EVALUATION OF DRIP IRRIGATION SYSTEM OF A COMMERCIAL TEA (*Camellia sinensis* L.) ESTATE: A CASE STUDY OF KIBENA TEA ESTATE IN THE SOUTHERN HIGHLANDS OF TANZANIA

BY

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ABSTRACT

A study was carried out at Kibena Tea Estate (KTE) to evaluate the performance of drip irrigation in commercial tea production. The undertaking of this study was necessitated by the need for a more water efficient method of water application given the water scarcity problems faced by KTE. The main objective of the study was to evaluate the performance of drip irrigation system at KTE. Specific objectives were to evaluate water use efficiency of drip irrigation. The second objective was to assess the yield response to water of four tea clones (i.e. S15/10, PC81, 207 and K35) and thirdly, to investigate if water savings would be attainable through employing drip irrigation in commercial tea. Six irrigation application levels representing four water replenishment levels of 25% evapotranspiration (ET_c). 50% ET_c, 75% ET_c and 100% ET_c and two variations of drip lateral placement (i.e. one drip lateral placed in each of the inter row spaces and one lateral placed every after each of the inter row spaces) were adopted. No significant differences were observed on tea yields among the 6 irrigation application levels. Clone S15/10 had the highest yield of 284 kg ha^{-1}, followed by clone PC81, 207, K35 which had made tea yields of 207 kg, 184 kg and 116 kg ha^{-1} respectively. Irrigation application 1 had the best performance in terms of IE, and WUE. Irrigation application levels 1, 2 and 5 had acceptable range of IE for drip irrigation systems. Whereas, irrigation application levels 3, 4, and 6 were below IE acceptable standards. Emission uniformity, for all irrigation application levels was within acceptable standards. The highest WUE for irrigation application level 1 was under clone S15/10 with 1.46 kg mm^{-1}, followed by PC81 with 1.07 kg mm^{-1}, clone 207 had 0.95 kg mm^{-1}. The least performing clone, K35, had 0.60 kg mm^{-1}. The cumulative depth of irrigation water application under irrigation application level 1 was 194 mm (1940 m^3 ha^{-1}).while irrigation application level 2, 3, 4, 5 and 6 received 350 mm, 467 mm, 623 mm,

208 mm and 659 mm respectively. The optimum level of irrigation water application under the prevailing conditions was irrigation application level 1. The recommendations from this study were that study should be repeated using proper drip scheduling methodology. Furthermore, the study should be done using irrigation requirements computed from recognised empirical methods such as Penman Monteith, Radiation with adherence to guidelines for scheduling of trickle systems. Possible research could be done to consider appropriate K_p and K_c combination for drip irrigation scheduling at Kibena.

DECLARATION

I, Mabvuso Christopher Sinda do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work. and has neither been submitted nor being concurrently submitted for a degree in any other University.

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DEDICATION

I dedicate this piece of work to my daughter Khozgani from whom I derive the motivation to carry on and to my nieces and nephews that they may achieve better than I may.

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LIST OF ABBREVIATIONS AND SYMBOLS

ACE	Arizona Cooperative Extension
ABSA	Agricultural Bureau of South Australia
ASAE	American Society of Agricultural Engineers
CRP	Coordinated research project
CSIRO	Commonwealth Science and Industrial Research Organisation
CSW	computed soil water curve
DTRDC	Darjeeling Tea Research and Development Centre
ET	Evapotranspiration
ET_m	Maximum crop evapotranspiration
ET_n	Net evapotranspiration
ET_o	Reference evapotranspiration
EU	Emission uniformity
FAO	Food and Agriculture Organisation of the United Nations
FC	Field capacity
FWR	Foundation for Water Research
GC	Ground cover
IAEA	International Atomic Energy Agency
IANR	Institute of Agriculture and Natural Resources
I_n	Net irrigation
I_g	Gross irrigation
IRYDA	Instituto de Reforma Y Desarrollo Agrario
ISW	Ideal soil water curve
K35	Tea clone K35

K_c	Crop coefficient
K_p	Pan coefficient
KTE	Kibena Tea Estate
LEPA	Low energy precision application
MAD	Management allowable depletion
9999	Missing value (Climatic data)
NPK	Nitrogen – phosphorus - potassium
NTRS	Ngwazi Tea Research Station
p	Soil depletion factor (MAD)
PC81	Tea clone PC81
P_e	Effective precipitation
PIS	planned irrigation schedule
PRD	Partial root zone drying
PWP	Permanent wilting point
RAM	Multi seasonal drip compensated system
RAW	Readily available water
S15/10	Tea clone S15/10
S_p	Tea - tree spacing
S_r	Row spacing of tea bushes
SPAC	Soil - Plant - Atmosphere - Continuum
SRC	Shoot replacement cycle
SWD	Soil water deficit
TAW	Total available water
TRIT	Tea research institute of Tanzania

207	Tea clone 207
URT	United Republic of Tanzania
WUE	Water use efficiency
WP	Soil wetted portion
WWD	Westlands Water District
WWEE	World Water and Environmental Engineering
Z_r	Effective rooting depth

CHAPTER ONE

1.0 INTRODUCTION

1.1 Overview

Globally tea estates have been facing a decrease in yields from irrigated fields. This has mainly been caused by inefficient and outdated irrigation methods (Netafim, 2003). Furthermore, there is now increasing evidence that water use exceeds sustainable levels around the world (Postel, 2000). Ground water depletion, low or non-existent river flows and worsening pollution levels are among the more obvious indicators of water stress. Thus in order to mitigate the effect of dwindling water resources, efficient irrigation methods have to be explored.

According to Rosegrant (1995), the foremost challenge related to water scarcity for developing countries is the need to increase water use efficiency in agriculture, urban areas and industry. Growth in irrigated output per unit of land and water is essential. Improved efficiency in agricultural water use is required for increasing productivity and reallocation of water from agriculture to urban and industrial uses. As the value of water increases, availability of appropriate technologies such as computerised control systems, sprinklers and drip irrigation in developing countries could be promising (Netafim, 2006).

As water becomes scarce and its quality continues to deteriorate, it has become imperative to explore new approaches to improve the management of water resources (Dinar, 2000). Good water policy frameworks may not ensure good water management. This is because the situation obtaining on the ground may be very different. Efficient and productive water use will only be assured if at the technical (field) level, efficient methods of water use are adopted. This will not only result in sustainability but also will lead to maximization of water utilisation (or profits), which is normally a goal for most institutions in industry (Penning *et al.*, 2002).

According to Mdemu *et al.* (2003), irrigation efficiency and water productivity should be used complementarily when assessing performance of irrigation management systems. While efficiency concepts provide indicative figures for a system performance in terms of water use for the intended purpose, the productivity concept provides fuller information on the amount of products that can be produced with an amount of available water. Productivity, especially the physical one (kg crop m^{-3} or kg crop mm^{-1}) has long been used as one of the indicators for irrigation efficiency.

In the context of improving water productivity, there is a growing interest in drip irrigation. Trickle or drip irrigation is the frequent, slow application of water either directly onto the land surface or into the root zone of the crop. Under conditions of scarce water supply and drought, drip irrigation can lead to greater economic gains thereby maximising yields per unit of water for a given crop (FAO, 2002).

Tea is the fifth largest export crop after cotton, coffee, cashew nuts, and tobacco in Tanzania. Total annual production amounts to 25 million kg, 90% of which is exported earning some US$30 million in foreign exchange, as such there is a substantial potential for raising tea production in the country (Ndunguru, 2001). However, limited supplies of water for irrigation restrict the opportunities for the expansion of its production. Limited supplies of water for irrigation restrict crop production from the existing tea estates and expansion of commercial estates in many tea growing areas of east and central Africa. Therefore, to increase tea production and the opportunities for expansion, the available water particularly for areas with limited sources has to be efficiently used. For these areas, efficient water delivery systems have to be investigated to allow increase in crop productivity and expansion of cultivated land (Kigalu, J. Personal communication, 2003).

For many years, tea at Kibena Tea Estate (KTE) has been irrigated using sprinkler irrigation system, which is estimated to have an efficiency of about 75% (Knox, 1993). However, conventional overhead irrigation system may not be appropriate for KTE due to water scarcity. Furthermore, several other areas in Tanzania such as Ngwazi and other estates in Mufindi, as well as other traditionally non-irrigating estates as those in the Usambara areas including smallholders have been affected by water resource shortages. These areas stand to benefit from water savings (water productivity) because of efficient water application (irrigation) methods, once immediate constraints to production related to agronomic practices, management and capital are minimized.

An initial 55 ha drip irrigation trial at Kibena tea estate resulted in a labour saving of up to 1 man-day ha^{-1} compared with twice the labour requirement for impact sprinkler irrigation on 690 ha. The drip irrigation also had a power requirement of 4.45 kWh, indicating a larger benefit of about 1 kWh on power saving than sprinkler irrigation 5.72 kWh. In terms of water saving efficiency, the drip trial indicated efficiency in water saving of 90% compared with 70% from the conventional sprinkler irrigation (Kigalu, J. personal communication, 2003).

Drip irrigation may be a solution, allowing direct placement of water to the root zone reducing losses from evaporation and wind drift, and therefore saving water and conserving the catchment water system. According to Meshkat *et al.* (2000), drip irrigation has no significant conveyance losses compared to furrow irrigation (with significant conveyance losses due to seepage) or sprinkler irrigation (with significant losses due to direct evaporation of the airborne water droplets).

It was therefore essential that an assessment of drip irrigation for commercial tea production be carried out in order to evaluate it performance given the management practices at KTE and to ascertain the optimum level of water application. The drip irrigation system at KTE was established in May 2003. By understanding the optimum amount of water application, substantial savings in water as well as costs could be realised, resulting in increased net profits. This type of study could therefore be beneficial in that it can aid management to decide on which practices need to be changed, adopted or discarded in order to enhance the performance of an irrigation system.

1.2 Objectives of the study

The main objective of this study was to evaluate the performance of a drip irrigation system at Kibena Tea Estate in Njombe district, Southern Highlands of Tanzania.

The specific objectives were:

i. To evaluate the water use efficiency (WUE) of drip irrigation;

ii. To assess the yield response to water of four tea clones;

iii. To investigate if water savings would be attainable through employment of drip irrigation in commercial tea production;

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview

Tea growing is an increasingly competitive business all over the world. Sharp declines in tea prices and the slump in profit margins are affecting growers, tea estate owners and investors (Netafim 2003). A wide spectrum of factors has lead to this decline in profit margins. Some of these factors include global warming and growing threats of drought, decreasing yields from irrigated tea fields, high drought sensitivity of new high yield clonal tea varieties, large fluctuations in annual tea production and inefficient and outdated irrigation systems. In view of this, new tea growing strategies will have to be implemented, to confront these concerns (Netafim, 2003). One of the ways to confront these concerns includes employment of good management practices, efficient and up to date irrigation systems.

Previous studies under sprinkler irrigation at KTE showed that an accumulated soil water deficit (SWD) of 200 mm/year does not affect tea production (Netafim, 2006). This finding according to Netafim (2006) contradicts Netafim's experience in intensive fertigation strategy in other crops. Moreover, drip technology has been found to be a sustainable irrigation solution for a tea estate environment with lower labour maintenance than overhead irrigation. Water distribution uniformity under drip irrigation technology was 90% after four seasons (Netafim, 2006).

2.2 Drip irrigation

Many authors (Bucks and Davis, 1986; Solomon, 1988; Dorota and Forrest, 1989; Bilderback and Powell, 1996; Shock, 2005 and Wilson and Bauer, 2005) have described drip irrigation as the slow, frequent application of water (usually every 1- 3 days), in small flow rates, on or below the soil surface. Ideally, the volume of water is applied directly to the root zone in quantities that approach the consumptive use of the plants. Through good management of the drip irrigation systems, the soil moisture content can be maintained near field capacity throughout the season providing a level of water and air balance close to optimum for plant growth.

According to Tekinel *et al.* (1989), farmers have made wide use of pressurised irrigation systems, to increase crop yield. The drip (trickle) irrigation system is the most important of these systems and has contributed to a marked increase in yield under open field and greenhouse conditions in the past decade (Tekinel *et al.*, 1989).

2.1.1 Crop yield under drip irrigation

Michelakis (1990) in Athens, Greece carried out a study in which he investigated the water use levels of 0.3Epan and 0.6Epan of a class "A" pan evaporation applied by drip irrigation and non-irrigation in *Kalamon* and *Amfissis* table-olives. Fruit yield per tree and fruit size were significantly higher in the irrigated treatments than in the non-irrigated one, but they did not differ significantly among the irrigated treatments. Under the *Koroneiki* variety of oil olives, Michelakis (1990) compared irrigation treatments of 1.00Epan, 0.30Epan, 0.45Epan and 0.60Epan applied by drip irrigation from February until May, with the non-irrigation treatment. Fruit yield per tree was significantly higher in all irrigated treatments than in the non-irrigated one. There were no yield variations among the irrigated treatments.

In order to determine the effects of various irrigation methods (furrow, stationery sprinkler, stationary drip, mobile sprinkler, mobile drip and low energy precision application (LEPA)), and irrigation water levels on yield quality and WUE, Cetin (1997) conducted a detailed research on irrigation of cotton in the Sanliurfa-Harran plain in Turkey. The results indicated that these irrigation methods have significant effects on the yield. Stationary drip gave the highest cotton yield and the lowest yield was obtained from stationary sprinkler.

Ertek (1998) did an experiment under the auspices of the University of Cukurova, in Turkey in order to develop a suitable program for drip irrigation of cotton, as well as studying the possibility of using drip systems to irrigate cotton. Two irrigation intervals (5 and 10 days), three pan coefficients (0.75, 0.90, and 1.05) and two wetting percentages (0.70 and the crop ground cover factor (K_r) of the crop) were used in the study. The results obtained in this experiment indicated that the effect of irrigation interval and wetting percentage on the cotton yield was not significantly different for the pan coefficients used in the first and second year. However, the interaction of wetting percentage and pan coefficient revealed significant differences in cotton yield between treatments at 5% ($P < 0.05$).

Ercan (1988) studied the effects of various irrigation intervals on yield, quality and earliness of eggplant (*Solanum melongena* L.) grown under drip irrigation. Two irrigation intervals (daily and every third day) were compared. The results from this study showed that there were significant differences in yield between daily irrigation and every third day irrigation applications. Daily irrigation resulted in slightly higher yields. In addition, daily applications tended to improve earliness of fruit bearing. From these studies, it is evident that drip irrigation is an effective and efficient way to irrigate most crops. The high frequency, low volume applications used in trickle irrigation maintain more favourable soil and plant water conditions. Drip irrigated crops can more effectively use water than furrow and sprinkler irrigated crops. The WUE is high in drip irrigation. The effect of drip irrigation on quality of crop yield is also clearly important (Tekinel and Kanber, 2005).

2.2 Irrigation system performance evaluation

Irrigation system evaluation is the analysis of any irrigation system performance based on measurements taken in the field under conditions and practices normally used (Merriam and Keller, 1978). According to Merriam (1980), irrigation system evaluation can be done for four purposes. Some of which could be to determine the efficiency of the system as it is being used, to determine how effectively the system can be operated and whether it can be improved, to obtain information to assist in designing other systems and obtain information to enable comparison of various methods, systems and operating procedures as basis for decision making.

Irrigation water management and design of a system affect performance of an irrigation system. Failure of irrigated farming to achieve its potential benefits in some areas is not inherent in the principle of irrigation as such, but in the frequently inappropriate practice of it. More often than not, the fault lies in the unmeasured and generally excessive application of water to the land, with little regard either for real cost of abstracting water from its source and delivering it to the farm, or for the cost of restoring the water resource after it has been depleted or polluted. Thus from the point of view of water use, some large-scale irrigation projects operate in an inherently inefficient way (Hillel, 1997).

In view of the prevailing circumstances, the aim of modem irrigation development must be to make the best use of water in conjunction with land and human resources, as well as with all other essential inputs (energy, machinery, fertilizers and pest control measures) to enhance and sustain crop production. The selection of an appropriate irrigation technology for any given combination of physical and socio-economic condition involves complex and sometimes conflicting considerations. Where water shortage is acute, the obvious overriding need is to raise the efficiency of water utilization. Where capital is short, the major requirement might be for an irrigation method with minimal dependence on capital investment or expensive equipment. In other cases, the deciding factor may be energy requirements, labour availability or maintenance costs (Hillel, 1997).

2.2.1 Drip irrigation efficiency

Drip irrigation systems are the most efficient and accurate method of applying water when properly designed, installed, and operated. This is because they try to simulate the optimal natural conditions in the field. However, poorly designed, installed or operated irrigation systems can lead to water wastage problems and inefficiency. It is possible to water at least half of the root zone of plants with the use of drip irrigation systems (ACE, 1999).

At the core of any consideration of irrigation performance analysis is an irrigation water balance and the determination of the fate of various fractions of the total irrigation water applied. Thus, irrigation efficiency (IE), a measure of irrigation performance, may be described in terms of the irrigation water balance approach as the ratio of the irrigation water beneficially used by the crops to the applied irrigation water (Burt *et al.*, 1997).

The classical concept of irrigation efficiency (IE) focuses on the objective of irrigation to meet actual evapotranspiration (ET_a) requirements of the crop (water utilisation ratio). This is a direct application of the basic concept of engineering efficiency, which considers the inflow and outflow relationship of a system (Seckler *et al.*, 2003 and Karmeli *et al.*, 1985). Stated simply, the outflow of irrigation is the amount of water released by the crop (ET_c). This is called net evapotranspiration (ET_n) as it excludes effective precipitation (P_e) (Seckler *et al.*, 2003 and Keller *et al.*, 1996). The inflow is the amount of water supplied by irrigation water to achieve ET_n. Equation 1 (Seckler *et al.*, 2003) determines the Irrigation efficiency. The degree of inefficiency is the compliment of IE.

$$IE = \frac{ET_n}{I_g} \qquad \text{...(1)}$$

Where:	IE	=	Irrigation efficiency
	ET_n	=	Net evapotranspiration ($ET_a - P_e$), P_e is the precipitation
	I_g	=	Supplied irrigation

Drip irrigation application efficiency can be estimated for all types of emitter flow profiles caused by hydraulic design. Wu and Gitlin (1983) determined the relationship between drip irrigation application efficiency and percent of water deficit for design criteria for 10% and 20% emitter flow rate variation stemming from both hydraulics and manufacturing. From the findings of Wu and Gitlin (1983), allowing a 3-6% deficit in depth of water applied can make water savings of 10-30%. The allowable deficit, however, depends on the crop tolerance to soil moisture deficiency. Deficit irrigation increases water application efficiency and can achieve an application efficiency approaching 100% (Wu and Gitlin, 1983).

Teare *et al.* (1973) attributes the high water use efficiency (WUE) and high yields and quality of crops obtained through drip irrigation to the low volume of water application. This is because the low volume application provides good aeration for plant roots to proliferate and thus enhance nutrient uptake. They also stated that water use efficiency is calculated as units of dry matter produced per unit irrigation water. Plants grown under optimum conditions use water efficiently but high yielding crops range widely in WUE and these differences may stem from the use of diverse irrigation methods.

2.2.2 Drip irrigation uniformity

Water application uniformity is a measure of how evenly the volumes of water are applied from each emitter. This uniformity can be determined by measuring emitter flow rates or the times required to fill a container of known volume (Smajstrla *et al.,* 2002). Emission Uniformity (EU) is a measure of the performance of the system. The EU is related to the manufacturer's coefficient of variation for the emitters (variation in the manufacturing process) and the variation in the flow rates in the various parts of the system (WWD, 2001). Equation 2 (Keller and Karmeli, 1975) expresses emission uniformity.

$$EU = 100\left(\frac{1-1.27C_v}{(n)^{0.5}}\right)\left(\frac{Q_m}{Q_a}\right) \quad \text{.......(2)}$$

Where:	n	=	the number of emitters per plant
	C_v	=	the manufacturer's coefficient of variation for point or line source emitters
	Q_m	=	the minimum emitter flow rate for the minimum pressure h_m in the system in L h^{-1}
	Q_a	=	the average, or design, emitter flow rate for the average or design pressure h_a in L h^{-1}

An evaluation will attempt to establish the EU, given aging of the system and other factors that degrade the system performance. With a perfect pressure compensating emitter the EU is dependent only on the coefficient of variation for the manufacturing process. For a well-maintained micro irrigation system, the EU can be in the range of 0.9 to 0.95. However, field topography can cause design values to be as low as 75 % (WWD, 2001).

A study conducted by the Foundation for Water Research (FWR, 2005) in South Africa in order to determine performance of various types of emitters showed that emission uniformity (EU) of the various emitters deteriorated over time under field conditions. Results from laboratory tests on drippers recovered from the field for two consecutive years showed that dripper lines with regular type emitters showed a general tendency of reduced average discharge. This was due to partial or total clogging of emitters. In contrast, drip lines with pressure compensated emitters showed a general tendency of increased discharge. Objects that were stuck between the compensating membrane and labyrinth, or the compensating membrane losing its elasticity caused this. The EU deteriorated from 87.1% in the first evaluation to 82.4% in the fourth evaluation. This indicates that the performance was affected by clogging due to water quality and lack of proper maintenance schedules (FWR, 2005).

2.2.3 Irrigation frequency

According to Swa and Frenken (2002), drip irrigation provides the means for high frequency of irrigation application. This entails the use of low soil moisture depletion levels. Depending on the type of soil and size of plants, the amount of water needed in drip irrigated orchards, vegetables and gardens ranges from 40 to 100 per cent of the evaporimeter loss. This is referred to as the replacement rate. The irrigation frequency in days can be expressed as (Burke and Parlevliet, 2005):

$$Irrigation\ Interval\ (days) = \frac{readily\ available\ water\ in\ the\ root\ zone\ (mm)}{Consumptive\ use\ rate\ (mm\ d^{-1})} \quad \text{............ (3)}$$

Readily available water (RAW) can be expressed as (Allen *et al.*, 1998):

$$RAW = Z_r \times p\,\frac{(\theta_{fc} - \theta_{pwp})}{100} \quad \text{.......................(4)}$$

Where: RAW = Readily available water (mm)

Z_r = Effective root zone depth (mm)

θ_{fc}	=	Field capacity in percentage (%) by volume
θ_{pwp}	=	permanent wilting point in percentage (%) by volume
p	=	Depletion fraction

Allen *et al.* (1998) suggest that for crops with a larger Z_r, an appropriate Z_r can be selected for irrigation scheduling purposes. Furthermore, Allen *et al.* (1998) suggested some values for Z_r and depletion fraction (p) for some crops at a daily ET_c level equal to 5 mm d^{-1} (Appendix 1). These values for p (depletion fraction) can be adjusted for different levels of ET_c using the expression (Allen *et al.*, 1998):

$$p\,(MAD) = p_{table} + 0.004\,(5 - ET_c) \quad \text{......(5)}$$

Where:	p	=	adjusted p for the location (%)
	p_{table}	=	p for particular crop obtained from a Table in Appendix 1
	ET_c	=	prevailing ET_c for the location

The water savings that can be made using drip irrigation are the reductions in deep percolation, in surface runoff and in evaporation from the soil. These savings depend as much on the user of the equipment as on the equipment itself. Drip irrigation is not a substitute for other methods of irrigation. It is just another way of applying water. It is best suited to areas where land is steeply sloping or undulating and of poor quality, where water or labour is scarce or where high value crops require frequent water application (Brouwer *et al.*, 1998).

2.2.4 Water requirements under drip irrigation

2.2.4.1 Soil wetted portion (WP)

Normally, with low intensity irrigation only part of the area is wetted. The soil-wetted percentage according to Swa and Frenken (2002) is the average horizontal area wetted within the top 0.30 m of the root zone depth in relation to the total cropped area. It is widely agreed to be a minimum of 33 % and a maximum of 67 % for widely spaced crops. Keller and Bliesener (1990) presented a relationship that may exist between the potential production and WP. They reported that production increases as WP approaches 100 % for closely spaced crops with rows and dripper laterals spaced less than 1.8 m apart. However, they do not provide recommendations for widely spaced crops with rows and emitters spaced more than 1.8 m apart. Savva and Frenken (2002) proposed a WP of 50 – 60 % for low rainfall areas and 40 % for high rainfall areas for widely spaced crops. Karmeli *et al.* (1985) suggest that WP should not be too large because many of the advantages of drip irrigation depend on keeping the strip between rows relatively dry. Equation 6 can b Seckler *et al.*, 2003 e used to determine WP (Karmeli *et al.,* 1985).

$$WP = \frac{(WD + X) \times 100}{R} \qquad (6)$$

Where: WP = Fraction of soil wetted portion (%)

WD = Wetted diameter (m)

X = Emitter discharge exponent which is design specific as per manufacturer (X = 0 for RAM 17 emitters (Netafim, 2003), but ranges between 0.1 – 0.3 for pressure compensated emitters (Karmeli *et al.*, 1985)

R = Drip lateral spacing (m)

The simplest and usually the least expensive lateral layout for drip irrigation is to have a single straight lateral with relatively closely spaced emitters. However to produce a sufficiently high wetted portion (WP) value in widely spaced crops, it is usually necessary to use a more complex layout of emitters. The percentage of wetted area under drip depends on the emitter discharge, the soil type and spacing of drippers (Karmeli *et al.*, 1985).

The wetting pattern is a function of only the dripper discharge and soil type and is independent of the dripper. Karmeli *et al.* (1985) suggested empirically derived equations relating the WD, to the emitter discharge for different soils. Once the wetted diameter is known, area wetted (AW) and WP can be calculated. The percentage of wetted area under drip irrigation is dependent on the soil type and spacing of the emitters. When there is no overlap between wetting zones of adjacent sprayers or emitters, only the wetted area is considered. Equations 7 to 9 show some empirically determined equations for WD (in meters) determination under various textural classes (Karmeli *et al.*, 1985).

$WD = 1.2 + 0.1q_e$ (Fine soils)..(7)

$WD = 0.7 + 0.11q_e$ (Medium soils)..(8)

$WD = 0.3 + 0.12q_e$ (Coarse soil)... (9)

Where: q_e = Emitter flow discharge (ls^{-1}).

2.2.4.2 Crop water requirements (CWR)

Doorenbos *et al.* (1979), states that crop production and optimum use of water are determined by the total environment hence are location specific. However, for many locations yield and water use data on which to base analysis are often lacking. According to Savva and Frenken (2002), crop water requirements under drip irrigation are less by a crop ground coverage factor (K_r). The ground coverage factor (K_r) can be obtained from of empirically determined values Kr values (Table 1).

Table 1: Values of K_r recommended by different authors

Ground cover (GC) (%)	Crop factor K_r according to		
	Keller & Karmeli (1975)	Freeman *et al.* (1976)	Decroix CTG REF (1980)
10	0.12	0.10	0.20
20	0.24	0.20	0.30
30	0.35	0.30	0.40
40	0.47	0.40	0.50
50	0.59	0.75	0.60
60	0.70	0.80	0.70
70	0.82	0.85	0.80
80	0.94	0.90	0.90
90	100	0.95	1.00
100	100	100	1.00

Source: FAO, 1984

2.2.4.3 Irrigation water requirements

Dorota and Forrest (1989) suggested that irrigation water requirements are less with micro irrigation when compared with other irrigation methods. This is due to irrigation of a smaller portion of the soil volume, decreased evaporation from the soil surface, and the reduction or elimination of the runoff. The losses due to the evaporation from the soil are significantly reduced compared with other irrigation systems because only a small surface area under the plant is wetted and it is usually well shaded by the foliage. Since the micro irrigation system allows for a high level of water application control, deep percolation can be minimized or avoided as water can be applied when needed.

FAO (1984) defines net irrigation requirements (IR_n) as the depth or volume of water required for normal crop production over the entire cropped area, excluding contributions from other sources. IR_n can be determined using Equation 10 (Savva and Frenken, 2002).

$$IR_n = (ET_c \times K_r) - R + LR \quad \text{.......... (10)}$$

Where:			
	IR_n	=	net irrigation requirement
	ET_c	=	crop evapotranspiration
	K_r	=	ground cover reduction factor
	R	=	water received by plant from rainfall
	LR	=	leaching requirement

Gross irrigation requirements can be estimated using Equation 11 (Swa and Frenken 2002).

$$IR_g = \frac{IR_n}{E_a} \quad \text{.......... (11)}$$

The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance of the root zone on a daily basis, the timing and the depth of future irrigations can be planned. To avoid crop water stress, irrigations should be applied before or at the time when the readily available soil water is depleted.

To avoid deep percolation losses that may leach relevant nutrients out of the root zone, the net irrigation depth should be smaller than or equal to the root zone depletion (Allen *et al.*, 1998). The daily water balance, expressed in terms of depletion at the end of the day is estimated from Equation 12 (Allen *et al.*, 1998 and Isidoro *et al.*, 2003).

$$SWD_{r,i} = SWD_{r,i-1} - (Pe_i - RO_i) - I_i - CR_i + ET_{c,i} + DP_i \qquad (12)$$

Where:	$SWD_{r,I}$	=	Root zone depletion at the end of day (mm)
	$SWD_{r,i-1}$	=	Root zone depletion at the end of the preceding day (mm)
	Pe_i	=	Precipitation on day i (mm)
	RO_i	=	Runoff from the soil surface on day i (mm)
	I_i	=	Net irrigation depth on day i (mm)
	CR_i	=	Capillary rise from the groundwater table on day i (mm)
	$ET_{c,i}$	=	Crop evapotranspiration measured on day I (mm)
	DP_i	=	Water loss out of the root zone by deep Percolation on day i (mm)

According to Clark (1993), water should be applied when no more than half of the available water has been depleted (less than 50 % depletion). Thus proper water management in drip irrigated systems requires knowledge of crop water requirements, soil water holding and distribution properties and close monitoring of the irrigation system, the crop and atmospheric conditions.

2.3 Irrigation scheduling

Various definitions have been proposed for irrigation scheduling by various authors (Pereira, 1996; Augier *et al.*, 1996; Bun, 1996; Goussard, 1996 and Cavazza *et al.*, 1996). Both of whom emphasise timeliness of application and quantification of the water to be applied.

According to Horst (1996), irrigation scheduling is based on soil-water-plant relationships and efficiency considerations. These schedules assume how farmers should cultivate and irrigate their lands and how irrigation personnel should operate the irrigation system. Evidence shows the existence of a large discrepancy in irrigation schedules, the actual operation and farmers' behaviour. The traditional irrigation-scheduling concept addresses two variables, namely, timing of irrigation and amount of irrigation. While the amount of required irrigation can be easily ascertained from routine soil moisture monitoring, the ability of the irrigator to apply the required irrigation amount is far less controllable or understood (Horst, 1996).

A relatively small proportion of irrigators utilise scientific scheduling practices. Because of increased competition for agricultural water due to various water needs, sound methodology for irrigation scheduling must be used. However, the challenge is to devise a methodology specific to various crops and environments (Martin *et al.*, 1990).

The search for an improved utilization of agricultural irrigation water, in periods of scarcity, has led to a rationale to quantify its apportionment, in date and in volume, according to the water requirements of plants. These requirements are estimated from various scheduling techniques (Augier *et al.*, 1996).

The appropriate time between successive irrigation depends on the financial significance of the yield losses that can occur at small deficits. The determination of how much water to apply is also important. This is because water that is applied to soil that is already full of water (i.e. SWD = 0) will be wasted and lost as runoff or drainage. In extreme cases, over-irrigation can cause leaching of nutrients, soil erosion and problems associated with water logging (Burgess, 1995).

Soil water affects plant growth directly by influencing plant water potential and indirectly through its influence on soil aeration, soil temperature and nutrient mobility. Traditionally, irrigation scheduling is based on soil moisture levels. Soil moisture can be measured directly or indirectly using various parameters (English *et al.*, 1990).

White (1997) and Hanks and Ashcroft (1980) emphasise the characterisation of soil moisture in terms of soil water potential in order to predict its movement in the soil plant atmosphere continuum (SPAC) so as to aid in irrigation scheduling. Both of them point out that there is no absolute scale of potential energy but one can measure changes in potential energy when useful work is done or when water does useful work. Therefore even without the full characterisation of the soil properties of a location, with proper placement of tensiometers in soil to measure soil potentials, one can get an overview of the status of moisture in that soil for irrigation management.

2.3.1 Deficit irrigation

Under deficit irrigation, the crop is exposed to some water stress without a significant reduction in yield. The aim is to maximise the efficiency of the water resource especially in areas where it is scarce. Deficit irrigation is needed where essential resources such as water, capital, energy, and labour are limited. Under deficit irrigation, the irrigator aims to increase water use efficiency (WUE) by reducing the amount of water during irrigation or by reducing the number of irrigations. In doing this, he must decide on what level of water deficit to allow, what water level has been reached, when not to allow a deficit to occur and when to apply water at a lower level of adequacy to achieve the highest WUE at minimum cost. In this context, deficit irrigation can play an important role in increasing WUE (English *et al.*, 1990).

In order to ensure successful deficit irrigation, it is necessary to consider the water retention capacity of the soil. In sandy soils plants may undergo water stress quickly under deficit irrigation whereas plants in deep soils of fine texture may have ample time to adjust to low soil water matric pressure and may remain unaffected by low soil water content for a considerable period. Therefore, success with deficit irrigation is more probable in finely textured soils (Kirda, 2002). Deficit irrigation is one way of maximising water use efficiency. Other methods for maximising water use efficiency for higher yields per unit of water include agronomic measures such as tillage practices, mulching and anti transpirants (Kirda, 2002).

There are uncertainties associated with deficit irrigation due to two reasons; one is that the cost of the water used and the yield function are not precisely known. Secondly, It is difficult to predict what yield would be produced by a given amount of water stored in the root zone. All these uncertainties imply economic risk. The use of deficit irrigation requires deep soils with high water holding capacity, though high frequency irrigation may compensate for lower capacity (Ragab, 1996).

Drought tolerant crops are adapted to water stress by limiting transpiration losses. Deep-rooted crops allow water deficit to develop gradually, which also facilitates short-term adaptation to water stress. Deep soils with high water holding capacity provide a buffering capacity to allow water stress to develop gradually, and not suddenly as in sandy soils (Brouwer *et al.*, 1998).

The relationship between the crop water stress and yield is very important in scheduling for deficit irrigation. Usually irrigators make use of indicators that measure soil water depletion and crop water stress via the measurement of soil water content/potential, and canopy temperature. Crop water potential and canopy temperature are the most relevant indicators for crop water stress but soil water content and potential are the most widely used for practical reasons (Ragab, 1992).

Enciso *et al.* (2003) investigated the yield and quality of cotton lint using different intervals under limited (deficit) water conditions (1.7 mm d^{-1}) in the St. Lawrence region of west Texas. Results of this investigation indicated that there were no significant differences between frequency treatments in lint yield, micronaire, fibre length, strength, uniformity or gross returns with no major advantage in increasing irrigation frequency under sub surface drip irrigation (SDI) under deficit conditions.

Similarly, Smith *et al.* (2002) used the FAO CROPWAT model to assess its applicability in deficit irrigation scheduling. The study utilised data provided from the FAO/IAEA coordinated research project (CRD) on 'the use of nuclear and related techniques in assessment of irrigation schedules of the field crops to increase effective use of water in irrigation projects carried out in Turkey, Morocco and Pakistan on cotton, sugar beet and potato respectively. From the findings of this study, Smith *et al.* (2002) concluded that the CROPWAT model can adequately simulate yield reduction as a result of imposed water stress, however they also observed two general problems in reported studies on deficit irrigation and that these problems were, lack of essential data or incomplete records that preclude meaningful comparisons.

Shock and Feibert (2002) conducted a study in which one of the objectives was to determine potato response to mild, season long precision deficit irrigation by partial ET_c replacement and a soil water pressure (SWP) of 80kPa. The results of this research showed that yield and grade responded linearly to the applied water.

In another study by Schneider and Howell (2001), a two-year deficit irrigation study was conducted to determine the water use efficiency of winter wheat (*Triticum aestivum* L.) irrigated with fractions of crop evapotranspiration during the spring and winter irrigation periods. Fully irrigated treatments received sufficient irrigation to meet crop evapotranspiration, as calculated by Penman - Monteith grass reference evapotranspiration equation and locally derived crop coefficients. The full irrigation and 50% spring irrigation treatments averaged 7000 and 6320 kg ha^{-1} respectively for two years. With 50% irrigation treatment, seasonal water use efficiency (WUE) averaged 0.95 kg m^{-3} and the overall spring irrigation WUE averaged 1.70 kg m^{-3}, both being larger than for all other irrigation amounts. The winter wheat, deficit irrigated with spring ET_c, efficiently utilised seasonal water consisting of irrigation, rainfall and stored soil water. Spring irrigation was most efficient at the 25% and 50% irrigation amounts.

Where water scarcity exists at the regional level, irrigation managers should adopt the deficit irrigation approach to sustain regional crop production, and thereby maximise income (Stegman *et al.*, 1980).

3.2 Water resource scarcity and irrigation performance

Scarce water resources and growing competition for water will reduce its availability for irrigation. At the same time the need to meet the growing demand for food will require increased crop production from less water ("more crop per drop"). Achieving greater efficiency of water use will be a primary challenge for the near future and will include the employment of techniques and practices that deliver a more accurate supply of water to crops (Smith *et al.*, 2002).

The water lost by transpiration from the leaf mesophyll cells is replaced by water drawn from the soil through roots, stems and leaves along the xylem vessels. This is a gaseous exchange process (water vapour for carbon dioxide gas) and the term transpiration efficiency is used to describe dry matter production per unit transpiration. Alternatively WUE describes dry matter production per unit water lost by evaporation (from soil or crop surface) and by transpiration. For commercial purposes though it is often easier to compare the water use efficiency of a crop based on the commercial yield per unit of evapotranspiration (evaporation plus transpiration) or per unit of rainfall and/or irrigation (Turner, 1986).

Sakthivadivel *et al.* (1999) suggested comparative indicators for assessing water use efficiency. According to Sakthivadivel *et al.* (1999), comparative indicators for assessing WUE should reveal general notions about the relative performance of the irrigation system. Furthermore, comparative indicators should not be too data intensive to discourage widespread and regular application. Such a set of indicators potentially will serve as a tool for comparison between countries, and regions, different infrastructures, management types and environments, and for assessment over time of the trend in performance of a specific project. They will allow an initial screening of systems that perform well in different environments and those that do not. They will allow both assessing of impacts of interventions and performance against strategic long-term objectives. Qualities or features for the selected indicators, which relate outputs from irrigated agriculture to the major inputs as defined by Sakthivadivel *et al.* (1999) are:

- They are based on a relative comparison of absolute values, rather than being referenced to standards or targets.
- They relate to phenomena that are common to irrigation and irrigated agriculture systems.
- The set of indicators is small, yet reveals key information about output of the systems.
- Data collection procedures are not too complicated and expensive.
- The indicators relate to output and are bulk measure of irrigated agricultural systems and thus provide limited information about internal processes

This set of indicators is designed to show gross relationships and trends and should be useful in indicating where more study that is detailed should take place. The four comparative indicators relating output to land and water are (Sakthivadivel *et al.*, 1999):

$$Output\ Per\ cropped\ Area\ \left(kgha^{-1}\right) = \frac{production}{irrigated\ cropped\ area} \qquad (13)$$

$$Output\ Per\ Unit\ Command\ \left(kgha^{-1}\right) = \frac{production}{command\ area} \qquad (14)$$

$$Output\ Per\ Unit\ Irrigation\ Supply\ \left(kgm^{3}\right) = \frac{production}{diverted\ irrigation} \qquad (15)$$

$$Output\ Per\ Unit\ Water\ Consumed\ \left(kgmm^{-1}\right) = \frac{production}{volume\ water\ consumed} \qquad (16)$$

Where: Production refers to production of the irrigated area in kg

Irrigated area is the sum of the area under crops during the period of analysis

Command area is the nominal or design area to be irrigated

Diverted irrigation is the volume of irrigation water diverted to the command area plus net removal from ground water

2.4 Tea productivity

Tea is grown under a regime of air temperature that varies between 8° and 35°C. The extension growth of the tea plant in general ceases below a minimum temperature of 13°C (DTRDC, 2003). Tea is traditionally a rain-fed crop. It is grown well in areas where annual rainfall varies from 1150 to 6000 mm. Tea should not normally be grown in areas where the annual rainfall is less than 1150 mm, unless irrigation is available. Solar radiation has an influence on the tea crop. The intensity and duration of sunshine has also an important influence on the growth of tea plant. Usually high yields are obtained during periods when average day length is longer (12 -13.5h) and thus contributes to high productivity (DTRDC, 2003).

Tea cultivated near the equator produces almost the same yield every month, but further from the equator, winter harvest gradually declines and at latitude beyond about 16^0, there is almost complete winter dormancy. It has been observed that tea bushes go dormant when the average day length remains approximately below 11 h 15 min for a period of about six weeks and this happens beyond 16° N or S latitudes. It has been postulated that low temperatures have a definite role in bud dormancy (DTRDC, 2003).

The maximum quantum of yield possible to harvest is only up to the fourth order of laterals; the fifth laterals onwards do not contribute much towards yield (Banerjee, 1993). According to Hajra (2002) harvesting practices influence productivity, health of the bush and the type of the shoots harvested. In most tea growing regions, growers specify a 'target' type of shoots that represents the most profitable compromise between the value and the quantity of the plucked leaf. In southern Tanzania many growers aim to maximise the proportion of harvested shoots that have three unfurled leaves (Burgess and Carr, 1998).

The interval between plucking rounds determines the type of shoots plucked and the yield. In Malawi, Clowes (1986) evolved a system of predicting the plucking intervals based on the period of time it takes for an axillary bud released from apical dominance to unfurl the third 'true' leaf. This system is termed Shoot Replacement Cycle (SRC) (Burgess and Carr, 1997). Das (1984) in Murty and Sharma (1989) in South India, proposed that harvest intervals could be based on the time that it takes a shoot to unfurl two successive leaves. Although this time period has been called the 'leaf expansion time', it is more correctly defined as a phyllochron (Bond, 1945). In Southern Tanzania, the phyllochron method of planning harvest intervals has been found useful particularly between May and the end of August when there are large changes in temperature (Burgess and Carr, 1998).

2.4.1 Tea yield response to water

Tea is grown in subtropical climates, which can include dry periods ranging from one to four months, (e.g. Kericho in Kenya) to eight months in some parts of Southern Tanzania. During these periods, in the absence of irrigation, tea yields and labour productivity can be low and thus processing capacity is under utilised. In some regions, where tea yields are limited by soil water content rather than the dryness of the air, irrigation has increased tea production, enabled companies to employ full time rather than seasonal labour and increased the productivity of costly resources like transport and factories (Burgess, 1995).

Many studies have been conducted in several areas on the yield response of tea to water. In a 3 year study (1967 – 1970) conducted in the Southern Highlands of Tanzania, Carr and Stephens (1992) observed a dry season yield increase of 500 – 600 kg ha^{-1} over a base yield of 1000 – 1200 kg ha^{-1} (at 1800 m altitude). The amount of water applied was 700 mm and the tea yield response to water was 0.80 kg mm^{-1}. In a similar study conducted at Mulanje in Malawi at an altitude of about 1200 m and a temperature equal to 23° C during the same period, Carr *et al.* (1987) reported tea yields of 2500 – 4000 kg $ha^{-1}$with tea WUE equal to 0.3 kg mm^{-1}.

During a period of 14 years (1971 – 1985) an annual tea yield increase rate of 120 kg ha^{-1} was recorded at Kapgwen Estate (2000 m altitude) in Kenya (Carr and Stephens, 1992). In a long term study carried out from 1955 to 1985 (30 years) at Kilima Estates in Mufindi in the Southern Highlands of Tanzania at an altitude of about 1800 m and mean temperature equal to 18° C (from May to August), Carr and Stephens (1992) reported yield increases from 500 – 600 kg ha^{-1} to 2500 kg ha^{-1} and 3000 kg ha^{-1} respectively by 1995. Whereas in a similar study carried out at Mulanje (1000 m altitude) in Malawi during the same period, an annual average yield increase of 90 kg ha^{-1} was observed, with yields in the range of 3550 kg ha^{-1} to 4750 kg ha^{-1} of made tea yield. The differences in yield increases were mainly due to differences in altitude and temperatures in the different locations.

In a study conducted by Kimambo (2001) at Ngwazi Tea Research Station (NTRS), at an altitude of 1800 m, yields of 2680 and 5460 kg ha^{-1} were recorded with tea yield response to water (WUE) equal to 5.3 kg mm^{-1}. In another study carried out at the same location, Kimambo (2002) recorded a tea WUE of 6.2 kg mm^{-1}. One of the main factors accounting for large differences in WUE obtained in these studies was the difference in duration for conducting the studies. Furthermore, later tea yields increased compared to yields of earlier studies due to development of higher yielding tea clones (Carr and Stephens, 1992).

According to Kuntze (2001), the most commonly used method of irrigation for tea is sprinkler irrigation and significant yield increases are observed under this method of irrigation. However, despite these yield increases, it is possible that there are significant water losses, which if saved would alleviate water competition among the various uses. These losses relate to wind distortion of sprinkler patterns, which causes uneven distribution of water. Moreover, fine textured soils that have a low infiltration rate cannot be irrigated efficiently in hot windy conditions. If water is applied at low rates required for these soils, the percentage lost by evaporation and wind drift increases (Michael, 1978). In contrast, drip irrigation has the highest application efficiency (Phocaides, 2001 and Wu and Gitlin, 1983).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

This study was undertaken at Kibena Tea Estate (KTE) in the Southern Highlands of Tanzania. Kibena Tea Estate is located in Njombe District, which is approximately 710 km South West of Dar-es-salaam. The drip irrigation site was located on the east bank of the Lihogosa swamp at a mean elevation of 1860 m above sea level and at latitude 09°25' S and longitude 34°45'E.

3.1.2 Geology and soils

The deep layers of the soil for this area consist of pre Cambrian metamorphic rocks. These rocks are mainly composed of gneiss, amphibolites, granulates, schists, quartzite and migmatites. These rocks form the bedrock. The soil is an intensively weathered clay loam, predominantly kaolinitic with low base saturation, deep and well drained, with a volcanic ash overlay horizon in the top 50 – 70 cm (Knox, 1993). These residual forest soils are characterised by free draining humus rich forest brown earths developed on the thicker accumulations of laterite throughout the upper Lihogosa catchment. They are thought to have been associated with the former distribution of natural forests occupying the level upland zones on which a large soil moisture store would have been maintained to sustain thick forest (Knox, 1993).

