is higher for SWAP. So we might expect that SWAP be given a more precise estimate.

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[11] In many days with rainfall, CROPWAT still requires irrigation while SWAP did not. That may be the reason why CROPWAT seems generating higher irrigation requirement than SWAP model.

6 Conclusion and recommendation

6.1 Conclusion

In the sense of competitive water use around the lake, agriculture is the biggest water consumer. It has effects on many aspect of the environment such as lake water level, inflow discharge, groundwater level and quality and also indirect effect on the wildlife around the lake. So, any research on agricultural water use around the lake is very important. This research can contribute to an overview of the irrigation practices around the lake. By evaluating the agricultural water requirements, suggestions can be given how these practices can be improved.

6.1.1 Irrigation efficiency

Irrigation of some vegetables has been compute for the period from November 1999 to September 2000. The results show that farmers over irrigate in the first half of crop cycle of almost types of vegetable and under irrigated for the second half. The total actual irrigation application for the whole growing season is more than total crop water requirement. This imbalanced irrigation distribution is a very important finding. Yields are strongly negatively effected by water shortage in the later stage

In case of irrigation for grass, it is clear that irrigation application of once a week with 30mm depth is not enough for grass development according to the model output. But observations from the field show that physical condition of irrigated grass was quite healthy and it seems that no or very little stress on crop development had occurred. This might raise a question on the accuracy of actual irrigation application schedule provided by farm manager. It is sure that it must be different from the assumed irrigation practice. Data on irrigation practices were obtained through interviews with farmers. They gave indications of irrigation gifts, no measuring devices irrigation volumes are used in the fields.
It is difficult to estimate the real losses through the groundwater in the field. The losses calculated with the model can be an under estimation as rainfall has been subtracted from the irrigation application (actually, irrigation practice in this thesis is assumed strictly the pre-decided schedule. It may be different in the real situation)

Other aspect, which should be considered in irrigation computation, is the climate condition. As mention in the early part of this thesis that, the period from October 1999 to September 2000 was very dry[12]. The model actually is used to evaluate irrigation practice for this period. If the same irrigation schedule to be applied for a year with higher rainfall, it may improve the soil moisture storage for crop growing in rainy season. But for the crop starting in dry season, the irrigation schedule should be verified and improved in the later part of crop development stage.

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[12] Rainfall of computing period was less than 400mm compared to average yearly rainfall of more than 600mm.

6.1.2 The usefulness of Agro-hydrological model in irrigation evaluation.

This is clear that SWAP model is a good software package for crop water requirement computation as the inputs of the model are based on the real field condition. As with any model the reliability of the results depend on the reliability of the input data. Swap requires a lot of data, which in some cases could not be collected in the field. The model can generate daily crop water need (or irrigation requirement) which may help the user to regulate irrigation schedule according to prevailing climate conditions. On the other hand, with SWAP estimation can be made of the losses due to over irrigation.

By entering actual irrigation application into the model, the user can evaluate day by day how good the practice is. The test (paragraph 5.4) for optimum irrigation schedule is a good way for the irrigation manager to adjust his schedule to obtain better efficiencies.

Beside the usefulness of SWAP in irrigation evaluation as presented here in this thesis. SWAP can be used for other purposes such as chemical transport, effects of irrigation practice on water quality as well as effects on groundwater on a regional scale. These functions of SWAP are not explored in this research.

SWAP requires a lot of detailed data from the field, which are normally not available to the irrigators. Detailed soil descriptions have to be made; soil hydraulic properties and crop development are difficult to measure.

6.2 Recommendation

For better evaluation of irrigation practices in the research area, long term detailed climate data are needed.

Research should be done on irrigation practices and needs of other type of crop under irrigation methods such as drip irrigation for flower and vegetable. Due to the constraint of time and data availability, this research could not be able to carry out the research for crops (vegetable and flower) for the soil conditions in the southern part of the Lake. Dominant irrigation type in the southern part is drip. It would be interesting to evaluate the irrigation practices for flowers under drip irrigation since large areas in the south are under these crops.

The most important finding from the SWAP model output is the imbalance irrigation gift. During the early stages of the crop a surplus of water is given while during the later development stages irrigation given does not satisfy the high crop water requirements. The farmers should change the irrigation schedule slightly higher for the later crop development stages and reduce the application for early period of crop cycles in order to reduce the losses from irrigation.

It is recommended that day to day water use for some selected crops should be recorded either in analogue or digital formats for better review and changes of the irrigation application.

Beside that, root development and crop yield also need to be carefully monitored in order to apply the flexible irrigation practice for better crop production.

Observations from the field show that, the crops were not developed with the same status but changed from place to place. This may lead to an issue that soil type may be spatially changed and current irrigation application has different effects on different soil type. So, the recommend for that is soil types from the field should be analysed carefully and irrigation should be adapted to the soil type. The results from the model may be more reliable if the soil samples of each field are analysed and the user can run the model even for different field of crop and SWAP can be used for irrigation evaluation more carefully.

In order to improve low water holding capacity of soil in Naivasha, it is recommended that some improving measures for the top soil layer should be done (for example, increasing the organic content).

Scientifically, irrigation manager should know the soil moisture in the field before starting irrigation. It means soil moisture status should be regularly monitored.

Is it possible to have a relationship between irrigation and maximum temperature of the day before???, perhaps another research should be conducted for such topic as it can help the irrigator decide a right amount of irrigation for the next day.

There is 2 ways to improve irrigation efficiency of pivot:

Firstly, the diameter of the pivot should not be too big in order to prevent the big drop and high rain intensity. The smaller the size of raindrop and longer time of irrigation the better irrigation efficiency will be.

Secondly, some changes in pivot design may be considered, for example, reduce the diameter of sprinkle jet of those installed at out ring of the pivot and increase the number of jets along the pivot moving direction. Of course, this technical matter should be carefully calculated and tested by pivot specialists but it might somewhat reduce the water losses of the out ring of pivot.

TO THE END

Although this research has not yet covered the whole agriculture land around the Lake Naivasha but I hope it can contribute an overview of how irrigation practices are happening and how good they are. I expect that it could help the irrigation managers in the research area to take care on their irrigation practice obtaining the better efficiency and protecting the environment of the area around and the Lake itself.

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ANNEX

LIST OF ANNEX