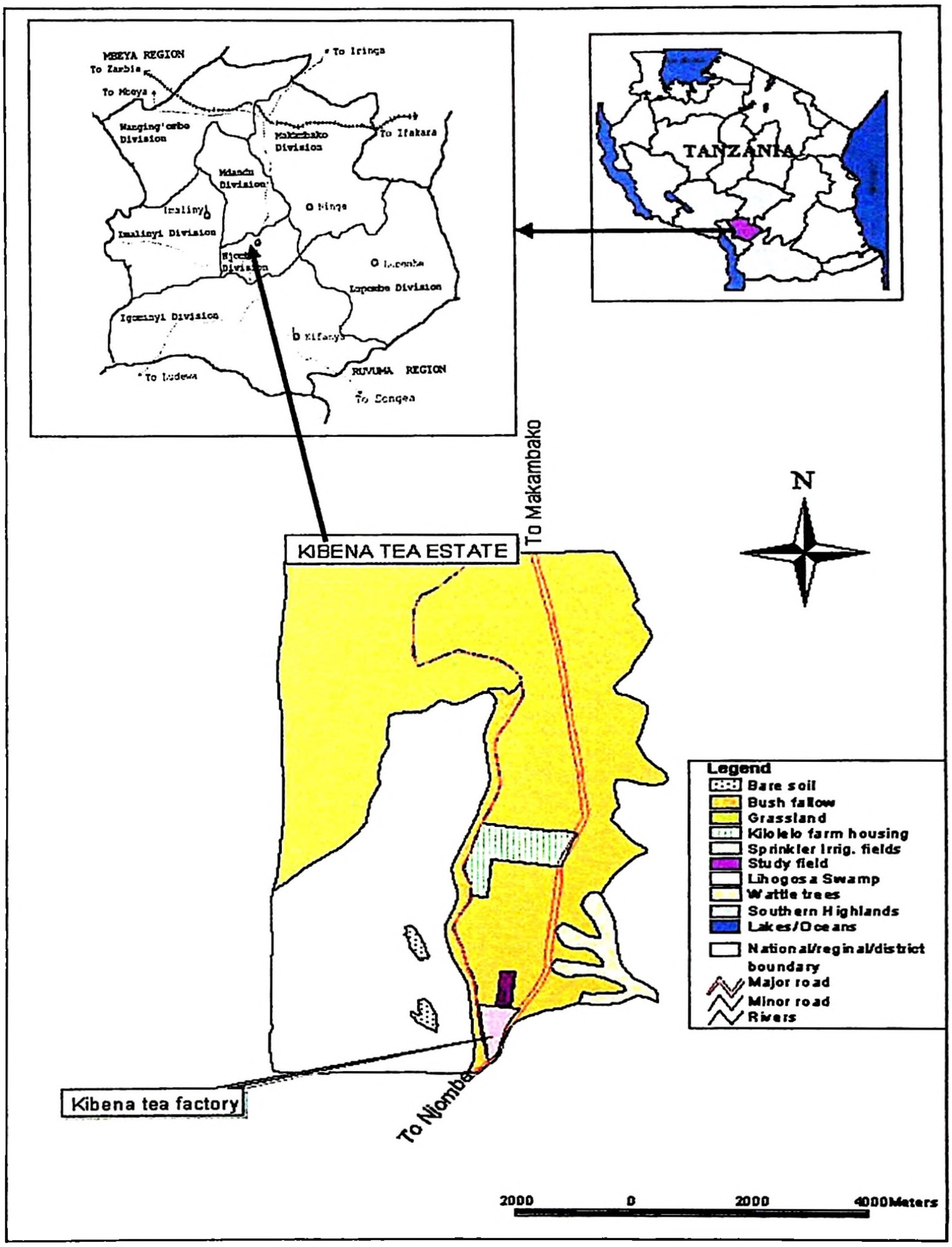

Figure 1: Sketch map showing location of Study Field at Kibena Tea Estate in Njombe District

3.1.3 Climate

3.1.3.1 Temperature

The climatic calendar at KTE can be divided into three distinct seasons based on rainfall and temperature. The rainy season extends from mid November to May. It is typically warm and wet. Temperatures are in the range of 16 °C to 18 °C and mean temperature of about 17° C. From May to August is the cool dry season with little or no rain and with temperatures in the range 13 °C to 16 °C and mean temperature of about 13 °C. The dry and warm season extends from September to November. During the dry and warm season, wind speed and evaporation rates increase steadily with temperatures ranging from 15 °C to 17 °C and mean temperature of about 16 °C with no rainfall. The warmest month at KTE is October with temperatures ranging from 9 °C to 26 °C (Knox, 1993).

3.1.3.2 Rainfall

The study area receives an annual rainfall ranging from 1200 mm to 1400 mm. The area has a unimodal rainfall regime i.e. one rainy and one dry season. The wet season begins in December and extends to May. The dry season extends from June to November. The average annual rainfall for the area is about 1070 mm (URT, 1976).

3.1.4 Hydrology

There are neither rivers (perennial or seasonal) nor streams that traverse KTE and its immediate surroundings. The hydrological disposition of KTE is further worsened by its siting. This is because much of the estate area is situated on a raised, undulating terrain. It therefore does not receive external runoff but rather drains to outlaying catchment areas. The only source of irrigation water is Lihogosa Swamp (Lihogosa catchment) whose water levels tend to fluctuate with season and completely dries out in some years (Knox, 1993). This is despite the fact that the water collected in the Lihogosa swamp has no naturally draining outlet. The water from the Lihogosa swamp is mostly lost to evaporation an through usage for irrigating the tea estate fields.

3.2 Background of study area

Kibena Tea Limited and Tanzania Tea Research Institute (TRIT) initiated this study. The purpose of the study was to investigate the water use efficiency (WUE) of drip irrigation in tea production and determine the level of water application at which WUE is optimal. The study was necessitated by the water scarcity problem faced by the Kibena Tea Estate and surrounding areas. Kibena Tea Estate has been using conventional sprinkler irrigation at the Estate. The search for a more water efficient method of irrigating tea culminated in the setting up of a 9 ha field with drip irrigation by Kibena Tea Limited management. This study was done in order to evaluate the performance of the drip irrigation system and come up with an objective assessment of the drip irrigation as it was operated at the estate.

3.2.1 Kibena tea estate

At Kibena Tea Estate in the Southern Highlands of Tanzania, preliminary results on the use of drip irrigation exposed a uniquely active root zone under the dripper at a depth of 0-50 cm. Figure 1 shows yield results from a preliminary study on drip irrigation at KTE. There was an observed increase in yield since the inception of drip irrigation. The observed high yields were attributed to the high water use efficiency (WUE) of drip irrigation (Netafim, 2006).

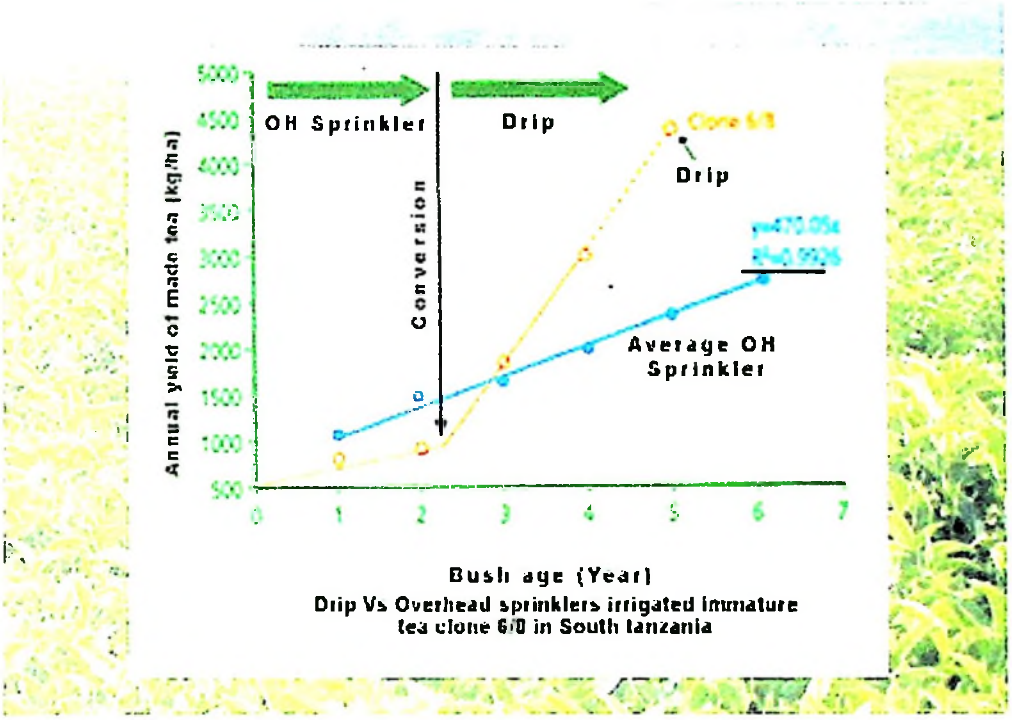

Figure 2: Graphical representation of preliminary drip irrigation results over a three year period

Source: Netafim (2006)

3.2.2 Description of field layout

Initially the field was used for sprinkler irrigation studies but was converted for drip irrigation trials in 2002. The tea was planted in December 1994 and was pruned in June 1999 and August 2002. Thus, the tea was in its maturity stage. The tea had been irrigated by overhead sprinkler irrigation since planting (total water applied annually was about 700 mm) (Kigalu, J. Personal communication, 2003). The study area covered 9 ha i.e. 500 m (833 bushes) x 180 m (150 rows). The tea spacing was 1.2 m (between rows) x 0.6 m (within rows) giving a count of 13 888 plants ha^{-1}.

Each clonal plot measured 90 m (75 rows) x 21 m (35 bushes), equivalent to 2625 bushes (gross) covering an area equal to 1890 m^2 (0.189 ha). The clonal plot was further subdivided into 3 smaller plots (treatment/net plots), which measured 30 m (25 rows) x 21 m (35 bushes) giving 875 bushes covering an area equal to 630 m^2 (0.063 ha). There was a provision for two guard rows around each irrigation treatment, giving 21 rows x 35 bushes thus a net 735 bushes per treatment plot. However these plots were still very large for sampling purposes, thus a sub sample of 100 bushes, at the centre of each treatment plot was demarcated. This was 12 m (10 rows) x 6 m (10 bushes) giving an area equal to 72 m^2 (0.0072 ha). This is what made up the net plot, which was sampled for yield and other related measurements. Figure 3 illustrates the layout of the plots.

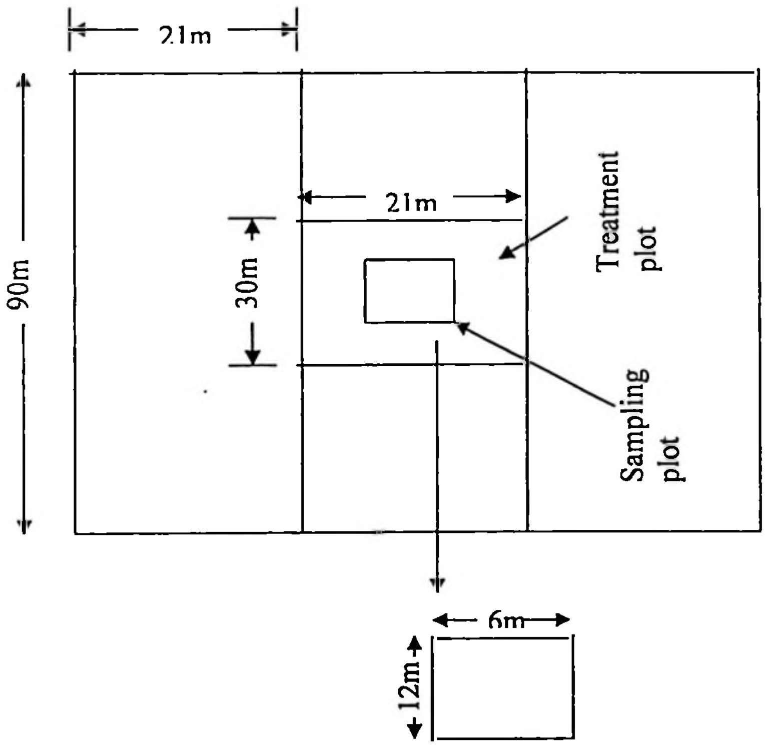

Figure 3: Schematic illustration of layout of plots

The field set up was a completely randomised factorial experiment, with two factors at different levels. The first factor was the tea clone type, which had four levels and the second factor was irrigation, which had six levels. This was essentially a 6 x 4 factorial experiment run in a randomised complete block design.

3.3 Treatment description

3.3.1 Tea clones

The four tea clone types used in the experiment were, clone S15/10 a high yielding clone under well watered and relatively dry conditions brought from Kenya. Clone 207 from Tanzania, susceptible to drought but responsive to irrigation, clone K35 from Kenya, an intermediate between clone 207 and clone S15/10 under dry conditions, but can give similar yields to clone 207 when fully irrigated and clone PC81 from Malawi.

3.3.2 Irrigation levels

The irrigation factor comprised of four evapotranspiration (ET) replenishment levels. For the purpose of notation, the four-water replenishment levels i.e. 0.25 ET, 0.50ET, 0.75ET and 1.00ET were denoted as I1, I2, I3 and I4 respectively. The number of rows of tea bushes served by one drip lateral line is indicated in parenthesis (Table 1). The number in parenthesis represents the two variants of lateral placement (i.e. 1 represents one lateral serving one row of tea while 2 represents one lateral serving 2 rows of tea) (Table 2).

Table 2: Irrigation levels

Irrigation Level	Notation	ET replenishment level (%)	Number of rows served by lateral	Lateral type
1	T1I1(1)	25	1	RAM 17 / 2.3 Lh^{-1}
2	T2I2(1)	50	1	RAM 17 / 2.3 Lh^{-1}
3	T3I3(1)	75	1	RAM 17 / 2.3 Lh^{-1}
4	T4I4(1)	100	1	RAM 17 / 2.3 Lh^{-1}
5	T5I1(2)	25	2	RAM 17 / 3.5 Lh^{-1}
6	T6I4(2)	100	2	RAM 17 / 3.5 Lh^{-1}

3.3.4 Treatment combinations

The different combinations of the six irrigation application levels and the four tea clone types comprised the actual treatments for the field experiment. This gave twenty-four treatment combinations as shown in Table 3.

Table 3: Actual (sub plot) treatment combinations

Irrigation	Clone			
level	S15/10	K35	PC81	207
1(25%)	S15/10T1I1(1)	K35T1I1(1)	PC81T1I1(1)	207T1I1(1)
2(50%)	S15/10T2I2(1)	K35T2I2(1)	PC81T2I2(1)	207T2I2(1)
3(75%)	S15/10T3I3(1)	K35T3I3(1)	PC81T3I3(1)	207T3I3(1)
4(100%)	S15/10T4I4(1)	K35T4I4(1)	PC81T4I4(1)	207T4I4(1)
5(25%)	S15/10T5I1(2)	K35T5I1(2)	PC81T5I1(2)	207T5I1(2)
6(100%)	S15/10T6I4(2)	K35T6I4(2)	PC81T6I4(2)	207T6I4(2)

The twenty-four treatment combinations were randomly replicated six times to give 144 replicate plots (Appendix 2). This implied that of the 144 replicates 96 comprised irrigation level 1 to 4 which had one drip lateral serving one row of tea and the other 48 replicates comprised irrigation levels 5 and 6 which had one lateral serving two rows of tea. Figure 4 shows a typical lateral placement arrangement for treatments 1 to 6 whereas Figure 5 shows a typical lateral placement arrangement for treatments 5 and 6.

Figure 4: Illustration of lateral placement for irrigation application levels 1–4 (i.e. one lateral per one row of tea bushes)

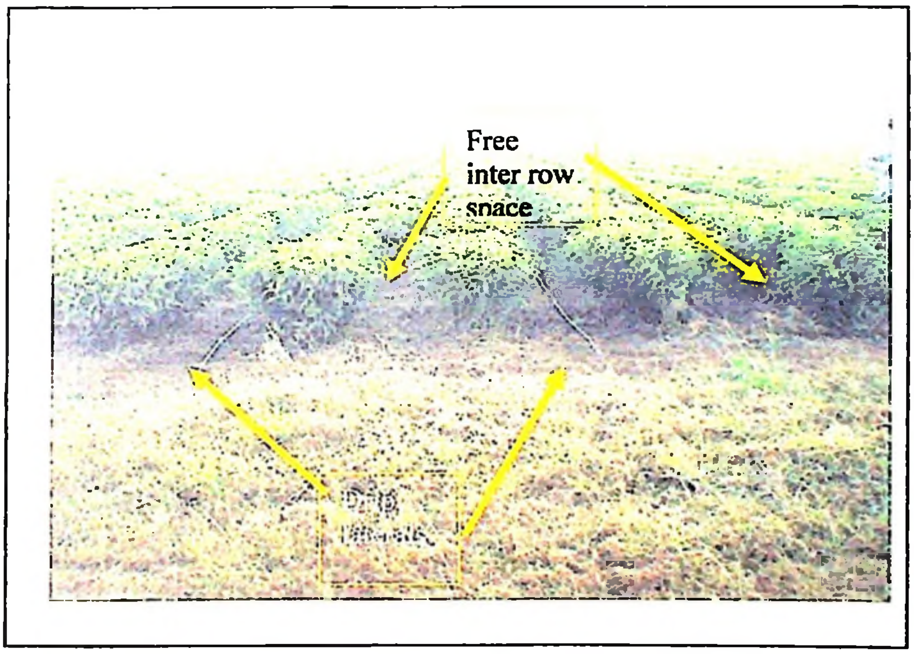

Figure 5: Illustration of lateral placement for irrigation application levels 5 and 6 (i.e. one lateral per 2 rows of tea bushes)

3.3.5 Tea crop water requirements

At KTE, crop water requirements were computed under the following assumptions:

- Pan evaporation measurements were considered equal to daily potential evapotranspiration from the tea bushes (crop) (i.e. Pan coefficient, K_p assumed to be equal to 1).
- The crop coefficient k_c of the tea bushes was 1.00, this agrees with FAO recommendations (Doorenbos *et al.*, 1979) and was considered to be constant throughout the study period;

Daily evaporation measurements were therefore used for computation of the crop water (irrigation) requirements. The tea crop was at maturity stage during the whole period of the study.

In order to compare with the irrigation assumptions at Kibena, crop evapotranspiration (ET_c) was computed by Class 'A' evaporation pan. Using suitable K_p for the area as suggested by FAO (1973).

$$ET_o = K_p \times E_p \quad \text{....................(17)}$$

Where: ET_o = Reference evapotranspiration (mm d^{-1})

K_p = 0.75 (for RH= 70%, u = 240 km/day and fetch = 100 m (FAO, 1973))

E_p = Open water surface evaporation

Using the determined ET_o by the Pan method, the tea crop evapotranspiration ET_c was determined using a k_c value selected from the range of k_c values suggested from previous research conducted in the Southern Highlands of Tanzania. A k_c value of 0.8 suggested by Squire and Callander (1981) was used in this study. The ET_c was determined using Equation 18 (Doorenbos *et al.*, 1979).

$$ET_c = k_c \times ET_o \quad (18)$$

Where: ET_c = Tea crop evapotranspiration (mm d^{-1})

k_c = 0.8 (the tea crop factor used in this study)

Reference evapotranspiration (ET_o) was also computed using the Penman-Monteith method (Allen *et al.*, 1998), which is considered one of the most accurate empirical methods for CWR determination. The Penman-Monteith ET_o computations were done using INSTAT for Windows version 2.5.

3.3.6 Irrigation

Two of the six irrigation application levels were operated daily at different times. All subplots belonging to the same irrigation application level were served by the same valves and were irrigated uniformly. Normally a pressure difference of 0.3 bars between the inlet and outlet was maintained. However, sometimes it was observed that the pressure difference rose to 0.4 bars due to clogging of some emitters caused by suspended solids in water. When the pressure difference reached 0.5 bars, the system could not operate properly until it was flushed. The laterals were placed in the inter row spaces (Figures 4 and 5) thus the emitter position was between two tea bushes of adjacent rows.

3.4 Description of the drip irrigation system

The drip irrigation system used was multi seasonal pressure compensated system manufactured by Netafim i.e. RAM17. The acronym RAM' is the Hebrew equivalent for 'Multi Seasonal Drip Pressure Compensated System'. The number 17 stands for outside diameter of the pipe in mm. The inside diameter was 14.60 mm (Netafim, 2003).

Lateral type RAM 17012 with an emitter flow rate of 2.3 lh^{-1} RAM 17 and drippers, spaced at 0.75 m was used in irrigation application levels 1, 2, 3 and 4, with one lateral serving one row of tea (Table 2). The same lateral type but with an emitter flow rate of 3.5 lh^{-1} and RAM17 drippers spaced at 0.6 m was employed in irrigation application levels 5 and 6 and had one lateral line serving 2 rows of tea (Table 2). The sub mains were subsurface Polyvinyl Chloride (PVC) pipes with a diameter of 50 mm. The main pipes were also subsurface PVC pipes and were of two types, one for 110 mm diameter running from the pumping station to the field. The other type of mainline had a diameter of 75 mm. There were also pressure regulators in the field. These comprised of 50 mm hydraulic valves with a pressure adjustment of up to 18 m. The field layout and the drip irrigation system are as illustrated in Appendix 20.

The control head had a 7.6 cm water meter. It also had primary and secondary filtration. This was accomplished by gravel filters 50.8 cm each and disc filters 7.5 cm x 5.1cm. The control head was also fitted with a 220 L fertilizer injector pressure tank, for fertigation. The outlet pressure from the control head was 30 m. The pumping station was fitted with a pump having a discharge (Q) equal to 38 m^3 $h^{-1}$and total head of 78 m (Appendix 20).

The system operation for the specific irrigation replenishment levels had some prescribed standards. The important parameters in relation to system operation were:

i. **Stabilised filter discharge pressure (bars)**

   This was the pressure reading on the outlet pressure gauge when there were no variations in the flow rate. This was attained after air bubbles were eliminated and any debris flushed by the system.

ii. **Stabilised filter intake pressure**

   This was the pressure reading on the inlet pressure gauge, which was attained when the inlet pressure was not varying i.e. when flow was stabilised.

iii. **Stabilised flow rate/discharge (m^3h^{-1})**

   This was the amount of water in cubic meters being discharged at the lateral outlet per hour, when the filter discharge pressure had been stabilised. The operational standards recommended by the manufacturer of the equipment (Netafim, 2003) are as shown in Table 4.

Table 4: Drip system operational standards for irrigation levels

Irrigation level	Specification		
	Stabilised filter intake pressure (bars)	Stabilised filter discharge pressure (bars)	Stabilised flow rate (m^3hr^{-1})
1	4.3	3.8	37.1
2	4.3	4.1	35.4
3	4.1	3.8	36.5
4	4.3	4.0	35.4
5	4.0	3.7	38.1
6	4.0	3.8	37.3

3.5 Irrigation scheduling

According to the KTE authorities, the irrigation scheduling was based on fixed interval of 3 days. The amounts of irrigation applied were variable depending on accumulated crop evapotranspiration (ET_c) and irrigation application level imposition. With the exception of plots under irrigation application levels 4 and 6, which had full irrigation, deficit irrigation was intended on the rest of the irrigation application levels. Pan evaporation was used for daily ET_c computations.

3.5.1 Irrigation Frequency

The 3 day irrigation interval which was used for all the six irrigation application levels at KTE was arbitrarily picked (i.e. there was no recorded evidence as to why it was selected). For evaluation purpose, in this study irrigation frequency (IF) was determined with consideration of the management allowable depletion of 50 % reported for tea by Allen *et al.* (1998), root zone effective depth of 1.0 m and the net crop consumptive use rate. The irrigation frequency for the six irrigation levels was estimated using Equation 3 (Savva and

Frenken, 2002). However, the RAW was taken with consideration of the replenishment level for each application level as being the soil moisture allowable depletion.

3.5.2 Irrigation application depth, Wetting diameter and Soil wetted portion

Irrigation application depth is the gross depth in mm (I_g) to which irrigation water was applied. Determination of I_g at KTE was done considering the ET_c replenishment percent for the irrigation application level, accumulated ET_c and application efficiency. Irrigation depth was computed using the expression:

$$I_g = \frac{(ET_c \text{ replenishment proportion} \times \text{Accumulated } ET_c)}{95} \times 100 \qquad (19)$$

Where: 95% = Application efficiency of the drip irrigation system at KTE

The soil wetting diameter (WD) and wetted portion (WP) were not considered in the KTE schedule. However, in this study WD was computed using Equation 8 (Karmeli *et al.*, 1985), since the soils of the area are medium textured clay loam (Knox, 1993). The soil WP area under drip irrigation was calculated using Equation 6 (Karmeli *et al.*, 1985).

3.5.3 Irrigation volume

Under the KTE scheduling criterion, the total treatment area instead of the total wetted treatment area was used for computation of irrigation water volume (V). However, in this study only the WP of the total area was used to compute what would have been the applied water volume for drip irrigation system. Irrigation volume was computed by the expression (Savva and Frenken, 2002):

$$V = I_g \times A \times 10 \quad (20)$$

Where:	A	=	Total area treatment area for KTE schedule whereas it was taken equal to wetted area for evaluation computations in this study (ha)
	I_g	=	Gross irrigation depth (mm)
	V	=	Volume of water applied (m^3)
	10	=	Unit conversion constant

3.5.4 Soil moisture status

Knox (1993) carried out a detailed evaluation of the existing sprinkler irrigation system at KTE. The evaluation included characterisation of water holding capacity of the Kibena Tea Estate soils. Knox (1993) determined the total available water (TAW) for the soils at KTE to be approximately 116.5 mm in the 1.0 m depth of soil. However, Qassim *et.al.* (2006) suggest an average value of 164 mm whereas ABSA (2007) propose a TAW value equal to 180 mm for clay loam soils. However figures vary depending on structure and organic matter content (ABSA, 2007). Since tea has a large effective rooting depth 0.9 – 1.5 m, an appropriate rooting depth was chosen for irrigation evaluation purposes as suggested by Allen *et al.* (1998). In this study the TAW determined by Knox (1993) in the 1.0 m depth was adopted

3.5.5 Soil Water Deficit (SWD)

The soil water depletion in the root zone (SWD_i) at the beginning of the experiment was estimated using Equation 12 (Allen *et al.*, 1998). From the initial day of taking observations for this study (01 July ≡ 182 day of the year 2003) the soil water deficit was monitored daily by means of a soil water balance. The daily water balance was estimated from Equation 12 (Allen *et al.*, 1998 and Isidoro *et al.*, 2003). The soil water depletion on day 181, i.e. 30 June, the preceding day was obtained from the daily water balance computations of KTE. Irrigation was done under the assumption that at equilibrium CR_i was equal to DP_i. Precipitation (Pe_i) and RO_i was equal to zero during the entire period of the study because there was no rain and drip system does not cause surface runoff. Microsoft excel was used to graphically plot the estimated soil moisture depletion. The ET_c computed using K_p equal to 0.75 and kc equal to 0.8 was used in estimation of soil water depletion in the root zone. The water balance equation used by KTE utilised ET_c computed by K_p and k_c equal to 1 whereas for evaluation the ET_c computed by K_p and kc of 0.75 and 0.8 respectively were used in the water balance.

3.6 Harvesting

Two leaves and a bud were harvested by hand (i.e. hand plucking). A phyllochron of 2 was used to determine when to harvest. Thus, the length of the harvest intervals was dependant on how long it took to attain a phyllochron of 2. Phyllochrons are influenced by mean temperature. The daily phyllochrons were read from predetermined phyllochron tables (provided from Ngwazi Tea Research Station) using daily mean temperatures read from Kibena meteorological station (Appendix 3) (i.e. for each mean temperature there is a corresponding phyllochron value which is recorded). The daily phyllochron measurements were accumulated and whenever the cumulative measurement was equal to 2.00, then the tea was harvested. The phyllochrons and harvest intervals are illustrated in Appendix 3.

3.6.1 Tea yield Functions

A plot of made tea yield against water applied was done using Microsoft Excel software to come up with water vs. tea yield functions.

3.7 Fertilisation

Prior to this study only one application 300 kg N ha^{-1} as NPK 25:5:10 (plus sulphur) was applied in solution through the drip system for all plots. However the intention by management was to have NPK applied in 3 split applications over a time interval of 3 months. Similarly only one application for Zinc was applied as a foliar spray application of 1.5 kg ZnO ha^{-1} (total 4.5 kg ha^{-1}). Zinc was to be applied in 3 split applications at intervals of four months. There were no further applications of fertilizer during the study period.

3.8 Tea crop height

Five plants were randomly selected from each treatment plot (subplot) and the height was measured for each of the five plants using a meter rule. The measurements were averaged to come up with a representative height for the particular treatment. These readings were recorded in centimetres (cm) and were to be repeated at intervals of 3 months. Only one measurement was recorded during this study.

3.9 Tea crop (ground) cover

The methodology for determination of the tea crop ground cover in this study was adapted from Kigalu (1997). Field measurements of ground (crop) cover were done on three-month intervals. Only one measurement of crop ground cover was recorded in this study. Two bushes were randomly selected from each treatment plot. In this way each sampling comprised 288 (2x144) estimates for the entire experimental area. To ensure representative measurements, each of the sampled bushes was bordered on all sides by bushes of the similar size. Measurements were done on these two bushes using a 0.60 m x 1.00 m frame that was divided into grid squares of 0.1 m x 0.1 m (0.01m^2). The frame was held in a horizontal position above the surface of the bushes and each square was examined individually. The frame was moved horizontally to cover the bushes initially outside the grid area in order to estimate total coverage of the canopy. Ground cover (or crop cover) was then estimated in such a way that if leaves covered 75% or more of a square, a count of two was recorded. A square which was 25% - 75% covered by leaves was given a count of one, whereas squares with less than 25% coverage were not given any count. One count was given a value equivalent to 0.01 m^2. The total number of squares counted was converted to area (m^2) and expressed as a fraction of the projected root zone area (i.e. row spacing × intra row spacing) for each bush. The obtained crop ground cover area per plant was multiplied by the number of tea bushes per hectare (13 888). The result was expressed as a fraction of the total area in 1 ha to obtain the crop ground cover percent per hectare.

3.10 Data analysis

3.10.1 Drip irrigation performance evaluation

In order to evaluate the performance of the drip irrigation application levels, three main parameters were used. These were emission uniformity (EU), irrigation efficiency (IE)/water utilisation ratio and water use efficiency (WUE)/water productivity.

3.10.1.1 Emission uniformity

In order to determine emission uniformity (EU) for the various irrigation application levels, 20 points located throughout each irrigation level zone were selected for measurement of flow rates. Smajstrla, *et al.* (2002) recommend a minimum of 18 points for EU measurement. Care was taken to distribute the measurements throughout the irrigated zone. Some points were located near the inlet, the centre and the distant end. EU was computed using Equation 2 (WWD, 2001).

3.10.1.2 Drip irrigation system efficiency

The irrigation efficiency (water utilisation ratio) for each irrigation application level was determined using Equation 1(Seckler *et al.*, 2003).

3.10.2 Water use efficiency

The water use efficiency (WUE) was determined using Equation 21 (Sakthivadivel *et. al.*, 1999).

$$WUE\left(kg\ mm^{-1}\right)=\frac{Yield\ of\ made\ tea\ (kg)}{Accumulated\ gross\ irrigation\ I_g\ (mm)} \quad \text{.................................} \quad (21)$$

3.10.3 Statistical analysis

In conformity with the experimental design described above, the statistical analysis model adopted was the Completely Randomised Factorial design having two factors (i.e. factor one being tea clone type with four levels and factor two being the irrigation application with six levels). The procedure is as outlined by Montgomery (1984). An Analysis of Variance (ANOVA) was done using SAS system for Windows version 6.12. The statistical equation for the model is as given below:

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \delta_k + \varepsilon_{ijk} \quad \begin{cases} i = 1, 2, 3, 4, 5, 6 \\ j = 1, 2, 3, 4 \\ k = 1, 2, 3, 4, 5, 6 \end{cases} \qquad \text{.......................(22)}$$

Where: Y_{ijk} = the yield of made tea due to i^{th} irrigation application, j^{th} tea clone, ij^{th} interaction of irrigation application and clone type random block effect and experimental error effect

μ = Overall mean

τ_i = effect of irrigation application level

β_j = effect of tea clone

$(\tau\beta_{ij})$ = interaction

δ_k = Block effect (random)

ε_{ijk} = the NID (o,σ^2) error component

3.10.4 Pearson correlation analysis

Pearson correlation analysis was run to test the association of the three variables i.e. made tea yield, crop height and ground (crop) cover. However, the focus in this case was on the made tea yield in relation to the other two variables (i.e. crop height and crop cover). This was also done using the SAS system for windows version 6.12.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Overview

Performance evaluation of an irrigation system is done for various reasons among which could be to improve system operations, to assess progress against set objectives, to assess in general the status of the system, to identify constraints, and to understand the determinants of performance etc. (Merriam and Keller, 1978).

Some of the factors, which affect performance of an irrigation system, include management practices, state of the irrigation equipment, agronomic practices required for the crop under irrigation, knowledge of the workers about operation of the system. All these factors are complimentary. However, depending on the objective of the evaluation or management, some of these factors will take precedence over the others. This chapter endeavours to highlight the findings of an evaluation of an existing deficit irrigation of a drip system given the environment and practices at Kibena Tea Estate (KTE).

4.2 Irrigation scheduling

4.2.1 Irrigation frequency

The design irrigation frequency (IF) at KTE was supposed to be 3 days for all irrigation application levels. However, in practice the IF for all irrigation application levels was very erratic in that the 3 day irrigation interval was hardly observed. Appendix 4a shows the observed irrigation frequencies for each irrigation application level whereas Appendix 4b shows the drip irrigation schedule. Analysis of this scheduling practice revealed the erratic pattern of IF for all irrigation application levels. Table 5 shows IFs computed in this study as an estimate of the required IF for the 6 irrigation application levels.

Table 5: Computed Irrigation schedule for the six irrigation application levels for MAD equal to 50 %

Irrigation level	Required Irrigation frequency (days)	Irrigation Depth/irrigation (mm)	Required volume/ha/ Irrigation (m^3ha^{-1})	Required Seasonal Volume (m^3ha^{-1})	Actual applied depth (mm)	Actual volume applied (m^3ha^{-1})
1(25%)	2	8.80	73.61	808.8	194.0	1940.0
2(50%)	4	17.5	145.82	1617.5	350.0	3500.0
3(75%)	5	26.3	219.43	2420.0	467.0	4670.0
4(100)	7	35.0	291.65	3235.0	622.6	6226.0
5(25%)	1(daily)	5.0	41.66	808.8	203.8	2038.0
6(100%)	4	16.8	140.24	323.5	659.4	6594.0

NB: Appendix 6 shows derivation of values of column 1, 2 and 3

Since the tea crop was at its maturity stage during the whole period of study, the water demand for the crop during any period could be assumed to have been dictated primarily by the evapotranspiration demand. Thus, the peak water demand was dictated by the prevailing whether conditions (temperature, wind and radiation). Based on the daily evaporation data (Appendix 5) of Kibena during the period of the study, the peak crop consumptive use (ET_c) for the tea crop was found to be 4 mm d^{-1}. However, Knox (1993) reported a peak ET_c equal to 3.5 mm d^{-1} for tea at KTE during the peak demand period (dry season). This implied that the tea crop should have been irrigated uniformly based on the prevailing ET_c and with the same interval. However, based on the treatment imposition, irrigation application levels were supposed to be scheduled differently. The ET_c replenishment levels were supposed to be $0.25ET_c$ for irrigation application levels 1 and 5, $1.00ET_c$ for irrigation application levels 4 and 6, $0.50ET_c$ and $0.75ET_c$, for irrigation application levels 2 and 3 respectively. Although having the same ET_c replenishment levels for irrigation application levels 1 and 5 and also for irrigation application levels 4 and 6, the difference in placement of the drip laterals implied differences in the size of wetted area thus were to be scheduled differently. In this study therefore, IFs for the six irrigation application levels were estimated. Table 6 shows the observed irrigation frequencies and the required application volumes for the six irrigation application levels. In terms of volume irrigation application levels received excess water above the required volume (Table 5). The excess amounts applied were 1131.1 m^3, 1882.0 m^3, 2250.0 m^3, 2991.0 m^3, 1229.2 m^3 and 3359 m^3 for irrigation application levels 1, 2, 3, 4, 5 and 6 respectively.

Furthermore, in order to ascertain whether there was under or over irrigation for the six irrigation application levels, the required amount of water for irrigation was computed based on the three days irrigation interval (Table 6). The peak ET_c for KTE is 4 mm/day. This gave crop consumptive use equal to 12 mm for three days. However, applying the K_r (0.95) used in this study gives a crop consumptive use equal to 11.4 mm for drip irrigation (Table 6). The required irrigation amount for each irrigation application level as imposed by the irrigation regime would have been as shown in Table 6.

Table 6: Computed amount of irrigation water for the six irrigation application levels based on the 3 day irrigation interval

Irrigation application level	Peak 3 day ET_c (mm)	Required depth for drip irrigation (mm)	Treatment imposed application depth (mm)	Required seasonal water depth (mm)	Observed water depth (mm)	Excess amount of water applied (mm)
1(0.25ET_c)	12	11.4	2.9	147.9	194.0	46.1
2(0.50ET_c)	12	11.4	5.8	295.8	350.8	55.0
3(0.75ET_c)	12	11.4	8.6	438.6	467.0	28.4
4(1.00ET_c)	12	11.4	11.4	581.4	622.5	41.1
5(0.25ET_c)	12	11.4	2.9	147.9	207.8	59.9
4(1.00ET_c)	12	11.4	11.4	581.4	659.4	78.0

The computation in Table 6 is based on the planned three day irrigation schedule, the adopted K_r factor (0.95), the peak ET_c (4 mm/day) for KTE. Analysis of the computed amounts in Table 6 reveals that all irrigation application levels received more water the required amount for the proposed three day irrigation interval. The excess amounts of water applied were 46.1 mm, 55.0 mm, 28.4 mm, 41.1 mm, 59.9 mm and 78.0 mm for irrigation application levels 1, 2, 3, 4, 5 and 6 respectively (Table 6) Furthermore, It is important to note that irrigation application levels 1and 5, 2 and 3 would have had irrigation deficit carry over of 75 %, 50 % and 25 %respectively to the next irrigation. Therefore, this would have implied that in proceeding irrigations, the proportion of ET_c replenishment under these irrigation application levels would have been based on the carry over irrigation deficit plus the consumptive demand for the three days. This would have implied that the irrigation amount for each of the proceeding irrigation events would have varied according to the occurring ET_c within the three days and the carry over irrigation deficit. Suffice it to say that irrigation application levels 1, 2, 3 and 5 would have risked having a net diminishing effect on the soil moisture status. On the contrary irrigation application levels 4 and 6 would have brought the soil to FC with each irrigation event.

Irrigation application level 4 was mostly irrigated at 3 and 4 day intervals as opposed to the estimated 7 day interval, which would have been appropriate. The estimated IF for irrigation application level 6 was 4 days but it was mostly irrigated at a 3 day interval. Similarly irrigation application level 3 was supposed to be irrigated at 5 day intervals but was irrigated at 3 and 4 day intervals. This could have resulted in excess water application and thus poor aeration. Under irrigation application 1 most irrigation events were done at 3 and 4 day intervals as opposed to the estimated IF of 2 days. This may have exposed the crop to moisture stress conditions. However, the crop was cushioned from the moisture stress because of the over application of water during some irrigation events (Appendix 7). Appendix 7 shows the actual water depth and volume applied during each irrigation event at KTE. Irrigation application level 5 was mostly irrigated at 3 and 4 day intervals. The soil moisture curve for this water application level like irrigation application 1 remained within the range of RAW. However, the prolonged intervals of irrigation coupled by prolonged exposure to drying of one side of the root zone. This could have affected the yield negatively. Except for irrigation application level, 4, which was to be irrigated at 7 day intervals, all irrigation application levels, had at least one 7 day dry period, which implied more stress for the plant and could have affected negatively on yield.

Research has shown that irrigation interval has a significant effect on crop yield (Ercan, 1988). Kashyap and Panda (2002) reported that fresh tuber yield in potatoes was significantly higher under high frequency than lower frequency irrigation in West Bengal, India. With delayed irrigation the overall effect was a reduction in tuber yield and total dry matter yield. In another study carried out in Turkey, Ertek *et al.* (2003) reported that a higher irrigation frequency of 5 days was recommended for summer squash (*Cucurbita pepo* L. cv. Sakÿz) grown under field conditions in order to get higher yield as opposed to a 10 day interval.

The methodology in this study was similar to that by Cetin (1997) and Ertek (1998) in that irrigation scheduling was based on cumulative pan evaporation measurements. Furthermore, the setup of the drip irrigation system in this study with regard to drip lateral placement was such that two wetting percentages of 80 % and 45 % were supposed to be observed. It is thus possible to come up with a suitable drip irrigation schedule for tea at Kibena taking into account the prevailing local conditions by considering a range of combinations of crop coefficients and soil-wetting level and appropriate rooting depth for irrigation purposes as suggested by Allen *et al.*, (1998). According to Allen *et al.* (1998), the tea crop has a rooting depth (Z_r) of 0.9 -1.5 m in deep soils with no obstructing parent material.

It is therefore probable that the yield performance could have been negatively affected because in all irrigation application levels, irrigation was done not as per designed IF. This is because inappropriate IF could have caused water stress conditions or poor aeration due to excess water application. Moreover the 3 day irrigation interval was inappropriate according to results shown in Table 5. Furthermore, adherence to the adopted schedule was not fully observed in a number of cases (Table 7). The observed frequencies in Table 7 were obtained by tallying each of the observed frequencies under the six irrigation application levels. In all irrigation application levels there is evidence of either more frequent or prolonged irrigation intervals than required (Appendix 4). It is therefore essential that management clearly outline the criteria for adoption of a particular irrigation schedule and ensure adherence. Failure to do so will affect performance of the drip irrigation system.

Table 7: Irrigation Frequencies observed under the six irrigation application levels and frequency of observation

Irrigation level	Design IF (days)	Estimated IF (days)	Observed Irrigation frequency (IF) days						
			1	2	3	4	5	6	7
1	3	2	0	0	20	20	0	0	2
2	3	4	0	2	20	14	4	1	1
3	3	5	0	2	21	14	3	1	1
4	3	7	0	1	19	20	0	0	2
5	3	1	0	4	18	17	1	1	1
6	3	4	0	1	20	16	1	1	2

Number of days (N) = 42

4.2.2 Irrigation water requirement

4.2.2.1 Crop ground cover

Goldberg *et al.* (1976) reported that in drip irrigation crop water requirements are lower than the crop water requirements for sprinkler irrigation by a crop ground cover factor K_r. The crop ground cover in all water application levels was found to be in the range of 83 – 92 % (Table 8) giving an average crop ground cover of 88 % whereas Table 1 shows values of K_r as recommended by different authors.

In scheduling for the drip irrigation system at Kibena the crop coverage factor was not taken into account. Thus in this study the crop coverage factor was considered in estimating the appropriate drip irrigation scheduling for drip irrigation of tea at KTE. According to Savva and Frenken (2002), Freeman *et al.* (1976) recommended K_r is the most conservative in terms of water application followed closely by Keller and Karmeli (1975) (Table 1). However, the difference between the three methods is negligible. In this study the average ground cover of 88 % is close to 90 %. Thus, going by the most water conservative K_r value based on Freeman *et al.* (1976) Kr value equal to 0.95 was adopted in determining the irrigation water requirement for evaluation purposes.

Table 8: Tea crop ground cover (%) for specific clone and treatment

Irrigation level	Clone			
	K35	PC81	S15/10	207
T1	$86^{a,a}$	$92^{a,a}$	$90^{a,a}$	$89^{a,a}$
T2	$85^{c,a}$	$92^{ab,a}$	$92^{a,a}$	$89^{abc,a}$
T3	$83^{b,a}$	$90^{a,a}$	$89^{ab,a}$	$88^{ab,a}$
T4	$83^{c,a}$	$90^{ab,a}$	$90^{a,a}$	$89^{abc,a}$
T5	$83^{c,a}$	$90^{ab,a}$	$90^{a,a}$	$88^{abc,a}$
T6	$83^{c,a}$	$92^{a,a}$	$90^{ab,a}$	$89^{abc,a}$

Means within a row with different lower case superscript letters on the left of the comma are significantly different (P<0.001); Means within a column with different lower case superscript letters on the right of the comma are significantly different (P<0.001).

The seasonal crop consumptive use at KTE during the study period was 323.5 mm. However, under drip irrigation, the irrigation water amount is reduced by the crop coverage factor K_r (Savva and Frenken, 2002) and only a portion of the soil is wetted. The drip system at KTE was not scheduled properly because crop ground cover and soil-wetted portion (WP) were not considered. Taken into account isolation into the treatment irrigation water application levels, crop ground cover and soil WP, the water application amounts would have been reduced. The water amount to be applied would have been 80.88 mm each for irrigation application 1 and 5, 323.5 mm each for irrigation application levels 4 and 6, 161.75 mm, 242.00 mm, for irrigation application 2 and 3 respectively (Table 9). In contrast, all irrigation application levels were supplied water above the intended target. Table 9 shows crop consumptive use (ET_c) during the study period, required proportion of ET_c replenishable per irrigation application level and the actual applied irrigation water. Except for irrigation application levels 1 and 5 which had deficit of irrigation water application, all irrigation applications had excess water above the seasonal crop consumptive use of 323.5 mm (Column 5 Table 5). Even the deficit observed under irrigation application levels 1 and 5 was above the intended target of 0.25 ET_c. The values of column 5 in Table 5 were obtained by subtracting the required water application amount for a properly scheduled drip irrigation system (Column 3) from the applied irrigation water (Column 4).

Table 9: Seasonal ET_c, ET_c replenishment proportion and I_g

Irrigation level	ET_c (mm)	Required I_n replen. (mm/ha)	Applied irrig (I_g) (mm/ha)	Excess water (mm/ha)	Applied ET_c (%)
1 (0.25ET)	323.5	80.88	194.0	113.12	0.60ET_c
2 (0.50ET)	323.5	161.75	350.0	188.25	1.08ET_c
3 (0.75ET)	323.5	242.0	467.0	225.00	1.44ET_c
4 (1.00ET)	323.5	323.5	622.6	299.10	1.92ET_c
5 (0.25ET)	323.5	80.88	203.8	122.92	0.63ET_c
6 (1.00ET)	323.5	323.5	659.4	335.9	2.04ET_c

In contrast, Irrigation application levels 1 and 5 received an excess of 113.12 mm and 122.92 mm respectively above the required amount for proper drip irrigation schedule of

$0.25ET_c$. This implies irrigation application level 1 and 5 had $0.60ET_c$ and $0.63ET_c$ replenishment respectively. Similarly, the rest of the treatments received an excess amount above what could have been the required amount of water for each irrigation level, had a proper scheduling procedure for the drip irrigation been followed. The discrepancy of irrigation frequency and amount of water replenished during irrigation resulted in over irrigation. All irrigation application levels were supplied with twice the intended amount of water supply.

The intention for management to plan an irrigation schedule based on different proportions of ET_c replenishment levels was to investigate the best deficit irrigation schedule of tea. However, the results in this study clearly indicate that deficit irrigation was not practised except for irrigation application levels 1 and 5 (Table 9). Even if there was deficit irrigation observed under irrigation application levels 1 and 5, it was not at a level of $0.25ET_c$ as planned by management. In contrast, in this study the actual ET_c replenishment in these irrigation replenishment levels was found to be 60 % and 63 % respectively (Table 9). A sample calculation of the seasonal irrigation amount for irrigation application level 1 is shown in Appendix 8.

4.2.2.2 Computation of evapotranspiration

Another cause for the excess water application was the assumption that K_p and k_c were equal to one. Selection of K_p using criteria proposed by FAO (1973) which considers climatic factors yields a K_p value equal to 0.75. Squire and Callander (1981) propose a k_c value equal to 0.8 for the tea crop in the Southern Highlands of Tanzania. Therefore, assumptions used in computation of ET_c at KTE resulted in an over estimation of the crop consumptive use, which was used, in the soil water balance equation. Figure 7 shows a comparison of water volume applied at KTE based on a K_p value of 1 and k_c value of 1 with the volume which would have been applied had the K_p of 0.75 and k_c equal to 0.8 been used. The adopted K_r value in this study, 0.95 (Freeman *et al.*, 1976) was closer to one there by having a minimal reduction effect on ET_c replenishment requirement.

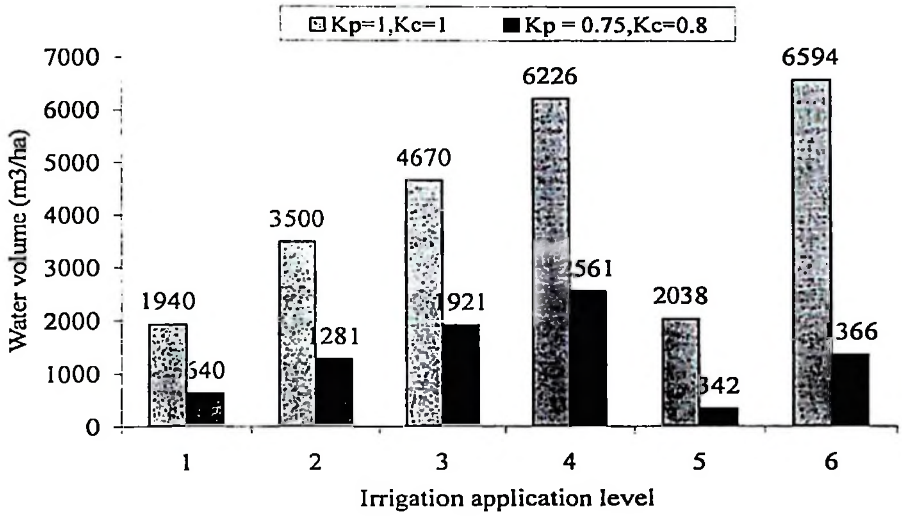

Figure 6: Irrigation water volume as influenced by pan coefficient (K_p) and crop coefficient (k_c) .

Under the irrigation schedule in practice at Kibena the actual amounts of water applied to irrigation application levels 1, 2, 3, and 4 were 1940 m^3ha^{-1}, 3500 m^3ha^{-1} 4670 $m^3ha^{-1}$and 6226 m^3 ha^{-1}each respectively whereas irrigation application levels 5 and 6 received 2038 m^3 ha^{-1} and 6594m^3 ha^{-1} respectively during the period of the study (Figure 7).

From this analysis, it is evident that there was excess water application based on K_p and k_c selection. Irrigation application levels 4 and 6 had the highest excess water application of 3665 m^3 ha^{-1} and 5228 m^3 ha^{-1} respectively. The least in terms of excess water application were irrigation application levels 1 and 5 with 1300 m^3 ha^{-1} and 1696 m^3 ha^{-1} respectively.

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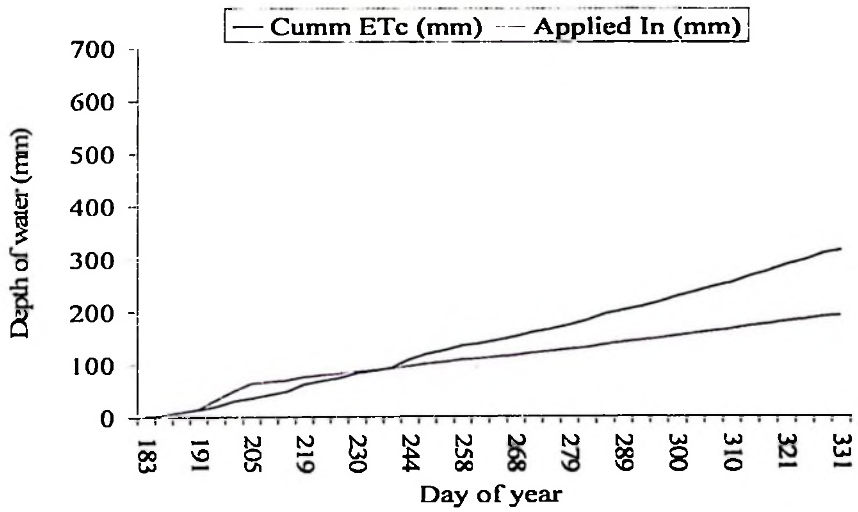

Figure 7: Comparison of cumulative ET_c and cumulative irrigation for irrigation application level 1.

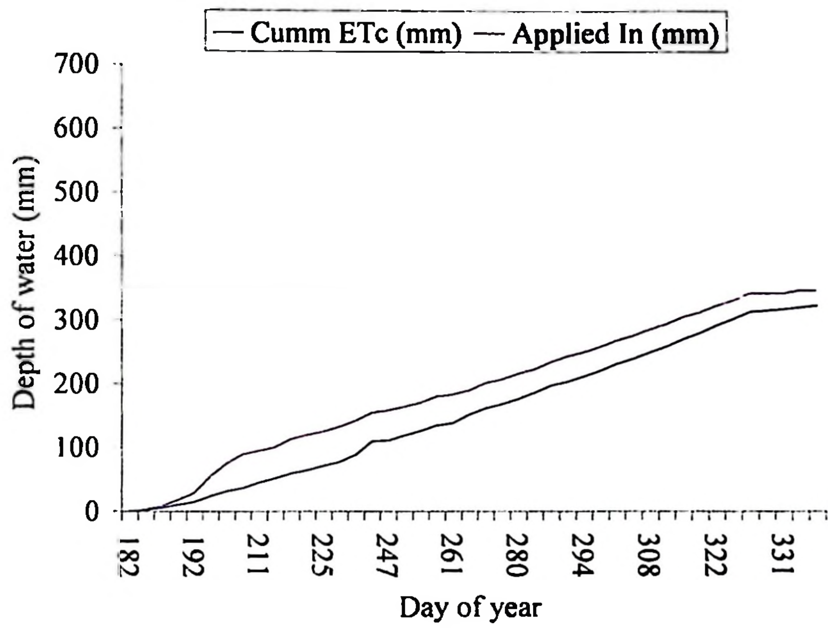

Figure 8: Comparison of cumulative ET_c and cumulative irrigation for irrigation application level 2.

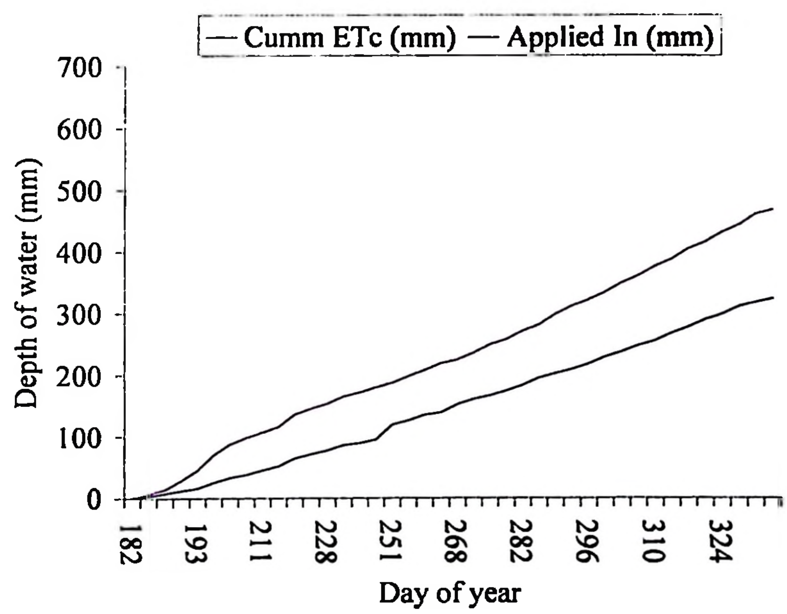

Figure 9: Comparison of cumulative ET_c and cumulative irrigation for irrigation application level 3.

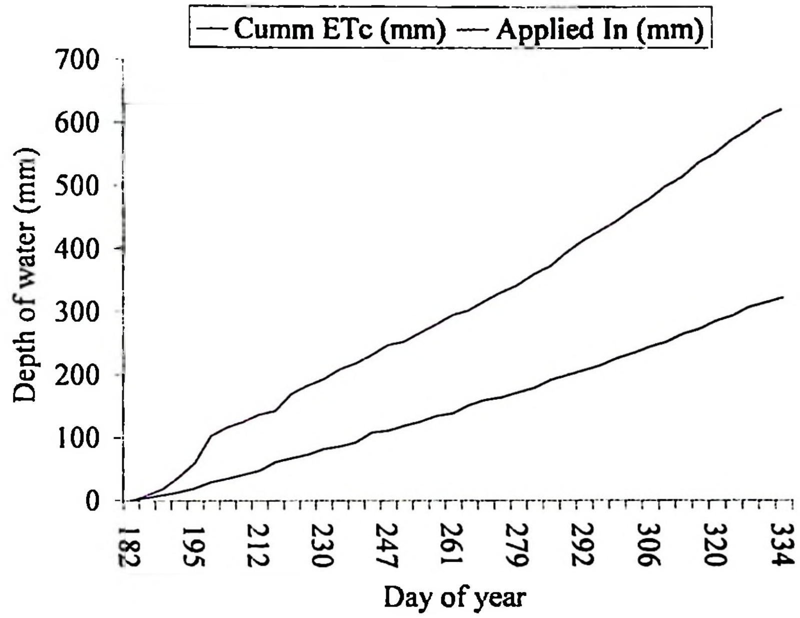

Figure 10: Comparison of cumulative ET_c and cumulative irrigation for irrigation application level 4.

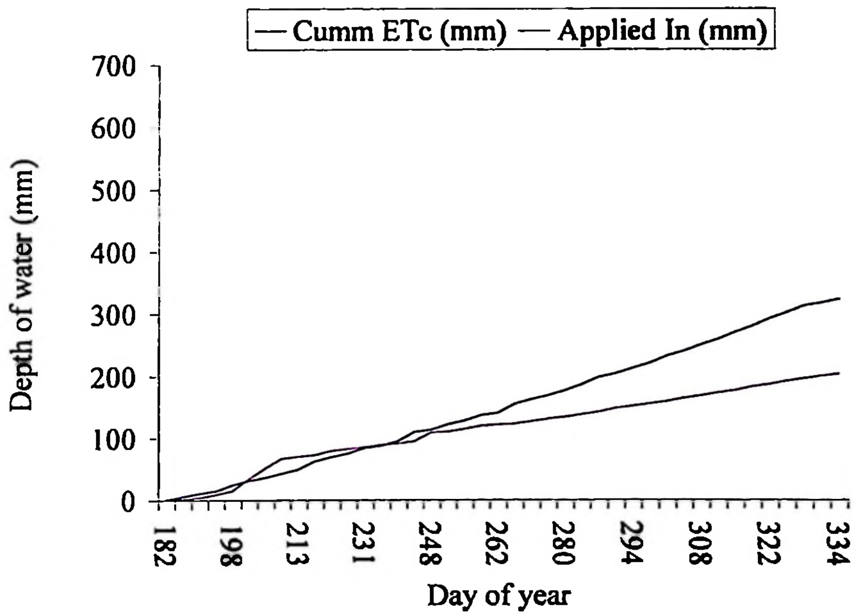

Figure 11: Comparison of cumulative ET_c and cumulative irrigation for irrigation application level 5.

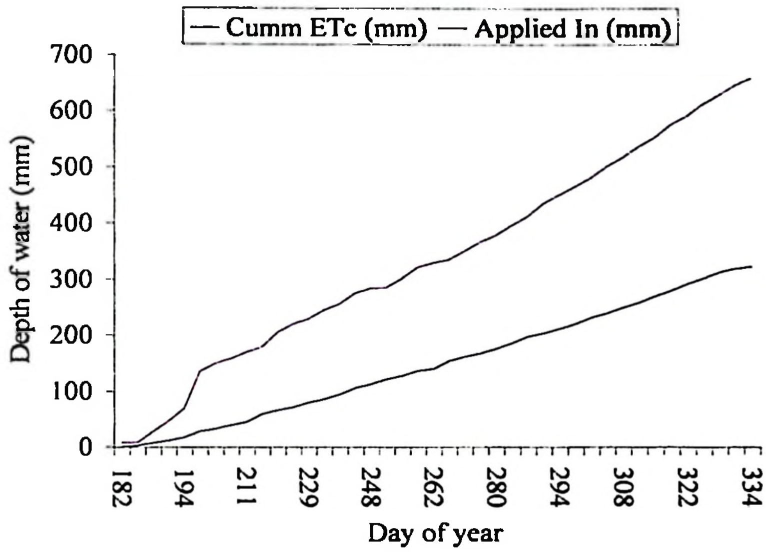

Figure 12: Comparison of cumulative ET_c and cumulative irrigation for irrigation application level 6.

Under irrigation application levels 1 and 5, although the accumulated applied irrigation water was lower than the seasonal ET_c, it was higher than irrigation water required for application under a proper schedule system. Figures 8 and 13 show that, the seasonal ET_c curves were mostly higher than the accumulated applied irrigation water eliminating/minimising possibilities of water logging conditions. Under irrigation application levels 2, 3, 4 and 6, the accumulated applied irrigation water curves were above the seasonal ET_c curves. This indicates irrigation water wastage.

Furthermore, computations of reference evapotranspiration by the Penman-Monteith method shows that the ET_c determined at Kibena Estate was higher than Penman ET_c and Pan ET_c employing Kp of 0.75 and kc of 0.8. Reference evapotranspiration values computed by the Penman-Monteith method were lower than the open water evapotranspiration measurements (Figure 14).

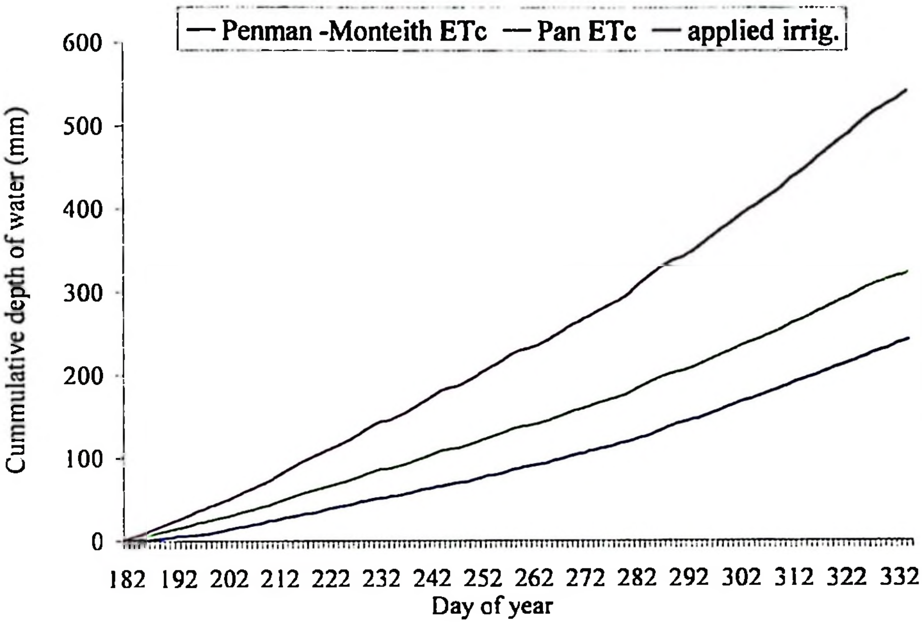

Figure 13: Comparison of cumulative Penman-Monteith ET_c, Pan ET_c and applied irrigation at Kibena tea estate.

Appendix 9 shows the daily meteorological data for KTE used to compute the Penman-Monteith ET_c whereas Appendix 10 shows the ET_c (computed for evaluation) and E_{pan} equal to I_g as estimated at KTE using K_p and k_c equal to 1. The cumulative Pan ET_c (estimated using K_p equal to 0.75 and k_c equal to 0.8) plotted in Figure 14 was obtained from Appendix 10.

4.2.2.3 Irrigation schedule discrepancy

Overall, the irrigation schedule reveals that in all the irrigation applications there was an excess of water applied above the targeted application. Figure 15 shows a discrepancy of the required irrigation amount, applied irrigation and also shows the excess water amount applied.

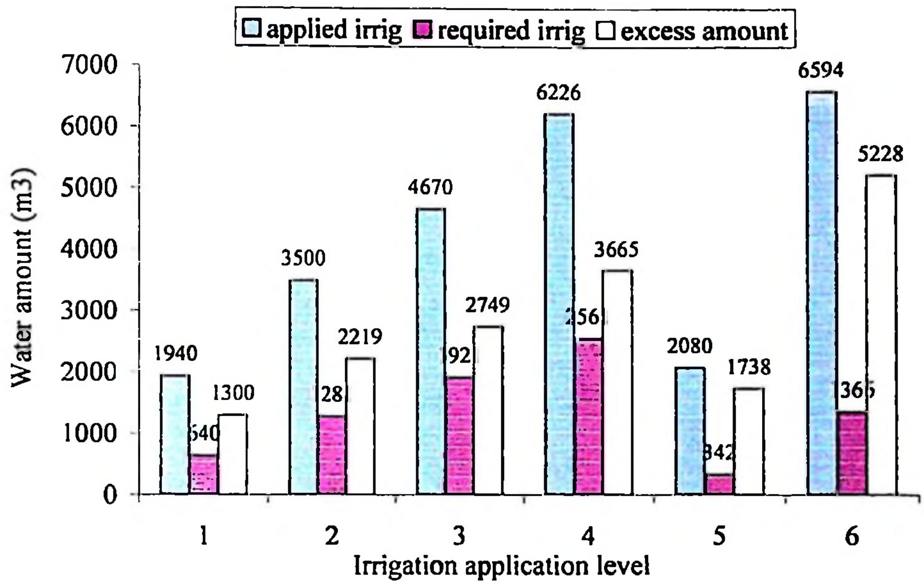

Figure 14: Discrepancy between required and applied irrigation water.

The drip irrigation system at KTE therefore did not perform well in terms of amount of irrigation water application.

4.2.2.4 Water saving potential under drip irrigation

Considering all the irrigation application levels, an excess of 16 857 m^3 ha^{-1} was applied implying that 151 713 m^3 of water was wasted over the entire 9 ha. Brouwer *et al.* (1998); Bucks and Davis (1986); Dorota and Forrest (1989) and Bilderback and Powell (1996) recommend that deficit irrigation is the preferred scheduling practice for drip irrigation. This is because the water requirements are less by the factors K_r and WP. Therefore, it implies that had deficit irrigation been practised in all the six irrigation application levels, 151 713 m^3 of water could have been saved. If one were to irrigate at $0.6ET_c$, as was the case under irrigation application 1, an extra 238 ha of land would be utilised for production from the saved amount of water.

4.2.3 Soil moisture status

From the first day for taking observations for this study (182 day of the year 2003 ≡ 01 July) to the final day of taking observations (333 day of the year 2003 ≡ 30 November) the soil moisture depletion in the root zone was computed by the water balance method (Allen *et al.*, 1998 and Isidoro *et al.*, 2003) (Appendix 10). Figures 16 to 21 show graphically, the calculated soil moisture depletion in the root zone for the six irrigation application levels in the upper 1.0 m. Generally, all Irrigation application levels had instances of excess water application. Figures 18, 19 and 21 indicate that water application was above the total available water (TAW) capacity in the 1.00 m depth of the soil. In case of irrigation application levels 1, 2 and 5 (Figures 16, 17 and 20) the water application levels were predominantly below the TAW curve. However, these amounts were above the required application amounts for the drip irrigation system at KTE suggesting wastage of water. In all irrigation application levels, irrigation was undertaken before soil moisture reached the threshold management allowable deficit (MAD) in the root zone.

The MAD in this study, was computed by adjusting the depletion factors (p) reported by Allen *et al.* (1998) for a crop consumptive use of 5 mm d^{-1} (Appendix 1) in order to derive the MAD under the prevailing crop consumptive use rate at KTE. Adjustment of p is shown in Appendix 6. Irrigation application levels 1 and 5 had the least occurrence of the computed soil water (CSW) curve going beyond the TAW curve. Irrigation application levels 3, 4, and 6 on many instances had CSW above the TAW, which indicates wastage. These conditions are not optimum for crop growth and may contribute to reduction in crop yield.

The irrigation schedule at KTE was not implemented according to plan both in terms of irrigation frequency and ET_c replenishment proportion. However, in order to gain insight into how the soil moisture depletion curves for the six irrigation application levels would have varied had the schedule been implemented according to plan, soil moisture curve PIS was plotted (Figures.16 to 21). The planned irrigation schedule (PIS) curve was plotted based on the planned 3-day irrigation interval and the four ET_c replenishment levels for the six irrigation application levels. Analysis of the PIS curves reveals that, irrigation application levels 1, 2, 3 and 5 (Figures 16, 17, 18 and 20) would have had generally a net gradual diminishing effect on the soil moisture status. The decrease in the soil moisture would have proceeded at a relatively higher rate for irrigation application levels 1 and 5 (Figures 16 and 20) as compared to the rate of soil moisture decrease under irrigation application levels 2 and 3 (Figures 17 and 18). By the end of the study period irrigation application levels 1, 2, 3 and 5 would have been approaching the MAD limit. Furthermore, although irrigation application 1 and 5 were essentially different in terms of lateral placement, the shape of the PIS curve is the same for both irrigation application levels. This is because based on ET_c replenishment alone, the PIS curve does not consider the soil wetted portion differences between the two irrigation application levels. The soil wetted portion would have accounted for differences in the amounts of water to apply in each case. However, the schedule at KTE was implemented without consideration for soil wetted portion.

Irrigation application levels 4 and 6 (Figures 19 and 21) in contrast to irrigation application levels 1 and 5 would have brought the soil to FC with each irrigation event.

Each irrigation event under the two application levels would have resulted in excess water above the water holding capacity of the soil being applied. Similarly the PIS curve does not consider soil wetted portion differences between irrigation application levels 4 and 6 hence the curves are identical. This therefore emphasises the need for reference to actual soil moisture measurements in order to schedule irrigation successfully.

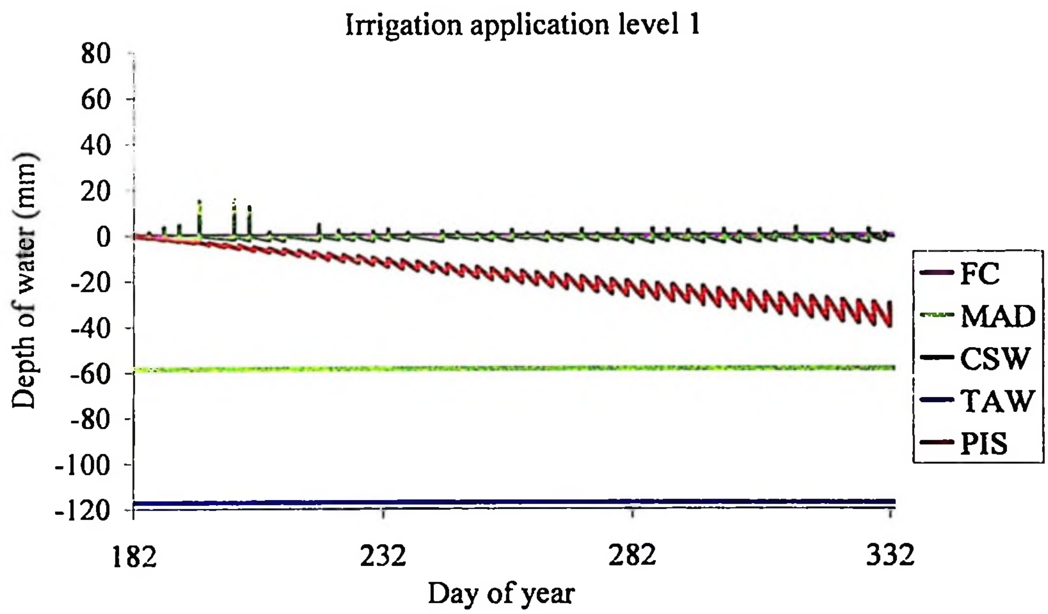

Figure 15: Soil moisture depletion in the root zone for irrigation application level 1, 25 % ET_c replenishment.

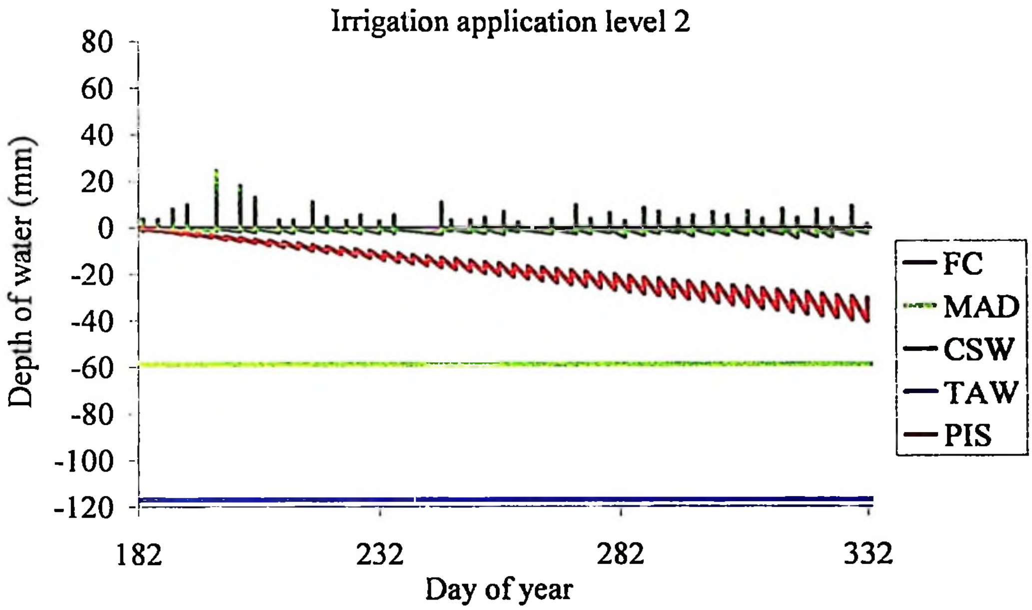

Figure16: Soil moisture depletion in the root zone for irrigation application level 2, 50 % ET_c replenishment.

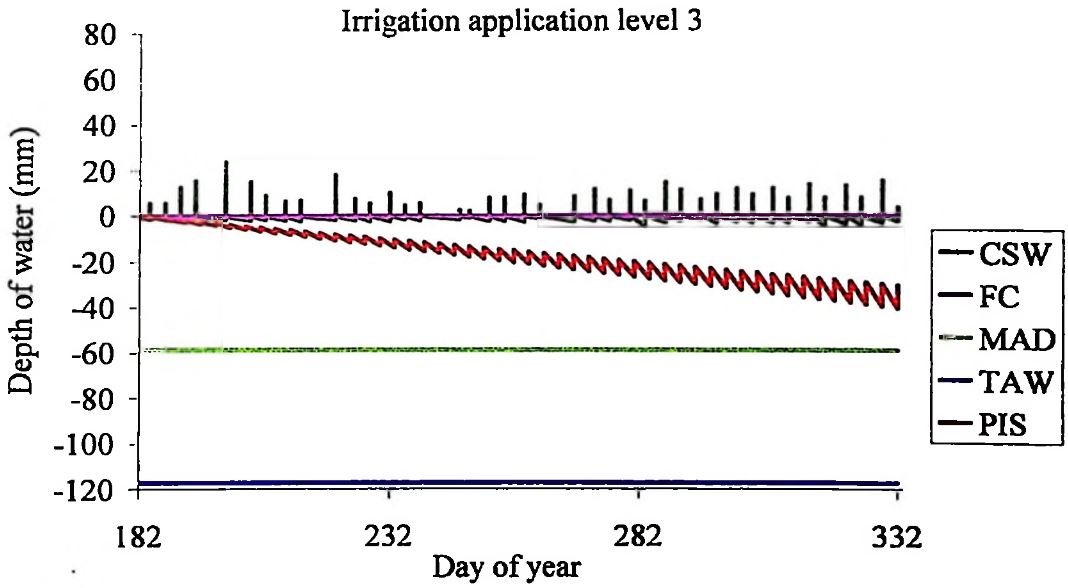

Figure 17: Soil moisture depletion in the root zone for irrigation application level 3, 75 % ET_c replenishment.

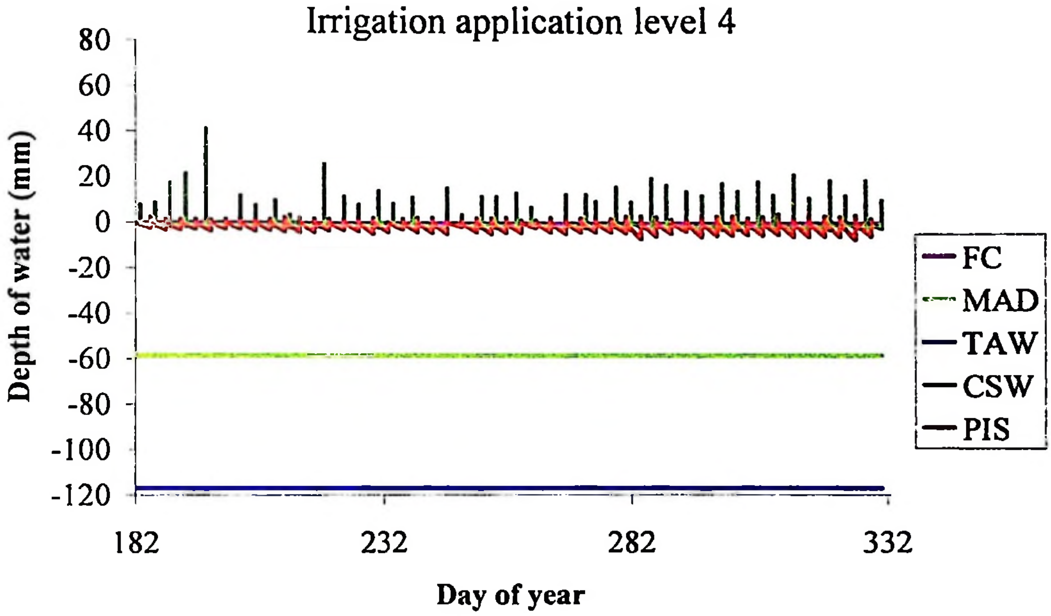

Figure 18: Soil moisture depletion in the root zone for irrigation application level 4, 100 % ET_c replenishment.

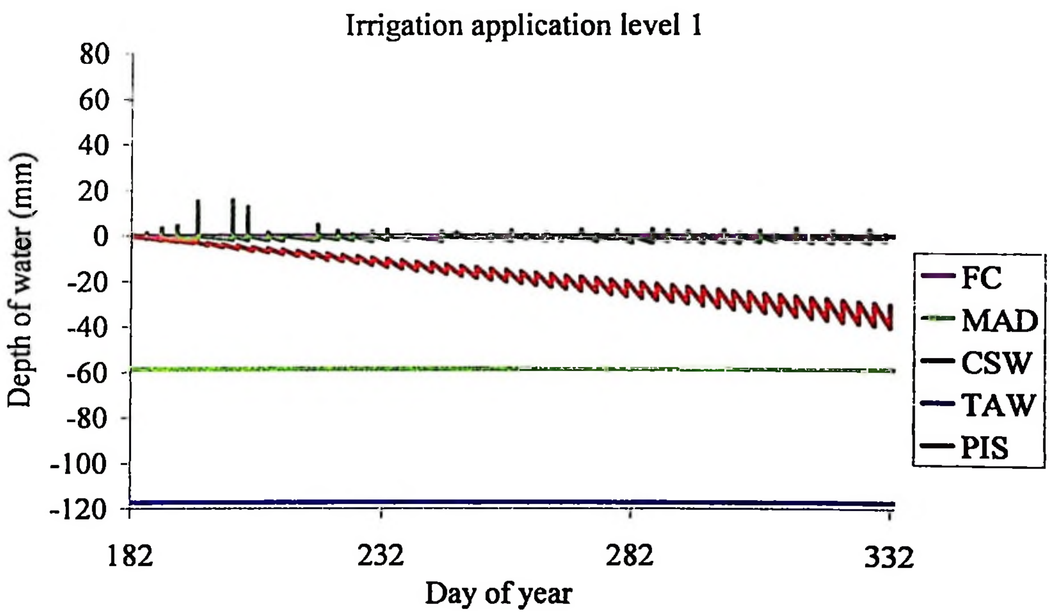

Figure 19: Soil moisture depletion in the root zone for irrigation application level 5,25 % ET_c replenishment.

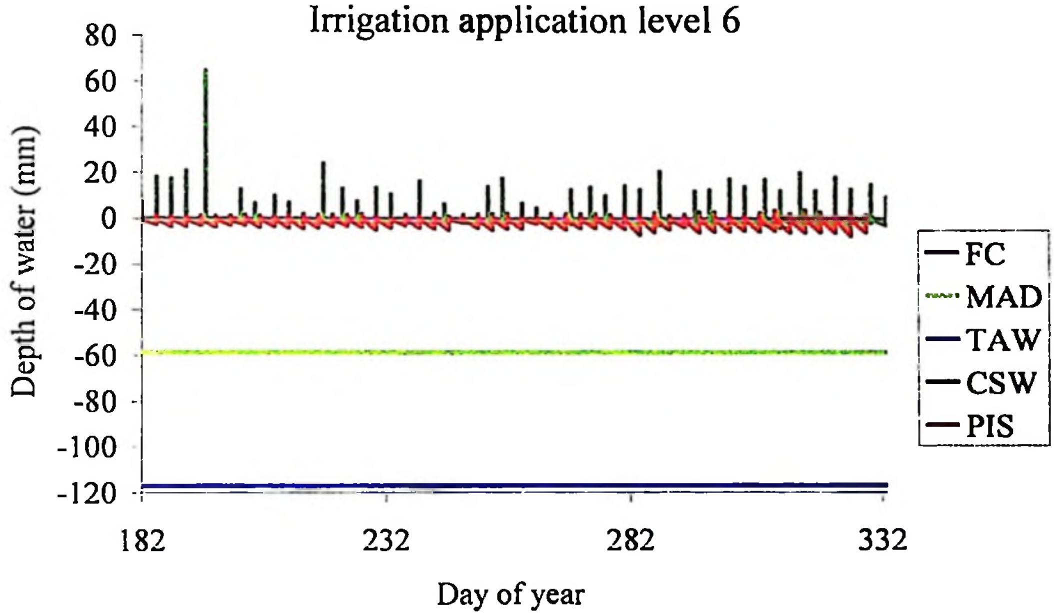

Figure 20: Soil moisture depletion in the root zone for irrigation application level 6, 100 % ET_c replenishment.

In irrigation, the aim is to refill the root zone moisture to field capacity (FC) (Kirkpatrick *et al.*, 2006). The criteria of when to irrigate is normally when the critical point (MAD) is reached (Kirkpatrick *et al.*, 2006 and Clause, 2005). In irrigation, water should remain above the MAD, which is usually taken to be equal to 50 % (Kirkpatrick *et al.*, 2006) or the determined MAD level in order to optimise yield. Beyond the MAD ease of water uptake is reduced thereby stressing the plant. The stress caused may result in yield reduction. The severity of water stress beyond the MAD will vary with soil type. The problem with the irrigation schedule at KTE is that the criteria of when to irrigate was based on the predetermined 3 day interval. This did not take into account the level of moisture depletion in the root zone. Instead the determination of irrigation water amount was based on accumulated ET_c which was over-estimated and instead of the accumulated soil water deficit. Consequently this resulted in over irrigation (Table 9). An alternative scheduling method would have been to let the moisture in the root zone be depleted to the MAD. From that point each irrigation application level would have been replenished differently depending on the ET_c replenishment proportion selected by management as in the schedule in Table 5.

4.2.3.1 Soil water balance

The soil water balance and climatic data have been widely used for irrigation scheduling in India (Bredero, 1991) and elsewhere (Isidoro *et al.*, 2003; Harrison 2005; Lombardini. and Basso 2005; Mandal *et al.*, 2002 and Topp *et al.*, 2000). This was the method used at KTE because determination of irrigation requirement and soil water deficit (SWD) was based on ET_c (water outflow) and irrigation (water inflow). In this study, initially the experimental field was irrigated to field capacity (i.e. ensuring that TAW was equal to 117 mm in the 100 cm depth of the soil). The amount of water replaced by irrigation was based on the accumulated ET_c (presumed SWD), and ET_c replenishment proportion calculated using Equation 19. Then, daily water accounting in order to determine the soil water deficit (SWD) on each day was computed using Equation 12. Appendix 10 shows the estimated SWD for each day. Although this method has been successfully used elsewhere (e.g. in Spain (Isidoro *et al.*, 2003), without stringent controls and accuracy in quantification of the variables which go into the water balance equation, it has resulted in over irrigation in some areas (Bredero, 1991; Mandal *et al.*, 2002 and Topp *et al.*, 2000). In this study the observations were similar in that, despite use of the water balance equation, there was excess application of water above the targeted amount since there was no actual measurement of soil parameters. Secondly, assumption of moisture content from possible evaporation and irrigation replenishment without actual soil moisture tension measurement ignores possible contributions from capillary rise and lateral soil moisture movement (Bredero, 1991). Some of the successful works on deficit irrigation (Shock and Faibert, 2002; Kirda, 2002; and Goodwin and Boland, 2002) have taken into account soil moisture tension information in order to aid in the scheduling of the deficit drip irrigation programs.

White, (1997) and Hanks and Ashcroft (1980) proposed the use of tensiometers for measurement of soil water potentials to aid in determining when and how much water to apply. Therefore, for soil water content data at KTE to be meaningful it would be desirable, firstly to come up with a soil water calibration (retentivity) curve, which would relate moisture content to the soil water potentials. This having been determined, it will be necessary to determine the allowable soil moisture depletion. Alternatively, management should have considered values suggested in literature for RAW with regard to specific MAD levels.

the irrigation schedule at KTE. However, for evaluation purpose, it was computed in this study. It was used in determining the area wetted for estimating amount of water required under drip irrigation. Given the manufacturer's specification (that emitter discharge exponent x, is equal to zero) for the RAM 17 emitters used in the drip irrigation system at KTE, the soil wetted portion (WP) was calculated. It was found to be approximately 80 % in irrigation application levels 1, 2, 3, and 4 whilst it was found to be 45 % in irrigation application levels 5 and 6 (Appendix 11).

4.3 Made tea yield

Overall tea clone type had a statistically significant ($P < 0.001$) influence on the crop yield of made tea (Table10) and (Appendix 12). The results for yield performance for each clone type and irrigation application levels are presented in Table 10. With regard to the six irrigation application levels in the four tea clone types all yield levels were insignificantly different. The only exception was clone S15/10 under which there was separation of the yield levels under the various irrigation levels.

Table 10: Made tea yields (kg ha^{-1}) for specific treatments and clones

Irrigation level	Clone			
	K35	PC81	S15/10	207
1	$116^{c,a}$	$207^{ab,a}$	$284^{a,a}$	$184^{bc,a}$
2	$129^{c,a}$	$222^{ab,a}$	$233^{a,ab}$	$207^{abc,a}$
3	$113^{b,a}$	$216^{a,a}$	$218^{a,ab}$	$216^{a,a}$
4	$98^{c,a}$	$198^{a,ab}$	$225^{a,ab}$	$199^{ab,a}$
5	$87^{c,a}$	$191^{a,a}$	$197^{a,b}$	$156^{ab,a}$
6	$94^{c,a}$	$258^{a,a}$	$203^{ab,ab}$	$184^{bc,a}$

Means within a row with different lower case superscript letters on the left of the comma are significantly different (P<0.001); Means within a column with different lower case superscript letters on the right of the comma are significantly different (P<0.001); means with different double lower case superscript are not significantly different whereas means with triple lower case are intermediate.

Under clone S15/10 irrigation application level 1 was higher in terms of yield although it was not significantly different to yields for irrigation levels 2, 3, 4, and 6. Irrigation application level 5 was inferior under this clone type though it was also not significantly different from the yield of irrigation levels 2, 3, 4, and 6. Figure 22 shows the yield performance of the four tea clones under six irrigation application levels. The yield ranges were 87-129 kg ha^{-1}, 197 – 284 kg ha^{-1}, 156 – 216 kg ha^{-1} and 191 – 258 kg ha-1 for clones K35, S15/10, 207 and PC81 respectively (Appendix 13).

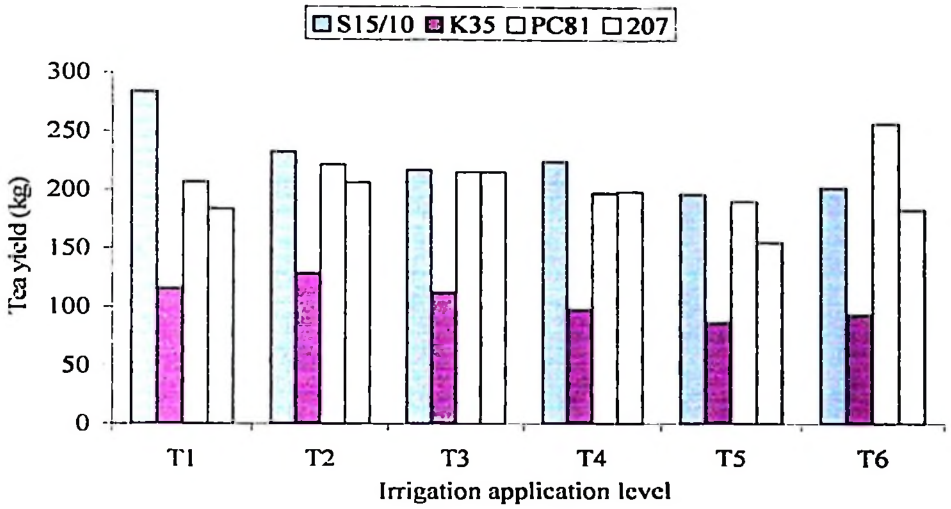

Figure 21: Mean made tea crop yield performance for different tea clone types under varying irrigation application levels.

Apart from irrigation application, 1 and 5 all irrigation applications were above the crop consumptive use. This trend of results indicates that high crop yields are not necessarily based on application of higher amounts of irrigation water rather water use efficiency (WUE) increases with reduced water application levels (Doorenbos *et al.*, 1979).

4.3.1 Tea clone yield response to water

The yield response to water was determined by plotting water use vs. yield for each irrigation application level using Microsoft Excel (Microsoft, 2000). The yield response to water of the four tea clones in all the 6 irrigation application levels showed a positive linear relationship. In this study the coefficient of determination, R^2 for the statistical model used for analysis was found to be equal to 0.60 (Appendix 14). This implies that 60% of the variance of tea yield can be attributed to the irrigation regime and tea clone type.

The tea yield response to water and the respective coefficient of determination for the four clones under each irrigation application are presented in Appendix 14. According to Harry and Althoen (1994), the coefficient of determination, R^2 is interpreted as the proportion of variance of Y (in this case tea yield) attributable to linear covariance of μ and β (which in this case refers to irrigation level and clone type). A coefficient of determination of zero implies an independent relationship, which was not the case in this study. From the yield functions determined in this study, it was evident that each clone type responds differently to water. The R^2 ranges were 0.35 - 0.40 for clone S15/10, 0.38 – 0.69 for PC81, 0.12 - 0.48 for clone 207 and 0.18 - 0.38 for clone K35 among all the six irrigation application levels. The ratio of the deviation from the mean for the model was also low with the coefficient of variation being equal to 22.98%. This implies that linear estimates of yield calculated from known values of irrigation amount and clone type can be characterised with significantly less uncertainty than estimates made in ignorance of the two factors (Harry and Althoen, 1994). However, since water application levels were in excess of the required amounts in all irrigation application levels in this study, the crop yield and water relationships may not be precise.

4.3.2 Tea clone yield as affected by drip irrigation

Drip lateral orientation and placement can affect production (Lamm *et al.*, 2003). Commonwealth Scientific and Industrial Research Organisation (CSIRO, 2005) has shown that a technique called partial root zone drying (PRD) can enable the use of significantly less water in vines in Australia. Partial root zone drying triggers biochemical changes that reduce the amount of water the plant needs (WWEE, 1999). Regarding the placement of laterals in this study, irrigation application levels 1 and 5 and irrigation application levels 4 and 6 had different lateral placement (Figures 4 and 5) but similar ET_c replenishment proportions of 25 % ET_c and 100 % ET_c respectively. Although there were no statistically significant differences in yield between irrigation application levels 1 and 5 and irrigation application levels 4 and 6 for each clone type, yields under irrigation application levels 5 and 6 were lower than yields for irrigation application levels 1 and 4 in all the four clones. The lower yield under irrigation applications level 5 and 6 could be attributed to the drip lateral placement. Under the lateral placement for irrigation application levels 5 and 6, only one side of the root zone was wetted (Figure 5) as opposed to the partial drying of the root zone suggested by CSIRO.

Partial root zone drying (PRD) involves the creation of simultaneous wet and dry (or drying) areas within the root zone. Only part of the root zone is irrigated and kept moist at any one time. Partial root zone drying is implemented by irrigating one side of the plant row and allowing the other side to dry out. The irrigations are then alternated to the dry side after a set period of time and then back and forth thereafter after the same interval of time. In Australia research done in PRD with vines has shown that PRD improves WUE of the crop and increases yield (Dry *et al.*, 2000; Chalmers and Kristic, 2001; Loveys *et al.*, 1997; Loveys *et al.*, 1998 and Stoll *et al.*, 2000). The drip lateral placement under irrigation application levels 5 and 6 failed to produce increased yield as there was no alternate wetting and drying of the root zone.

4.4 Irrigation system performance

4.4.1 Emission uniformity

The measured drip irrigation emission uniformity was high (91 -95 %) in all the irrigation application levels (Table 11). The emission uniformity calculations are presented in Appendix 15 whereas Appendix 16 shows the emitter flow rate data on which EU calculations were based. The drip irrigation system at Kibena Tea Estate was classified according to the EU values obtained following the criteria by Merriam and Keller (1978), Bralts *et al.* (1987) and that by the IRYDA (1983) (Table12).

Table 11: Emission uniformity performance for irrigation application levels

Irrigation level	Minimum flow rate Q_m (m^3hr^{-1})	Average flow rate Q_a (m^3hr^{-1})	Emission Uniformity (EU) %
1	35.40	37.44	91.0
2	35.75	36.20	95.0
3	35.51	36.50	93.6
4	35.20	36.10	94.0
5	37.83	38.30	95.0
6	35.86	37.90	91.0

The classification criteria of EU for irrigation systems, according to Merriam and Keller (1978) and the IRYDA (1983) are presented in Table 12. The performance of irrigation application levels 1, 3, 4, and 6 was classified as excellent following Merriam and Keller (1978) criterion and was classified as good according to the IRYDA (1983) and Bralts *et al.* (1987) criteria. The EU performance of irrigation application levels 2 and 5 was excellent under all criteria.

Table 12: System classification according to Emission Uniformity (EU) values

EU (%)	Classification		
	Merriam and Keller (1978)	Bralts, *et al.* (1987)	IRYDA (1983)
< 70	Poor	Unacceptable	Unacceptable
70 – 80	Acceptable	Poor	Poor
80 – 86	Good	Good	Acceptable
86 – 90	Good	Good	Good
90 – 94	Excellent	Good	Good
> 94	Excellent	Excellent	Excellent

Source: Ortega *et al.*, (2002) and Lamm *et al.* (2003).

The minimum flow rate (Q_m) (Table 11) was the lowest recorded flow rate under each irrigation application level obtained from Appendix 15. The average flow rate (Q_a) (Table 11) was the average of the sampled flow rates for each irrigation application level in Appendix 15. The results on EU indicate that system performance in terms of water allocation to points where it was required was less affected by clogging. Since EU performance was acceptable/good, any negative effects on yield performance of the crop could be attributable to sources such as temperature, frost, altitude and genetically inherent tolerance of the clone type adverse effects.

4.4.2 Irrigation efficiency

With regard to irrigation efficiency (IE)/water utilisation ratio, irrigation application levels 1 and 5 were the most efficient with irrigation efficiency coefficients equal to 1.7 and 1.6 respectively (Table 13).

A sample calculation for IE is shown in Appendix 15. Because of the deficit observed under irrigation application levels 1 and 5, the IE was greater than 1.0. In this case the outflow (ET_c) was higher than the inflow (I_g). Irrigation application level 2 had IE equal to 0.9, which is acceptable for drip irrigation systems. However, the WUE under this application level was lower compared to that for irrigation application 1 and 5.

Table 13: Irrigation efficiency performance for irrigation application levels

Irrigation level	Input (Irrigation supply) (m^3)	Output (ET_n) (m^3)	Irrigation efficiency (IE)
1	1940	3235	1.7
2	3500	3235	0.9
3	4670	3235	0.7
4	6226	3235	0.5
5	2080	3235	1.6
6	6594	3235	0.5

The reduced WUE performance resulted from the applied irrigation water, stored soil moisture and capillary water which may have reduced aeration and hence yield. Irrigation application level 3 was third with IE equal to 0.7. The least efficient irrigation application levels were levels 4 and 6, which had IE equal to 0.5 each (Table 13). Appendix 15 shows a sample calculation for IE. The reduced IEs under irrigation levels 3, 4 and 6 were due to the excess irrigation water application above the seasonal crop consumptive use. These findings are consistent with the findings reported by Ertek *et al.* (2003) that, applying excess irrigation water results in reduced IE. Table 13 shows irrigation efficiency performance for the 6 irrigation application levels. In a study to investigate the effect of frequency and amount on yield in summer squash (*Cucurbita pepo* L.), Ertek *et al.* (2003) reported that applying higher amounts of water generally gave lower irrigation efficiencies. They further reported IE range of 0.12 to 1.6 for three levels of ET_c (i.e. $0.45ET_c$, $0.65ET_c$, and $0.85ET_c$).

Merriam (1980) and Wolters and Bos (1990), have recommended characteristic irrigation efficiencies for different irrigation systems which are presented in Table 14. Thus, referring to characteristic IEs recommended for various irrigation systems in Table 14, only irrigation application levels 1, 2 and 5 are within the acceptable limits in terms of irrigation efficiency performance for drip irrigation and this is simply because their actual water applications were $0.6ET_c$, $1.08ET_c$ and $0.63ET_c$ respectively (Table 5). The observed high IE under irrigation application level 1 and 5 could be attributed to the observed deficit irrigation under these irrigation application levels. This is because reduced water application under deficit irrigation increases use water efficiency (Kirda, 2002).

Table 14: Characteristic IEs of various irrigation systems at farm level (Merriam (1980) and Wolters and Bos (1990)

Irrigation system	Characteristic Irrigation efficiency (IE) %	Remark
Conventional gravity	30 -50	The lower limit range is mainly in paddy irrigation to flooded fields
Level basin	40 -70	The high value is achieved with laser beam leveling
Sprinkler	60 - 75	-
Drip	80 - 90	-

4.4.3 Water use efficiency

Water use efficiency (WUE) describes dry matter production per unit water used by the crop through evapotranspiration. For commercial purposes it has been found to be easier to compare the water use efficiency of a crop on the basis of the commercial yield per unit of crop evapotranspiration (ET_c) or per unit of rainfall or both (Turner, 1986). There was less variation in terms of yield in all the irrigation application levels (Appendix 12); the scenario was different as regards WUE. The most efficient irrigation application was irrigation application level 1. Despite the reduced water input, irrigation application 1 produced the highest yields and hence had the highest WUE. This implies that under this irrigation application level, soil conditions were optimum for crop growth. Furthermore, there was reduced possibility of plant stress due to poor aeration (Figure 16) under this application and the crop was able to optimise the utilisation of water contributed from other sources such as stored soil moisture, capillary water etc. However, contribution from these sources could not be quantified, as there was no actual measurement of these parameters.

Water use efficiency reduced as the proportion of evapotranspiration replenishment increased (i.e. irrigation application levels 3, 4 and 6). The WUE was low because there may have been water loss due to deep percolation under these irrigation application levels (Figures 18, 19 and 21). Table 15 presents results for WUE performance for the six irrigation application levels.

Since the yield trends tended to be the same in all the six irrigation application levels in each of the four tea clones. There was higher water productivity (kg mm^{-1}) in irrigation applications with a lower proportion. Overall irrigation application level 1, which had the least ET_c replenishment 60% (Table 9), had the highest water productivity (kg mm^{-1}). Although irrigation application level 5 was supposed to have a similar water application level to irrigation application level 1, the reduced WP due to drip lateral placement resulted in reduced water use optimisation by the crop.

Table 15: WUE of irrigation levels and tea clone type (kg mm)

Irrigation level	Clone type			
	K35	PC81	S15/10	207
1	0.69	1.23	1.47	0.95
2	0.40	0.17	0.70	0.60
3	0.28	0.56	0.47	0.46
4	0.19	0.36	0.36	0.32
5	0.66	1.08	0.97	0.77
6	0.17	0.42	0.31	0.28

The lowest water productivity values (kg mm ^{1}) were observed under irrigation application levels 4 and 6, which conversely had the highest (192% and 204% respectively) ET_c replenished. Water productivity values were as high as 1.46 kg mm ^{1} under irrigation application level 1 of clone S15/10 to as low as 0.14 kg mm ^{1} under irrigation application level 6 of clone K35. Irrigation application levels 2 and 3 were intermediate in terms of water productivity. Figure 23 illustrates the WUE among irrigation levels and clone type diagrammatically.

Made tea yield gave a good response to water especially with respect to the irrigation depth used. Irrigation application levels 1 and 5 (Table 15) gave crop water response values, which are higher in some instances than some results reported elsewhere in Tanzania including some estates in Kenya (Carr and Stephens, 1992) and in Malawi (Carr *et al.*, 1987) (Table 16). Under irrigation application level 1 with the exception of clone, K35 the WUE recorded for the three clones (i.e. PC81, S15/10 and 207) exceeded the WUE results reported by Carr (1992) by a range of 0.15 kg mm $^{-1}$ – 0.7 kg mm $^{-1}$ (Table,16). Some WUE results reported under all the six irrigation application levels and in all the four clone types, exceeded results on WUE reported by Carr *et al.* (1987) by a range of about 0.1 kg mm $^{-1}$ – 1.16 kg mm $^{-1}$. However, it can be deduced from the results that, in terms of comparison that, in terms of comparison with other areas, WUE values obtained in this study were low due to excess water application above the required amount. The magnitude of the over application above the required amount was 35 % (113 mm), 57 % (184 mm), 69 % (223 mm), 92 % (298 mm), 38 % (123 m) and 104 % (336 mm) for irrigation application levels 1, 2, 3, 4, 5, and 6 respectively. This excess irrigation tended to lower the WUE of the tea clones in this study. Table 16 compares WUE results obtained in this study with some of the results obtained by other researchers in other locations.

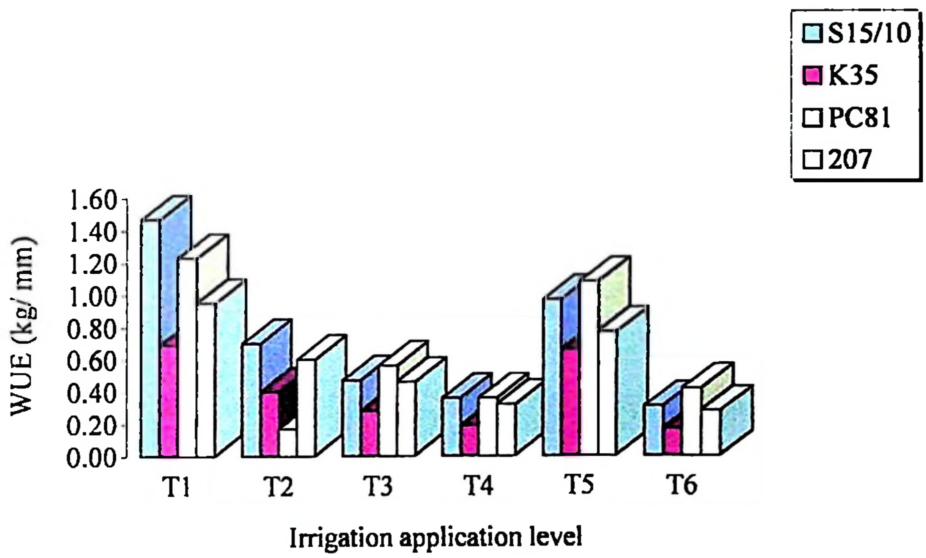

Figure 22: Comparison of WUE among irrigation levels and clone types.

Table 16: Comparison of WUE results obtained in this study with results obtained elsewhere in other studies

Researcher/ Author	Period of or study	Location	Water productivity (kg mm^{-1})
This study	2003	Kibena tea estate	*0.14 – 1.46
Carr and Stephens (1992)	1967 –1970 (3 years)	Southern highlands Tanzania	0.80
Carr *et al.* (1987)	1967 –1970 (3 years)	Malawi	0.30
Kimambo (2001)	2000 -2001	Ngwazi, Tanzania	5.30
Kimambo (2002)	2002	Ngwazi, Tanzania	6.20

* WUE range for the 6 irrigation application levels and 4 tea clone types.

However, most of these yield averages have been considered over longer periods of time. i.e. as long as 3 years for studies done by Carr and Stephens (1992) and Carr *et al.* (1987) while in this study yield was only considered for a period of five months (1 July to 30 November, 2003). Periods solely dependent on rainfall for crop moisture were not considered.

In a study on comparison of yield over time at three contrasting locations in eastern Africa, Carr and Stephens (1992) concluded that it was difficult to isolate the effects of individual technological and management changes on production. Rather the observation was that there were long term steady increases in yield, which resulted from the combined effects of a number of changes such as advancements in tea clone breeding and periodical practices such as pruning and cultural practices etc. The rate of yield increase varied in these locations and the notable factors responsible for this variation are altitude and temperature. Yield increase per year tended to be higher in Malawi at an altitude of 600 m and moderate temperatures and was lower in Kenya at a high altitude (2200 m) where low temperatures derailed improvement in yield (Carr *et al.*, 1987).

These observations seem to be valid for Kibena Estate in that from the climatic point of view of the area, the 'dry and warm' season (supposedly the warmest), which extends from September to November has a temperature range of 15.1° - 17.4° C and average temperature of about 16.2°C (Hajra, 2002). This is relatively lower (cooler) compared to other tea growing areas such as Assam in Bangladesh with a temperature of 26°C - 29°C and Mulange in Malawi with average temperature of about 23°C (Stephen *et al.*, 1998). The effect of these lower temperatures was evidenced in the length of the harvest cycle (i.e. number of days from one plucking to the next). At KTE, the harvest cycle was between 21 – 25 days (Appendix 3) between August to September. The peak harvest period was from September - November (with mean temperature equal to 18°C) with the harvest cycle equal to about 14 days. After November harvest reduced due to advent cooling brought about by the rains. The harvest cycle reached its peak length of 35 days in the cooler months of June – July (mean temperatures equal to 13°C). The lower yields of clone K35 were also largely attributable to scorching of shoots/leaves due to cold.

According to Hajra (2002) the average harvest cycle of Malawi is 42 days whereas it is 30 days for Bangladesh. In comparison with the harvest cycles observed in this study, the observed harvest cycles at KTE all shorter than the average for Malawi. However, compared to the average harvest cycle for Bangladesh, the harvest cycle (14 days) observed in the warmer months of September to November at was shorter. The harvest cycles for KTE observed between August to September were also shorter except for that observed between June to July (35 days) which was longer than the average harvest cycle for Bangladesh.

Phyllochron (leaf appearance interval) affects the interval between plucking rounds, which tend to be shorter with warmer temperatures and longer with cool temperatures. The interval between plucking rounds determines the type of shoots plucked and the yield. During this period, the basal population of shoots develops to harvestable size and produces the first peak in crop production. The shoots, which are produced throughout the year, take between 5 and 15 weeks to grow to a harvestable length of 15 cm, and the frequency of harvests is varied to accommodate these differences in growth rate; shoots are harvested every 7 to 9 days in the fastest growing season and every 3 to 4 weeks in the slowest. This effect has a considerable influence on the distribution of crop (Hajra, 2002). Furthermore, harvesting policies particularly a switch from plucking predominantly two leaves and bud to a larger proportion of three leaves and a bud may also affect yield (Carr and Stephens 1992). The practice at Kibena as in other parts of southern Tanzania is to harvest three unfurled leaves (Burgess and Carr, 1998). The harvest cycle was varied from about 35 days during the initial stages (July) to 14 in the final period of this study. This extended cycle lowered yield in comparison to studies conducted in areas with reduced cycles.

4.5 Tea crop height and tea crop ground cover

Irrigation application level had no statistically significant influence on the tea crop height within the six treatments whereas tea clone type had a statistically significant influence on crop height ($P < 0.05$) (Appendix 12). Differences in crop height from this experiment are attributable to tea clone type in that the tea clones had significant differences in height (Table 17). The raw data on tea crop height is shown in Appendix 17. Clones 207 and PC81 had the tallest bushes with an average of 70.07 cm and 68.77 cm respectively. The two clones were not significantly different in terms of height. Clone S15/10 followed with a height of 66.18 cm and the least clone in terms of height was K35 with a height of 61.01 cm.

Table 17: Mean tea crop height (cm) for specific treatment combinations

Irrigation level	Clone			
	K35	PC81	S15/10	207
1	$61.50^{b,a}$	$67.99^{ab,ab}$	$66.06^{ab,a}$	$70.58^{a,a}$
2	$63.01^{a,a}$	$68.01^{a,ab}$	$66.68^{a,a}$	$69.78^{a,a}$
3	$62.42^{b,a}$	$68.60^{ab,ab}$	$66.89^{ab,a}$	$70.87^{a,a}$
4	$59.09^{c,a}$	$66.83^{ab,b}$	$65.18^{abc,a}$	$70.09^{a,a}$
5	$59.97^{c,a}$	$67.18^{ab,ab}$	$66.47^{abc,a}$	$69.40^{a,a}$
6	$60.10^{c,a}$	$74.03^{a,a}$	$65.81^{bc,a}$	$69.68^{a,a}$

Means within a row with different lower case superscript letters on the left of the slash are significantly different ($P<0.001$); Means within a column with different lower case superscript letters on the right of the slash are significantly different ($P<0.001$).

The rate of water use by the tea crop is determined by both plant (e.g. crop height and GC) and environmental factors (altitude and temperature) (Burgess, 1995). Despite the fact that not much can be deduced from the relationship between irrigation and crop height or crop ground cover, there was a positive association between crop height and tea yield and between GC and tea yield. The lowest yielding tea clone K35 (Table 10) had the least crop height and GC. The higher yielding clones PC 81 and S15/10 (Table 15) had a higher crop ground cover and crop height (Table 7 and Table 17). As suggested by Carr (1992), the hypothesis could be that clones with a greater crop height and cover had the ability to intercept more radiation which in turn positively influenced evapotranspiration rates from the bushes and hence the yield.

The raw data for crop ground cover is shown in Appendix 18 whereas Appendix 19 shows the calculation procedure for crop ground cover. From Table 8 clone S15/10 and PC81 had a GC range of 89 – 90 % and 90 – 92 % respectively. Clone 207 was second with 88 -89 % and the clone with the least GC was clone K35, which had a range 83 – 86 %.

Crop cover (canopy) has a significant role in the interception of radiation. This capability of radiation interception is normally affected by pruning. Bushes on a three-year pruning cycle will probably intercept less light than those on a four-year cycle. The rate of recovery from pruning will also depend on the prevailing temperatures and level of water stress at the time of pruning (Carr and Stephens, 1992). However, in the case of this experiment, all tea clones in all treatments were pruned at the same time in August 2002 prior to the start of the experiment. Thus, crop cover (canopy) differences cannot be attributed to pruning but rather to clonal differences as indicated by the analysis of variance (ANOVA).

4.5.1 Pearson correlation analysis

Pearson correlation analysis was conducted between made tea yield and crop height and between made tea yield and crop cover. The results for the correlation analysis are presented in Table 18.

Table 18: Pearson correlation coefficient (r) for made tea yield, crop height and crop cover .

	Made tea	Crop height	Crop cover
Made tea	-	0.50356	0.62555
Crop height	0.50356	-	0.43324
Crop cover	0.62555	0.43324	-

From the results of the Pearson correlation analysis it is evidently revealed that there was a strong positive correlation between made tea yield and crop height and between made tea yield and crop cover. However, these results may have no major relevance as regards to possible irrigation interventions to boost the yield of made tea from the four clone types. Since the water application to the crop was in excess of the target amounts for all treatments, no meaningful relationship between crop cover and crop height could not be precisely established.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

From the study, the following conclusions were made:

1. Overall the IE performance of the drip irrigation system was lower because of the excess amounts applied above what would be required for a properly scheduled drip system. However, under the prevailing conditions irrigation application level 1 had the best performance both in terms of IE and tea crop WUE. This so because despite having the lowest amount of water applied ($0.6ET_c$) it had the highest IE equal to 1.7 and also had comparatively the highest WUE for all 4 tea clone types than for the other five irrigation application levels. The Emission uniformity (EU) of the drip irrigation system was within the recommended range of uniformity for drip irrigation systems. The drip irrigation system at KTE was not properly scheduled according to the recommendations for scheduling of drip irrigation systems. Under the prevailing practices and conditions, $0.6ET_c$ was the best ET_c replenishment level. The best lateral placement was 1 drip lateral serving one row of tea. Thus, irrigation application level 1 was the best irrigation application level in terms of performance.

2. Clone S15/10 had the best yield response to water with a yield equal to 1.46 kg mm^{-1} under the prevailing environment. However, since the experiment was not performed according to plan, these results may not be of much significance. i.e. not much can be inferred from these results.

3. There is potential for water saving with drip irrigation in commercial tea production. This is because under the prevailing schedule at KTE, 151 713 m^3 of water would have been saved through proper scheduling of the drip irrigation system.

5.2 Recommendations

In order to come up with reliable and precise data on the performance of drip irrigation in commercial tea production for the Southern highlands, this study should be repeated observing the proper methodology for drip irrigation system scheduling.

For the soil water balance method to be successfully used, actual soil moisture measurements have to be done using tensiometers. This is in order to accurately quantify parameters to be used in the soil water balance equation.

To mitigate the water scarcity problem, a study to investigate drip lateral placement and potential for PRD in tea commercial tea production is recommended.

In view of the crop water requirements determination method at Kibena Tea Estate, it will be important that this experiment is performed using irrigation requirements computed using recognised empirical methods such as the F.A.O. Penman-Monteith method, Radiation method etc. It will be essential also in future trials to observe guidelines for scheduling trickle systems if benefits of the drip system are to be realised. Possibly research could be done to consider the appropriate K_p and K_c combination for drip irrigation scheduling at Kibena.

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APPENDICES

Appendix 1: Effective rooting depth and depletion fraction for some crops

Crop	Maximum Root Depth (m)	Depletion Fraction [2] (for ET 5 mm/day) p
	a. Small Vegetables	
Broccoli	0.4-0.6	0.45
Brussel Sprouts	0.4-0.6	0.45
Cabbage	0.5-0.8	0.45
Carrots	0.5-1.0	0.35
Cauliflower	0.4-0.7	0.45
Celery	0.3-0.5	0.20
Garlic	0.3-0.5	0.30
Lettuce	0.3-0.5	0.30
Onions		
- dry	0.3-0.6	0.30
- green	0.3-0.6	0.30
- seed	0.3-0.6	0.35
Spinach	0.3-0.5	0.20
Radishes	0.3-0.5	0.30
b. Vegetables - Solarium Family *(Solanaceae)*		
Egg Plant	0.7-1.2	0.45
Sweet Peppers (bell)	0.5-1.0	0.30
Tomato	0.7-1.5	0.40
c. Vegetables - Cucumber Family (*Cucurbitaceae*)		
Cantaloupe	0.9-1.5	0.45
Cucumber		
- Fresh Market	0.7-1.2	0.50
- Machine harvest	0.7-1.2	0.50
Pumpkin, Winter Squash	1.0-1.5	0.35
Squash, Zucchini	0.6-1.0	0.50
Sweet Melons	0.8-1.5	0.40
Watermelon	0.8-1.5	0.40
d. Roots and Tubers		
Beets, table	0.6-1.0	0.50
Cassava		
- year 1	0.5-0.8	0.35
- year 2	0.7-1.0	0.40
Parsnip	0.5-1.0	0.40
Potato	0.4-0.6	0.35
Sweet Potato	1.0-1.5	0.65
Turnip (and Rutabaga)	0.5-1.0	0.50
Sugar Beet	0.7-1.2	0.55[3]
e. Legumes *(Leguminosae)*		
Beans, green	0.5-0.7	0.45
Beans, dry and Pulses	0.6-0.9	0.45
Beans, lima, large vines	0.8-1.2	0.45
Chick pea	0.6-1.0	0.50

Fababean (broad bean)		
- Fresh	0.5-0.7	0.45
- Dry/Seed	0.5-0.7	0.45
Grabanzo	0.6-1.0	0.45
Green Gram and Cowpeas	0.6-1.0	0.45
Groundnut (Peanut)	0.5-1.0	0.50
Lentil	0.6-0.8	0.50
Peas		
- Fresh	0.6-1.0	0.35
- Dry/Seed	0.6-1.0	0.40
Soybeans	0.6-1.3	0.50
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)		
Artichokes	0.6-0.9	0.45
Asparagus	1.2-1.8	0.45
Mint	0.4-0.8	0.40
Strawberries	0.2-0.3	0.20
g. Fibre Crops		
Cotton	1.0-1.7	0.65
Flax	1.0-1.5	0.50
Sisal	0.5-1.0	0.80
h. Oil Crops		
Castorbean *(Ricinus)*	1.0-2.0	0.50
Rapeseed, Canola	1.0-1.5	0.60
Safflower	1.0-2.0	0.60
Sesame	1.0-1.5	0.60
Sunflower	0.8-1.5	0.45
i. Cereals		
Barley	1.0-1.5	0.55
Oats	1.0-1.5	0.55
Spring Wheat	1.0-1.5	0.55
Winter Wheat	1.5-1.8	0.55
Maize, Field (grain) *(field corn)*	1.0-1.7	0.55
Maize, Sweet *(sweet corn)*	0.8-1.2	0.50
Millet	1.0-2.0	0.55
Sorghum		
- grain	1.0-2.0	0.55
- sweet	1.0-2.0	0.50
Rice	0.5-1.0	0.20[4]
j. Forages		
Alfalfa		
- for hay	1.0-2.0	0.55
- for seed	1.0-3.0	0.60
Bermuda		
- for hay	1.0-1.5	0.55
- Spring crop for seed	1.0-1.5	0.60
Clover hay, Berseem	0.6-0.9	0.50
Rye Grass hay	0.6-1.0	0.60
Sudan Grass hay (annual)	1.0-1.5	0.55

Grazing Pasture		
- Rotated Grazing	0.5-1.5	0.60
- Extensive Grazing	0.5-1.5	0.60
Turf grass		
- cool season [5]	0.5-1.0	0.40
- warm season [5]	0.5-1.0	0.50
k. Sugar Cane	1.2-2.0	0.65
l. Tropical Fruits and Trees		
Banana		
- 1st year	0.5-0.9	0.35
- 2nd year	0.5-0.9	0.35
Cacao	0.7-1.0	0.30
Coffee	0.9-1.5	0.40
Date Palms	1.5-2.5	0.50
Palm Trees	0.7-1.1	0.65
Pineapple	0.3-0.6	0.50
Rubber Trees	1.0-1.5	0.40
Tea		
- non-shaded	0.9-1.5	0.40
- shaded	0.9-1.5	0.45
m. Grapes and Berries		
Berries (bushes)	0.6-1.2	0.50
Grapes		
- Table or Raisin	1.0-2.0	0.35
- Wine	1.0-2.0	0.45
Hops	1.0-1.2	0.50
n. Fruit Trees		
Almonds	1.0-2.0	0.40
Apples, Cherries, Pears	1.0-2.0	0.50
Apricots, Peaches, Stone Fruit	1.0-2.0	0.50
Avocado	0.5-1.0	0.70
Citrus		
- 70% canopy	1.2-1.5	0.50
- 50% canopy	1.1-1.5	0.50
- 20% canopy	0.8-1.1	0.50
Conifer Trees	1.0-1.5	0.70
Kiwi	0.7-1.3	0.35
Olives (40 to 60% ground coverage by canopy)	1.2-1.7	0.65
Pistachios	1.0-1.5	0.40
Walnut Orchard	1.7-2.4	0.50

Source: Allen et. al., (1998)

The values for p apply for $ET_c \geq 5$ mm/day. The value for p can be adjusted for different ET_c according to $p = p_{table\ a} + 0.04\ (5 - ET_c)$

Where:

p is expressed as a fraction and ET_c as mm/day (Allen *et al.*, 1998).

Appendix 2: Illustration of subplot distribution in the 9 ha drip irrigation field

Plot N0 121 PC 81 T2	Plot N0 122 K35 T2	Plot N0 123 S15 T2	Plot N0 124 207 T2	Plot N0 125 K35 T2	Plot N0 126 207 T2	F	Plot N0 127 PC 81 T6	Plot N0 128 S15 T6	Plot N0 129 PC 81 T6	Plot N0 130 207 T6	Plot N0 131 K35 T6	Plot N0 132 S15 T6	Plot N0 133 K35 T6	Plot N0 134 S15 T6	Plot N0 135 PC 81 T6	Plot N0 136 207 T6	Plot N0 137 PC 81 T6	Plot N0 138 S15 T6	L	Plot N0 139 K35 T6	Plot N0 140 207 T6	Plot N0 141 S15 T6	Plot N0 142 K35 T6	Plot N0 143 207 T6	Plot N0 144 PC 81 T6
Plot N0 97 PC 81 T3	Plot N0 98 K35 T3	Plot N0 99 S15 T3	Plot N0 100 207 T3	Plot N0 101 K35 T3	Plot N0 102 207 T3	E	Plot N0 103 PC 81 T3	Plot N0 104 S15 T3	Plot N0 105 PC 81 T3	Plot N0 106 207 T3	Plot N0 107 K35 T3	Plot N0 108 S15 T3	Plot N0 109 K35 T5	Plot N0 110 S15 T5	Plot N0 111 PC 81 T5	Plot N0 112 207 T5	Plot N0 113 PC 81 T5	Plot N0 114 S15 T5	K	Plot N0 115 K35 T5	Plot N0 116 207 T5	Plot N0 117 S15 T5	Plot N0 118 K35 T5	Plot N0 119 207 T5	Plot N0 120 PC 81 T5
Plot N0 73 PC 81 T1	Plot N0 74 K35 T1	Plot N0 75 S15 T1	Plot N0 76 207 T1	Plot N0 77 K35 T1	Plot N0 78 207 T1	D	Plot N0 79 PC 81 T1	Plot N0 80 S15 T1	Plot N0 81 PC 81 T1	Plot N0 82 207 T1	Plot N0 83 K35 T1	Plot N0 84 S15 T1	Plot N0 85 K35 T4	Plot N0 86 S15 T4	Plot N0 87 PC 81 T4	Plot N0 88 207 T4	Plot N0 89 PC 81 T4	Plot N0 90 S15 T4	J	Plot N0 91 K35 T4	Plot N0 92 207 T4	Plot N0 93 S15 T4	Plot N0 94 K35 T4	Plot N0 95 207 T4	Plot N0 96 PC 81 T4
Plot N0 49 207 T6	Plot N0 50 S15 T6	Plot N0 51 K35 T6	Plot N0 52 PC81 T6	Plot N0 53 S15 T6	Plot N0 54 K35 T6	C	Plot N0 55 207 T6	Plot N0 56 PC81 T6	Plot N0 57 K35 T6	Plot N0 58 S15 T6	Plot N0 59 PC 81 T6	Plot N0 60 207 T6	Plot N0 61 S15 T2	Plot N0 62 K35 T2	Plot N0 63 207 T2	Plot N0 64 PC 81 T2	Plot N0 65 S15 T2	Plot N0 66 207 T2	I	Plot N0 67 PC 81 T2	Plot N0 68 K35 T2	Plot N0 69 207 T2	Plot N0 70 PC 81 T2	Plot N0 71 K35 T2	Plot N0 72 S15 T2
Plot N0 25 207 T5	Plot N0 26 S15 T5	Plot N0 27 K35 T5	Plot N0 28 PC81 T5	Plot N0 29 S15 T5	Plot N0 30 K35 T5	B	Plot N0 31 207 T5	Plot N0 32 PC81 T5	Plot N0 33 K35 T5	Plot N0 34 S15 T5	Plot N0 35 PC 81 T5	Plot N0 36 207 T5	Plot N0 37 S15 T4	Plot N0 38 K35 T4	Plot N0 39 207 T4	Plot N0 40 PC 81 T4	Plot N0 41 S15 T4	Plot N0 42 207 T4	H	Plot N0 43 PC 81 T4	Plot N0 44 K35 T4	Plot N0 45 207 T4	Plot N0 46 PC 81 T4	Plot N0 47 K35 T4	Plot N0 48 S15 T4
Plot N0 1 207 T3	Plot N0 2 S15 T3	Plot N0 3 K35 T3	Plot N0 4 PC81 T3	Plot N0 5 S15 T3	Plot N0 6 K35 T3	A	Plot N0 7 207 T3	Plot N0 8 PC81 T3	Plot N0 9 K35 T3	Plot N0 10 S15 T3	Plot N0 11 PC 81 T3	Plot N0 12 207 T3	Plot N0 13 S15 T1	Plot N0 14 K35 T1	Plot N0 15 207 T1	Plot N0 16 PC 81 T1	Plot N0 17 S15 T1	Plot N0 18 207 T1	G	Plot N0 19 PC 81 T1	Plot N0 20 K35 T1	Plot N0 21 207 T1	Plot N0 22 PC 81 T1	Plot N0 23 K35 T1	Plot N0 24 S15 T1

Appendix 3: Phyllochron measurement and harvest interval as dictated by Phyllochron

Month: July

Day	Maximum temperature	Minimum temperature	Mean temperature	Phyllochron measurement	Cumulative phyllochron
				Brought forward:	1.062
1	14.00	10.00	12.00	0.048	1.110
2	15.50	9.50	12.50	0.056	1.166
3	17.00	10.00	13.50	0.072	1.238
4	17.00	10.00	13.50	0.072	1.310
5	17.50	8.50	13.00	0.064	1.374
6	16.00	8.00	12.00	0.048	1.422
7	14.50	8.50	11.50	0.040	1.462
8	14.50	5.50	10.00	0.016	1.478
9	14.00	5.50	9.75	0.012	1.490
10*[a]	17.50	6.00	11.75	0.044	1.534
11	17.50	8.00	12.75	0.060	0.060
12	16.00	6.00	11.00	0.032	0.092
13	17.00	6.00	11.50	0.040	0.132
14	16.00	5.50	10.75	0.028	0.160
15	16.50	5.00	10.75	0.028	0.188
16	16.50	5.00	10.75	0.028	0.216
17	16.00	5.00	10.50	0.024	0.240
18	17.50	7.00	12.25	0.052	0.292
19	18.50	6.50	12.50	0.056	0.348
20	20.00	8.00	14.00	0.081	0.429
21	20.50	9.00	14.75	0.093	0.522
22	15.50	8.00	11.75	0.044	0.566
23	21.00	8.50	14.75	0.093	0.659
24	17.00	8.00	12.50	0.056	0.715
25	19.00	6.50	12.75	0.060	0.775
26	15.00	5.50	10.25	0.020	0.795
27	17.00	9.00	13.00	0.064	0.859
28	19.00	7.00	13.00	0.064	0.923
29	17.00	6.50	11.75	0.044	0.967
30	20.00	6.50	13.25	0.068	1.035
31	20.50	8.50	14.50	0.089	1.124

Note: * signifies day plucking was done. [a] plucked early (before a phyllochron of 2.00 was reached, due to fear of frost damage)

Harvest interval as dictated by leaf appearance interval (Phyllochron) Month: August

Day	Maximum temperature	Minimum temperature	Mean temperature	Phyllochron measurement	Cumulative phyllochron
				Brought forward:	1.124
1	17.50	8.00	12.75	0.060	1.184
2	17.50	3.50	10.50	0.024	1.208
3	19.50	5.00	12.25	0.052	1.260
4	19.50	5.00	12.25	0.052	1.312
5	17.50	6.00	11.75	0.044	1.356
6	14.00	6.50	10.25	0.020	1.376
7	16.50	5.50	11.00	0.032	1.408
8	19.00	7.50	13.25	0.068	1.476
9	19.50	8.50	14.00	0.081	1.557
10	21.50	8.50	15.00	0.097	1.654
11	19.50	10.50	15.00	0.097	1.751
12	20.00	9.50	14.75	0.093	1.844
13	20.50	8.00	14.25	0.085	1.929
14*	22.50	8.50	15.50	0.105	2.034
15	24.00	6.00	15.00	0.097	0.097
16	23.50	8.00	15.75	0.109	0.206
17	21.50	5.50	13.50	0.072	0.278
18	22.50	5.50	14.00	0.081	0.359
19	22.50	7.50	15.00	0.097	0.456
20	20.50	8.50	14.50	0.089	0.545
21	18.00	9.50	13.75	0.076	0.621
22	20.00	9.50	14.75	0.093	0.714
23	16.00	8.50	12.25	0.052	0.766
24	19.00	8.50	13.75	0.076	0.842
25	21.50	8.50	15.00	0.097	0.939
26	23.50	7.00	15.25	0.101	1.040
27	24.00	10.00	17.00	0.129	1.169
28	24.00	8.00	16.00	0.113	1.282
29	20.50	8.50	14.50	0.089	1.371
30	20.50	6.50	13.50	0.072	1.443
31	23.00	6.50	14.75	0.093	1.536

Harvest interval as dictated by leaf appearance interval (Phyllochron) Month: September

Day	Maximum temperature	Minimum temperature	Mean temperature	Phyllochron measurement	Cumulative phyllochron
				Brought forward:	1.536
1	20.50	9.00	14.75	0.093	1.629
2	19.50	9.50	14.50	0.089	1.718
3	19.50	8.50	14.00	0.081	1.799
4	15.00	10.00	12.50	0.056	1.855
5	14.50	9.50	12.00	0.048	1.903
6	20.50	10.50	15.50	0.105	2.008
7	23.50	10.50	17.00	0.129	2.137
8*	20.50	10.50	15.50	0.105	2.242
9	21.50	9.50	15.50	0.105	0.105
10	21.50	9.50	15.50	0.105	0.210
11	20.50	7.50	14.00	0.081	0.291
12	21.50	9.00	15.25	0.101	0.392
13	21.50	10.50	16.00	0.113	0.505
14	24.00	11.00	17.50	0.137	0.642
15	23.50	11.50	17.50	0.137	0.779
16	20.00	9.50	14.75	0.093	0.872
17	20.00	9.50	14.75	0.093	0.965
18	18.00	10.50	14.25	0.085	1.050
19	19.50	10.50	15.00	0.092	1.142
20	19.50	10.50	15.00	0.097	1.239
21	19.50	11.00	15.25	0.101	1.340
22	19.00	11.00	15.00	0.097	1.437
23	23.50	11.50	17.50	0.137	1.574
24	21.00	10.50	15.75	0.109	1.683
25	21.50	9.50	15.50	0.105	1.788
26	22.50	10.00	16.25	0.117	1.905
27	21.50	10.50	16.00	0.113	2.018
28	22.00	10.00	16.00	0.113	2.131
29*	19.50	10.50	15.00	0.097	2.228
30	21.50	10.50	16.00	0.105	0.105

Harvest interval as dictated by leaf appearance interval (Phyllochron) Month: October

Day	Maximum temperature	Minimum temperature	Mean temperature	Phyllochron measurement	Cumulative phyllochron
				Brought forward:	0.105
1	20.50	6.50	13.500	0.072	0.177
2	21.50	9.50	15.500	0.105	0.282
3	20.50	10.00	15.250	0.101	0.383
4	21.50	9.50	15.500	0.105	0.488
5	21.50	10.00	15.750	0.109	0.597
6	23.00	11.00	17.000	0.129	0.726
7	21.50	12.00	16.750	0.125	0.851
8	23.50	11.50	17.500	0.137	0.988
9	24.00	9.50	16.750	0.125	1.113
10	23.50	9.00	16.250	0.117	1.230
11	22.50	9.00	15.750	0.109	1.339
12	24.50	10.50	17.500	0.137	1.476
13	25.00	11.50	18.250	0.149	1.625
14	23.50	11.00	17.250	0.133	1.758
15	26.00	11.50	18.750	0.157	1.915
16	25.00	11.50	18.250	0.149	2.064
17*	26.00	12.50	19.250	0.165	2.229
18	21.50	13.50	17.500	0.137	0.137
19	26.00	12.00	19.000	0.161	0.298
20	21.50	13.50	17.500	0.137	0.435
21	16.50	14.00	15.250	0.101	0.536
22	24.50	12.00	18.250	0.149	0.685
23	24.00	11.50	17.750	0.141	0.826
24	23.50	9.00	16.250	0.117	0.943
25	22.00	11.50	16.750	0.125	1.068
26	24.00	12.00	18.000	0.145	1.213
27	25.50	13.00	19.250	0.165	1.378
28	23.50	12.50	18.000	0.145	1.523
29	23.00	12.50	17.750	0.141	1.664
30	23.00	11.50	17.250	0.133	1.797
31*	22.50	11.50	17.00	0.129	1.926

Harvest interval as dictated by leaf appearance interval (Phyllochron) Month: November

Day	Maximum temperature	Minimum temperature	Mean temperature	Phyllochron measurement	Cumulative phyllochron
				Brought forward:	0.000
1	23.50	12.00	17.750	0.141	0.141
2	23.50	11.50	17.500	0.137	0.278
3	24.50	11.50	18.000	0.145	0.423
4	24.00	12.50	18.250	0.149	0.572
5	24.00	12.00	18.000	0.145	0.717
6	24.50	12.00	18.250	0.149	0.866
7	26.00	13.00	19.500	0.169	1.035
8	27.00	12.00	19.500	0.169	1.204
9	25.00	13.50	19.250	0.165	1.369
10	24.00	11.00	17.500	0.137	1.506
11	24.00	13.50	18.750	0.157	1.663
12	21.50	12.50	17.000	0.129	1.792
13	25.00	12.00	18.500	0.153	1.945
14*	25.00	13.00	19.000	0.161	2.106
15	25.00	9.50	17.250	0.133	0.133
16	23.00	12.00	17.500	0.137	0.270
17	26.50	13.50	20.000	0.177	0.447
18	24.50	13.00	18.750	0.157	0.604
19	24.50	13.00	18.750	0.157	0.761
20	24.00	13.50	18.750	0.157	0.918
21	23.50	13.50	18.500	0.153	1.071
22	23.00	13.00	18.000	0.145	1.216
23	26.00	13.00	19.500	0.169	1.385
24	24.50	13.00	18.750	0.157	1.542
25	25.00	13.00	19.000	0.161	1.703
26	24.50	13.50	19.000	0.161	1.864
27*	27.00	13.50	20.250	0.181	2.045
28	26.50	14.50	20.500	0.185	0.185
29	24.00	13.50	18.750	0.157	0.342
30	26.00	12.50	19.250	0.165	0.507

Appendix 4a: Observed irrigation frequencies (IFs) in days for the six irrigation application levels

Interval number	Irrigation application level					
	1(0.25ETc)	2(0.50ETc)	3(0.75ETc)	4(1.00ETc)	5(0.25ETc)	6(1.00ETc)
1	2	2	2	2	2	2
2	2	2	2	2	2	2
3	2	2	2	2	2	2
4	3	5	2	3	2	3
5	6	4	4	6	5	6
6	2	1	5	2	4	2
7	6	3	2	3	2	3
8	3	2	3	2	3	2
9	2	6	2	6	2	6
10	3	3	6	3	6	3
11	2	2	3	2	3	2
12	3	3	2	3	2	3
13	2	2	3	2	3	2
14	3	2	2	3	2	5
15	2	2	2	2	3	2
16	3	4	2	3	2	1
17	2	1	4	2	3	4
18	3	3	1	3	2	3
19	2	2	3	2	3	2
20	3	3	2	3	2	3
21	2	2	3	2	3	2
22	3	3	2	3	2	3
23	2	2	3	2	3	2
24	3	4	2	3	2	3
25	2	2	3	1	3	2
26	3	3	2	3	2	3
27	2	2	3	2	3	2
28	3	3	2	3	2	3
29	2	2	3	2	3	2
30	3	3	2	3	2	3
31	2	2	3	2	3	2
32	3	3	2	3	2	3
33	2	2	3	2	3	2
34	3	3	2	3	2	3
35	2	2	3	2	3	2
33	3	3	2	3	2	3
37	2	2	3	2	3	2
38	3	3	2	3	2	3
39	2	4	4	2	3	2
40	3	1	1	3	2	3
50	2	2	2	2	2	2
51	3	-	-	3	-	2

Appendix 4b: Drip irrigation schedule for Kibena Tea Estate
July

Met data			Irrigation level											
			1		2		3		4		5		6	
Day	Rainfall	Epan	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)
1	0	2.00	2.00	2.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	9.0
2	0	2.00	2.00	0.0	2.00	4.0	2.00	0.0	2.00	9.0	2.00	0.0	2.00	0.0
3	0	2.00	2.00	0.0	2.00	0.0	2.00	7.0	2.00	0.0	2.00	2.0	2.00	0.0
4	0	2.00	2.00	1.6	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	6.3
5	0	2.50	2.50	0.0	2.50	3.2	2.50	0.0	2.50	6.3	2.50	0.0	2.50	0.0
6	0	3.00	3.00	0.0	3.00	0.0	3.00	5.1	3.00	0.0	3.00	1.7	3.00	0.0
7	0	2.50	2.50	2.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	7.9
8	0	2.50	2.50	0.0	2.50	4.2	2.50	0.0	2.50	8.4	2.50	0.0	2.50	0.0
9	0	2.50	2.50	0.0	2.50	0.0	2.50	6.3	2.50	0.0	2.50	2.1	2.50	0.0
10	0	2.50	2.50	2.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	7.9
11	0	2.00	2.00	0.0	2.00	3.9	2.00	0.0	2.00	7.9	2.00	0.0	2.00	0.0
12	0	2.50	2.50	0.0	2.50	0.0	2.50	5.5	2.50	0.0	2.50	1.8	2.50	0.0
13	0	2.50	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0
14	0	3.00	3.00	2.5	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	10.0
15	0	3.00	3.00	0.0	3.00	0.0	3.00	0.0	3.00	10.5	3.00	0.0	3.00	0.0
16	0	2.00	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0
17	0	2.50	2.50	0.0	2.50	7.9	2.50	10.3	2.50	0.0	2.50	0.0	2.50	0.0
18	0	2.00	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	4.1	2.00	0.0
19	0	2.50	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0
20	0	2.50	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0
21	0	2.00	2.00	4.6	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	18.4
22	0	3.00	3.00	0.0	3.00	6.1	3.00	0.0	3.00	17.4	3.00	0.0	3.00	0.0
23	0	3.00	3.00	0.0	3.00	0.0	3.00	11.4	3.00	0.0	3.00	3.2	3.00	0.0
24	0	3.00	3.00	2.1	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	8.4
25	0	2.50	2.50	0.0	2.50	4.7	2.50	0.0	2.50	9.5	2.50	0.0	2.50	0.0
26	0	2.50	2.50	0.0	2.50	0.0	2.50	6.7	2.50	0.0	2.50	2.2	2.50	0.0
27	0	3.00	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0
28	0	2.50	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	11.6
29	0	3.00	3.00	0.0	3.00	5.5	3.00	0.0	3.00	11.1	3.00	0.0	3.00	0.0
30	0	3.50	3.50	0.0	3.50	0.0	3.50	8.7	3.50	0.0	3.50	2.9	3.50	0.0
31	0	4.00	4.00	5.3	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	9.5

NB: I_g was based on proportion of accumulated ET_c

August

Met data			Irrigation level											
			1		2		3		4		5		6	
Day	Rainfall	Epan	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)
1	0	3.50	3.50	0.0	3.50	5.5	3.50	0.0	3.50	11.1	3.50	0.0	3.50	0.0
2	0	3.50	3.50	0.0	3.50	0.0	3.50	8.7	3.50	0.0	3.50	2.9	3.50	0.0
3	0	3.50	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0
4	0	3.50	3.50	3.8	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0
5	0	3.00	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0
6	0	3.00	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0
7	0	3.00	3.00	2.5	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	25.3
8	0	2.50	2.50	0.0	2.50	12.1	2.50	0.0	2.50	24.2	2.50	0.0	2.50	0.0
9	0	3.00	3.00	0.0	3.00	0.0	3.00	17.4	3.00	0.0	3.00	5.8	3.00	0.0
10	0	2.50	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0
11	0	2.50	2.50	2.9	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	11.6
12	0	3.00	3.00	0.0	3.00	5.5	3.00	0.0	3.00	11.1	3.00	0.0	3.00	0.0
13	0	3.00	3.00	0.0	3.00	0.0	3.00	8.7	3.00	0.0	3.00	2.9	3.00	0.0
14	0	3.00	3.00	2.2	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	8.9
15	0	3.50	3.50	0.0	3.50	4.7	3.50	0.0	3.50	9.5	3.50	0.0	3.50	0.0
16	0	4.00	4.00	0.0	4.00	0.0	4.00	7.5	4.00	0.0	4.00	2.5	4.00	0.0
17	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0
18	0	3.50	3.50	3.8	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	15.3
19	0	3.50	3.50	0.0	3.50	7.9	3.50	0.0	3.50	15.8	3.50	0.0	3.50	0.0
20	0	3.00	3.00	0.0	3.00	0.0	3.00	11.8	3.00	0.0	3.00	3.9	3.00	0.0
21	0	0.50	0.50	2.6	0.50	0.0	0.50	0.0	0.50	0.0	0.50	0.0	0.50	10.5
22	0	2.00	2.00	0.0	2.00	3.7	2.00	0.0	2.00	7.4	2.00	0.0	2.00	0.0
23	0	2.50	2.50	0.0	2.50	0.0	2.50	4.3	2.50	0.0	2.50	1.4	2.50	0.0
24	0	3.00	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0
25	0	3.00	3.00	2.1	3.00	3.9	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0
26	0	3.50	3.50	0.0	3.50	0.0	3.50	6.7	3.50	11.1	3.50	0.0	3.50	0.0
27	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	3.2	4.00	15.3
28	0	3.50	3.50	2.8	3.50	5.5	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0
29	0	3.50	3.50	0.0	3.50	0.0	3.50	8.7	3.50	11.6	3.50	0.0	3.50	0.0
30	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	2.9	4.00	11.6
31	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0

NB: I_g was based on proportion of accumulated ET_c

September

			Irrigation level											
			1		2		3		4		5		6	
Day	Rainfall	Epan	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)
1	0	4.00	4.00	3.9	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	8.4
2	0	2.00	2.00	0.0	2.00	10.0	2.00	0.0	2.00	16.3	2.00	0.0	2.00	0.0
3	0	1.50	1.50	0.0	1.50	0.0	1.50	13.8	1.50	0.0	1.50	3.7	1.50	0.0
4	0	1.00	1.00	2.0	1.00	1.8	1.00	0.0	1.00	0.0	1.00	0.0	1.00	0.0
5	0	3.00	3.00	0.0	3.00	0.0	3.00	2.0	3.00	4.7	3.00	0.0	3.00	0.0
6	0	3.50	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	1.4	3.50	12.1
7	0	3.00	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0
8	0	3.50	3.50	2.8	3.50	5.5	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0
9	0	4.50	4.50	0.0	4.50	0.0	4.50	10.3	4.50	13.7	4.50	0.0	4.50	0.0
10	0	3.50	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	3.8	3.50	15.3
11	0	3.50	3.50	3.0	3.50	6.1	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0
12	0	3.00	3.00	0.0	3.00	0.0	3.00	9.1	3.00	12.1	3.00	0.0	3.00	0.0
13	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	2.6	4.00	10.5
14	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0
15	0	4.00	4.00	3.8	4.00	7.6	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0
16	0	3.00	3.00	0.0	3.00	0.0	3.00	11.8	3.00	15.8	3.00	0.0	3.00	0.0
17	0	2.00	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	3.9	2.00	15.8
18	0	1.50	1.50	2.4	1.50	4.7	1.50	0.0	1.50	0.0	1.50	0.0	1.50	0.0
19	0	2.00	2.00	0.0	2.00	0.0	2.00	5.1	2.00	6.8	2.00	0.0	2.00	0.0
20	0	2.00	2.00	0.0	2.00	0.0	2.00	0.0	2.00	0.0	2.00	1.4	2.00	5.8
21	0	3.50	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0
22	0	3.00	3.00	2.4	3.00	4.7	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0
23	0	4.00	4.00	0.0	4.00	0.0	4.00	8.3	4.00	11.1	4.00	0.0	4.00	0.0
24	0	3.50	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	3.3	3.50	13.2
25	0	4.00	4.00	2.8	4.00	5.5	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0
26	0	4.00	4.00	0.0	4.00	0.0	4.00	9.1	4.00	12.1	4.00	0.0	4.00	0.0
27	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	3.0	4.00	12.1
28	0	2.50	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0	2.50	0.0
29	0	3.50	3.50	3.8	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0
30	0	2.50	2.50	0.0	2.50	9.5	2.50	11.1	2.50	14.7	2.50	0.0	2.50	0.0

NB: I_g was based on proportion of accumulated ET_c

October

	Met data		Irrigation level											
			1		2		3		4		5		6	
Day	Rainfall	Epan	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)
1	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	3.3	4.00	13.2
2	0	3.50	3.50	2.6	3.50	0.0	3.50	0.0	3.50	6.8	3.50	0.0	3.50	0.0
3	0	3.00	3.00	0.0	3.00	5.3	3.00	7.9	3.00	0.0	3.00	0.0	3.00	0.0
4	0	3.50	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	2.8	3.50	11.1
5	0	3.00	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0	3.00	0.0
6	0	3.00	3.00	3.4	3.00	0.0	3.00	0.0	3.00	13.7	3.00	0.0	3.00	0.0
7	0	4.00	4.00	0.0	4.00	6.6	4.00	9.9	4.00	0.0	4.00	0.0	4.00	0.0
8	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	3.6	5.00	14.2
9	0	6.00	6.00	3.2	6.00	0.0	6.00	0.0	6.00	12.6	6.00	0.0	6.00	0.0
10	0	5.50	5.50	0.0	5.50	7.9	5.50	11.8	5.50	0.0	5.50	0.0	5.50	0.0
11	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	4.3	5.00	17.4
12	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0
13	0	4.50	4.50	5.7	4.50	0.0	4.50	0.0	4.50	22.6	4.50	0.0	4.50	0.0
14	0	4.50	4.50	0.0	4.50	10.5	4.50	15.8	4.50	0.0	4.50	0.0	4.50	0.0
15	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	5.0	4.00	20.0
16	0	3.50	3.50	3.4	3.50	0.0	3.50	0.0	3.50	13.7	3.50	0.0	3.50	0.0
17	0	2.50	2.50	0.0	2.50	6.3	2.50	9.5	2.50	0.0	2.50	0.0	2.50	0.0
18	0	1.90	1.90	0.0	1.90	0.0	1.90	0.0	1.90	0.0	1.90	2.6	1.90	10.5
19	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0
20	0	3.00	3.00	3.1	3.00	0.0	3.00	0.0	3.00	12.5	3.00	0.0	3.00	0.0
21	0	5.00	5.00	0.0	5.00	6.0	5.00	9.0	5.00	0.0	5.00	0.0	5.00	0.0
22	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	3.7	5.00	14.6
23	0	5.00	5.00	3.4	5.00	0.0	5.00	0.0	5.00	13.7	5.00	0.0	5.00	0.0
24	0	4.50	4.50	0.0	4.50	7.9	4.50	11.8	4.50	0.0	4.50	0.0	4.50	0.0
25	0	4.50	4.50	0.0	4.50	0.0	4.50	0.0	4.50	0.0	4.50	3.8	4.50	15.3
26	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0
27	0	4.00	4.00	5.0	4.00	0.0	4.00	0.0	4.00	20.0	4.00	0.0	4.00	0.0
28	0	5.00	5.00	0.0	5.00	9.5	5.00	14.2	5.00	0.0	5.00	0.0	5.00	0.0
29	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	4.9	5.00	19.5
30	0	4.50	4.50	3.7	4.50	0.0	4.50	0.0	4.50	14.7	4.50	0.0	4.50	0.0
31	0	4.00	4.00	0.0	4.00	7.6	4.00	11.4	4.00	0.0	4.00	0.0	4.00	0.0

NB: I_g was based on proportion of accumulated ET_c

November

Met data			Irrigation level											
			1		2		3		4		5		6	
Day	Rainfall	Epan	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)	ET_c (mm)	I_g (mm)
1	0	3.50	3.50	0.0	3.50	0.0	3.50	0.0	3.50	0.0	3.50	3.6	3.50	14.2
2	0	4.50	4.50	0.0	4.50	0.0	4.50	0.0	4.50	0.0	4.50	0.0	4.50	0.0
3	0	4.50	4.50	4.3	4.50	0.0	4.50	0.0	4.50	17.4	4.50	0.0	4.50	0.0
4	0	4.50	4.50	0.0	4.50	8.7	4.50	13.0	4.50	0.0	4.50	0.0	4.50	0.0
5	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	4.5	4.00	17.9
6	0	4.50	4.50	3.4	4.50	0.0	4.50	0.0	4.50	13.7	4.50	0.0	4.50	0.0
7	0	6.50	6.50	0.0	6.50	6.8	6.50	10.3	6.50	0.0	6.50	0.0	6.50	0.0
8	0	6.00	6.00	0.0	6.00	0.0	6.00	0.0	6.00	0.0	6.00	3.9	6.00	15.8
9	0	4.00	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0	4.00	0.0
10	0	4.00	4.00	5.5	4.00	0.0	4.00	0.0	4.00	22.1	4.00	0.0	4.00	0.0
11	0	5.00	5.00	0.0	5.00	10.8	5.00	16.2	5.00	0.0	5.00	0.0	5.00	0.0
12	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	5.0	5.00	20.0
13	0	6.50	6.50	3.7	6.50	0.0	6.50	0.0	6.50	14.7	6.50	0.0	6.50	0.0
14	0	4.50	4.50	0.0	4.50	8.7	4.50	13.0	4.50	0.0	4.50	0.0	4.50	0.0
15	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	4.2	5.00	16.8
16	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0
17	0	5.50	5.50	5.5	5.50	0.0	5.50	0.0	5.50	22.1	5.50	0.0	5.50	0.0
18	0	4.50	4.50	0.0	4.50	10.5	4.50	15.8	4.50	0.0	4.50	0.0	4.50	0.0
19	0	4.50	4.50	0.0	4.50	0.0	4.50	0.0	4.50	0.0	4.50	5.3	4.50	21.1
20	0	6.00	6.00	3.8	6.00	0.0	6.00	0.0	6.00	15.3	6.00	0.0	6.00	0.0
21	0	6.00	6.00	0.0	6.00	7.9	6.00	11.8	6.00	0.0	6.00	0.0	6.00	0.0
22	0	5.50	5.50	0.0	5.50	0.0	5.50	0.0	5.50	0.0	5.50	4.3	5.50	17.4
23	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0
24	0	4.50	4.50	5.9	4.50	0.0	4.50	0.0	4.50	23.7	4.50	0.0	4.50	0.0
25	0	3.20	3.20	0.0	3.20	0.0	3.20	0.0	3.20	0.0	3.20	0.0	3.20	0.0
26	0	4.00	4.00	0.0	4.00	12.7	4.00	19.1	4.00	0.0	4.00	4.8	4.00	19.2
27	0	3.50	3.50	3.1	3.50	0.0	3.50	0.0	3.50	12.3	3.50	0.0	3.50	0.0
28	0	3.50	3.50	0.0	3.50	3.9	3.50	5.9	3.50	0.0	3.50	0.0	3.50	0.0
29	0	5.00	5.00	0.0	5.00	0.0	5.00	0.0	5.00	0.0	5.00	2.9	5.00	11.6
30	0	4.60	4.60	0.0	4.60	0.0	4.60	0.0	4.60	0.0	4.60	0.0	4.60	0.0

NB: I_g was based on proportion of accumulated ET_c

Appendix 5: Daily Meteorological data for Kibena Tea Estates (2003)

MONTH	DATE	Dry Bulb	Wet Bulb	Max. Temp.	Min. Temp.	Wind km/day	Rad. cm2	E pan mm
July	1	13.00	12.00	14.00	10.00	148.69	6.50	2.00
	2	13.00	12.50	15.50	9.50	153.29	9.50	2.00
	3	13.00	12.00	16.50	10.00	205.22	11.90	2.00
	4	13.50	12.50	17.00	10.00	189.44	12.00	2.00
	5	12.00	10.50	17.50	8.50	230.35	13.50	2.50
	6	10.00	9.00	16.00	8.00	236.07	14.80	3.00
	7	9.50	9.00	14.50	8.50	174.32	12.50	2.50
	8	9.00	8.50	14.50	5.50	172.34	8.50	2.50
	9	9.50	8.50	14.00	5.50	142.00	12.00	2.50
	10	13.00	12.00	17.50	6.00	177.74	18.00	2.50
	11	12.00	11.00	17.50	8.00	130.61	17.50	2.00
	12	12.00	11.00	16.00	6.00	146.71	11.90	2.50
	13	11.00	9.50	17.00	6.00	154.78	13.20	2.50
	14	9.50	9.00	16.50	5.50	165.98	16.00	3.00
	15	11.00	9.50	16.50	5.00	163.90	14.50	3.00
	16	11.00	9.50	16.50	5.00	158.95	17.50	2.00
	17	10.50	8.50	16.00	5.00	176.82	16.50	2.50
	18	10.50	10.00	17.50	7.00	151.38	15.80	2.00
	19	13.00	11.50	18.50	6.50	152.18	14.60	2.50
	20	13.50	12.50	20.00	8.00	182.54	19.20	2.50
	21	13.50	12.00	20.50	9.00	195.99	15.80	2.00
	22	13.50	11.50	15.50	8.00	212.53	11.40	3.00
	23	14.00	12.00	21.00	8.50	220.26	18.50	3.00
	24	14.00	12.50	17.00	8.00	175.15	14.50	3.00
	25	13.00	12.00	19.00	6.50	151.93	19.10	2.50
	26	13.00	11.50	17.50	5.50	134.77	18.60	2.50
	27	12.50	10.50	17.50	6.00	162.69	11.90	3.00
	28	11.50	10.50	19.00	7.00	161.33	19.70	2.50
	29	10.50	10.00	17.00	6.00	179.18	14.10	3.00
	30	11.00	9.00	20.00	6.50	231.32	19.60	3.50
	31	12.50	9.00	20.50	8.50	235.95	18.10	4.00

MONTH	DATE	Dry Bulb	Wet Bulb	Max. Temp.	Min. Temp.	Wind km/day	Rad. cm2	E pan mm
August	1	12.50	8.00	17.50	8.00	155.80	18.90	3.50
	2	11.50	8.50	17.50	3.50	149.49	19.80	3.50
	3	11.50	9.00	19.50	5.00	184.86	20.00	3.50
	4	11.50	9.00	19.50	5.00	186.18	19.80	3.50
	5	10.00	8.50	17.50	6.00	199.02	19.30	3.00
	6	12.50	9.00	14.00	6.50	206.28	11.30	3.00
	7	11.50	8.50	16.50	5.50	173.52	18.10	3.00
	8	12.50	11.00	19.00	7.50	163.77	18.30	2.50
	9	12.50	11.50	19.50	8.50	141.06	16.70	3.00
	10	10.50	10.50	21.50	8.50	161.24	16.60	2.50
	11	12.00	11.50	19.50	10.50	178.47	14.00	2.50
	12	11.00	11.00	20.00	9.50	154.03	14.50	3.00
	13	11.50	11.00	20.50	8.00	169.56	18.50	3.00
	14	14.50	12.00	22.50	8.50	156.01	19.20	3.00
	15	15.00	12.50	24.00	6.00	210.26	20.60	3.50
	16	14.50	10.50	23.50	8.00	178.83	19.10	4.00
	17	14.00	10.50	21.50	5.50	144.23	18.10	4.00
	18	14.00	10.50	22.50	5.50	178.95	21.20	3.50
	19	11.00	10.50	22.50	7.50	161.03	18.80	3.50
	20	10.50	10.00	20.50	8.50	163.03	16.00	3.00
	21	13.50	13.00	18.00	9.50	211.50	14.00	0.50
	22	10.50	10.50	20.00	9.50	126.48	15.10	2.00
	23	11.00	10.50	16.00	8.50	178.68	8.50	2.50
	24	13.50	11.50	19.00	8.50	137.27	13.00	3.00
	25	14.50	12.00	21.50	8.50	148.15	19.00	3.00
	26	11.50	11.00	23.50	7.00	158.06	19.80	3.50
	27	16.50	13.00	24.00	10.00	215.43	17.60	4.00
	28	13.00	11.00	24.00	8.00	177.78	19.50	3.50
	29	14.00	11.50	20.50	8.50	171.59	18.50	3.50
	30	10.50	10.00	20.50	6.50	177.01	18.20	4.00
	31	12.00	10.50	23.00	6.50	213.08	20.00	4.00

MONTH	DATE	Dry Bulb	Wet Bulb	Max. Temp.	Min. Temp.	Wind km/day	Rad. cm2	E pan mm
September	1	13.00	11.50	20.50	9.00	214.71	18.20	4.00
	2	12.00	11.50	19.50	9.50	230.97	16.20	2.00
	3	10.50	10.00	19.50	8.50	189.06	8.20	1.50
	4	11.00	11.00	15.00	10.00	148.04	6.40	1.00
	5	13.50	12.50	14.50	9.50	163.04	5.20	3.00
	6	14.50	12.50	20.50	10.50	209.38	13.10	3.50
	7	15.00	13.00	23.50	10.50	217.41	17.80	3.00
	8	13.50	12.00	20.50	10.50	198.49	17.50	3.50
	9	15.00	12.50	21.50	9.50	204.48	18.50	4.50
	10	12.00	11.00	21.50	9.50	164.47	20.10	3.50
	11	13.50	11.50	20.50	7.50	211.17	15.20	3.50
	12	11.00	11.00	21.50	9.00	175.98	18.50	3.00
	13	15.00	12.50	21.50	10.50	190.72	14.30	4.00
	14	13.50	12.50	24.00	11.00	248.46	18.80	4.00
	15	14.00	12.50	23.50	11.50	222.93	17.50	4.00
	16	14.00	11.50	20.00	9.50	209.79	10.60	3.00
	17	13.50	11.50	20.00	9.50	170.63	17.00	2.00
	18	14.50	13.00	18.00	10.50	240.18	10.50	1.50
	19	12.50	12.50	19.50	10.50	201.79	13.10	2.00
	20	12.50	12.50	19.50	10.50	186.72	11.50	2.00
	21	12.50	12.50	19.50	11.00	223.00	13.00	3.50
	22	14.00	13.00	19.00	11.00	208.50	16.00	3.00
	23	14.00	12.50	23.50	11.50	193.90	16.00	4.00
	24	15.50	13.00	21.00	10.50	218.36	15.20	3.50
	25	15.00	12.50	21.50	9.50	202.92	19.50	4.00
	26	14.00	12.50	22.50	10.00	207.49	20.00	4.00
	27	14.00	12.50	21.50	10.50	235.64	17.40	4.00
	28	12.50	11.50	22.00	10.00	208.67	18.20	2.50
	29	15.00	12.50	19.50	10.50	239.67	12.20	3.50
	30	17.50	17.00	21.50	10.50	9999	19.20	2.50

MONTH	DATE	Dry Bulb	Wet Bulb	Max. Temp.	Min. Temp.	Wind km/day	Rad. cm2	E pan mm
October	1	15.50	12.50	20.50	6.50	233.80	9999	4.00
	2	12.50	11,50	21.50	9.50	196.00	19.80	3.50
	3	14.00	12.50	20.50	10.00	195.00	14.80	3.00
	4	14.00	12.50	21.50	9.50	180.69	14.50	3.50
	5	13.00	12.50	21.50	10.00	191.19	16.60	3.00
	6	13.50	13.00	23.00	11.00	197.83	18.80	3.00
	7	14.50	13.50	21.50	12.00	228.60	18.20	4.00
	8	17.00	14.00	23.50	11.50	230.38	17.50	5.00
	9	18.00	13.00	24.00	9.50	270.91	22.50	6.00
	10	13.50	12.00	23.50	9.00	248.75	22.50	5.50
	11	14.00	12.50	22.50	9.00	197.33	17.20	5.00
	12	21.00	13.00	24.50	10.50	191.51	22.80	5.00
	13	19.00	14.00	25.00	11.00	205.81	23.50	4.50
	14	18.00	14.50	23.50	11.00	178.59	19.50	4.50
	15	16.00	14.50	26.00	11.50	165.36	21.60	4.00
	16	15.00	13.50	25.00	11.50	149.06	16.40	3.50
	17	17.50	15.00	26.00	12.50	125.67	17.60	2.50
	18	20.00	16.50	21.50	13.50	167.96	10.90	1.90
	19	14.50	13.50	26.00	12.00	235.71	15.00	4.00
	20	14.50	14.00	21.50	13.50	216.17	15.60	3.00
	21	16.50	14.00	21.00	11.50	250.24	11.00	5.00
	22	16.50	13.50	24.50	12.00	247.43	22.50	5.00
	23	15.50	13.00	24.00	11.50	205.18	21.00	5.00
	24	16.00	13.50	23.50	9.00	191.90	23.00	4.50
	25	16.00	14.00	22.00	11.50	198.41	19.50	4.50
	26	17.50	14.50	24.00	12.00	227.34	21.50	5.00
	27	16.50	14.00	25.50	13.00	234.85	20.50	4.00
	28	16.50	14.00	23.50	12.50	245.25	20.50	5.00
	29	16.00	14.00	23.00	12.50	230.11	19.50	5.00
	30	15.50	14.00	23.00	11.50	210.98	17.70	4.50
	31	15.00	13.50	22.50	11.50	202.04	17.00	4.00

MONTH	DATE	Dry Bulb	Wet Bulb	Max. Temp.	Min. Temp.	Wind km/day	Rad. cm2	E pan mm
November	1	19.00	15.00	23.50	12.00	187.81	18.00	3.50
	2	19.00	14.50	23.50	11.50	208.67	18.80	4.50
	3	17.50	15.00	24.50	11.50	212.00	19.60	4.50
	4	17.00	14.50	24.00	12.50	218.84	19.90	4.50
	5	18.50	15.50	24.00	12.00	174.84	17.50	4.00
	6	19.50	16.00	24.50	12.00	168.46	20.80	4.50
	7	18.50	15.50	26.00	13.00	247.47	19.40	6.50
	8	19.00	15.50	27.00	12.00	195.62	23.00	6.00
	9	19.00	15.50	25.00	13.50	252.38	21.00	4.00
	10	18.50	16.00	24.00	11.00	9999	14.50	4.00
	11	17.50	15.00	24.00	13.50	215.65	16.00	5.00
	12	16.00	14.00	21.50	12.50	192.15	19.50	5.00
	13	18.00	15.50	25.00	12.00	233.55	21.00	6.50
	14	18.50	15.00	25.50	13.00	190.24	20.20	4.50
	15	18.50	15.50	25.00	9.50	184.97	20.90	5.00
	16	19.00	16.00	26.50	13.50	210.95	21.00	5.00
	17	18.00	15.00	23.00	12.00	236.57	21.50	5.50
	18	17.00	15.00	24.50	13.00	222.43	17.00	4.50
	19	16.00	14.00	24.50	13.00	225.98	18.50	4.50
	20	15.50	13.50	24.00	13.00	235.07	17.80	6.00
	21	18.00	14.50	23.50	13.50	9999	20.00	6.00
	22	16.50	14.50	23.00	13.00	9999	20.90	5.50
	23	17.00	14.50	26.00	13.00	9999	21.50	5.00
	24	17.00	14.50	24.50	13.00	9999	19.20	4.50
	25	17.50	16.00	25.00	13.50	9999	16.70	3.20
	26	17.50	16.50	24.50	13.50	9999	14.90	4.00
	27	17.50	16.50	27.00	13.50	9999	19.60	3.50
	28	20.50	17.00	26.50	14.00	9999	17.50	9999
	29	19.00	16.50	24.00	13.50	9999	11.50	5.00
	30	19.50	16.50	26.00	12.50	9999	18.50	4.60

Appendix 6: Calculation Irrigation Frequency (IF)

Irrigation frequency treatment 1, 2, 3 and 4
Effective rooting depth = 1.0 m
Readily available soil moisture for clay loam soils = 70 mm/m at MAD equal to 50 %
(Burke and Parlevliet, 2005)
Net irrigation requirement = 4 mm

$$Net\ irrigation\ requirement\ per\ treee\ per\ day = \left(\frac{4}{1000}\right) \times S_p \times S_r$$

Where S_p = Plant spacing with rows
S_r = Row spacing

$$= 0.004 \times 0.6 \times 1.2$$
$$\cong 0.003\ m^3\ per\ tea\ bush$$

$$Area\ of\ soil\ wetted = root\ zone\ area \times WP$$
$$= (S_p \times S_r) \times WP$$
$$= (1.2 \times 0.6) \times 0.8$$
$$= 0.58\ m^2$$
$$\cong 0.60\ m^2$$

$$\text{Re}adily\ available\ soil\ moisture\ per\ tea\ bush = 70\ mm/m$$
$$= \left(\frac{70}{1000}\right) \times 0.60\ m^2$$
$$= 0.042\ m^3$$

Readily available moisture for drip system to be replenished by irrigation

$$= RAW\ per\ tea\ bush \times p$$

$p = 0.45 + 0.004(5 - ET_c)$ Where ET_c = 4 mm d^{-1} (Consumptive use rate)

$$p = 0.45 + 0.004(5 - 4)$$
$$= 0.454$$
$$\cong 0.5 \Rightarrow MAD = 50\ \%$$
$$= 0.042 \times 0.50$$
$$\cong 0.021\ m^3/\text{tea bush}$$

Irrigation frequency at peak demand (Sample calculation)

i. Treatment 1

$$\text{Re}plenishable\ vol.\ (m^3) = ET\ replenishment\ proportion \times replenishable\ RAW/tea\ bush$$
$$= 0.25 \times 0.021$$
$$\cong 0.0053$$

$$Irrigation\ Frequency,\ IF\ (days) = \frac{\text{Re}plenishable\ volume\ (m^3)}{Consumptive\ use\ rate\ (mm\ d^{-1})}$$

$$IF = \frac{0.0053}{0.003}$$
$$\cong 2\ days$$

ii. Treatment 6

Effective rooting depth = 1.0 m

Available soil moisture = 70 mm/m
Management allowable depletion (MAD) = 50 %
Net irrigation requirement = 4 mm

$$\text{Net irrigation requirement per tree} = \left(\frac{4}{1000}\right) \times S_p \times S_r$$

$$= 0.004 \times 0.6 \times 1.2$$

$$\cong 0.003\ m^3$$

$$\text{Area of soil wetted} = \text{root zone area} \times WP$$

$$= (S_p \times S_r) \times WP$$

$$= (0.6 \times 1.2) \times 0.45$$

$$\cong 0.32\ m^2$$

$$\text{Available soil moisture per tea bush} = 70\ mm/m$$

$$= \left(\frac{70}{1000}\right) \times 0.32$$

$$\cong 0.0224\ m^3$$

Readily available moisture for drip system to be replenished by irrigation

$$= 0.0224 \times 0.5$$

$$\cong 0.0112\ m^3/\text{tea bush}$$

Irrigation frequency:

$$IF = \frac{0.0112}{0.003}$$

$$= 4\ days$$

Appendix 7: Actual applied water depth and volumes

Irrigation application level 1

DAY	depth In (mm)	Cumm I (mm)	Vol (m^3) netplot	Cumm vol. netplot	Treatment Plot (ha)	Total trt area (ha)	Vol. (m^3)/ trt area	Cumm vol trtarea
01/07/03	2.0	2.0	0.14	0.14	0.0072	1.5	30.0	30.0
04/07/03	2.5	4.5	0.18	0.32	0.0072	1.5	37.5	67.5
07/07/03	5.0	9.5	0.36	0.68	0.0072	1.5	75.0	142.5
10/07/03	6.0	15.5	0.43	1.12	0.0072	1.5	90.0	232.5
14/07/03	17.0	32.5	1.22	2.34	0.0072	1.5	255.0	487.5
21/07/03	17.0	49.5	1.22	3.56	0.0072	1.5	255.0	742.5
24/07/03	14.5	64.0	1.04	4.61	0.0072	1.5	217.5	960.0
28/07/03	3.0	67.0	0.22	4.82	0.0072	1.5	45.0	1005.0
31/07/03	2.4	69.4	0.17	5.00	0.0072	1.5	36.0	1041.0
07/08/03	6.6	76.0	0.48	5.47	0.0072	1.5	99.0	1140.0
11/08/03	3.7	79.7	0.27	5.74	0.0072	1.5	55.5	1195.5
14/08/03	2.4	82.1	0.17	5.91	0.0072	1.5	36.0	1231.5
18/08/03	3.9	86.0	0.28	6.19	0.0072	1.5	58.5	1290.0
21/08/03	3.0	89.0	0.22	6.41	0.0072	1.5	45.0	1335.0
25/08/03	3.0	92.0	0.22	6.62	0.0072	1.5	45.0	1380.0
01/09/03	4.3	96.3	0.31	6.93	0.0072	1.5	64.5	1444.5
04/09/03	2.0	98.3	0.14	7.08	0.0072	1.5	30.0	1474.5
08/09/03	2.8	101.1	0.20	7.28	0.0072	1.5	42.0	1516.5
11/09/03	3.3	104.4	0.24	7.52	0.0072	1.5	49.5	1566.0
15/09/03	4.7	109.1	0.34	7.86	0.0072	1.5	70.5	1636.5
18/09/03	1.7	110.8	0.12	7.98	0.0072	1.5	25.5	1662.0
22/09/03	3.2	114.0	0.23	8.21	0.0072	1.5	48.0	1710.0
25/09/03	2.8	116.8	0.20	8.41	0.0072	1.5	42.0	1752.0
29/09/03	4.7	121.5	0.34	8.75	0.0072	1.5	70.5	1822.5
02/1003	2.8	124.3	0.20	8.95	0.0072	1.5	42.0	1864.5
06/10/03	4.3	128.6	0.31	9.26	0.0072	1.5	64.5	1929.0
09/10/03	3.2	131.8	0.23	9.49	0.0072	1.5	48.0	1977.0
13/10/03	5.5	137.3	0.40	9.89	0.0072	1.5	82.5	2059.5
16/10/03	4.6	141.9	0.33	10.22	0.0072	1.5	69.0	2128.5
20/10/03	3.8	145.7	0.27	10.49	0.0072	1.5	57.0	2185.5
23/10/03	3.7	149.4	0.27	10.76	0.0072	1.5	55.5	2241.0
27/10/03	4.9	154.3	0.35	11.11	0.0072	1.5	73.5	2314.5
30/10/03	4.0	158.3	0.29	11.40	0.0072	1.5	60.0	2374.5
03/11/03	5.1	163.4	0.37	11.76	0.0072	1.5	76.5	2451.0
06/11/03	3.7	167.1	0.27	12.03	0.0072	1.5	55.5	2506.5
10/11/03	5.8	172.9	0.42	12.45	0.0072	1.5	87.0	2593.5
13/11/03	3.7	176.6	0.27	12.72	0.0072	1.5	55.5	2649.0
17/11/03	5.4	182.0	0.39	13.10	0.0072	1.5	81.0	2730.0
20/11/03	3.8	185.8	0.27	13.38	0.0072	1.5	57.0	2787.0
24/11/03	5.3	191.1	0.38	13.76	0.0072	1.5	79.5	2866.5
27/11/03	2.9	194.0	0.21	13.97	0.0072	1.5	43.5	2910.0

Irrigation application level 2

DAY	depth d (mm)	Cumm d (mm)	Vol (m^3) netplot	Cumm vol. netplot	Treatment Plot (ha)	Total trt area (ha)	Vol. (m^3)/ trt area	Cumm vol trtarea
02/07/03	4.0	4.0	0.29	0.29	0.0072	1.5	60.0	60.0
05/07/03	5.0	9.0	0.36	0.65	0.0072	1.5	75.0	135.0
08/07/03	9.5	18.5	0.68	1.33	0.0072	1.5	142.5	277.5
11/07/03	11.0	29.5	0.79	2.12	0.0072	1.5	165.0	442.5
15/07/03	26.0	55.5	1.87	4.00	0.0072	1.5	390.0	832.5
22/07/03	20.0	75.5	1.44	5.44	0.0072	1.5	300.0	1132.5
25/07/03	14.5	90.0	1.04	6.48	0.0072	1.5	217.5	1350.0
29/07/03	5.5	95.5	0.40	6.88	0.0072	1.5	82.5	1432.5
01/08/03	5.5	101.0	0.40	7.27	0.0072	1.5	82.5	1515.0
08/08/03	13.0	114.0	0.94	8.21	0.0072	1.5	195.0	1710.0
12/08/03	6.6	120.6	0.48	8.68	0.0072	1.5	99.0	1809.0
15/08/03	5.0	125.6	0.36	9.04	0.0072	1.5	75.0	1884.0
19/08/03	7.9	133.5	0.57	9.61	0.0072	1.5	118.5	2002.5
22/08/03	4.7	138.2	0.34	9.95	0.0072	1.5	70.5	2073.0
25/08/03	7.9	146.1	0.57	10.52	0.0072	1.5	118.5	2191.5
02/09/03	12.2	158.3	0.88	11.40	0.0072	1.5	183.0	2374.5
04/09/03	4.0	162.3	0.29	11.69	0.0072	1.5	60.0	2434.5
08/09/03	5.5	167.8	0.40	12.08	0.0072	1.5	82.5	2517.0
11/09/03	6.6	174.4	0.48	12.56	0.0072	1.5	99.0	2616.0
15/09/03	9.5	183.9	0.68	13.24	0.0072	1.5	142.5	2758.5
18/09/03	3.4	187.3	0.24	13.49	0.0072	1.5	51.0	2809.5
22/09/03	6.3	193.6	0.45	13.94	0.0072	1.5	94.5	2904.0
25/09/03	11.5	205.1	0.83	14.77	0.0072	1.5	172.5	3076.5
30/09/03	5.8	210.9	0.42	15.18	0.0072	1.5	87.0	3163.5
03/10/03	8.9	219.8	0.64	15.83	0.0072	1.5	133.5	3297.0
07/10/03	6.6	226.4	0.48	16.30	0.0072	1.5	99.0	3396.0
10/10/03	11.6	238.0	0.84	17.14	0.0072	1.5	174.0	3570.0
14/10/03	8.7	246.7	0.63	17.76	0.0072	1.5	130.5	3700.5
17/10/03	6.9	253.6	0.50	18.26	0.0072	1.5	103.5	3804.0
21/10/03	8.2	261.8	0.59	18.85	0.0072	1.5	123.0	3927.0
24/10/03	10.0	271.8	0.72	19.57	0.0072	1.5	150.0	4077.0
28/10/03	7.9	279.7	0.57	20.14	0.0072	1.5	118.5	4195.5
31/10/03	10.0	289.7	0.72	20.86	0.0072	1.5	150.0	4345.5
04/11/03	7.9	297.6	0.57	21.43	0.0072	1.5	118.5	4464.0
07/01/03	11.3	308.9	0.81	22.24	0.0072	1.5	169.5	4633.5
11/11/03	7.1	316.0	0.51	22.75	0.0072	1.5	106.5	4740.0
14/11/03	10.8	326.8	0.78	23.53	0.0072	1.5	162.0	4902.0
18/11/03	7.9	334.7	0.57	24.10	0.0072	1.5	118.5	5020.5
21/11/03	11.4	346.1	0.82	24.92	0.0072	1.5	171.0	5191.5
25/11/03	4.5	350.6	0.32	25.24	0.0072	1.5	67.5	5259.0

Irrigation application level 3

DAY	depth d (mm)	Cumm d (mm)	Vol (m^3) netplot	Cumm vol. netplot	Treatment Plot (ha)	Total trt area (ha)	Vol. (m^3)/ trt area	Cumm vol trtarea
03/07/03	7.0	7.0	0.50	0.50	0.0072	1.5	105.0	105.0
06/07/03	7.5	14.5	0.54	1.04	0.0072	1.5	112.5	217.5
09/07/03	14.3	28.8	1.03	2.07	0.0072	1.5	213.8	431.3
12/07/03	17.0	45.8	1.22	3.29	0.0072	1.5	255.0	686.3
18/07/03	25.0	70.8	1.80	5.09	0.0072	1.5	375.0	1061.3
23/07/03	17.0	87.8	1.22	6.32	0.0072	1.5	255.0	1316.3
26/07/03	10.5	98.3	0.76	7.07	0.0072	1.5	157.5	1473.8
30/07/03	8.7	107.0	0.63	7.70	0.0072	1.5	130.5	1604.3
02/08/03	9.0	116.0	0.65	8.35	0.0072	1.5	135.0	1739.3
09/08/03	20.0	136.0	1.44	9.79	0.0072	1.5	300.0	2039.3
13/08/03	9.5	145.5	0.68	10.47	0.0072	1.5	142.5	2181.8
16/08/03	7.9	153.4	0.57	11.04	0.0072	1.5	118.5	2300.3
20/08/03	12.0	165.4	0.86	11.91	0.0072	1.5	180.0	2480.3
23/08/03	6.3	171.7	0.45	12.36	0.0072	1.5	94.5	2574.8
26/08/03	7.9	179.6	0.57	12.93	0.0072	1.5	118.5	2693.3
03/09/03	3.6	183.2	0.26	13.19	0.0072	1.5	54.0	2747.3
05/09/03	4.0	187.2	0.29	13.47	0.0072	1.5	60.0	2807.3
09/09/03	10.7	197.9	0.77	14.25	0.0072	1.5	160.5	2967.8
12/09/03	9.9	207.8	0.71	14.96	0.0072	1.5	148.5	3116.3
16/09/03	11.0	218.8	0.79	15.75	0.0072	1.5	165.0	3281.3
19/09/03	6.0	224.8	0.43	16.18	0.0072	1.5	90.0	3371.3
23/09/03	11.0	235.8	0.79	16.97	0.0072	1.5	165.0	3536.3
26/09/03	13.3	249.1	0.96	17.93	0.0072	1.5	199.5	3735.8
30/09/03	8.7	257.8	0.63	18.56	0.0072	1.5	130.5	3866.3
03/10/03	13.4	271.2	0.96	19.52	0.0072	1.5	201.0	4067.3
07/10/03	9.9	281.1	0.71	20.24	0.0072	1.5	148.5	4215.8
10/10/03	17.4	298.5	1.25	21.49	0.0072	1.5	261.0	4476.8
14/10/03	13.0	311.5	0.94	22.42	0.0072	1.5	195.0	4671.8
17/10/03	10.3	321.8	0.74	23.17	0.0072	1.5	154.5	4826.3
21/10/03	12.2	334.0	0.88	24.04	0.0072	1.5	183.0	5009.3
24/10/03	15.0	349.0	1.08	25.12	0.0072	1.5	225.0	5234.3
28/10/03	11.8	360.8	0.85	25.97	0.0072	1.5	177.0	5411.3
31/10/03	15.0	375.8	1.08	27.05	0.0072	1.5	225.0	5636.3
04/11/03	11.8	387.6	0.85	27.90	0.0072	1.5	177.0	5813.3
07/11/03	16.9	404.5	1.22	29.12	0.0072	1.5	253.5	6066.8
11/11/03	10.7	415.2	0.77	29.89	0.0072	1.5	160.5	6227.3
14/11/03	16.1	431.3	1.16	31.05	0.0072	1.5	241.5	6468.8
18/11/03	11.8	443.1	0.85	31.90	0.0072	1.5	177.0	6645.8
21/11/03	17.5	460.6	1.26	33.16	0.0072	1.5	262.5	6908.3
25/11/03	6.7	467.3	0.48	33.64	0.0072	1.5	100.5	7008.8

Irrigation application level 4

DAY	depth d (mm)	Cumm d (mm)	Vol (m^3) netplot	Cumm vol. netplot	Treatment Plot (ha)	Total trt area (ha)	Vol. (m^3)/ trt area	Cumm vol trtarea
02/07/03	9.0	9.0	0.65	0.65	0.0072	1.5	135.0	135.0
05/07/03	10.0	19.0	0.72	1.37	0.0072	1.5	150.0	285.0
08/07/03	19.0	38.0	1.37	2.74	0.0072	1.5	285.0	570.0
11/07/03	22.5	60.5	1.62	4.36	0.0072	1.5	337.5	907.5
15/07/03	43.0	103.5	3.10	7.45	0.0072	1.5	645.0	1552.5
22/07/03	13.5	117.0	0.97	8.42	0.0072	1.5	202.5	1755.0
25/07/03	9.0	126.0	0.65	9.07	0.0072	1.5	135.0	1890.0
29/07/03	11.6	137.6	0.84	9.91	0.0072	1.5	174.0	2064.0
01/08/03	5.5	143.1	0.40	10.30	0.0072	1.5	82.5	2146.5
08/08/03	27.0	170.1	1.94	12.25	0.0072	1.5	405.0	2551.5
12/08/03	13.2	183.3	0.95	13.20	0.0072	1.5	198.0	2749.5
15/08/03	10.0	193.3	0.72	13.92	0.0072	1.5	150.0	2899.5
19/08/03	15.8	209.1	1.14	15.06	0.0072	1.5	237.0	3136.5
22/08/03	9.5	218.6	0.68	15.74	0.0072	1.5	142.5	3279.0
26/08/03	13.2	231.8	0.95	16.69	0.0072	1.5	198.0	3477.0
02/09/03	16.3	248.1	1.17	17.86	0.0072	1.5	244.5	3721.5
05/09/03	5.3	253.4	0.38	18.24	0.0072	1.5	79.5	3801.0
09/09/03	14.2	267.6	1.02	19.27	0.0072	1.5	213.0	4014.0
12/09/03	13.2	280.8	0.95	20.22	0.0072	1.5	198.0	4212.0
16/09/03	14.7	295.5	1.06	21.28	0.0072	1.5	220.5	4432.5
19/09/03	8.0	303.5	0.58	21.85	0.0072	1.5	120.0	4552.5
23/09/03	14.7	318.2	1.06	22.91	0.0072	1.5	220.5	4773.0
26/09/03	13.7	331.9	0.99	23.90	0.0072	1.5	205.5	4978.5
29/09/03	11.4	343.3	0.82	24.72	0.0072	1.5	171.0	5149.5
02/10/03	17.4	360.7	1.25	25.97	0.0072	1.5	261.0	5410.5
06/10/03	12.6	373.3	0.91	26.88	0.0072	1.5	189.0	5599.5
09/10/03	22.1	395.4	1.59	28.47	0.0072	1.5	331.5	5931.0
13/10/03	18.4	413.8	1.32	29.79	0.0072	1.5	276.0	6207.0
16/10/03	15.4	429.2	1.11	30.90	0.0072	1.5	231.0	6438.0
20/10/03	14.7	443.9	1.06	31.96	0.0072	1.5	220.5	6658.5
23/10/03	19.5	463.4	1.40	33.36	0.0072	1.5	292.5	6951.0
27/10/03	16.3	479.7	1.17	34.54	0.0072	1.5	244.5	7195.5
30/10/03	20.5	500.2	1.48	36.01	0.0072	1.5	307.5	7503.0
03/11/03	14.7	514.9	1.06	37.07	0.0072	1.5	220.5	7723.5
06/11/03	23.2	538.1	1.67	38.74	0.0072	1.5	348.0	8071.5
10/11/03	14.7	552.8	1.06	39.80	0.0072	1.5	220.5	8292.0
13/11/03	21.6	574.4	1.56	41.36	0.0072	1.5	324.0	8616.0
17/11/03	15.3	589.7	1.10	42.46	0.0072	1.5	229.5	8845.5
20/11/03	21.1	610.8	1.52	43.98	0.0072	1.5	316.5	9162.0
24/11/03	11.8	622.6	0.85	44.83	0.0072	1.5	177.0	9339.0

Irrigation application level 5

DAY	depth d (mm)	Cumm d (mm)	Vol (m^3) netplot	Cumm vol. netplot	Treatment Plot (ha)	Total trt area (ha)	Vol. (m^3)/ trt area	Cumm vol trtarea
03/07/03	2.0	2.0	0.14	0.14	0.0072	1.5	30.0	30.0
06/07/03	2.5	4.5	0.18	0.32	0.0072	1.5	37.5	67.5
09/07/03	5.0	9.5	0.36	0.68	0.0072	1.5	75.0	142.5
12/07/03	6.0	15.5	0.43	1.12	0.0072	1.5	90.0	232.5
18/07/03	19.0	34.5	1.37	2.48	0.0072	1.5	285.0	517.5
23/07/03	17.5	52.0	1.26	3.74	0.0072	1.5	262.5	780.0
26/07/03	15.4	67.4	1.11	4.85	0.0072	1.5	231.0	1011.0
30/07/03	2.9	70.3	0.21	5.06	0.0072	1.5	43.5	1054.5
02/08/03	3.0	73.3	0.22	5.28	0.0072	1.5	45.0	1099.5
09/08/03	6.6	79.9	0.48	5.75	0.0072	1.5	99.0	1198.5
13/08/03	3.2	83.1	0.23	5.98	0.0072	1.5	48.0	1246.5
16/08/03	2.6	85.7	0.19	6.17	0.0072	1.5	39.0	1285.5
20/08/03	3.9	89.6	0.28	6.45	0.0072	1.5	58.5	1344.0
23/08/03	2.1	91.7	0.15	6.60	0.0072	1.5	31.5	1375.5
27/08/03	3.4	95.1	0.24	6.85	0.0072	1.5	51.0	1426.5
03/09/03	14.2	109.3	1.02	7.87	0.0072	1.5	213.0	1639.5
06/09/03	1.3	110.6	0.09	7.96	0.0072	1.5	19.5	1659.0
10/09/03	4.1	114.7	0.30	8.26	0.0072	1.5	61.5	1720.5
13/09/03	5.0	119.7	0.36	8.62	0.0072	1.5	75.0	1795.5
17/09/03	2.0	121.7	0.14	8.76	0.0072	1.5	30.0	1825.5
20/09/03	1.4	123.1	0.10	8.86	0.0072	1.5	21.0	1846.5
24/09/03	3.8	126.9	0.27	9.14	0.0072	1.5	57.0	1903.5
27/09/03	4.0	130.9	0.29	9.42	0.0072	1.5	60.0	1963.5
01/10/03	3.0	133.9	0.22	9.64	0.0072	1.5	45.0	2008.5
04/10/03	4.3	138.2	0.31	9.95	0.0072	1.5	64.5	2073.0
08/10/03	4.0	142.2	0.29	10.24	0.0072	1.5	60.0	2133.0
11/10/03	5.8	148.0	0.42	10.66	0.0072	1.5	87.0	2220.0
15/10/03	3.8	151.8	0.27	10.93	0.0072	1.5	57.0	2277.0
18/10/03	3.8	155.6	0.27	11.20	0.0072	1.5	57.0	2334.0
22/10/03	3.8	159.4	0.27	11.48	0.0072	1.5	57.0	2391.0
25/10/03	5.1	164.5	0.37	11.84	0.0072	1.5	76.5	2467.5
29/10/03	4.0	168.5	0.29	12.13	0.0072	1.5	60.0	2527.5
01/11/03	4.9	173.4	0.35	12.48	0.0072	1.5	73.5	2601.0
05/11/03	3.9	177.3	0.28	12.77	0.0072	1.5	58.5	2659.5
08/11/03	5.8	183.1	0.42	13.18	0.0072	1.5	87.0	2746.5
12/11/03	3.8	186.9	0.27	13.46	0.0072	1.5	57.0	2803.5
15/11/03	5.2	192.1	0.37	13.83	0.0072	1.5	78.0	2881.5
19/11/03	4.1	196.2	0.30	14.13	0.0072	1.5	61.5	2943.0
22/11/03	4.4	200.6	0.32	14.44	0.0072	1.5	66.0	3009.0
26/11/03	3.2	203.8	0.23	14.67	0.0072	1.5	48.0	3057.0

Irrigation application level 6

DAY	depth d (mm)	Cumm d (mm)	Vol (m^3) netplot	Cumm vol. netplot	Treatment Plot (ha)	Total trt area (ha)	Vol. (m^3)/ trt area	Cumm vol trtarea
01/07/03	9.0	9.0	0.65	0.65	0.0072	1.5	135.0	135.0
04/07/03	19.5	28.5	1.40	2.05	0.0072	1.5	292.5	427.5
07/07/03	19.0	47.5	1.37	3.42	0.0072	1.5	285.0	712.5
10/07/03	22.5	70.0	1.62	5.04	0.0072	1.5	337.5	1050.0
14/07/03	66.5	136.5	4.79	9.83	0.0072	1.5	997.5	2047.5
21/07/03	14.0	150.5	1.01	10.84	0.0072	1.5	210.0	2257.5
24/07/03	8.5	159.0	0.61	11.45	0.0072	1.5	127.5	2385.0
28/07/03	11.5	170.5	0.83	12.28	0.0072	1.5	172.5	2557.5
31/07/03	9.5	180.0	0.68	12.96	0.0072	1.5	142.5	2700.0
07/08/03	26.0	206.0	1.87	14.83	0.0072	1.5	390.0	3090.0
11/08/03	14.7	220.7	1.06	15.89	0.0072	1.5	220.5	3310.5
14/08/03	9.5	230.2	0.68	16.57	0.0072	1.5	142.5	3453.0
18/08/03	15.7	245.9	1.13	17.70	0.0072	1.5	235.5	3688.5
21/08/03	11.0	256.9	0.79	18.50	0.0072	1.5	165.0	3853.5
25/08/03	18.9	275.8	1.36	19.86	0.0072	1.5	283.5	4137.0
01/09/03	8.7	284.5	0.63	20.48	0.0072	1.5	130.5	4267.5
04/09/03	1.3	285.8	0.09	20.58	0.0072	1.5	19.5	4287.0
08/09/03	16.3	302.1	1.17	21.75	0.0072	1.5	244.5	4531.5
11/09/03	20.0	322.1	1.44	23.19	0.0072	1.5	300.0	4831.5
15/09/03	7.9	330.0	0.57	23.76	0.0072	1.5	118.5	4950.0
18/09/03	5.8	335.8	0.42	24.18	0.0072	1.5	87.0	5037.0
22/09/03	15.2	351.0	1.09	25.27	0.0072	1.5	228.0	5265.0
25/09/03	16.1	367.1	1.16	26.43	0.0072	1.5	241.5	5506.5
29/09/03	12.1	379.2	0.87	27.30	0.0072	1.5	181.5	5688.0
02/1003	17.4	396.6	1.25	28.56	0.0072	1.5	261.0	5949.0
06/10/03	15.8	412.4	1.14	29.69	0.0072	1.5	237.0	6186.0
09/10/03	23.2	435.6	1.67	31.36	0.0072	1.5	348.0	6534.0
13/10/03	15.3	450.9	1.10	32.46	0.0072	1.5	229.5	6763.5
16/10/03	15.1	466.0	1.09	33.55	0.0072	1.5	226.5	6990.0
20/10/03	15.3	481.3	1.10	34.65	0.0072	1.5	229.5	7219.5
23/10/03	20.5	501.8	1.48	36.13	0.0072	1.5	307.5	7527.0
27/10/03	16.3	518.1	1.17	37.30	0.0072	1.5	244.5	7771.5
30/10/03	19.5	537.6	1.40	38.71	0.0072	1.5	292.5	8064.0
03/11/03	15.8	553.4	1.14	39.84	0.0072	1.5	237.0	8301.0
06/11/03	23.2	576.6	1.67	41.52	0.0072	1.5	348.0	8649.0
10/11/03	15.3	591.9	1.10	42.62	0.0072	1.5	229.5	8878.5
13/11/03	21.0	612.9	1.51	44.13	0.0072	1.5	315.0	9193.5
17/11/03	16.3	629.2	1.17	45.30	0.0072	1.5	244.5	9438.0
20/11/03	17.6	646.8	1.27	46.57	0.0072	1.5	264.0	9702.0
24/11/03	12.6	659.4	0.91	47.48	0.0072	1.5	189.0	9891.0

Appendix 8: Calculation of required seasonal water application volume for drip irrigation application levels

From Equation 10:

$$IR_n = (ET_c \times K_r) - R + LR$$

Where R = rainfall, LR = Leaching Requirement.

ET_c = 323.5mm, Kr = 0.95 Freeman and Garzoli (FAO, 1984), R = 0 and LR =0.

$$\Rightarrow IR_n = (ET_c \times K_r)$$

$$\Rightarrow IR_n = (323.5 \times 0.95)$$

$$= 307.33\ mm$$

Treatments 1 to 4 Sample calculation

Area wetted

$$AW = (S_p \times S_r) \times WP$$

Where: $(S_p \times S_r)$ = Rootzone area, S_p = Plant spacing, S_r = Row spacing

$$\Rightarrow AW = (0.6 \times 1.2) \times 0.8$$

$$\Rightarrow AW = 0.60\ m^2/tea\ bush \times 13\,888\ tea\ bushes/ha$$

$$\cong 8332.8\ m^2/ha$$

Required application volume (V) assuming 100 % ET_c replacement (Treatment 4)

$$V = 8332.8 \times \left(\frac{307.33}{1000}\right)$$

$$= 2561\ m^3\ ha^{-1}$$

Treatment 1

$$V = ET_c\ replenishment\ proportion \times 2561\ m^3$$

$$= 0.25 \times 2561$$

$$\cong 640\ m^3\ ha^{-1}$$

Treatment 5 and 6

Area wetted

$$AW = (0.6 \times 1.2) \times 0.45$$

$$\Rightarrow AW = 0.32\ m^2/tea\ bush \times 13\,888\ tea\ bushes/ha$$

$$= 4444.16\ m^2$$

Required volume (V) assuming 100 % ET_c replenishment (Treatment 6)

$$= 4444.16 \times \left(\frac{307.33}{1000}\right)$$

$$\cong 1366\ m^3\ ha^{-1}$$

Treatment 5

$$V = 0.25 \times 1366$$

$$\cong 342\ m^3\ ha^{-1}$$

Appendix 9: Evapotranspiration data (Penman Monteith reference evapotranspiration and evapotranspiration as computed at Kibena Tea Estate)

	Month									
	July		August		September		October		November	
Date	Penman ET_o	ET_o (Kibena)	Penman ET_o	ET_o (Kibena)	Penman ET_o	ET_o (Kibena)	Penman ET_o	ET_o (Kibena)	Penman ET_o	ET_o (Kibena)
1	0.28	2.00	1.80	3.50	0.61	4.00	0.76	4.00	2.16	3.50
2	0.28	2.00	0.92	3.50	1.82	2.00	2.12	3.50	2.19	4.50
3	0.37	2.00	1.09	3.50	1.09	1.50	1.12	3.00	2.62	4.50
4	0.25	2.00	1.26	3.50	1.03	1.00	1.26	3.50	2.51	4.50
5	0.25	2.50	1.66	3.00	1.03	3.00	2.07	3.00	2.09	4.00
6	0.50	3.00	0.18	3.00	0.46	3.50	2.19	3.00	2.50	4.50
7	0.80	2.50	0.71	3.00	2.23	3.00	1.17	4.00	2.20	6.50
8	0.80	2.50	1.84	2.50	1.41	3.50	1.48	5.00	3.27	6.00
9	0.57	2.50	1.93	3.00	1.62	4.50	2.12	6.00	2.48	4.00
10	0.41	2.50	1.78	2.50	2.21	3.50	1.89	5.50	1.64	4.00
11	1.58	2.00	1.07	2.50	0.44	3.50	1.29	5.00	2.45	5.00
12	0.36	2.50	1.13	3.00	1.38	3.00	2.76	5.00	1.77	5.00
13	0.17	2.50	0.95	3.00	1.24	4.00	2.86	4.50	2.26	6.50
14	0.56	3.00	1.24	3.00	1.98	4.00	2.42	4.50	2.86	4.50
15	0.30	3.00	1.50	3.50	2.43	4.00	2.86	4.00	2.10	5.00
16	0.82	2.00	1.92	4.00	0.79	3.00	1.98	3.50	2.93	5.00
17	0.65	2.50	0.76	4.00	2.13	2.00	2.98	2.50	2.09	5.50
18	0.93	2.00	1.39	3.50	0.62	1.50	1.33	1.90	2.37	4.50
19	1.19	2.50	1.28	3.50	1.29	2.00	1.81	4.00	2.47	4.50
20	1.48	2.50	0.97	3.00	1.32	2.00	2.29	3.00	2.13	6.00
21	1.48	2.00	0.32	0.50	1.12	3.50	0.35	5.00	2.72	6.00
22	1.49	3.00	2.06	2.00	1.12	3.00	2.67	5.00	2.26	5.50
23	1.72	3.00	0.17	2.50	2.36	4.00	2.36	5.00	3.23	5.00
24	0.36	3.00	1.18	3.00	1.40	3.50	2.46	4.50	2.46	4.50
25	1.28	2.50	1.55	3.00	1.73	4.00	2.13	4.50	2.11	3.20
26	1.48	2.50	1.19	3.50	2.05	4.00	2.90	5.00	1.20	4.00
27	0.28	3.00	1.75	4.00	1.58	4.00	2.80	4.00	2.73	3.50
28	1.86	2.50	1.52	3.50	1.71	2.50	2.48	5.00	3.87	3.50
29	1.87	3.00	1.55	3.50	0.53	3.50	2.25	5.00	1.26	5.00
30	0.29	3.50	0.70	4.00	2.62	2.50	2.02	4.50	2.43	4.60
31	1.67	4.00	1.52	4.00	-	-	1.52	4.00	-	-

Appendix 10: Monitored Soil water deficit for Irrigation application

Replenishment 1 (25% Evapotranspiration 1Lateral per 1 row) July

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
07/01/03	-47.5	-47.5	2.0	0.75	1.5	0.8	1.2	1.2	2.0	2.0
07/02/03	-48.7	-48.7	2.0	0.75	1.5	0.8	1.2	2.5	0.0	2.0
07/03/03	-49.9	-49.9	2.0	0.75	1.5	0.8	1.2	3.7	0.0	2.0
07/04/03	-48.6	-51.1	2.0	0.75	1.5	0.8	1.2	4.9	2.5	4.5
07/05/03	-49.8	-52.3	2.5	0.75	1.9	0.8	1.5	6.4	0.0	4.5
07/06/03	-51.3	-53.8	3.0	0.75	2.3	0.8	1.8	8.2	0.0	4.5
07/07/03	-48.1	-55.6	2.5	0.75	1.9	0.8	1.5	9.7	5.0	9.5
07/08/03	-49.6	-57.1	2.5	0.75	1.9	0.8	1.5	11.2	0.0	9.5
07/09/03	-51.1	-58.6	2.5	0.75	1.9	0.8	1.5	12.7	0.0	9.5
07/10/03	-46.6	-60.1	2.5	0.75	1.9	0.8	1.5	14.2	6.0	15.5
07/11/03	-48.1	-61.6	2.0	0.75	1.5	0.8	1.2	15.4	0.0	15.5
07/12/03	-49.3	-62.8	2.5	0.75	1.9	0.8	1.5	16.9	0.0	15.5
07/13/03	-50.8	-64.3	2.5	0.75	1.9	0.8	1.5	18.4	0.0	15.5
07/14/03	-35.3	-65.8	3.0	0.75	2.3	0.8	1.8	20.2	17.0	32.5
07/15/03	-37.1	-67.6	3.0	0.75	2.3	0.8	1.8	22.0	0.0	32.5
07/16/03	-38.9	-69.4	2.0	0.75	1.5	0.8	1.2	23.2	0.0	32.5
07/17/03	-40.1	-70.6	2.5	0.75	1.9	0.8	1.5	24.7	0.0	32.5
07/18/03	-41.6	-72.1	2.0	0.75	1.5	0.8	1.2	25.9	0.0	32.5
07/19/03	-42.8	-73.3	2.5	0.75	1.9	0.8	1.5	27.4	0.0	32.5
07/20/03	-44.3	-74.8	2.5	0.75	1.9	0.8	1.5	28.9	0.0	32.5
07/21/03	-28.8	-76.3	2.0	0.75	1.5	0.8	1.2	30.1	17.0	49.5
07/22/03	-30.0	-77.5	3.0	0.75	2.3	0.8	1.8	31.9	0.0	49.5
07/23/03	-31.8	-79.3	3.0	0.75	2.3	0.8	1.8	33.7	0.0	49.5
07/24/03	-19.1	-81.1	3.0	0.75	2.3	0.8	1.8	35.5	14.5	64.0
07/25/03	-20.9	-82.9	2.5	0.75	1.9	0.8	1.5	37.0	0.0	64.0
07/26/03	-22.4	-84.4	2.5	0.75	1.9	0.8	1.5	38.5	0.0	64.0
07/27/03	-23.9	-85.9	3.0	0.75	2.3	0.8	1.8	40.3	0.0	64.0
07/28/03	-22.7	-87.7	2.5	0.75	1.9	0.8	1.5	41.8	3.0	67.0
07/29/03	-24.2	-89.2	3.0	0.75	2.3	0.8	1.8	43.6	0.0	67.0
07/30/03	-26.0	-91.0	3.5	0.75	2.6	0.8	2.1	45.7	0.0	67.0
07/31/03	-25.7	-93.1	4.0	0.75	3.0	0.8	2.4	48.1	2.4	69.4

Replenishment 1 (25% Evapotranspiration 1 Lateral per 1 row) August

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
08/01/03	-25.7	-95.5	3.5	0.75	2.6	0.8	2.1	50.2	0.0	69.4
08/02/03	-27.8	-97.6	3.5	0.75	2.6	0.8	2.1	52.3	0.0	69.4
08/03/03	-29.9	-99.7	3.5	0.75	2.6	0.8	2.1	54.4	0.0	69.4
08/04/03	-32.0	-101.8	3.5	0.75	2.6	0.8	2.1	56.5	0.0	69.4
08/05/03	-34.1	-103.9	3.0	0.75	2.3	0.8	1.8	58.3	0.0	69.4
08/06/03	-35.9	-105.7	3.0	0.75	2.3	0.8	1.8	60.1	0.0	69.4
08/07/03	-37.7	-107.5	3.0	0.75	2.3	0.8	1.8	61.9	6.6	76.0
08/08/03	-32.9	-109.3	2.5	0.75	1.9	0.8	1.5	63.4	0.0	76.0
08/09/03	-34.4	-110.8	3.0	0.75	2.3	0.8	1.8	65.2	0.0	76.0
08/10/03	-36.2	-112.6	2.5	0.75	1.9	0.8	1.5	66.7	0.0	76.0
08/11/03	-37.7	-114.1	2.5	0.75	1.9	0.8	1.5	68.2	3.7	79.7
08/12/03	-35.5	-115.6	3.0	0.75	2.3	0.8	1.8	70.0	0.0	79.7
08/13/03	-37.3	.-117.4	3.0	0.75	2.3	0.8	1.8	71.8	0.0	79.7
08/14/03	-39.1	-119.2	3.0	0.75	2.3	0.8	1.8	73.6	2.4	82.1
08/15/03	-38.5	-121.0	3.5	0.75	2.6	0.8	2.1	75.7	0.0	82.1
08/16/03	-40.6	-123.1	4.0	0.75	3.0	0.8	2.4	78.1	0.0	82.1
08/17/03	-43.0	-125.5	4.0	0.75	3.0	0.8	2.4	80.5	0.0	82.1
08/18/03	-45.4	-127.9	3.5	0.75	2.6	0.8	2.1	82.6	3.9	86.0
08/19/03	-43.6	-130.0	3.5	0.75	2.6	0.8	2.1	84.7	0.0	86.0
08/20/03	-45.7	-132.1	3.0	0.75	2.3	0.8	1.8	86.5	0.0	86.0
08/21/03	-47.5	-133.9	0.5	0.75	0.4	0.8	0.3	86.8	3.0	89.0
08/22/03	-44.8	-134.2	2.0	0.75	1.5	0.8	1.2	88.0	0.0	89.0
08/23/03	-46.0	-135.4	2.5	0.75	1.9	0.8	1.5	89.5	0.0	89.0
08/24/03	-47.5	-136.9	3.0	0.75	2.3	0.8	1.8	91.3	0.0	89.0
08/25/03	-49.3	-138.7	3.0	0.75	2.3	0.8	1.8	93.1	3.0	92.0
08/26/03	-48.1	-140.5	3.5	0.75	2.6	0.8	2.1	95.2	0.0	92.0
08/27/03	-50.2	-142.6	4.0	0.75	3.0	0.8	2.4	97.6	0.0	92.0
08/28/03	-52.6	-145.0	3.5	0.75	2.6	0.8	2.1	99.7	0.0	92.0
08/29/03	-54.7	-147.1	3.5	0.75	2.6	0.8	2.1	101.8	0.0	92.0
08/30/03	-56.8	-149.2	4.0	0.75	3.0	0.8	2.4	104.2	0.0	92.0
08/31/03	-59.2	-151.6	4.0	0.75	3.0	0.8	2.4	106.6	0.0	92.0

Replenishment 1 (25% Evapotranspiration 1 Lateral per 1 row) September

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
09/01/03	-61.6	-154.0	4.0	0.75	3	0.8	2.4	109.0	4.3	96.3
09/02/03	-59.7	-156.4	2.0	0.75	1.5	0.8	1.2	110.2	0.0	96.3
09/03/03	-60.9	-157.6	1.5	0.75	1.1	0.8	0.9	111.1	0.0	96.3
09/04/03	-61.8	-158.5	1.0	0.75	0.8	0.8	0.6	111.7	2.0	98.3
09/05/03	-60.4	-159.1	3.0	0.75	2.3	0.8	1.8	113.5	0.0	98.3
09/06/03	-62.2	-160.9	3.5	0.75	2.6	0.8	2.1	115.6	0.0	98.3
09/07/03	-64.3	-163.0	3.0	0.75	2.3	0.8	1.8	117.4	0.0	98.3
09/08/03	-66.1	-164.8	3.5	0.75	2.6	0.8	2.1	119.5	2.8	101.1
09/09/03	-65.4	-166.9	4.5	0.75	3.4	0.8	2.7	122.2	0.0	101.1
09/10/03	-68.1	-169.6	3.5	0.75	2.6	0.8	2.1	124.3	0.0	101.1
09/11/03	-70.2	-171.7	3.5	0.75	2.6	0.8	2.1	126.4	3.3	104.4
09/12/03	-69.0	-173.8	3.0	0.75	2.3	0.8	1.8	128.2	0.0	104.4
09/13/03	-70.8	-175.6	4.0	0.75	3.0	0.8	2.4	130.6	0.0	104.4
09/14/03	-73.2	-178.0	4.0	0.75	3.0	0.8	2.4	133.0	0.0	104.4
09/15/03	-75.6	-180.4	4.0	0.75	3.0	0.8	2.4	135.4	4.7	109.1
09/16/03	-73.3	-182.8	3.0	0.75	2.3	0.8	1.8	137.2	0.0	109.1
09/17/03	-75.1	-184.6	2.0	0.75	1.5	0.8	1.2	138.4	0.0	109.1
09/18/03	-76.3	-185.8	1.5	0.75	1.1	0.8	0.9	139.3	1.7	110.8
09/19/03	-75.5	-186.7	2.0	0.75	1.5	0.8	1.2	140.5	0.0	110.8
09/20/03	-76.7	-187.9	2.0	0.75	1.5	0.8	1.2	141.7	0.0	110.8
09/21/03	-77.9	-189.1	3.5	0.75	2.6	0.8	2.1	143.8	0.0	110.8
09/22/03	-80.0	-191.2	3.0	0.75	2.3	0.8	1.8	145.6	3.2	114.0
09/23/03	-78.6	-193.0	4.0	0.75	3.0	0.8	2.4	148.0	0.0	114.0
09/24/03	-81.0	-195.4	3.5	0.75	2.6	0.8	2.1	150.1	0.0	114.0
09/25/03	-83.1	-197.5	4.0	0.75	3.0	0.8	2.4	152.5	2.8	116.8
09/26/03	-82.7	-199.9	4.0	0.75	3.0	0.8	2.4	154.9	0.0	116.8
09/27/03	-85.1	-202.3	4.0	0.75	3.0	0.8	2.4	157.3	0.0	116.8
09/28/03	-87.5	-204.7	2.5	0.75	1.9	0.8	1.5	158.8	0.0	116.8
09/29/03	-89.0	-206.2	3.5	0.75	2.6	0.8	2.1	160.9	4.7	121.5
09/30/03	-86.4	-208.3	2.5	0.75	1.9	0.8	1.5	162.4	0.0	121.5

Replenishment 1 (25% Evapotranspiration 1 Lateral per 1 row) October

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
10/01/03	-87.9	-209.8	4.0	0.75	3	0.8	2.4	164.8	0.0	121.5
10/02/03	-90.3	-212.2	3.5	0.75	2.6	0.8	2.1	166.9	2.8	124.3
10/03/03	-89.6	-214.3	3.0	0.75	2.3	0.8	1.8	168.7	0.0	124.3
10/04/03	-91.4	-216.1	3.5	0.75	2.6	0.8	2.1	170.8	0.0	124.3
10/05/03	-93.5	-218.2	3.0	0.75	2.3	0.8	1.8	172.6	0.0	124.3
10/06/03	-95.3	-220.0	3.0	0.75	2.3	0.8	1.8	174.4	4.3	128.6
10/07/03	-92.8	-221.8	4.0	0.75	3.0	0.8	2.4	176.8	0.0	128.6
10/08/03	-95.2	-224.2	5.0	0.75	3.8	0.8	3.0	179.8	0.0	128.6
10/09/03	-98.2	-227.2	6.0	0.75	4.5	0.8	3.6	183.4	3.2	131.8
10/10/03	-98.6	-230.8	5.5	0.75	4.1	0.8	3.3	186.7	0.0	131.8
10/11/03	-101.9	-234.1	5.0	0.75	3.8	0.8	3.0	189.7	0.0	131.8
10/12/03	-104.9	-237.1	5.0	0.75	3.8	0.8	3.0	192.7	0.0	131.8
10/13/03	-107.9	-240.1	4.5	0.75	3.4	0.8	2.7	195.4	5.5	137.3
10/14/03	-105.1	-242.8	4.5	0.75	3.4	0.8	2.7	198.1	0.0	137.3
10/15/03	-107.8	-245.5	4.0	0.75	3.0	0.8	2.4	200.5	0.0	137.3
10/16/03	-110.2	-247.9	3.5	0.75	2.6	0.8	2.1	202.6	4.6	141.9
10/17/03	-107.7	-250.0	2.5	0.75	1.9	0.8	1.5	204.1	0.0	141.9
10/18/03	-109.2	-251.5	1.9	0.75	1.4	0.8	1.1	205.2	0.0	141.9
10/19/03	-110.3	-252.6	4.0	0.75	3.0	0.8	2.4	207.6	0.0	141.9
10/20/03	-112.7	-255.0	3.0	0.75	2.3	0.8	1.8	209.4	3.8	145.7
10/21/03	-110.7	-256.8	5.0	0.75	3.8	0.8	3.0	212.4	0.0	145.7
10/22/03	-113.7	-259.8	5.0	0.75	3.8	0.8	3.0	215.4	0.0	145.7
10/23/03	-116.7	-262.8	5.0	0.75	3.8	0.8	3.0	218.4	3.7	149.4
10/24/03	-116.0	-265.8	4.5	0.75	3.4	0.8	2.7	221.1	0.0	149.4
10/25/03	-118.7	-268.5	4.5	0.75	3.4	0.8	2.7	223.8	0.0	149.4
10/26/03	-121.4	-271.2	5.0	0.75	3.8	0.8	3.0	226.8	0.0	149.4
10/27/03	-124.4	-274.2	4.0	0.75	3.0	0.8	2.4	229.2	4.9	154.3
10/28/03	-121.9	-276.6	5.0	0.75	3.8	0.8	3.0	232.2	0.0	154.3
10/29/03	-124.9	-279.6	5.0	0.75	3.8	0.8	3.0	235.2	0.0	154.3
10/30/03	-127.9	-282.6	4.5	0.75	3.4	0.8	2.7	237.9	4.0	158.3
10/31/03	-126.6	-285.3	4.0	0.75	3.0	0.8	2.4	240.3	0.0	158.3

Replenishment 1 (25% Evapotranspiration 1 Lateral per 1 row) November

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
11/01/03	-129.0	-287.7	3.5	0.75	2.625	0.8	2.1	242.4	0.0	158.3
11/02/03	-131.1	-289.8	4.5	0.75	3.4	0.8	2.7	245.1	0.0	158.3
11/03/03	-133.8	-292.5	4.5	0.75	3.4	0.8	2.7	247.8	5.1	163.4
11/04/03	-131.4	-295.2	4.5	0.75	3.4	0.8	2.7	250.5	0.0	163.4
11/05/03	-134.1	-297.9	4.0	0.75	3.0	0.8	2.4	252.9	0.0	163.4
11/06/03	-136.5	-300.3	4.5	0.75	3.4	0.8	2.7	255.6	3.7	167.1
11/07/03	-135.5	-303.0	6.5	0.75	4.9	0.8	3.9	259.5	0.0	167.1
11/08/03	-139.4	-306.9	6.0	0.75	4.5	0.8	3.6	263.1	0.0	167.1
11/09/03	-143.0	-310.5	4.0	0.75	3.0	0.8	2.4	265.5	0.0	167.1
11/10/03	-145.4	-312.9	4.0	0.75	3.0	0.8	2.4	267.9	5.8	172.9
11/11/03	-142.0	-315.3	5.0	0.75	3.8	0.8	3.0	270.9	0.0	172.9
11/12/03	-145.0	-318.3	5.0	0.75	3.8	0.8	3.0	273.9	0.0	172.9
11/13/03	-148.0	-321.3	6.5	0.75	4.9	0.8	3.9	277.8	3.7	176.6
11/14/03	-148.2	-325.2	4.5	0.75	3.4	0.8	2.7	280.5	0.0	176.6
11/15/03	-150.9	-327.9	5.0	0.75	3.8	0.8	3.0	283.5	0.0	176.6
11/16/03	-153.9	-330.9	5.0	0.75	3.8	0.8	3.0	286.5	0.0	176.6
11/17/03	-156.9	-333.9	5.5	0.75	4.1	0.8	3.3	289.8	5.4	182.0
11/18/03	-154.8	-337.2	4.5	0.75	3.4	0.8	2.7	292.5	0.0	182.0
11/19/03	-157.5	-339.9	4.5	0.75	3.4	0.8	2.7	295.2	0.0	182.0
11/20/03	-160.2	-342.6	6.0	0.75	4.5	0.8	3.6	298.8	3.8	185.8
11/21/03	-160.0	-346.2	6.0	0.75	4.5	0.8	3.6	302.4	0.0	185.8
11/22/03	-163.6	-349.8	5.5	0.75	4.1	0.8	3.3	305.7	0.0	185.8
11/23/03	-166.9	-353.1	5.0	0.75	3.8	0.8	3.0	308.7	0.0	185.8
11/24/03	-169.9	-356.1	4.5	0.75	3.4	0.8	2.7	311.4	5.3	191.1
11/25/03	-167.3	-358.8	3.2	0.75	2.4	0.8	1.9	313.4	0.0	191.1
11/26/03	-169.3	-360.8	4.0	0.75	3.0	0.8	2.4	315.8	0.0	191.1
11/27/03	-171.7	-363.2	3.5	0.75	2.6	0.8	2.1	317.9	2.9	194.0
11/28/03	9999	9999	9999	0.75	9999	0.8	9999	9999	0.0	194.0
11/29/03	-170.9	-365.3	5.0	0.75	3.8	0.8	3.0	320.9	0.0	194.0
11/30/03	-173.9	-368.3	4.6	0.75	3.5	0.8	2.8	323.5	0.0	194.0

Replenishment 2 (50% Evapotranspiration 1 Lateral per 1 row) July

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
07/01/03	-41.5	-41.5	2.0	0.75	1.5	0.8	1.2	1.2	0.0	0.0
07/02/03	-38.7	-42.7	2.0	0.75	1.5	0.8	1.2	2.4	5.0	4.0
07/03/03	-39.9	-43.9	2.0	0.75	1.5	0.8	1.2	3.6	0.0	4.0
07/04/03	-41.1	-45.1	2.0	0.75	1.5	0.8	1.2	4.8	0.0	4.0
07/05/03	-37.6	-46.3	2.5	0.75	1.9	0.8	1.5	6.3	5.0	9.0
07/06/03	-39.4	-47.8	3.0	0.75	2.3	0.8	1.8	8.1	0.0	9.0
07/07/03	-40.9	-49.6	2.5	0.75	1.9	0.8	1.5	9.6	0.0	9.0
07/08/03	-32.9	-51.1	2.5	0.75	1.9	0.8	1.5	11.1	9.5	18.5
07/09/03	-34.4	-52.6	2.5	0.75	1.9	0.8	1.5	12.6	0.0	18.5
07/10/03	-35.9	-54.1	2.5	0.75	1.9	0.8	1.5	14.1	0.0	18.5
07/11/03	-26.1	-55.6	2.0	0.75	1.5	0.8	1.2	15.3	11.0	29.5
07/12/03	-27.6	-56.8	2.5	0.75	1.9	0.8	1.5	16.8	0.0	29.5
07/13/03	-29.1	-58.3	2.5	0.75	1.9	0.8	1.5	18.3	0.0	29.5
07/14/03	-30.9	-59.8	3.0	0.75	2.3	0.8	1.8	20.1	0.0	29.5
07/15/03	-32.7	-61.6	3.0	0.75	2.3	0.8	1.8	21.9	0.0	29.5
07/16/03	-33.9	-63.4	2.0	0.75	1.5	0.8	1.2	23.1	0.0	29.5
07/17/03	-9.4	-64.6	2.5	0.75	1.9	0.8	1.5	24.6	26.0	55.5
07/18/03	-10.6	-66.1	2.0	0.75	1.5	0.8	1.2	25.8	0.0	55.5
07/19/03	-12.1	-67.3	2.5	0.75	1.9	0.8	1.5	27.3	0.0	55.5
07/20/03	-13.6	-68.8	2.5	0.75	1.9	0.8	1.5	28.8	0.0	55.5
07/21/03	-14.8	-70.3	2.0	0.75	1.5	0.8	1.2	30.0	0.0	55.5
07/22/03	3.4	-71.5	3.0	0.75	2.3	0.8	1.8	31.8	20.0	75.5
07/23/03	1.6	-73.3	3.0	0.75	2.3	0.8	1.8	33.6	0.0	75.5
07/24/03	-0.2	-75.1	3.0	0.75	2.3	0.8	1.8	35.4	0.0	75.5
07/25/03	12.8	-76.9	2.5	0.75	1.9	0.8	1.5	36.9	14.5	90.0
07/26/03	11.3	-78.4	2.5	0.75	1.9	0.8	1.5	38.4	0.0	90.0
07/27/03	9.5	-79.9	3.0	0.75	2.3	0.8	1.8	40.2	0.0	90.0
07/28/03	8.0	-81.7	2.5	0.75	1.9	0.8	1.5	41.7	0.0	90.0
07/29/03	6.2	-83.2	3.0	0.75	2.3	0.8	1.8	43.5	0.0	90.0
07/30/03	9.6	-85.0	3.5	0.75	2.6	0.8	2.1	45.6	5.5	95.5
07/31/03	7.2	-87.1	4.0	0.75	3.0	0.8	2.4	48.0	0.0	95.5

Replenishment 2 (50% Evapotranspiration 1 Lateral per 1 row) August

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
08/01/03	-87.9	-209.8	4.0	0.75	3	0.8	2.4	164.8	0.0	95.5
08/02/03	-90.3	-212.2	3.5	0.75	2.6	0.8	2.1	166.9	5.5	101.0
08/03/03	-89.6	-214.3	3.0	0.75	2.3	0.8	1.8	168.7	0.0	101.0
08/04/03	-91.4	-216.1	3.5	0.75	2.6	0.8	2.1	170.8	0.0	101.0
08/05/03	-93.5	-218.2	3.0	0.75	2.3	0.8	1.8	172.6	0.0	101.0
08/06/03	-95.3	-220.0	3.0	0.75	2.3	0.8	1.8	174.4	13.0	114.0
08/07/03	-92.8	-221.8	4.0	0.75	3.0	0.8	2.4	176.8	0.0	114.0
08/08/03	-95.2	-224.2	5.0	0.75	3.8	0.8	3.0	179.8	0.0	114.0
08/09/03	-98.2	-227.2	6.0	0.75	4.5	0.8	3.6	183.4	6.6	120.6
08/10/03	-98.6	-230.8	5.5	0.75	4.1	0.8	3.3	186.7	0.0	120.6
08/11/03	-101.9	-234.1	5.0	0.75	3.8	0.8	3.0	189.7	0.0	120.6
08/12/03	-104.9	-237.1	5.0	0.75	3.8	0.8	3.0	192.7	0.0	120.6
08/13/03	-107.9	-240.1	4.5	0.75	3.4	0.8	2.7	195.4	5.0	125.6
08/14/03	-105.1	-242.8	4.5	0.75	3.4	0.8	2.7	198.1	0.0	125.6
08/15/03	-107.8	-245.5	4.0	0.75	3.0	0.8	2.4	200.5	0.0	125.6
08/16/03	-110.2	-247.9	3.5	0.75	2.6	0.8	2.1	202.6	7.9	133.5
08/17/03	-107.7	-250.0	2.5	0.75	1.9	0.8	1.5	204.1	0.0	133.5
08/18/03	-109.2	-251.5	1.9	0.75	1.4	0.8	1.1	205.2	0.0	133.5
08/19/03	-110.3	-252.6	4.0	0.75	3.0	0.8	2.4	207.6	0.0	133.5
08/20/03	-112.7	-255.0	3.0	0.75	2.3	0.8	1.8	209.4	4.7	138.2
08/21/03	-110.7	-256.8	5.0	0.75	3.8	0.8	3.0	212.4	0.0	138.2
08/22/03	-113.7	-259.8	5.0	0.75	3.8	0.8	3.0	215.4	0.0	138.2
08/23/03	-116.7	-262.8	5.0	0.75	3.8	0.8	3.0	218.4	4.7	142.9
08/24/03	-116.0	-265.8	4.5	0.75	3.4	0.8	2.7	221.1	0.0	142.9
08/25/03	-118.7	-268.5	4.5	0.75	3.4	0.8	2.7	223.8	0.0	142.9
08/26/03	-121.4	-271.2	5.0	0.75	3.8	0.8	3.0	226.8	0.0	142.9
08/27/03	-124.4	-274.2	4.0	0.75	3.0	0.8	2.4	229.2	0.0	142.9
08/28/03	-121.9	-276.6	5.0	0.75	3.8	0.8	3.0	232.2	0.0	142.9
08/29/03	-124.9	-279.6	5.0	0.75	3.8	0.8	3.0	235.2	0.0	142.9
08/30/03	-127.9	-282.6	4.5	0.75	3.4	0.8	2.7	237.9	0.0	142.9
08/31/03	-126.6	-285.3	4.0	0.75	3.0	0.8	2.4	240.3	0.0	95.5

Replenishment 2 (50% Evapotranspiration 1 Lateral per 1 row) September

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
09/01/03	-3.1	-148.0	4.0	0.75	3	0.8	2.4	108.9	0.0	142.9
09/02/03	7.9	-150.4	2.0	0.75	1.5	0.8	1.2	110.1	12.2	155.1
09/03/03	7.0	-151.6	1.5	0.75	1.1	0.8	0.9	111.0	0.0	155.1
09/04/03	10.4	-152.5	1.0	0.75	0.8	0.8	0.6	111.6	4.0	159.1
09/05/03	8.6	-153.1	3.0	0.75	2.3	0.8	1.8	113.4	0.0	159.1
09/06/03	6.5	-154.9	3.5	0.75	2.6	0.8	2.1	115.5	0.0	159.1
09/07/03	4.7	-157.0	3.0	0.75	2.3	0.8	1.8	117.3	0.0	159.1
09/08/03	8.1	-158.8	3.5	0.75	2.6	0.8	2.1	119.4	5.5	164.6
09/09/03	5.4	-160.9	4.5	0.75	3.4	0.8	2.7	122.1	0.0	164.6
09/10/03	3.3	-163.6	3.5	0.75	2.6	0.8	2.1	124.2	0.0	164.6
09/11/03	7.8	-165.7	3.5	0.75	2.6	0.8	2.1	126.3	6.6	171.2
09/12/03	6.0	-167.8	3.0	0.75	2.3	0.8	1.8	128.1	0.0	171.2
09/13/03	3.6	-169.6	4.0	0.75	3.0	0.8	2.4	130.5	0.0	171.2
09/14/03	1.2	-172.0	4.0	0.75	3.0	0.8	2.4	132.9	0.0	171.2
09/15/03	8.3	-174.4	4.0	0.75	3.0	0.8	2.4	135.3	9.5	180.7
09/16/03	6.5	-176.8	3.0	0.75	2.3	0.8	1.8	137.1	0.0	180.7
09/17/03	5.3	-178.6	2.0	0.75	1.5	0.8	1.2	138.3	0.0	180.7
09/18/03	7.8	-179.8	1.5	0.75	1.1	0.8	0.9	139.2	3.4	184.1
09/19/03	6.6	-180.7	2.0	0.75	1.5	0.8	1.2	140.4	0.0	184.1
09/20/03	5.4	-181.9	2.0	0.75	1.5	0.8	1.2	141.6	0.0	184.1
09/21/03	3.3	-183.1	3.5	0.75	2.6	0.8	2.1	143.7	0.0	184.1
09/22/03	1.5	-185.2	3.0	0.75	2.3	0.8	1.8	145.5	0.0	184.1
09/23/03	-0.9	-187.0	4.0	0.75	3.0	0.8	2.4	147.9	0.0	184.1
09/24/03	-3.0	-189.4	3.5	0.75	2.6	0.8	2.1	150.0	0.0	184.1
09/25/03	0.9	-191.5	4.0	0.75	3.0	0.8	2.4	152.4	6.3	190.4
09/26/03	-1.5	-193.9	4.0	0.75	3.0	0.8	2.4	154.8	0.0	190.4
09/27/03	-3.9	-196.3	4.0	0.75	3.0	0.8	2.4	157.2	0.0	190.4
09/28/03	-5.4	-198.7	2.5	0.75	1.9	0.8	1.5	158.7	0.0	190.4
09/29/03	-7.5	-200.2	3.5	0.75	2.6	0.8	2.1	160.8	0.0	190.4
09/30/03	2.5	-202.3	2.5	0.75	1.9	0.8	1.5	162.3	11.5	201.9

Replenishment 2 (50% Evapotranspiration 1 Lateral per 1 row) October

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
10/01/03	0.1	-203.8	4.0	0.75	3	0.8	2.4	164.7	0.0	201.9
10/02/03	-2.0	-206.2	3.5	0.75	2.6	0.8	2.1	166.8	0.0	201.9
10/03/03	2.0	-204.2	3.0	0.75	2.3	0.8	1.8	168.6	5.8	207.7
10/04/03	-0.1	-204.3	3.5	0.75	2.6	0.8	2.1	170.7	0.0	207.7
10/05/03	-1.9	-206.2	3.0	0.75	2.3	0.8	1.8	172.5	0.0	207.7
10/06/03	-3.7	-209.9	3.0	0.75	2.3	0.8	1.8	174.3	0.0	207.7
10/07/03	2.8	-207.1	4.0	0.75	3.0	0.8	2.4	176.7	8.9	216.6
10/08/03	-0.2	-207.3	5.0	0.75	3.8	0.8	3.0	179.7	0.0	216.6
10/09/03	-3.8	-211.1	6.0	0.75	4.5	0.8	3.6	183.3	0.0	216.6
10/10/03	-0.5	-211.6	5.5	0.75	4.1	0.8	3.3	186.6	6.6	223.2
10/11/03	-3.5	-215.1	5.0	0.75	3.8	0.8	3.0	189.6	0.0	223.2
10/12/03	-6.5	-221.6	5.0	0.75	3.8	0.8	3.0	192.6	0.0	223.2
10/13/03	-9.2	-230.8	4.5	0.75	3.4	0.8	2.7	195.3	0.0	223.2
10/14/03	-0.3	-231.1	4.5	0.75	3.4	0.8	2.7	198.0	11.6	234.8
10/15/03	-2.7	-233.8	4.0	0.75	3.0	0.8	2.4	200.4	0.0	234.8
10/16/03	-4.8	-238.6	3.5	0.75	2.6	0.8	2.1	202.5	0.0	234.8
10/17/03	2.4	-236.2	2.5	0.75	1.9	0.8	1.5	204.0	8.7	243.5
10/18/03	1.3	-234.9	1.9	0.75	1.4	0.8	1.1	205.1	0.0	243.5
10/19/03	-1.1	-236.1	4.0	0.75	3.0	0.8	2.4	207.5	0.0	243.5
10/20/03	-2.9	-239.0	3.0	0.75	2.3	0.8	1.8	209.3	0.0	243.5
10/21/03	1.0	-238.1	5.0	0.75	3.8	0.8	3.0	212.3	6.9	250.4
10/22/03	-2.0	-240.1	5.0	0.75	3.8	0.8	3.0	215.3	0.0	250.4
10/23/03	-5.0	-245.1	5.0	0.75	3.8	0.8	3.0	218.3	0.0	250.4
10/24/03	0.5	-244.7	4.5	0.75	3.4	0.8	2.7	221.0	8.2	258.6
10/25/03	-2.2	-246.9	4.5	0.75	3.4	0.8	2.7	223.7	0.0	258.6
10/26/03	-5.2	-252.2	5.0	0.75	3.8	0.8	3.0	226.7	0.0	258.6
10/27/03	-7.6	-259.8	4.0	0.75	3.0	0.8	2.4	229.1	0.0	258.6
10/28/03	-0.6	-260.4	5.0	0.75	3.8	0.8	3.0	232.1	10.0	268.6
10/29/03	-3.6	-264.1	5.0	0.75	3.8	0.8	3.0	235.1	0.0	268.6
10/30/03	-6.3	-270.4	4.5	0.75	3.4	0.8	2.7	237.8	0.0	268.6
10/31/03	-0.8	-271.3	4.0	0.75	3.0	0.8	2.4	240.2	7.9	276.5

Replenishment 2 (50% Evapotranspiration 1 Lateral per 1 row) November

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
11/01/03	-2.9	-273.7	3.5	0.75	2.625	0.8	2.1	242.3	0.0	276.5
11/02/03	-5.6	-275.8	4.5	0.75	3.4	0.8	2.7	245.0	0.0	276.5
11/03/03	-8.3	-278.5	4.5	0.75	3.4	0.8	2.7	247.7	0.0	276.5
11/04/03	-1.0	-281.2	4.5	0.75	3.4	0.8	2.7	250.4	10.0	286.5
11/05/03	-3.4	-283.9	4.0	0.75	3.0	0.8	2.4	252.8	0.0	286.5
11/06/03	-6.1	-286.3	4.5	0.75	3.4	0.8	2.7	255.5	0.0	286.5
11/07/03	-2.1	-289.0	6.5	0.75	4.9	0.8	3.9	259.4	7.9	294.4
11/08/03	-5.7	-292.9	6.0	0.75	4.5	0.8	3.6	263.0	0.0	294.4
11/09/03	-8.1	-296.5	4.0	0.75	3.0	0.8	2.4	265.4	0.0	294.4
11/10/03	-10.5	-298.9	4.0	0.75	3.0	0.8	2.4	267.8	0.0	294.4
11/11/03	-2.2	-301.3	5.0	0.75	3.8	0.8	3.0	270.8	11.3	305.7
11/12/03	-5.2	-304.3	5.0	0.75	3.8	0.8	3.0	273.8	0.0	305.7
11/13/03	-9.1	-307.3	6.5	0.75	4.9	0.8	3.9	277.7	0.0	305.7
11/14/03	-4.7	-311.2	4.5	0.75	3.4	0.8	2.7	280.4	7.1	312.8
11/15/03	-7.7	-313.9	5.0	0.75	3.8	0.8	3.0	283.4	0.0	312.8
11/16/03	-10.7	-316.9	5.0	0.75	3.8	0.8	3.0	286.4	0.0	312.8
11/17/03	-14.0	-319.9	5.5	0.75	4.1	0.8	3.3	289.7	0.0	312.8
11/18/03	-5.9	-323.2	4.5	0.75	3.4	0.8	2.7	292.4	10.8	323.6
11/19/03	-8.6	-325.9	4.5	0.75	3.4	0.8	2.7	295.1	0.0	323.6
11/20/03	-12.2	-328.6	6.0	0.75	4.5	0.8	3.6	298.7	0.0	323.6
11/21/03	-7.9	-332.2	6.0	0.75	4.5	0.8	3.6	302.3	7.9	331.5
11/22/03	-11.2	-335.8	5.5	0.75	4.1	0.8	3.3	305.6	0.0	331.5
11/23/03	-14.2	-339.1	5.0	0.75	3.8	0.8	3.0	308.6	0.0	331.5
11/24/03	-16.9	-342.1	4.5	0.75	3.4	0.8	2.7	311.3	0.0	331.5
11/25/03	-7.5	-344.8	3.2	0.75	2.4	0.8	1.9	313.3	11.4	342.9
11/26/03	-9.9	-346.7	4.0	0.75	3.0	0.8	2.4	315.7	0.0	342.9
11/27/03	-12.0	-349.1	3.5	0.75	2.6	0.8	2.1	317.8	0.0	342.9
11/28/03	9999	9999	9999	0.75	9999	0.8	9999	9999	4.5	347.4
11/29/03	-15.0	-351.2	5.0	0.75	3.8	0.8	3.0	320.8	0.0	347.4
11/30/03	-17.7	-354.2	4.6	0.75	3.5	0.8	2.8	323.5	0.0	347.4

Replenishment 3 (75% Evapotranspiration 1 Lateral per 1 row) July

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
07/01/03	-35.0	-35.0	2.0	0.75	1.5	0.8	1.2	1.2	0.0	0.0
07/02/03	-36.2	-36.2	2.0	0.75	1.5	0.8	1.2	2.4	0.0	0.0
07/03/03	-30.4	-37.4	2.0	0.75	1.5	0.8	1.2	3.6	7.0	7.0
07/04/03	-31.6	-38.6	2.0	0.75	1.5	0.8	1.2	4.8	0.0	7.0
07/05/03	-33.1	-39.8	2.5	0.75	1.9	0.8	1.5	6.3	0.0	7.0
07/06/03	-27.4	-41.3	3.0	0.75	2.3	0.8	1.8	8.1	7.5	14.5
07/07/03	-28.9	-43.1	2.5	0.75	1.9	0.8	1.5	9.6	0.0	14.5
07/08/03	-30.4	-44.6	2.5	0.75	1.9	0.8	1.5	11.1	0.0	14.5
07/09/03	-17.7	-46.1	2.5	0.75	1.9	0.8	1.5	12.6	14.3	28.8
07/10/03	-19.2	-47.6	2.5	0.75	1.9	0.8	1.5	14.1	0.0	28.8
07/11/03	-20.4	-49.1	2.0	0.75	1.5	0.8	1.2	15.3	0.0	28.8
07/12/03	-4.9	-50.3	2.5	0.75	1.9	0.8	1.5	16.8	17.0	45.8
07/13/03	-6.4	-51.8	2.5	0.75	1.9	0.8	1.5	18.3	0.0	45.8
07/14/03	-8.2	-53.3	3.0	0.75	2.3	0.8	1.8	20.1	0.0	45.8
07/15/03	-10.0	-55.1	3.0	0.75	2.3	0.8	1.8	21.9	0.0	45.8
07/16/03	-11.2	-56.9	2.0	0.75	1.5	0.8	1.2	23.1	0.0	45.8
07/17/03	-12.7	-58.1	2.5	0.75	1.9	0.8	1.5	24.6	0.0	45.8
07/18/03	11.2	-59.6	2.0	0.75	1.5	0.8	1.2	25.8	25.0	70.8
07/19/03	9.7	-60.8	2.5	0.75	1.9	0.8	1.5	27.3	0.0	70.8
07/20/03	8.2	-62.3	2.5	0.75	1.9	0.8	1.5	28.8	0.0	70.8
07/21/03	6.9	-63.8	2.0	0.75	1.5	0.8	1.2	30.0	0.0	70.8
07/22/03	5.2	-65.0	3.0	0.75	2.3	0.8	1.8	31.8	0.0	70.8
07/23/03	20.4	-66.8	3.0	0.75	2.3	0.8	1.8	33.6	17.0	87.8
07/24/03	18.6	-68.6	3.0	0.75	2.3	0.8	1.8	35.4	0.0	87.8
07/25/03	17.1	-70.4	2.5	0.75	1.9	0.8	1.5	36.9	0.0	87.8
07/26/03	26.1	-71.9	2.5	0.75	1.9	0.8	1.5	38.4	10.5	98.3
07/27/03	24.3	-73.4	3.0	0.75	2.3	0.8	1.8	40.2	0.0	98.3
07/28/03	22.8	-75.2	2.5	0.75	1.9	0.8	1.5	41.7	0.0	98.3
07/29/03	21.0	-76.7	3.0	0.75	2.3	0.8	1.8	43.5	0.0	98.3
07/30/03	27.6	-78.5	3.5	0.75	2.6	0.8	2.1	45.6	8.7	107.0
07/31/03	25.2	-80.6	4.0	0.75	3.0	0.8	2.4	48.0	0.0	107.0

Replenishment 3 (75% Evapotranspiration 1 Lateral per 1 row) August

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
08/01/03	23.1	-83.0	3.5	0.75	2.6	0.8	2.1	50.1	0.0	107.0
08/02/03	30.0	-85.1	3.5	0.75	2.6	0.8	2.1	52.2	9.0	116.0
08/03/03	27.9	-87.2	3.5	0.75	2.6	0.8	2.1	54.3	0.0	116.0
08/04/03	25.8	-89.3	3.5	0.75	2.6	0.8	2.1	56.4	0.0	116.0
08/05/03	24.0	-91.4	3.0	0.75	2.3	0.8	1.8	58.2	0.0	116.0
08/06/03	22.2	-93.2	3.0	0.75	2.3	0.8	1.8	60.0	0.0	116.0
08/07/03	20.4	-95.0	3.0	0.75	2.3	0.8	1.8	61.8	0.0	116.0
08/08/03	18.9	-96.8	2.5	0.75	1.9	0.8	1.5	63.3	0.0	116.0
08/09/03	37.1	-98.3	3.0	0.75	2.3	0.8	1.8	65.1	20.0	136.0
08/10/03	35.6	-100.1	2.5	0.75	1.9	0.8	1.5	66.6	0.0	136.0
08/11/03	34.1	-101.6	2.5	0.75	1.9	0.8	1.5	68.1	0.0	136.0
08/12/03	32.3	-103.1	3.0	0.75	2.3	0.8	1.8	69.9	0.0	136.0
08/13/03	40.0	-104.9	3.0	0.75	2.3	0.8	1.8	71.7	9.5	145.5
08/14/03	38.2	-106.7	3.0	0.75	2.3	0.8	1.8	73.5	0.0	145.5
08/15/03	36.1	-108.5	3.5	0.75	2.6	0.8	2.1	75.6	0.0	145.5
08/16/03	41.6	-110.6	4.0	0.75	3.0	0.8	2.4	78.0	7.9	153.4
08/17/03	39.2	-113.0	4.0	0.75	3.0	0.8	2.4	80.4	0.0	153.4
08/18/03	37.1	-115.4	3.5	0.75	2.6	0.8	2.1	82.5	0.0	153.4
08/19/03	35.0	-117.5	3.5	0.75	2.6	0.8	2.1	84.6	0.0	153.4
08/20/03	45.2	-119.6	3.0	0.75	2.3	0.8	1.8	86.4	12.0	165.4
08/21/03	44.9	-121.4	0.5	0.75	0.4	0.8	0.3	86.7	0.0	165.4
08/22/03	43.7	-121.7	2.0	0.75	1.5	0.8	1.2	87.9	0.0	165.4
08/23/03	48.5	-122.9	2.5	0.75	1.9	0.8	1.5	89.4	6.3	171.7
08/24/03	46.7	-124.4	3.0	0.75	2.3	0.8	1.8	91.2	0.0	171.7
08/25/03	44.9	-126.2	3.0	0.75	2.3	0.8	1.8	93.0	0.0	171.7
08/26/03	50.7	-128.0	3.5	0.75	2.6	0.8	2.1	95.1	7.9	179.6
08/27/03	48.3	-130.1	4.0	0.75	3.0	0.8	2.4	97.5	0.0	179.6
08/28/03	46.2	-132.5	3.5	0.75	2.6	0.8	2.1	99.6	0.0	179.6
08/29/03	44.1	-134.6	3.5	0.75	2.6	0.8	2.1	101.7	0.0	179.6
08/30/03	41.7	-136.7	4.0	0.75	3.0	0.8	2.4	104.1	0.0	179.6
08/31/03	39.3	-139.1	4.0	0.75	3.0	0.8	2.4	106.5	0.0	179.6

Replenishment 3 (75% Evapotranspiration 1 Lateral per 1 row) September

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
09/01/03	36.9	-141.5	4.0	0.75	3	0.8	2.4	108.9	0.0	179.6
09/02/03	35.7	-143.9	2.0	0.75	1.5	0.8	1.2	110.1	0.0	179.6
09/03/03	38.4	-145.1	1.5	0.75	1.1	0.8	0.9	111.0	3.6	183.2
09/04/03	37.8	-146.0	1.0	0.75	0.8	0.8	0.6	111.6	0.0	183.2
09/05/03	40.0	-146.6	3.0	0.75	2.3	0.8	1.8	113.4	4.0	187.2
09/06/03	37.9	-148.4	3.5	0.75	2.6	0.8	2.1	115.5	0.0	187.2
09/07/03	36.1	-150.5	3.0	0.75	2.3	0.8	1.8	117.3	0.0	187.2
09/08/03	34.0	-152.3	3.5	0.75	2.6	0.8	2.1	119.4	0.0	187.2
09/09/03	42.0	-154.4	4.5	0.75	3.4	0.8	2.7	122.1	10.7	197.9
09/10/03	39.9	-157.1	3.5	0.75	2.6	0.8	2.1	124.2	0.0	197.9
09/11/03	37.8	-159.2	3.5	0.75	2.6	0.8	2.1	126.3	0.0	197.9
09/12/03	45.9	-161.3	3.0	0.75	2.3	0.8	1.8	128.1	9.9	207.8
09/13/03	43.5	-163.1	4.0	0.75	3.0	0.8	2.4	130.5	0.0	207.8
09/14/03	41.1	-165.5	4.0	0.75	3.0	0.8	2.4	132.9	0.0	207.8
09/15/03	38.7	-167.9	4.0	0.75	3.0	0.8	2.4	135.3	0.0	207.8
09/16/03	47.9	-170.3	3.0	0.75	2.3	0.8	1.8	137.1	11.0	218.8
09/17/03	46.7	-172.1	2.0	0.75	1.5	0.8	1.2	138.3	0.0	218.8
09/18/03	45.8	-173.3	1.5	0.75	1.1	0.8	0.9	139.2	0.0	218.8
09/19/03	50.6	-174.2	2.0	0.75	1.5	0.8	1.2	140.4	6.0	224.8
09/20/03	49.4	-175.4	2.0	0.75	1.5	0.8	1.2	141.6	0.0	224.8
09/21/03	47.3	-176.6	3.5	0.75	2.6	0.8	2.1	143.7	0.0	224.8
09/22/03	45.5	-178.7	3.0	0.75	2.3	0.8	1.8	145.5	0.0	224.8
09/23/03	43.1	-180.5	4.0	0.75	3.0	0.8	2.4	147.9	0.0	224.8
09/24/03	41.0	-182.9	3.5	0.75	2.6	0.8	2.1	150.0	0.0	224.8
09/25/03	38.6	-185.0	4.0	0.75	3.0	0.8	2.4	152.4	0.0	224.8
09/26/03	47.2	-187.4	4.0	0.75	3.0	0.8	2.4	154.8	11.0	235.8
09/27/03	44.8	-189.8	4.0	0.75	3.0	0.8	2.4	157.2	0.0	235.8
09/28/03	43.3	-192.2	2.5	0.75	1.9	0.8	1.5	158.7	0.0	235.8
09/29/03	41.2	-193.7	3.5	0.75	2.6	0.8	2.1	160.8	0.0	235.8
09/30/03	53.0	-195.8	2.5	0.75	1.9	0.8	1.5	162.3	13.3	249.1

Replenishment 3 (75% Evapotranspiration 1 Lateral per 1 row) October

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
10/01/03	50.6	-197.3	4.0	0.75	3	0.8	2.4	164.7	0.0	249.1
10/02/03	48.5	-199.7	3.5	0.75	2.6	0.8	2.1	166.8	0.0	249.1
10/03/03	55.4	-201.8	3.0	0.75	2.3	0.8	1.8	168.6	8.7	257.8
10/04/03	53.3	-203.6	3.5	0.75	2.6	0.8	2.1	170.7	0.0	257.8
10/05/03	51.5	-205.7	3.0	0.75	2.3	0.8	1.8	172.5	0.0	257.8
10/06/03	49.7	-207.5	3.0	0.75	2.3	0.8	1.8	174.3	0.0	257.8
10/07/03	60.7	-209.3	4.0	0.75	3.0	0.8	2.4	176.7	13.4	271.2
10/08/03	57.7	-211.7	5.0	0.75	3.8	0.8	3.0	179.7	0.0	271.2
10/09/03	54.1	-214.7	6.0	0.75	4.5	0.8	3.6	183.3	0.0	271.2
10/10/03	60.7	-218.3	5.5	0.75	4.1	0.8	3.3	186.6	9.9	281.1
10/11/03	57.7	-221.6	5.0	0.75	3.8	0.8	3.0	189.6	0.0	281.1
10/12/03	54.7	-224.6	5.0	0.75	3.8	0.8	3.0	192.6	0.0	281.1
10/13/03	52.0	-227.6	4.5	0.75	3.4	0.8	2.7	195.3	0.0	281.1
10/14/03	66.7	-230.3	4.5	0.75	3.4	0.8	2.7	198.0	17.4	298.5
10/15/03	64.3	-233.0	4.0	0.75	3.0	0.8	2.4	200.4	0.0	298.5
10/16/03	62.2	-235.4	3.5	0.75	2.6	0.8	2.1	202.5	0.0	298.5
10/17/03	73.7	-237.5	2.5	0.75	1.9	0.8	1.5	204.0	13.0	311.5
10/18/03	72.5	-239.0	1.9	0.75	1.4	0.8	1.1	205.1	0.0	311.5
10/19/03	70.1	-240.1	4.0	0.75	3.0	0.8	2.4	207.5	0.0	311.5
10/20/03	68.3	-242.5	3.0	0.75	2.3	0.8	1.8	209.3	0.0	311.5
10/21/03	75.6	-244.3	5.0	0.75	3.8	0.8	3.0	212.3	10.3	321.8
10/22/03	72.6	-247.3	5.0	0.75	3.8	0.8	3.0	215.3	0.0	321.8
10/23/03	69.6	-250.3	5.0	0.75	3.8	0.8	3.0	218.3	0.0	321.8
10/24/03	79.1	-253.3	4.5	0.75	3.4	0.8	2.7	221.0	12.2	334.0
10/25/03	76.4	-256.0	4.5	0.75	3.4	0.8	2.7	223.7	0.0	334.0
10/26/03	73.4	-258.7	5.0	0.75	3.8	0.8	3.0	226.7	0.0	334.0
10/27/03	71.0	-261.7	4.0	0.75	3.0	0.8	2.4	229.1	0.0	334.0
10/28/03	83.0	-264.1	5.0	0.75	3.8	0.8	3.0	232.1	15.0	349.0
10/29/03	80.0	-267.1	5.0	0.75	3.8	0.8	3.0	235.1	0.0	349.0
10/30/03	77.3	-270.1	4.5	0.75	3.4	0.8	2.7	237.8	0.0	349.0
10/31/03	86.7	-272.8	4.0	0.75	3.0	0.8	2.4	240.2	11.8	360.8

Replenishment 3 (75% Evapotranspiration 1 Lateral per 1 row) November

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
11/01/03	84.6	-275.2	3.5	0.75	2.625	0.8	2.1	242.3	0.0	360.8
11/02/03	81.9	-277.3	4.5	0.75	3.4	0.8	2.7	245.0	0.0	360.8
11/03/03	79.2	-280.0	4.5	0.75	3.4	0.8	2.7	247.7	0.0	360.8
11/04/03	91.5	-282.7	4.5	0.75	3.4	0.8	2.7	250.4	15.0	375.8
11/05/03	89.1	-285.4	4.0	0.75	3.0	0.8	2.4	252.8	0.0	375.8
11/06/03	86.4	-287.8	4.5	0.75	3.4	0.8	2.7	255.5	0.0	375.8
11/07/03	94.3	-290.5	6.5	0.75	4.9	0.8	3.9	259.4	11.8	387.6
11/08/03	90.7	-294.4	6.0	0.75	4.5	0.8	3.6	263.0	0.0	387.6
11/09/03	88.3	-298.0	4.0	0.75	3.0	0.8	2.4	265.4	0.0	387.6
11/10/03	85.9	-300.4	4.0	0.75	3.0	0.8	2.4	267.8	0.0	387.6
11/11/03	99.8	-302.8	5.0	0.75	3.8	0.8	3.0	270.8	16.9	404.5
11/12/03	96.8	-305.8	5.0	0.75	3.8	0.8	3.0	273.8	0.0	404.5
11/13/03	92.9	-308.8	6.5	0.75	4.9	0.8	3.9	277.7	0.0	404.5
11/14/03	100.9	-312.7	4.5	0.75	3.4	0.8	2.7	280.4	10.7	415.2
11/15/03	97.9	-315.4	5.0	0.75	3.8	0.8	3.0	283.4	0.0	415.2
11/16/03	94.9	-318.4	5.0	0.75	3.8	0.8	3.0	286.4	0.0	415.2
11/17/03	91.6	-321.4	5.5	0.75	4.1	0.8	3.3	289.7	0.0	415.2
11/18/03	105.0	-324.7	4.5	0.75	3.4	0.8	2.7	292.4	16.1	431.3
11/19/03	102.3	-327.4	4.5	0.75	3.4	0.8	2.7	295.1	0.0	431.3
11/20/03	98.7	-330.1	6.0	0.75	4.5	0.8	3.6	298.7	0.0	431.3
11/21/03	106.9	-333.7	6.0	0.75	4.5	0.8	3.6	302.3	11.8	443.1
11/22/03	103.6	-337.3	5.5	0.75	4.1	0.8	3.3	305.6	0.0	443.1
11/23/03	100.6	-340.6	5.0	0.75	3.8	0.8	3.0	308.6	0.0	443.1
11/24/03	97.9	-343.6	4.5	0.75	3.4	0.8	2.7	311.3	0.0	443.1
11/25/03	113.5	-346.3	3.2	0.75	2.4	0.8	1.9	313.3	17.5	460.6
11/26/03	111.1	-348.3	4.0	0.75	3.0	0.8	2.4	315.7	0.0	460.6
11/27/03	109.0	-350.7	3.5	0.75	2.6	0.8	2.1	317.8	0.0	460.6
11/28/03	9999	9999	9999	0.75	9999	0.8	9999	9999	6.7	467.3
11/29/03	106.0	-352.8	5.0	0.75	3.8	0.8	3.0	320.8	0.0	467.3
11/30/03	103.2	-355.8	4.6	0.75	3.5	0.8	2.8	323.5	0.0	467.3

Replenishment 4 (100% Evapotranspiration 1 Lateral per 1 row) July

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
07/01/03	-24.5	-24.5	2.0	0.75	1.5	0.8	1.2	1.2	0.0	0.0
07/02/03	-25.7	-25.7	2.0	0.75	1.5	0.8	1.2	2.4	9.0	9.0
07/03/03	-17.9	-26.9	2.0	0.75	1.5	0.8	1.2	3.6	0.0	9.0
07/04/03	-19.1	-28.1	2.0	0.75	1.5	0.8	1.2	4.8	0.0	9.0
07/05/03	-20.3	-29.3	2.5	0.75	1.9	0.8	1.5	6.3	10.0	19.0
07/06/03	-11.8	-30.8	3.0	0.75	2.3	0.8	1.8	8.1	0.0	19.0
07/07/03	-13.6	-32.6	2.5	0.75	1.9	0.8	1.5	9.6	0.0	19.0
07/08/03	-15.1	-34.1	2.5	0.75	1.9	0.8	1.5	11.1	19.0	38.0
07/09/03	2.4	-35.6	2.5	0.75	1.9	0.8	1.5	12.6	0.0	38.0
07/10/03	0.9	-37.1	2.5	0.75	1.9	0.8	1.5	14.1	0.0	38.0
07/11/03	-0.6	-38.6	2.0	0.75	1.5	0.8	1.2	15.3	22.5	60.5
07/12/03	20.7	-39.8	2.5	0.75	1.9	0.8	1.5	16.8	0.0	60.5
07/13/03	19.2	-41.3	2.5	0.75	1.9	0.8	1.5	18.3	0.0	60.5
07/14/03	17.7	-42.8	3.0	0.75	2.3	0.8	1.8	20.1	0.0	60.5
07/15/03	15.9	-44.6	3.0	0.75	2.3	0.8	1.8	21.9	43.0	103.5
07/16/03	57.1	-46.4	2.0	0.75	1.5	0.8	1.2	23.1	0.0	103.5
07/17/03	55.9	-47.6	2.5	0.75	1.9	0.8	1.5	24.6	0.0	103.5
07/18/03	54.4	-49.1	2.0	0.75	1.5	0.8	1.2	25.8	0.0	103.5
07/19/03	53.2	-50.3	2.5	0.75	1.9	0.8	1.5	27.3	0.0	103.5
07/20/03	51.7	-51.8	2.5	0.75	1.9	0.8	1.5	28.8	0.0	103.5
07/21/03	50.2	-53.3	2.0	0.75	1.5	0.8	1.2	30.0	0.0	103.5
07/22/03	49.0	-54.5	3.0	0.75	2.3	0.8	1.8	31.8	13.5	117.0
07/23/03	60.7	-56.3	3.0	0.75	2.3	0.8	1.8	33.6	0.0	117.0
07/24/03	58.9	-58.1	3.0	0.75	2.3	0.8	1.8	35.4	0.0	117.0
07/25/03	57.1	-59.9	2.5	0.75	1.9	0.8	1.5	36.9	9.0	126.0
07/26/03	64.6	-61.4	2.5	0.75	1.9	0.8	1.5	38.4	0.0	126.0
07/27/03	63.1	-62.9	3.0	0.75	2.3	0.8	1.8	40.2	0.0	126.0
07/28/03	61.3	-64.7	2.5	0.75	1.9	0.8	1.5	41.7	0.0	126.0
07/29/03	59.8	-66.2	3.0	0.75	2.3	0.8	1.8	43.5	11.6	137.6
07/30/03	69.6	-68.0	3.5	0.75	2.6	0.8	2.1	45.6	0.0	137.6
07/31/03	67.5	-70.1	4.0	0.75	3.0	0.8	2.4	48.0	0.0	137.6

Replenishment 4 (100% Evapotranspiration 1 Lateral per 1 row) August

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
08/01/03	65.1	-72.5	3.5	0.75	2.6	0.8	2.1	50.1	5.5	143.1
08/02/03	68.5	-74.6	3.5	0.75	2.6	0.8	2.1	52.2	0.0	143.1
08/03/03	66.4	-76.7	3.5	0.75	2.6	0.8	2.1	54.3	0.0	143.1
08/04/03	64.3	-78.8	3.5	0.75	2.6	0.8	2.1	56.4	0.0	143.1
08/05/03	62.2	-80.9	3.0	0.75	2.3	0.8	1.8	58.2	0.0	143.1
08/06/03	60.4	-82.7	3.0	0.75	2.3	0.8	1.8	60.0	0.0	143.1
08/07/03	58.6	-84.5	3.0	0.75	2.3	0.8	1.8	61.8	0.0	143.1
08/08/03	56.8	-86.3	2.5	0.75	1.9	0.8	1.5	63.3	27.0	170.1
08/09/03	82.3	-87.8	3.0	0.75	2.3	0.8	1.8	65.1	0.0	170.1
08/10/03	80.5	-89.6	2.5	0.75	1.9	0.8	1.5	66.6	0.0	170.1
08/11/03	79.0	-91.1	2.5	0.75	1.9	0.8	1.5	68.1	0.0	170.1
08/12/03	77.5	-92.6	3.0	0.75	2.3	0.8	1.8	69.9	13.2	183.3
08/13/03	88.9	-94.4	3.0	0.75	2.3	0.8	1.8	71.7	0.0	183.3
08/14/03	87.1	-96.2	3.0	0.75	2.3	0.8	1.8	73.5	0.0	183.3
08/15/03	85.3	-98.0	3.5	0.75	2.6	0.8	2.1	75.6	10.0	193.3
08/16/03	93.2	-100.1	4.0	0.75	3.0	0.8	2.4	78.0	0.0	193.3
08/17/03	90.8	-102.5	4.0	0.75	3.0	0.8	2.4	80.4	0.0	193.3
08/18/03	88.4	-104.9	3.5	0.75	2.6	0.8	2.1	82.5	0.0	193.3
08/19/03	86.3	-107.0	3.5	0.75	2.6	0.8	2.1	84.6	15.8	209.1
08/20/03	100.0	-109.1	3.0	0.75	2.3	0.8	1.8	86.4	0.0	209.1
08/21/03	98.2	-110.9	0.5	0.75	0.4	0.8	0.3	86.7	0.0	209.1
08/22/03	97.9	-111.2	2.0	0.75	1.5	0.8	1.2	87.9	9.5	218.6
08/23/03	106.2	-112.4	2.5	0.75	1.9	0.8	1.5	89.4	0.0	218.6
08/24/03	104.7	-113.9	3.0	0.75	2.3	0.8	1.8	91.2	0.0	218.6
08/25/03	102.9	-115.7	3.0	0.75	2.3	0.8	1.8	93.0	0.0	218.6
08/26/03	101.1	-117.5	3.5	0.75	2.6	0.8	2.1	95.1	13.2	231.8
08/27/03	112.2	-119.6	4.0	0.75	3.0	0.8	2.4	97.5	0.0	231.8
08/28/03	109.8	-122.0	3.5	0.75	2.6	0.8	2.1	99.6	0.0	231.8
08/29/03	107.7	-124.1	3.5	0.75	2.6	0.8	2.1	101.7	0.0	231.8
08/30/03	105.6	-126.2	4.0	0.75	3.0	0.8	2.4	104.1	0.0	231.8
08/31/03	103.2	-128.6	4.0	0.75	3.0	0.8	2.4	106.5	0.0	231.8

Replenishment 4 (100% Evapotranspiration 1 Lateral per 1 row) September

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
09/01/03	100.8	-131.0	4.0	0.75	3	0.8	2.4	108.9	0.0	231.8
09/02/03	98.4	-133.4	2.0	0.75	1.5	0.8	1.2	110.1	16.3	248.1
09/03/03	113.5	-134.6	1.5	0.75	1.1	0.8	0.9	111.0	0.0	248.1
09/04/03	112.6	-135.5	1.0	0.75	0.8	0.8	0.6	111.6	0.0	248.1
09/05/03	112.0	-136.1	3.0	0.75	2.3	0.8	1.8	113.4	5.3	253.4
09/06/03	115.5	-137.9	3.5	0.75	2.6	0.8	2.1	115.5	0.0	253.4
09/07/03	113.4	-140.0	3.0	0.75	2.3	0.8	1.8	117.3	0.0	253.4
09/08/03	111.6	-141.8	3.5	0.75	2.6	0.8	2.1	119.4	0.0	253.4
09/09/03	109.5	-143.9	4.5	0.75	3.4	0.8	2.7	122.1	14.2	267.6
09/10/03	121.0	-146.6	3.5	0.75	2.6	0.8	2.1	124.2	0.0	267.6
09/11/03	118.9	-148.7	3.5	0.75	2.6	0.8	2.1	126.3	0.0	267.6
09/12/03	116.8	-150.8	3.0	0.75	2.3	0.8	1.8	128.1	13.2	280.8
09/13/03	128.2	-152.6	4.0	0.75	3.0	0.8	2.4	130.5	0.0	280.8
09/14/03	125.8	-155.0	4.0	0.75	3.0	0.8	2.4	132.9	0.0	280.8
09/15/03	123.4	-157.4	4.0	0.75	3.0	0.8	2.4	135.3	0.0	280.8
09/16/03	121.0	-159.8	3.0	0.75	2.3	0.8	1.8	137.1	14.7	295.5
09/17/03	133.9	-161.6	2.0	0.75	1.5	0.8	1.2	138.3	0.0	295.5
09/18/03	132.7	-162.8	1.5	0.75	1.1	0.8	0.9	139.2	0.0	295.5
09/19/03	131.8	-163.7	2.0	0.75	1.5	0.8	1.2	140.4	8.0	303.5
09/20/03	138.6	-164.9	2.0	0.75	1.5	0.8	1.2	141.6	0.0	303.5
09/21/03	137.4	-166.1	3.5	0.75	2.6	0.8	2.1	143.7	0.0	303.5
09/22/03	135.3	-168.2	3.0	0.75	2.3	0.8	1.8	145.5	0.0	303.5
09/23/03	133.5	-170.0	4.0	0.75	3.0	0.8	2.4	147.9	0.0	303.5
09/24/03	131.1	-172.4	3.5	0.75	2.6	0.8	2.1	150.0	0.0	303.5
09/25/03	129.0	-174.5	4.0	0.75	3.0	0.8	2.4	152.4	0.0	303.5
09/26/03	126.6	-176.9	4.0	0.75	3.0	0.8	2.4	154.8	14.7	318.2
09/27/03	138.9	-179.3	4.0	0.75	3.0	0.8	2.4	157.2	0.0	318.2
09/28/03	136.5	-181.7	2.5	0.75	1.9	0.8	1.5	158.7	0.0	318.2
09/29/03	135.0	-183.2	3.5	0.75	2.6	0.8	2.1	160.8	0.0	318.2
09/30/03	132.9	-185.3	2.5	0.75	1.9	0.8	1.5	162.3	13.7	331.9

Replenishment 4 (100% Evapotranspiration 1 Lateral per 1 row) October

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
10/01/03	145.1	-186.8	4.0	0.75	3	0.8	2.4	164.7	0.0	331.9
10/02/03	142.7	-189.2	3.5	0.75	2.6	0.8	2.1	166.8	11.4	343.3
10/03/03	152.0	-191.3	3.0	0.75	2.3	0.8	1.8	168.6	0.0	343.3
10/04/03	150.2	-193.1	3.5	0.75	2.6	0.8	2.1	170.7	0.0	343.3
10/05/03	148.1	-195.2	3.0	0.75	2.3	0.8	1.8	172.5	0.0	343.3
10/06/03	146.3	-197.0	3.0	0.75	2.3	0.8	1.8	174.3	17.4	360.7
10/07/03	161.9	-198.8	4.0	0.75	3.0	0.8	2.4	176.7	0.0	360.7
10/08/03	159.5	-201.2	5.0	0.75	3.8	0.8	3.0	179.7	0.0	360.7
10/09/03	156.5	-204.2	6.0	0.75	4.5	0.8	3.6	183.3	12.6	373.3
10/10/03	165.5	-207.8	5.5	0.75	4.1	0.8	3.3	186.6	0.0	373.3
10/11/03	162.2	-211.1	5.0	0.75	3.8	0.8	3.0	189.6	0.0	373.3
10/12/03	159.2	-214.1	5.0	0.75	3.8	0.8	3.0	192.6	0.0	373.3
10/13/03	156.2	-217.1	4.5	0.75	3.4	0.8	2.7	195.3	22.1	395.4
10/14/03	175.6	-219.8	4.5	0.75	3.4	0.8	2.7	198.0	0.0	395.4
10/15/03	172.9	-222.5	4.0	0.75	3.0	0.8	2.4	200.4	0.0	395.4
10/16/03	170.5	-224.9	3.5	0.75	2.6	0.8	2.1	202.5	18.4	413.8
10/17/03	186.8	-227.0	2.5	0.75	1.9	0.8	1.5	204.0	0.0	413.8
10/18/03	185.3	-228.5	1.9	0.75	1.4	0.8	1.1	205.1	0.0	413.8
10/19/03	184.2	-229.6	4.0	0.75	3.0	0.8	2.4	207.5	0.0	413.8
10/20/03	181.8	-232.0	3.0	0.75	2.3	0.8	1.8	209.3	15.4	429.2
10/21/03	195.4	-233.8	5.0	0.75	3.8	0.8	3.0	212.3	0.0	429.2
10/22/03	192.4	-236.8	5.0	0.75	3.8	0.8	3.0	215.3	0.0	429.2
10/23/03	189.4	-239.8	5.0	0.75	3.8	0.8	3.0	218.3	14.7	443.9
10/24/03	201.1	-242.8	4.5	0.75	3.4	0.8	2.7	221.0	0.0	443.9
10/25/03	198.4	-245.5	4.5	0.75	3.4	0.8	2.7	223.7	0.0	443.9
10/26/03	195.7	-248.2	5.0	0.75	3.8	0.8	3.0	226.7	0.0	443.9
10/27/03	192.7	-251.2	4.0	0.75	3.0	0.8	2.4	229.1	19.5	463.4
10/28/03	209.8	-253.6	5.0	0.75	3.8	0.8	3.0	232.1	0.0	463.4
10/29/03	206.8	-256.6	5.0	0.75	3.8	0.8	3.0	235.1	0.0	463.4
10/30/03	203.8	-259.6	4.5	0.75	3.4	0.8	2.7	237.8	16.3	479.7
10/31/03	217.4	-262.3	4.0	0.75	3.0	0.8	2.4	240.2	0.0	479.7

Replenishment 4 (100% Evapotranspiration 1 Lateral per 1 row) November

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
11/01/03	215.0	-264.7	3.5	0.75	2.625	0.8	2.1	242.3	0.0	479.7
11/02/03	212.9	-266.8	4.5	0.75	3.4	0.8	2.7	245.0	0.0	479.7
11/03/03	210.2	-269.5	4.5	0.75	3.4	0.8	2.7	247.7	20.5	500.2
11/04/03	228.0	-272.2	4.5	0.75	3.4	0.8	2.7	250.4	0.0	500.2
11/05/03	225.3	-274.9	4.0	0.75	3.0	0.8	2.4	252.8	0.0	500.2
11/06/03	222.9	-277.3	4.5	0.75	3.4	0.8	2.7	255.5	14.7	514.9
11/07/03	234.9	-280.0	6.5	0.75	4.9	0.8	3.9	259.4	0.0	514.9
11/08/03	231.0	-283.9	6.0	0.75	4.5	0.8	3.6	263.0	0.0	514.9
11/09/03	227.4	-287.5	4.0	0.75	3.0	0.8	2.4	265.4	0.0	514.9
11/10/03	225.0	-289.9	4.0	0.75	3.0	0.8	2.4	267.8	23.2	538.1
11/11/03	245.8	-292.3	5.0	0.75	3.8	0.8	3.0	270.8	0.0	538.1
11/12/03	242.8	-295.3	5.0	0.75	3.8	0.8	3.0	273.8	0.0	538.1
11/13/03	239.8	-298.3	6.5	0.75	4.9	0.8	3.9	277.7	14.7	552.8
11/14/03	250.6	-302.2	4.5	0.75	3.4	0.8	2.7	280.4	0.0	552.8
11/15/03	247.9	-304.9	5.0	0.75	3.8	0.8	3.0	283.4	0.0	552.8
11/16/03	244.9	-307.9	5.0	0.75	3.8	0.8	3.0	286.4	0.0	552.8
11/17/03	241.9	-310.9	5.5	0.75	4.1	0.8	3.3	289.7	21.6	574.4
11/18/03	260.2	-314.2	4.5	0.75	3.4	0.8	2.7	292.4	0.0	574.4
11/19/03	257.5	-316.9	4.5	0.75	3.4	0.8	2.7	295.1	0.0	574.4
11/20/03	254.8	-319.6	6.0	0.75	4.5	0.8	3.6	298.7	15.3	589.7
11/21/03	266.5	-323.2	6.0	0.75	4.5	0.8	3.6	302.3	0.0	589.7
11/22/03	262.9	-326.8	5.5	0.75	4.1	0.8	3.3	305.6	0.0	589.7
11/23/03	259.6	-330.1	5.0	0.75	3.8	0.8	3.0	308.6	0.0	589.7
11/24/03	256.6	-333.1	4.5	0.75	3.4	0.8	2.7	311.3	21.1	610.8
11/25/03	275.0	-335.8	3.2	0.75	2.4	0.8	1.9	313.3	0.0	610.8
11/26/03	273.0	-337.8	4.0	0.75	3.0	0.8	2.4	315.7	0.0	610.8
11/27/03	270.6	-340.2	3.5	0.75	2.6	0.8	2.1	317.8	11.8	622.6
11/28/03	280.3	9999	9999	0.75	9999	0.8	9999	9999	9999	9999
11/29/03	280.3	-342.3	5.0	0.75	3.8	0.8	3.0	320.8	0.0	622.6
11/30/03	277.3	-345.3	4.6	0.75	3.5	0.8	2.8	323.5	0.0	622.6

Replenishment 5 (25% Evapotranspiration 1 Lateral per 2 rows) July

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
07/01/03	-52.0	-52.0	2.0	0.75	1.5	0.8	1.2	1.2	0.0	0.0
07/02/03	-53.2	-53.2	2.0	0.75	1.5	0.8	1.2	2.4	0.0	0.0
07/03/03	-54.4	-54.4	2.0	0.75	1.5	0.8	1.2	3.6	2.0	2.0
07/04/03	-53.6	-55.6	2.0	0.75	1.5	0.8	1.2	4.8	0.0	2.0
07/05/03	-54.8	-56.8	2.5	0.75	1.9	0.8	1.5	6.3	0.0	2.0
07/06/03	-56.3	-58.3	3.0	0.75	2.3	0.8	1.8	8.1	2.5	4.5
07/07/03	-55.6	-60.1	2.5	0.75	1.9	0.8	1.5	9.6	0.0	4.5
07/08/03	-57.1	-61.6	2.5	0.75	1.9	0.8	1.5	11.1	0.0	4.5
07/09/03	-58.6	-63.1	2.5	0.75	1.9	0.8	1.5	12.6	5.0	9.5
07/10/03	-55.1	-64.6	2.5	0.75	1.9	0.8	1.5	14.1	0.0	9.5
07/11/03	-56.6	-66.1	2.0	0.75	1.5	0.8	1.2	15.3	0.0	9.5
07/12/03	-57.8	-67.3	2.5	0.75	1.9	0.8	1.5	16.8	6.0	15.5
07/13/03	-53.3	-68.8	2.5	0.75	1.9	0.8	1.5	18.3	0.0	15.5
07/14/03	-54.8	-70.3	3.0	0.75	2.3	0.8	1.8	20.1	0.0	15.5
07/15/03	-56.6	-72.1	3.0	0.75	2.3	0.8	1.8	21.9	0.0	15.5
07/16/03	-58.4	-73.9	2.0	0.75	1.5	0.8	1.2	23.1	0.0	15.5
07/17/03	-59.6	-75.1	2.5	0.75	1.9	0.8	1.5	24.6	0.0	15.5
07/18/03	-61.1	-76.6	2.0	0.75	1.5	0.8	1.2	25.8	19.0	34.5
07/19/03	-43.3	-77.8	2.5	0.75	1.9	0.8	1.5	27.3	0.0	34.5
07/20/03	-44.8	-79.3	2.5	0.75	1.9	0.8	1.5	28.8	0.0	34.5
07/21/03	-46.3	-80.8	2.0	0.75	1.5	0.8	1.2	30.0	0.0	34.5
07/22/03	-47.5	-82.0	3.0	0.75	2.3	0.8	1.8	31.8	0.0	34.5
07/23/03	-49.3	-83.8	3.0	0.75	2.3	0.8	1.8	33.6	17.5	52.0
07/24/03	-33.6	-85.6	3.0	0.75	2.3	0.8	1.8	35.4	0.0	52.0
07/25/03	-35.4	-87.4	2.5	0.75	1.9	0.8	1.5	36.9	0.0	52.0
07/26/03	-36.9	-88.9	2.5	0.75	1.9	0.8	1.5	38.4	15.4	67.4
07/27/03	-23.0	-90.4	3.0	0.75	2.3	0.8	1.8	40.2	0.0	67.4
07/28/03	-24.8	-92.2	2.5	0.75	1.9	0.8	1.5	41.7	0.0	67.4
07/29/03	-26.3	-93.7	3.0	0.75	2.3	0.8	1.8	43.5	0.0	67.4
07/30/03	-28.1	-95.5	3.5	0.75	2.6	0.8	2.1	45.6	2.9	70.3
07/31/03	-27.3	-97.6	4.0	0.75	3.0	0.8	2.4	48.0	0.0	70.3

Replenishment 5 (25% Evapotranspiration 1 Lateral per 2 rows) August

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
08/01/03	-29.7	-100.0	3.5	0.75	2.6	0.8	2.1	50.1	0.0	70.3
08/02/03	-31.8	-102.1	3.5	0.75	2.6	0.8	2.1	52.2	3.0	73.3
08/03/03	-30.9	-104.2	3.5	0.75	2.6	0.8	2.1	54.3	0.0	73.3
08/04/03	-33.0	-106.3	3.5	0.75	2.6	0.8	2.1	56.4	0.0	73.3
08/05/03	-35.1	-108.4	3.0	0.75	2.3	0.8	1.8	58.2	0.0	73.3
08/06/03	-36.9	-110.2	3.0	0.75	2.3	0.8	1.8	60.0	0.0	73.3
08/07/03	-38.7	-112.0	3.0	0.75	2.3	0.8	1.8	61.8	0.0	73.3
08/08/03	-40.5	-113.8	2.5	0.75	1.9	0.8	1.5	63.3	0.0	73.3
08/09/03	-42.0	-115.3	3.0	0.75	2.3	0.8	1.8	65.1	6.6	79.9
08/10/03	-37.2	-117.1	2.5	0.75	1.9	0.8	1.5	66.6	0.0	79.9
08/11/03	-38.7	-118.6	2.5	0.75	1.9	0.8	1.5	68.1	0.0	79.9
08/12/03	-40.2	-120.1	3.0	0.75	2.3	0.8	1.8	69.9	0.0	79.9
08/13/03	-42.0	-121.9	3.0	0.75	2.3	0.8	1.8	71.7	3.2	83.1
08/14/03	-40.6	-123.7	3.0	0.75	2.3	0.8	1.8	73.5	0.0	83.1
08/15/03	-42.4	-125.5	3.5	0.75	2.6	0.8	2.1	75.6	0.0	83.1
08/16/03	-44.5	-127.6	4.0	0.75	3.0	0.8	2.4	78.0	2.6	85.7
08/17/03	-44.3	-130.0	4.0	0.75	3.0	0.8	2.4	80.4	0.0	85.7
08/18/03	-46.7	-132.4	3.5	0.75	2.6	0.8	2.1	82.5	0.0	85.7
08/19/03	-48.8	-134.5	3.5	0.75	2.6	0.8	2.1	84.6	0.0	85.7
08/20/03	-50.9	-136.6	3.0	0.75	2.3	0.8	1.8	86.4	3.9	89.6
08/21/03	-48.8	-138.4	0.5	0.75	0.4	0.8	0.3	86.7	0.0	89.6
08/22/03	-49.1	-138.7	2.0	0.75	1.5	0.8	1.2	87.9	0.0	89.6
08/23/03	-50.3	-139.9	2.5	0.75	1.9	0.8	1.5	89.4	2.1	91.7
08/24/03	-49.7	-141.4	3.0	0.75	2.3	0.8	1.8	91.2	0.0	91.7
08/25/03	-51.5	-143.2	3.0	0.75	2.3	0.8	1.8	93.0	0.0	91.7
08/26/03	-53.3	-145.0	3.5	0.75	2.6	0.8	2.1	95.1	0.0	91.7
08/27/03	-55.4	-147.1	4.0	0.75	3.0	0.8	2.4	97.5	3.4	95.1
08/28/03	-54.4	-149.5	3.5	0.75	2.6	0.8	2.1	99.6	0.0	95.1
08/29/03	-56.5	-151.6	3.5	0.75	2.6	0.8	2.1	101.7	0.0	95.1
08/30/03	-58.6	-153.7	4.0	0.75	3.0	0.8	2.4	104.1	0.0	95.1
08/31/03	-61.0	-156.1	4.0	0.75	3.0	0.8	2.4	106.5	0.0	95.1

Replenishment 5 (25% Evapotranspiration 1 Lateral per 2 rows) September

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
09/01/03	-63.4	-158.5	4.0	0.75	3	0.8	2.4	108.9	0.0	95.1
09/02/03	-65.8	-160.9	2.0	0.75	1.5	0.8	1.2	110.1	0.0	95.1
09/03/03	-67.0	-162.1	1.5	0.75	1.1	0.8	0.9	111.0	14.2	109.3
09/04/03	-53.7	-163.0	1.0	0.75	0.8	0.8	0.6	111.6	0.0	109.3
09/05/03	-54.3	-163.6	3.0	0.75	2.3	0.8	1.8	113.4	0.0	109.3
09/06/03	-56.1	-165.4	3.5	0.75	2.6	0.8	2.1	115.5	1.3	110.6
09/07/03	-56.9	-167.5	3.0	0.75	2.3	0.8	1.8	117.3	0.0	110.6
09/08/03	-58.7	-169.3	3.5	0.75	2.6	0.8	2.1	119.4	0.0	110.6
09/09/03	-60.8	-171.4	4.5	0.75	3.4	0.8	2.7	122.1	0.0	110.6
09/10/03	-63.5	-174.1	3.5	0.75	2.6	0.8	2.1	124.2	4.1	114.7
09/11/03	-61.5	-176.2	3.5	0.75	2.6	0.8	2.1	126.3	0.0	114.7
09/12/03	-63.6	-178.3	3.0	0.75	2.3	0.8	1.8	128.1	0.0	114.7
09/13/03	-65.4	-180.1	4.0	0.75	3.0	0.8	2.4	130.5	5.0	119.7
09/14/03	-62.8	-182.5	4.0	0.75	3.0	0.8	2.4	132.9	0.0	119.7
09/15/03	-65.2	-184.9	4.0	0.75	3.0	0.8	2.4	135.3	0.0	119.7
09/16/03	-67.6	-187.3	3.0	0.75	2.3	0.8	1.8	137.1	0.0	119.7
09/17/03	-69.4	-189.1	2.0	0.75	1.5	0.8	1.2	138.3	2.0	121.7
09/18/03	-68.6	-190.3	1.5	0.75	1.1	0.8	0.9	139.2	0.0	121.7
09/19/03	-69.5	-191.2	2.0	0.75	1.5	0.8	1.2	140.4	0.0	121.7
09/20/03	-70.7	-192.4	2.0	0.75	1.5	0.8	1.2	141.6	1.4	123.1
09/21/03	-70.5	-193.6	3.5	0.75	2.6	0.8	2.1	143.7	0.0	123.1
09/22/03	-72.6	-195.7	3.0	0.75	2.3	0.8	1.8	145.5	0.0	123.1
09/23/03	-74.4	-197.5	4.0	0.75	3.0	0.8	2.4	147.9	0.0	123.1
09/24/03	-76.8	-199.9	3.5	0.75	2.6	0.8	2.1	150.0	0.0	123.1
09/25/03	-78.9	-202.0	4.0	0.75	3.0	0.8	2.4	152.4	0.0	123.1
09/26/03	-81.3	-204.4	4.0	0.75	3.0	0.8	2.4	154.8	0.0	123.1
09/27/03	-83.7	-206.8	4.0	0.75	3.0	0.8	2.4	157.2	3.8	126.9
09/28/03	-82.3	-209.2	2.5	0.75	1.9	0.8	1.5	158.7	0.0	126.9
09/29/03	-83.8	-210.7	3.5	0.75	2.6	0.8	2.1	160.8	0.0	126.9
09/30/03	-85.9	-212.8	2.5	0.75	1.9	0.8	1.5	162.3	0.0	126.9

Replenishment 5 (25% Evapotranspiration 1 Lateral per 2 rows) October

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
10/01/03	-87.4	-214.3	4.0	0.75	3	0.8	2.4	164.7	4.0	130.9
10/02/03	-85.8	-216.7	3.5	0.75	2.6	0.8	2.1	166.8	0.0	130.9
10/03/03	-87.9	-218.8	3.0	0.75	2.3	0.8	1.8	168.6	0.0	130.9
10/04/03	-89.7	-220.6	3.5	0.75	2.6	0.8	2.1	170.7	3.0	133.9
10/05/03	-88.8	-222.7	3.0	0.75	2.3	0.8	1.8	172.5	0.0	133.9
10/06/03	-90.6	-224.5	3.0	0.75	2.3	0.8	1.8	174.3	0.0	133.9
10/07/03	-92.4	-226.3	4.0	0.75	3.0	0.8	2.4	176.7	0.0	133.9
10/08/03	-94.8	-228.7	5.0	0.75	3.8	0.8	3.0	179.7	4.3	138.2
10/09/03	-93.5	-231.7	6.0	0.75	4.5	0.8	3.6	183.3	0.0	138.2
10/10/03	-97.1	-235.3	5.5	0.75	4.1	0.8	3.3	186.6	0.0	138.2
10/11/03	-100.4	-238.6	5.0	0.75	3.8	0.8	3.0	189.6	4.0	142.2
10/12/03	-99.4	-241.6	5.0	0.75	3.8	0.8	3.0	192.6	0.0	142.2
10/13/03	-102.4	-244.6	4.5	0.75	3.4	0.8	2.7	195.3	0.0	142.2
10/14/03	-105.1	-247.3	4.5	0.75	3.4	0.8	2.7	198.0	0.0	142.2
10/15/03	-107.8	-250.0	4.0	0.75	3.0	0.8	2.4	200.4	5.8	148.0
10/16/03	-104.4	-252.4	3.5	0.75	2.6	0.8	2.1	202.5	0.0	148.0
10/17/03	-106.5	-254.5	2.5	0.75	1.9	0.8	1.5	204.0	0.0	148.0
10/18/03	-108.0	-256.0	1.9	0.75	1.4	0.8	1.1	205.1	3.8	151.8
10/19/03	-105.3	-257.1	4.0	0.75	3.0	0.8	2.4	207.5	0.0	151.8
10/20/03	-107.7	-259.5	3.0	0.75	2.3	0.8	1.8	209.3	0.0	151.8
10/21/03	-109.5	-261.3	5.0	0.75	3.8	0.8	3.0	212.3	0.0	151.8
10/22/03	-112.5	-264.3	5.0	0.75	3.8	0.8	3.0	215.3	3.8	155.6
10/23/03	-111.7	-267.3	5.0	0.75	3.8	0.8	3.0	218.3	0.0	155.6
10/24/03	-114.7	-270.3	4.5	0.75	3.4	0.8	2.7	221.0	0.0	155.6
10/25/03	-117.4	-273.0	4.5	0.75	3.4	0.8	2.7	223.7	3.8	159.4
10/26/03	-116.3	-275.7	5.0	0.75	3.8	0.8	3.0	226.7	0.0	159.4
10/27/03	-119.3	-278.7	4.0	0.75	3.0	0.8	2.4	229.1	0.0	159.4
10/28/03	-121.7	-281.1	5.0	0.75	3.8	0.8	3.0	232.1	0.0	159.4
10/29/03	-124.7	-284.1	5.0	0.75	3.8	0.8	3.0	235.1	5.1	164.5
10/30/03	-122.6	-287.1	4.5	0.75	3.4	0.8	2.7	237.8	0.0	164.5
10/31/03	-125.3	-289.8	4.0	0.75	3.0	0.8	2.4	240.2	0.0	164.5

Replenishment 5 (25% Evapotranspiration 1 Lateral per 2 rows) November

ay	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
11/01/03	-127.7	-292.2	3.5	0.75	2.625	0.8	2.1	242.3	4.0	168.5
11/02/03	-125.8	-294.3	4.5	0.75	3.4	0.8	2.7	245.0	0.0	168.5
11/03/03	-128.5	-297.0	4.5	0.75	3.4	0.8	2.7	247.7	0.0	168.5
11/04/03	-131.2	-299.7	4.5	0.75	3.4	0.8	2.7	250.4	0.0	168.5
11/05/03	-133.9	-302.4	4.0	0.75	3.0	0.8	2.4	252.8	4.9	173.4
11/06/03	-131.4	-304.8	4.5	0.75	3.4	0.8	2.7	255.5	0.0	173.4
11/07/03	-134.1	-307.5	6.5	0.75	4.9	0.8	3.9	259.4	0.0	173.4
11/08/03	-138.0	-311.4	6.0	0.75	4.5	0.8	3.6	263.0	3.9	177.3
11/09/03	-137.7	-315.0	4.0	0.75	3.0	0.8	2.4	265.4	0.0	177.3
11/10/03	-140.1	-317.4	4.0	0.75	3.0	0.8	2.4	267.8	0.0	177.3
11/11/03	-142.5	-319.8	5.0	0.75	3.8	0.8	3.0	270.8	0.0	177.3
11/12/03	-145.5	-322.8	5.0	0.75	3.8	0.8	3.0	273.8	5.8	183.1
11/13/03	-142.7	-325.8	6.5	0.75	4.9	0.8	3.9	277.7	0.0	183.1
11/14/03	-146.6	-329.7	4.5	0.75	3.4	0.8	2.7	280.4	0.0	183.1
11/15/03	-149.3	-332.4	5.0	0.75	3.8	0.8	3.0	283.4	3.8	186.9
11/16/03	-148.5	-335.4	5.0	0.75	3.8	0.8	3.0	286.4	0.0	186.9
11/17/03	-151.5	-338.4	5.5	0.75	4.1	0.8	3.3	289.7	0.0	186.9
11/18/03	-154.8	-341.7	4.5	0.75	3.4	0.8	2.7	292.4	0.0	186.9
11/19/03	-157.5	-344.4	4.5	0.75	3.4	0.8	2.7	295.1	5.2	192.1
11/20/03	-155.0	-347.1	6.0	0.75	4.5	0.8	3.6	298.7	0.0	192.1
11/21/03	-158.6	-350.7	6.0	0.75	4.5	0.8	3.6	302.3	0.0	192.1
11/22/03	-162.2	-354.3	5.5	0.75	4.1	0.8	3.3	305.6	4.1	196.2
11/23/03	-161.4	-357.6	5.0	0.75	3.8	0.8	3.0	308.6	0.0	196.2
11/24/03	-164.4	-360.6	4.5	0.75	3.4	0.8	2.7	311.3	0.0	196.2
11/25/03	-167.1	-363.3	3.2	0.75	2.4	0.8	1.9	313.3	0.0	196.2
11/26/03	-169.1	-365.3	4.0	0.75	3.0	0.8	2.4	315.7	4.4	200.6
11/27/03	-167.1	-367.7	3.5	0.75	2.6	0.8	2.1	317.8	0.0	200.6
11/28/03	9999	9999	9999	0.75	9999	0.8	9999	9999	0.0	9999
11/29/03	-169.2	-369.8	5.0	0.75	3.8	0.8	3.0	320.8	3.2	203.8
11/30/03	-169.0	-372.8	4.6	0.75	3.5	0.8	2.8	323.5	0.0	203.8

Replenishment 6 (100% Evapotranspiration 1 Lateral per 2 rows) July

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
07/01/03	-22.5	-22.5	2.0	0.75	1.5	0.8	1.2	1.2	9.0	9.0
07/02/03	-14.7	-23.7	2.0	0.75	1.5	0.8	1.2	2.4	0.0	9.0
07/03/03	-15.9	-24.9	2.0	0.75	1.5	0.8	1.2	3.6	0.0	9.0
07/04/03	-17.1	-26.1	2.0	0.75	1.5	0.8	1.2	4.8	19.5	28.5
07/05/03	1.2	-27.3	2.5	0.75	1.9	0.8	1.5	6.3	0.0	28.5
07/06/03	-0.3	-28.8	3.0	0.75	2.3	0.8	1.8	8.1	0.0	28.5
07/07/03	-2.1	-30.6	2.5	0.75	1.9	0.8	1.5	9.6	19.0	47.5
07/08/03	15.4	-32.1	2.5	0.75	1.9	0.8	1.5	11.1	0.0	47.5
07/09/03	13.9	-33.6	2.5	0.75	1.9	0.8	1.5	12.6	0.0	47.5
07/10/03	12.4	-35.1	2.5	0.75	1.9	0.8	1.5	14.1	22.5	70.0
07/11/03	33.4	-36.6	2.0	0.75	1.5	0.8	1.2	15.3	0.0	70.0
07/12/03	32.2	-37.8	2.5	0.75	1.9	0.8	1.5	16.8	0.0	70.0
07/13/03	30.7	-39.3	2.5	0.75	1.9	0.8	1.5	18.3	0.0	70.0
07/14/03	29.2	-40.8	3.0	0.75	2.3	0.8	1.8	20.1	66.5	136.5
07/15/03	93.9	-42.6	3.0	0.75	2.3	0.8	1.8	21.9	0.0	136.5
07/16/03	92.1	-44.4	2.0	0.75	1.5	0.8	1.2	23.1	0.0	136.5
07/17/03	90.9	-45.6	2.5	0.75	1.9	0.8	1.5	24.6	0.0	136.5
07/18/03	89.4	-47.1	2.0	0.75	1.5	0.8	1.2	25.8	0.0	136.5
07/19/03	88.2	-48.3	2.5	0.75	1.9	0.8	1.5	27.3	0.0	136.5
07/20/03	86.7	-49.8	2.5	0.75	1.9	0.8	1.5	28.8	0.0	136.5
07/21/03	85.2	-51.3	2.0	0.75	1.5	0.8	1.2	30.0	14.0	150.5
07/22/03	98.0	-52.5	3.0	0.75	2.3	0.8	1.8	31.8	0.0	150.5
07/23/03	96.2	-54.3	3.0	0.75	2.3	0.8	1.8	33.6	0.0	150.5
07/24/03	94.4	-56.1	3.0	0.75	2.3	0.8	1.8	35.4	8.5	159.0
07/25/03	101.1	-57.9	2.5	0.75	1.9	0.8	1.5	36.9	0.0	159.0
07/26/03	99.6	-59.4	2.5	0.75	1.9	0.8	1.5	38.4	0.0	159.0
07/27/03	98.1	-60.9	3.0	0.75	2.3	0.8	1.8	40.2	0.0	159.0
07/28/03	96.3	-62.7	2.5	0.75	1.9	0.8	1.5	41.7	11.5	170.5
07/29/03	106.3	-64.2	3.0	0.75	2.3	0.8	1.8	43.5	0.0	170.5
07/30/03	104.5	-66.0	3.5	0.75	2.6	0.8	2.1	45.6	0.0	170.5
07/31/03	102.4	-68.1	4.0	0.75	3.0	0.8	2.4	48.0	9.5	180.0

Replenishment 6 (100% Evapotranspiration 1 Lateral per 2 rows) August

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
08/01/03	109.5	-70.5	3.5	0.75	2.6	0.8	2.1	50.1	0.0	180.0
08/02/03	107.4	-72.6	3.5	0.75	2.6	0.8	2.1	52.2	0.0	180.0
08/03/03	105.3	-74.7	3.5	0.75	2.6	0.8	2.1	54.3	0.0	180.0
08/04/03	103.2	-76.8	3.5	0.75	2.6	0.8	2.1	56.4	0.0	180.0
08/05/03	101.1	-78.9	3.0	0.75	2.3	0.8	1.8	58.2	0.0	180.0
08/06/03	99.3	-80.7	3.0	0.75	2.3	0.8	1.8	60.0	0.0	180.0
08/07/03	97.5	-82.5	3.0	0.75	2.3	0.8	1.8	61.8	26.0	206.0
08/08/03	121.7	-84.3	2.5	0.75	1.9	0.8	1.5	63.3	0.0	206.0
08/09/03	120.2	-85.8	3.0	0.75	2.3	0.8	1.8	65.1	0.0	206.0
08/10/03	118.4	-87.6	2.5	0.75	1.9	0.8	1.5	66.6	0.0	206.0
08/11/03	116.9	-89.1	2.5	0.75	1.9	0.8	1.5	68.1	14.7	220.7
08/12/03	130.1	-90.6	3.0	0.75	2.3	0.8	1.8	69.9	0.0	220.7
08/13/03	128.3	-92.4	3.0	0.75	2.3	0.8	1.8	71.7	0.0	220.7
08/14/03	126.5	-94.2	3.0	0.75	2.3	0.8	1.8	73.5	9.5	230.2
08/15/03	134.2	-96.0	3.5	0.75	2.6	0.8	2.1	75.6	0.0	230.2
08/16/03	132.1	-98.1	4.0	0.75	3.0	0.8	2.4	78.0	0.0	230.2
08/17/03	129.7	-100.5	4.0	0.75	3.0	0.8	2.4	80.4	0.0	230.2
08/18/03	127.3	-102.9	3.5	0.75	2.6	0.8	2.1	82.5	15.7	245.9
08/19/03	140.9	-105.0	3.5	0.75	2.6	0.8	2.1	84.6	0.0	245.9
08/20/03	138.8	-107.1	3.0	0.75	2.3	0.8	1.8	86.4	0.0	245.9
08/21/03	137.0	-108.9	0.5	0.75	0.4	0.8	0.3	86.7	11.0	256.9
08/22/03	147.7	-109.2	2.0	0.75	1.5	0.8	1.2	87.9	0.0	256.9
08/23/03	146.5	-110.4	2.5	0.75	1.9	0.8	1.5	89.4	0.0	256.9
08/24/03	145.0	-111.9	3.0	0.75	2.3	0.8	1.8	91.2	0.0	256.9
08/25/03	143.2	-113.7	3.0	0.75	2.3	0.8	1.8	93.0	0.0	256.9
08/26/03	141.4	-115.5	3.5	0.75	2.6	0.8	2.1	95.1	0.0	256.9
08/27/03	139.3	-117.6	4.0	0.75	3.0	0.8	2.4	97.5	18.9	275.8
08/28/03	155.8	-120.0	3.5	0.75	2.6	0.8	2.1	99.6	0.0	275.8
08/29/03	153.7	-122.1	3.5	0.75	2.6	0.8	2.1	101.7	0.0	275.8
08/30/03	151.6	-124.2	4.0	0.75	3.0	0.8	2.4	104.1	0.0	275.8
08/31/03	149.2	-126.6	4.0	0.75	3.0	0.8	2.4	106.5	0.0	275.8

Replenishment 6 (100% Evapotranspiration 1 Lateral per 2 rows) September

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
09/01/03	146.8	-129.0	4.0	0.75	3	0.8	2.4	108.9	8.7	284.5
09/02/03	153.1	-131.4	2.0	0.75	1.5	0.8	1.2	110.1	0.0	284.5
09/03/03	151.9	-132.6	1.5	0.75	1.1	0.8	0.9	111.0	0.0	284.5
09/04/03	151.0	-133.5	1.0	0.75	0.8	0.8	0.6	111.6	0.0	284.5
09/05/03	150.4	-134.1	3.0	0.75	2.3	0.8	1.8	113.4	0.0	284.5
09/06/03	148.6	-135.9	3.5	0.75	2.6	0.8	2.1	115.5	1.3	285.8
09/07/03	147.8	-138.0	3.0	0.75	2.3	0.8	1.8	117.3	0.0	285.8
09/08/03	146.0	-139.8	3.5	0.75	2.6	0.8	2.1	119.4	0.0	285.8
09/09/03	143.9	-141.9	4.5	0.75	3.4	0.8	2.7	122.1	0.0	285.8
09/10/03	141.2	-144.6	3.5	0.75	2.6	0.8	2.1	124.2	16.3	302.1
09/11/03	155.4	-146.7	3.5	0.75	2.6	0.8	2.1	126.3	0.0	302.1
09/12/03	153.3	-148.8	3.0	0.75	2.3	0.8	1.8	128.1	0.0	302.1
09/13/03	151.5	-150.6	4.0	0.75	3.0	0.8	2.4	130.5	20.0	322.1
09/14/03	169.1	-153.0	4.0	0.75	3.0	0.8	2.4	132.9	0.0	322.1
09/15/03	166.7	-155.4	4.0	0.75	3.0	0.8	2.4	135.3	0.0	322.1
09/16/03	164.3	-157.8	3.0	0.75	2.3	0.8	1.8	137.1	0.0	322.1
09/17/03	162.5	-159.6	2.0	0.75	1.5	0.8	1.2	138.3	7.9	330.0
09/18/03	169.2	-160.8	1.5	0.75	1.1	0.8	0.9	139.2	0.0	330.0
09/19/03	168.3	-161.7	2.0	0.75	1.5	0.8	1.2	140.4	0.0	330.0
09/20/03	167.1	-162.9	2.0	0.75	1.5	0.8	1.2	141.6	5.8	335.8
09/21/03	171.7	-164.1	3.5	0.75	2.6	0.8	2.1	143.7	0.0	335.8
09/22/03	169.6	-166.2	3.0	0.75	2.3	0.8	1.8	145.5	0.0	335.8
09/23/03	167.8	-168.0	4.0	0.75	3.0	0.8	2.4	147.9	0.0	335.8
09/24/03	165.4	-170.4	3.5	0.75	2.6	0.8	2.1	150.0	0.0	335.8
09/25/03	163.3	-172.5	4.0	0.75	3.0	0.8	2.4	152.4	0.0	335.8
09/26/03	160.9	-174.9	4.0	0.75	3.0	0.8	2.4	154.8	0.0	335.8
09/27/03	158.5	-177.3	4.0	0.75	3.0	0.8	2.4	157.2	15.2	351.0
09/28/03	171.3	-179.7	2.5	0.75	1.9	0.8	1.5	158.7	0.0	351.0
09/29/03	169.8	-181.2	3.5	0.75	2.6	0.8	2.1	160.8	0.0	351.0
09/30/03	167.7	-183.3	2.5	0.75	1.9	0.8	1.5	162.3	0.0	351.0

Replenishment 6 (100% Evapotranspiration 1 Lateral per 2 rows) October

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
10/01/03	166.2	-184.8	4.0	0.75	3	0.8	2.4	164.7	16.1	367.1
10/02/03	179.9	-187.2	3.5	0.75	2.6	0.8	2.1	166.8	0.0	367.1
10/03/03	177.8	-189.3	3.0	0.75	2.3	0.8	1.8	168.6	0.0	367.1
10/04/03	176.0	-191.1	3.5	0.75	2.6	0.8	2.1	170.7	12.1	379.2
10/05/03	186.0	-193.2	3.0	0.75	2.3	0.8	1.8	172.5	0.0	379.2
10/06/03	184.2	-195.0	3.0	0.75	2.3	0.8	1.8	174.3	0.0	379.2
10/07/03	182.4	-196.8	4.0	0.75	3.0	0.8	2.4	176.7	0.0	379.2
10/08/03	180.0	-199.2	5.0	0.75	3.8	0.8	3.0	179.7	17.4	396.6
10/09/03	194.4	-202.2	6.0	0.75	4.5	0.8	3.6	183.3	0.0	396.6
10/10/03	190.8	-205.8	5.5	0.75	4.1	0.8	3.3	186.6	0.0	396.6
10/11/03	187.5	-209.1	5.0	0.75	3.8	0.8	3.0	189.6	15.8	412.4
10/12/03	200.3	-212.1	5.0	0.75	3.8	0.8	3.0	192.6	0.0	412.4
10/13/03	197.3	-215.1	4.5	0.75	3.4	0.8	2.7	195.3	0.0	412.4
10/14/03	194.6	-217.8	4.5	0.75	3.4	0.8	2.7	198.0	0.0	412.4
10/15/03	191.9	-220.5	4.0	0.75	3.0	0.8	2.4	200.4	23.2	435.6
10/16/03	212.7	-222.9	3.5	0.75	2.6	0.8	2.1	202.5	0.0	435.6
10/17/03	210.6	-225.0	2.5	0.75	1.9	0.8	1.5	204.0	0.0	435.6
10/18/03	209.1	-226.5	1.9	0.75	1.4	0.8	1.1	205.1	15.3	450.9
10/19/03	223.3	-227.6	4.0	0.75	3.0	0.8	2.4	207.5	0.0	450.9
10/20/03	220.9	-230.0	3.0	0.75	2.3	0.8	1.8	209.3	0.0	450.9
10/21/03	219.1	-231.8	5.0	0.75	3.8	0.8	3.0	212.3	0.0	450.9
10/22/03	216.1	-234.8	5.0	0.75	3.8	0.8	3.0	215.3	15.1	466.0
10/23/03	228.2	-237.8	5.0	0.75	3.8	0.8	3.0	218.3	0.0	466.0
10/24/03	225.2	-240.8	4.5	0.75	3.4	0.8	2.7	221.0	0.0	466.0
10/25/03	222.5	-243.5	4.5	0.75	3.4	0.8	2.7	223.7	15.3	481.3
10/26/03	235.1	-246.2	5.0	0.75	3.8	0.8	3.0	226.7	0.0	481.3
10/27/03	232.1	-249.2	4.0	0.75	3.0	0.8	2.4	229.1	0.0	481.3
10/28/03	229.7	-251.6	5.0	0.75	3.8	0.8	3.0	232.1	0.0	481.3
10/29/03	226.7	-254.6	5.0	0.75	3.8	0.8	3.0	235.1	20.5	501.8
10/30/03	244.2	-257.6	4.5	0.75	3.4	0.8	2.7	237.8	0.0	501.8
10/31/03	241.5	-260.3	4.0	0.75	3.0	0.8	2.4	240.2	0.0	501.8

Replenishment 6 (100% Evapotranspiration 1 Lateral per 2 rows) November

Day	Actual SWD (mm)	Cumm SWD (mm)	Epan (mm)	Kpan	ETo (mm)	kc	ET_c (mm)	Cumm ET_c(mm)	I_g (mm)	Cumm I_g (mm)
11/01/03	239.1	-262.7	3.5	0.75	2.625	0.8	2.1	242.3	16.3	518.1
11/02/03	253.3	-264.8	4.5	0.75	3.4	0.8	2.7	245.0	0.0	518.1
11/03/03	250.6	-267.5	4.5	0.75	3.4	0.8	2.7	247.7	0.0	518.1
11/04/03	247.9	-270.2	4.5	0.75	3.4	0.8	2.7	250.4	0.0	518.1
11/05/03	245.2	-272.9	4.0	0.75	3.0	0.8	2.4	252.8	19.5	537.6
11/06/03	262.3	-275.3	4.5	0.75	3.4	0.8	2.7	255.5	0.0	537.6
11/07/03	259.6	-278.0	6.5	0.75	4.9	0.8	3.9	259.4	0.0	537.6
11/08/03	255.7	-281.9	6.0	0.75	4.5	0.8	3.6	263.0	15.8	553.4
11/09/03	267.9	-285.5	4.0	0.75	3.0	0.8	2.4	265.4	0.0	553.4
11/10/03	265.5	-287.9	4.0	0.75	3.0	0.8	2.4	267.8	0.0	553.4
11/11/03	263.1	-290.3	5.0	0.75	3.8	0.8	3.0	270.8	0.0	553.4
11/12/03	260.1	-293.3	5.0	0.75	3.8	0.8	3.0	273.8	23.2	576.6
11/13/03	280.3	-296.3	6.5	0.75	4.9	0.8	3.9	277.7	0.0	576.6
11/14/03	276.4	-300.2	4.5	0.75	3.4	0.8	2.7	280.4	0.0	576.6
11/15/03	273.7	-302.9	5.0	0.75	3.8	0.8	3.0	283.4	15.3	591.9
11/16/03	286.0	-305.9	5.0	0.75	3.8	0.8	3.0	286.4	0.0	591.9
11/17/03	283.0	-308.9	5.5	0.75	4.1	0.8	3.3	289.7	0.0	591.9
11/18/03	279.7	-312.2	4.5	0.75	3.4	0.8	2.7	292.4	0.0	591.9
11/19/03	277.0	-314.9	4.5	0.75	3.4	0.8	2.7	295.1	21.0	612.9
11/20/03	295.3	-317.6	6.0	0.75	4.5	0.8	3.6	298.7	0.0	612.9
11/21/03	291.7	-321.2	6.0	0.75	4.5	0.8	3.6	302.3	0.0	612.9
11/22/03	288.1	-324.8	5.5	0.75	4.1	0.8	3.3	305.6	16.3	629.2
11/23/03	301.1	-328.1	5.0	0.75	3.8	0.8	3.0	308.6	0.0	629.2
11/24/03	298.1	-331.1	4.5	0.75	3.4	0.8	2.7	311.3	0.0	629.2
11/25/03	295.4	-333.8	3.2	0.75	2.4	0.8	1.9	313.3	0.0	629.2
11/26/03	293.4	-335.8	4.0	0.75	3.0	0.8	2.4	315.7	17.6	646.8
11/27/03	308.6	-338.2	3.5	0.75	2.6	0.8	2.1	317.8	0.0	646.8
11/28/03	306.5	-340.3	3.5	0.75	2.6	0.8	2.1	319.9	0.0	646.8
11/29/03	304.4	-342.4	5.0	0.75	3.8	0.8	3.0	320.8	12.6	659.4
11/30/03	314.0	-345.4	4.6	0.75	3.5	0.8	2.8	323.5	0.0	659.4

Appendix 11: Calculation Procedure for Soil wetted Portion (WP)

WP Irrigation for application 1, 2, 3, and 4

From Equation 8: => $WD = 0.7 + 0.11q_e$ q_e=2.3

Where: WD = Wetted diameter, qe = Emitter discharge L hr^{-1}

$$\Rightarrow = 0.7 + (0.11 * 2.3)$$
$$= 0.953$$
$$= \underline{0.95}$$

$$WP = \frac{(WD + X)}{R} \times 100$$ R = 1.2m, X = 0 (for RAM 17)

$$= \frac{(0.95 + 0) \times 100}{1.2}$$
$$= 79.2\ \%$$
$$= \underline{0.80}$$

Therefore WP for irrigation application level 1, 2, 3 and 4 was supposed to be 0.80.

WP for irrigation application 5 and 6

$$WD = 0.7 + q_e$$ $q_e = 3.5$

$$= 0.7 + (0.11 * 3.5)$$
$$= 1.085$$
$$= \underline{1.09}$$

$$WD = \frac{(WD + X)}{R} \times 100$$ R = 2.4 X = 0

$$= \frac{(1.09 + 0) \times 100}{2.4}$$
$$= 45.4\ \%$$
$$= \underline{0.45}$$

Appendix 12: Analysis of Variance (ANOVA)

1. Dependent variable yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Clone	3	296.41095764	98.80365255	45.76	0.0001
Irrigation	5	20.26348958	4.05269792	1.88	0.1037
Replication	5	17.84506458	3.56901292	1.65	0.1517
Clone*Irrigation	15	41.73519653	2.78234644	1.29	0.2206
Error	115	248.31768542	2.15928422		
Corrected Total	143	624.57239375			

R-Square: 0. 602420, C.V.: 22.97886, Root MSE: 1.46945031, Green leaf yield Mean: 197.6168259

2. Dependent variable crop height

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Clone	3	1730.51317431	576.83772477	39.75	0.0001
Irrigation	5	82.60355347	16.52071069	1.14	0.3441
Replication	5	88.13069514	17.62613903	1.21	0.1517
Clone*Irrigation	15	221.25908819	14.75060588	1.29	0.3067
Error	115	1668.72578819	14.51065903		
Corrected Total	143	3791.23229931			

R-Square: 0. 559846, C.V.: 5.727490, Root MSE: 3.80928589, Crop height Mean: 66.50881944

3. Dependent variable crop cover

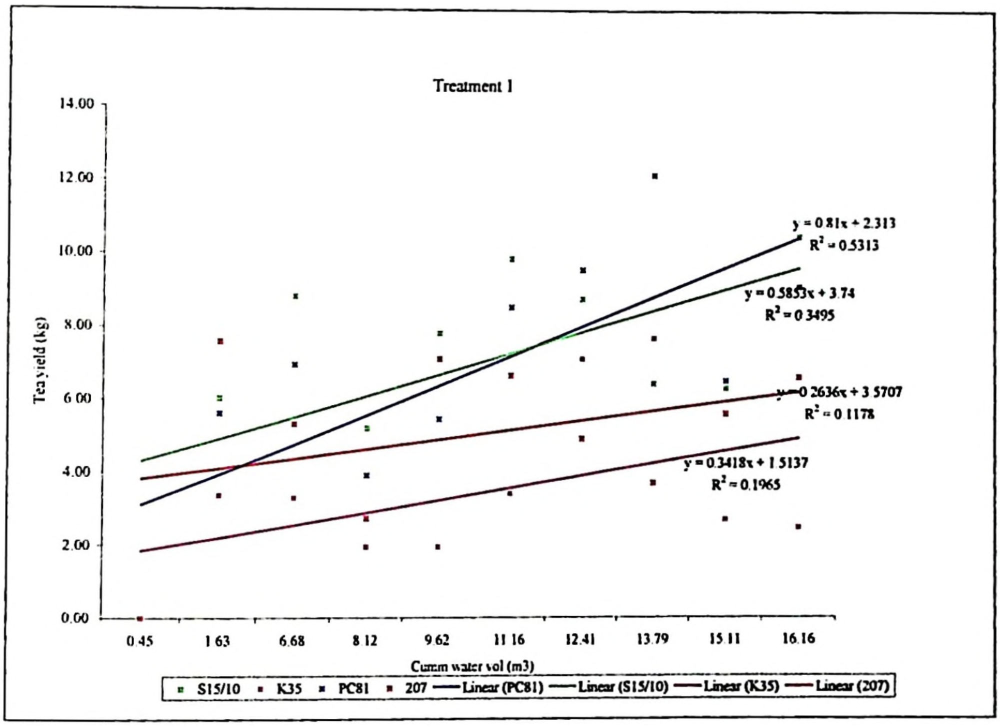
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Clone	3	2071.67144097	690.55714699	32.31	0.0001
Irrigation	5	161.64800347	32.32960069	1.51	0.1913
Replication	5	143.95529514	28.79105903	1.35	0.2496
Clone*Irrigation	15	98.89887153	6.59325810	0.31	0.9938
Error	115	2457.80512153	21.37221845		
Corrected Total	143	4933.97873264			

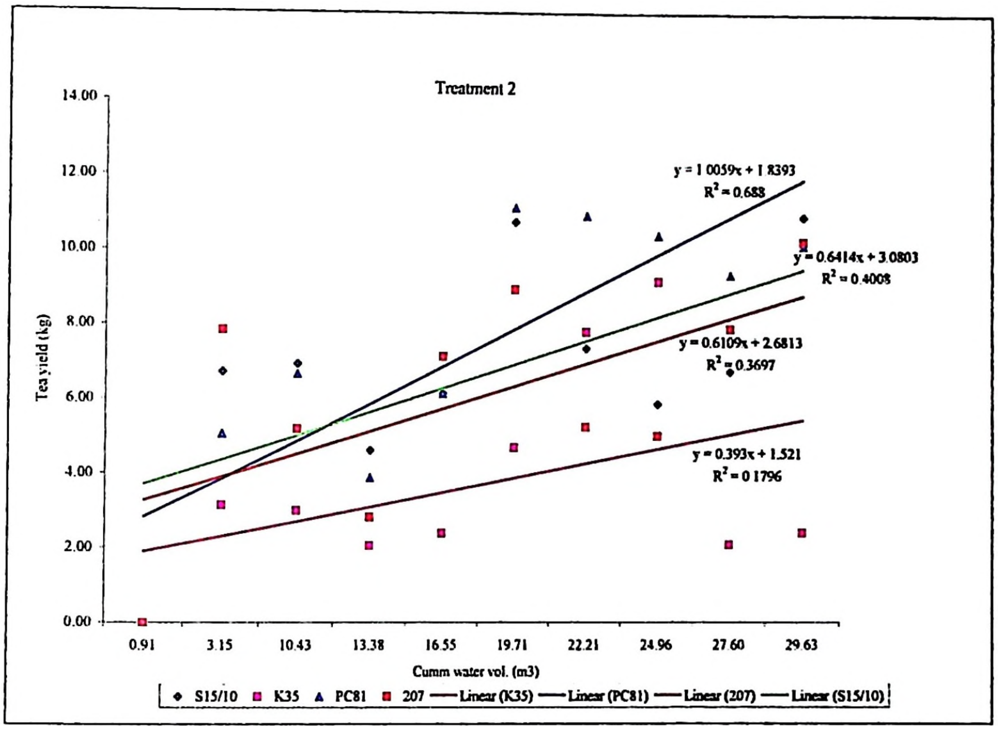
R-Square: 0. 501861, C.V.: 3.637828, Root MSE: 4.62300967, Crop cover Mean: 0.635457986

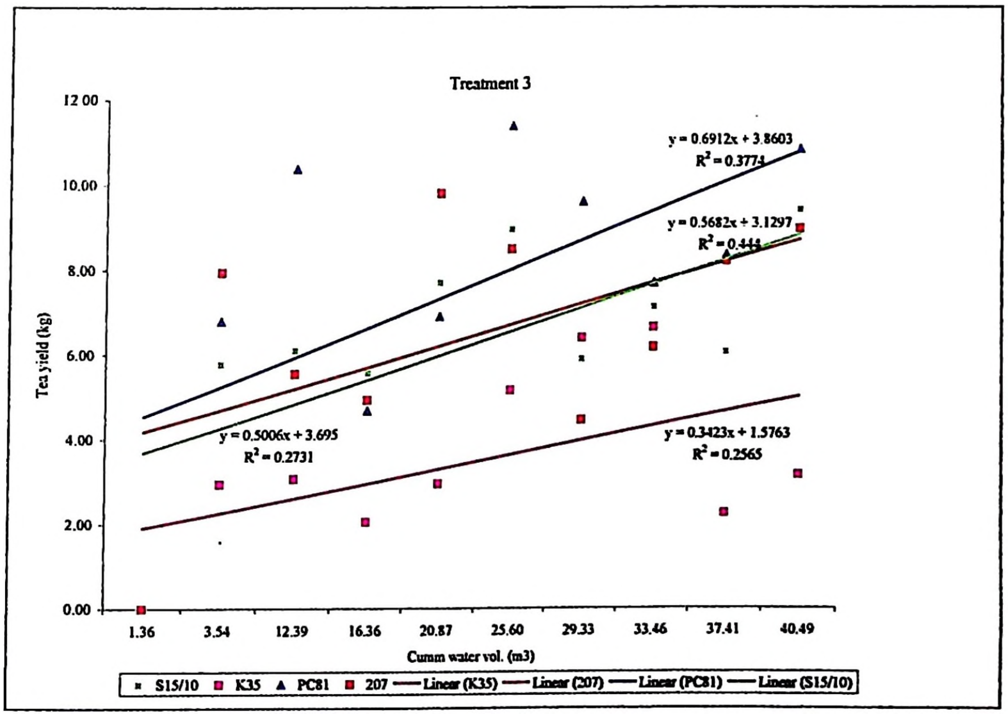
Appendix 13: Raw data of Made tea yield (kgha^{-1})

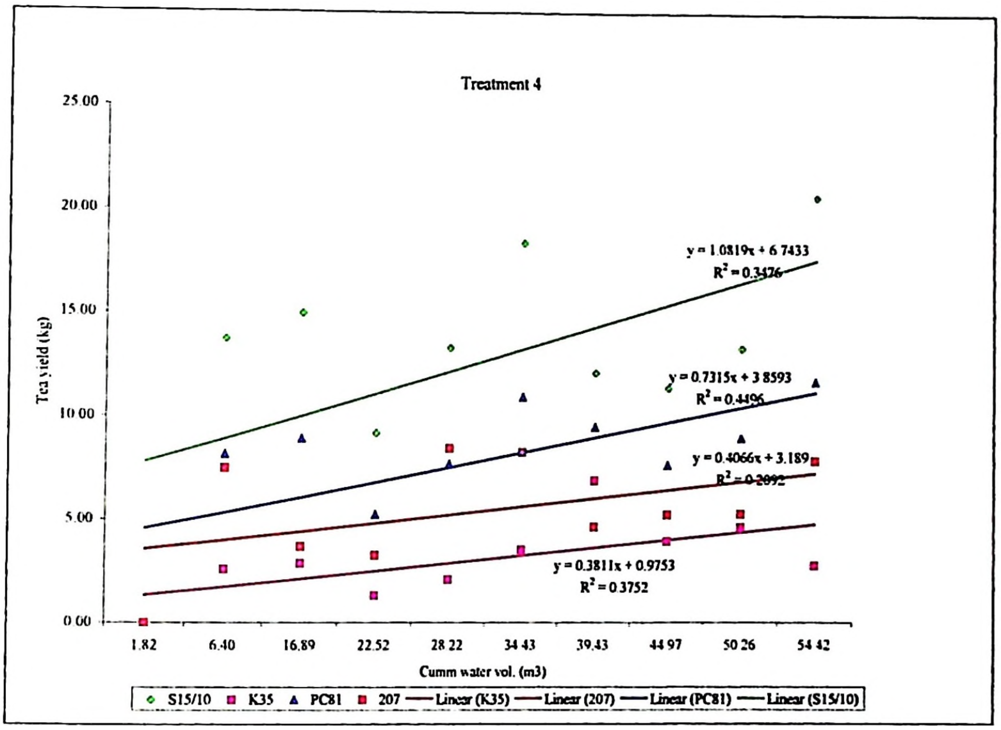
	Replication					
	1	2	3	4	5	6
			Clone S15/10			
Irrigation						
I1 (1)	226.39	515.28	286.11	177.78	254.17	245.83
I2 (1)	255.56	163.89	254.17	252.78	226.39	247.22
I3 (1)	180.56	255.56	227.78	197.22	226.39	218.06
I4 (1)	252.78	202.78	265.28	208.33	176.39	244.44
I1 (2)	186.11	234.72	206.94	172.22	177.78	205.56
I4 (2)	225.00	212.50	208.33	197.22	181.94	193.06
			CloneK35			
I1 (1)	119.44	26.39	173.61	147.22	118.06	112.50
I2 (1)	173.61	38.89	122.22	155.56	95.83	190.28
I3 (1)	116.67	26.39	148.61	123.61	133.33	127.78
I4 (1)	113.89	25.00	169.44	100.00	87.50	90.28
I1 (2)	102.78	22.22	109.72	104.17	97.22	87.50
I4 (2)	125.00	27.78	81.94	93.06	104.17	131.94
			Clone PC81			
I1 (1)	252.78	56.94	220.83	229.17	256.94	225.00
I2 (1)	233.33	51.39	252.78	281.94	258.33	255.56
I3 (1)	229.17	51.39	276.39	251.39	275.00	215.28
I4 (1)	219.44	48.61	212.50	230.56	200.00	279.17
I1 (2)	227.78	50.00	195.83	231.94	195.83	245.83
I4 (2)	500.00	111.11	230.56	200.00	183.33	320.83
			Clone 207			
I1 (1)	181.94	206.94	215.28	168.06	173.61	156.94
I2 (1)	208.33	187.50	197.22	209.72	230.56	208.33
I3 (1)	248.61	240.28	229.17	197.22	234.72	143.06
I4 (1)	205.56	190.28	186.11	173.61	195.83	244.44
I1 (2)	188.89	156.94	150.00	145.83	162.50	134.72
I4 (2)	200.00	172.22	179.17	151.39	175.00	227.78

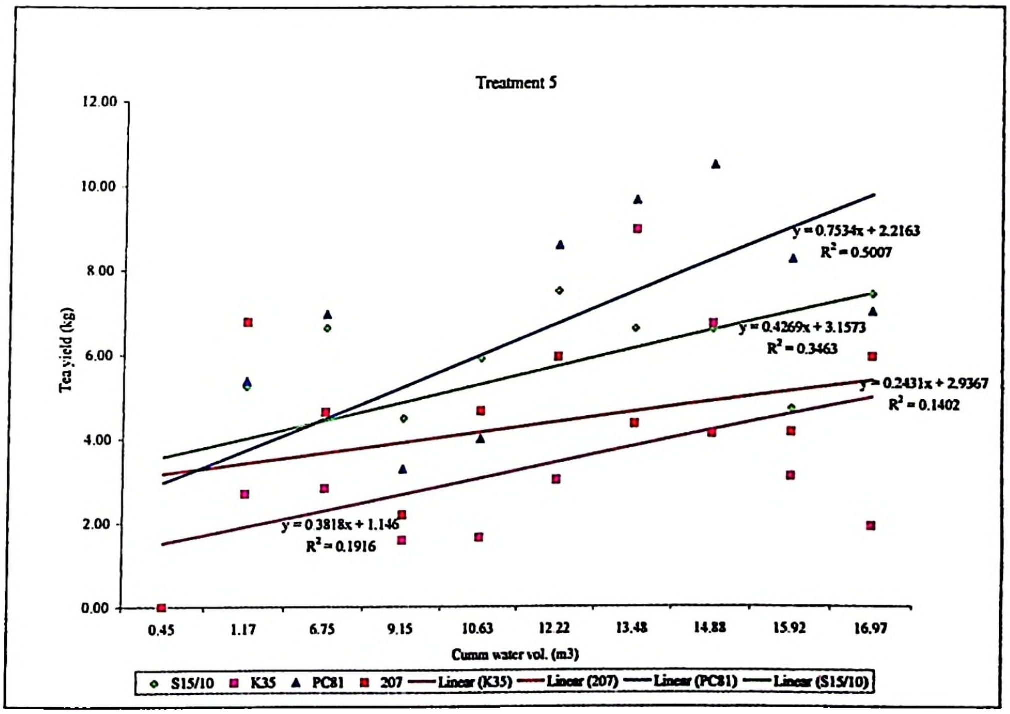
Appendix 14: Clonal yield functions

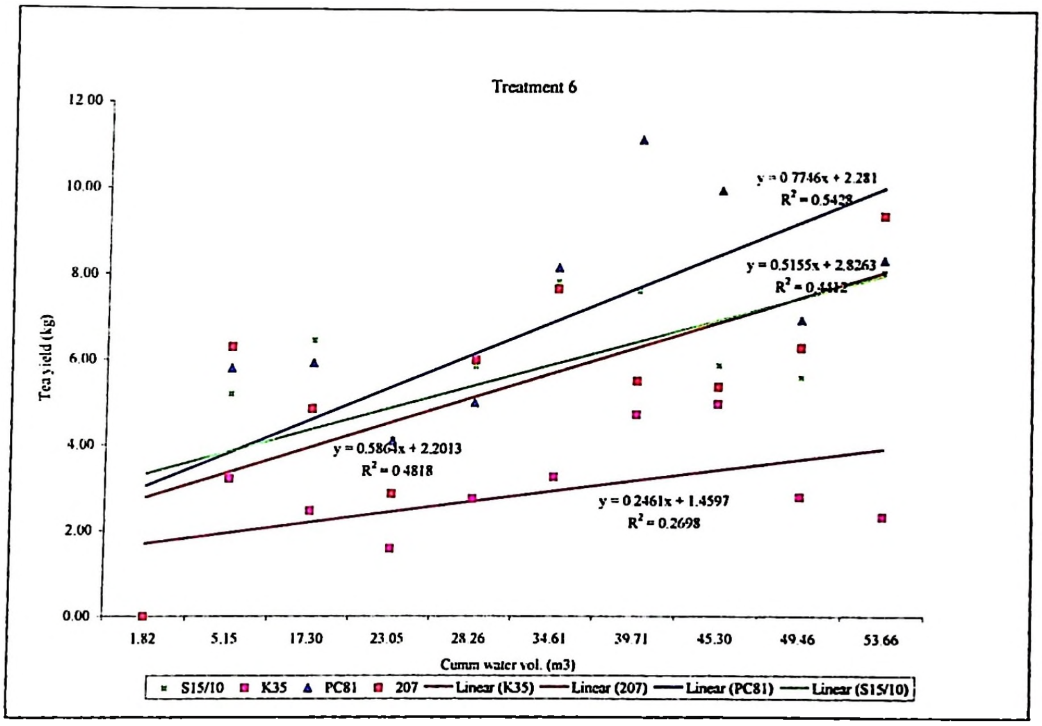



Treatment 2
y = 1.0059x + 1.8393
R² = 0.688
y = 0.6414x + 3.0803
R² = 0.4008
y = 0.6109x + 2.6813
R² = 0.3697
y = 0.393x + 1.521
R² = 0.1796
Tea yield (kg)
Cumm water vol. (m3)
S15/10 K35 PC81 207 Linear (K35) Linear (PC81) Linear (207) Linear (S15/10)


Treatment 3
y = 0.6912x + 3.8603
R² = 0.3774
y = 0.5682x + 3.1297
R² = 0.444
y = 0.5006x + 3.695
R² = 0.2731
y = 0.3423x + 1.5763
R² = 0.2565
Tea yield (kg)
Cumm water vol. (m3)
S15/10 K35 PC81 207 Linear (K35) Linear (207) Linear (PC81) Linear (S15/10)


Treatment 4
25.00
20.00
15.00
10.00
5.00
0.00
Tea yield (kg)
1.82
6.40
16.89
22.52
28.22
34.43
39.43
44.97
50.26
54.42
Cumm water vol. (m3)
y = 1.0819x + 6.7433
R² = 0.3476
y = 0.7315x + 3.8593
R² = 0.4496
y = 0.4066x + 3.189
R² = 0.2092
y = 0.3811x + 0.9753
R² = 0.3752
S15/10
K35
PC81
207
Linear (K35)
Linear (207)
Linear (PC81)
Linear (S15/10)


Treatment 5
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Tea yield (kg)
0.45
1.17
6.75
9.15
10.63
12.22
13.48
14.88
15.92
16.97
Cumm water vol. (m3)
y = 0.7534x + 2.2163
R² = 0.5007
y = 0.4269x + 3.1573
R² = 0.3463
y = 0.2431x + 2.9367
R² = 0.1402
y = 0.3818x + 1.146
R² = 0.1916
S15/10
K35
PC81
207
Linear (K35)
Linear (207)
Linear (PC81)
Linear (S15/10)



Treatment 6
Tea yield (kg)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1.82
5.15
17.30
23.05
28.26
34.61
39.71
45.30
49.46
53.66
Cumm water vol. (m3)
y = 0.7746x + 2.281
R² = 0.5428
y = 0.5155x + 2.8263
R² = 0.4412
y = 0.5864x + 2.2013
R² = 0.4818
y = 0.2461x + 1.4597
R² = 0.2698
S15/10
K35
PC81
207
Linear (K35)
Linear (207)
Linear (PC81)
Linear (S15/10)

Appendix 15: Sample calculation for drip irrigation Emission uniformity & Irrigation efficiency

1. Irrigation efficiency (IE)
Irrigation application level 1

$$IE = \frac{ET_n\,(mm)}{I_g\,(mm)}$$ $ET_n = ET_c = 3235\ m^3$, $I_g = 1940\ m^3$

Computation of ET_c
From Equation 16,

$ET_{ai} = K_p + E_p$ Where ET_{ai} = Actual evapotranspiration on the first day of study (day 1)

$\Rightarrow ET = 0.75 \times 2 = 1.5\ mm\ d^{-1}$

From Equation 17

$ET_{ci} = k_c \times ET_{ai}$

$ET_c = \Sigma\, ET_{ai}, = 323.5$

$$\Rightarrow IE = \frac{323.5}{1940}$$

$\Rightarrow IE = 1.66$

$\Rightarrow IE \cong 1.7$

2. Emission uniformity
Treatment 1

$$EU = 100\left(1.0 - \frac{1.27C_v}{\sqrt{n}}\right)\left(\frac{Q_m}{Q_a}\right)$$ $C_v = 0.03$, manufacturer's coefficient of variation (Netafim, 2006)

$Q_m = 35.40 m^3hr^{-1}$, $Qa = 37.44\ m^3hr^{-1}$, $n=1$

Q_m = minimum observed flow rate (Appendix 10), Qa = average flow rate based on Appendix 10

$$\Rightarrow EU = 100\left(1.0 - \frac{1.27 \times 0.03}{\sqrt{1}}\right)\left(\frac{35.40}{37.44}\right)$$

$\Rightarrow EU = 90.95 \cong 91\%$

Appendix 16: Emitter flow rate data

Flow rate (lhr^{-1})					
Irrigation level					
1	2	3	4	5	6
39.0	36.0	37.2	35.4	37.8	38.0
36.6	36.9	36.5	35.2	38.9	37.9
35.4	35.9	36.8	37.2	38.3	37.7
38.6	36.5	36.2	36.1	38.5	37.9
36.1	36.0	37.4	35.8	37.9	35.9
37.3	36.4	35.8	35.9	38.2	37.9
38.4	36.2	36.1	36.8	38.0	37.9
35.9	35.8	36.9	36.2	38.0	38.5
39.0	36.5	35.5	36.0	38.8	37.9
36.9	36.4	36.8	35.8	38.0	38.8
38.8	35.8	35.9	36.9	38.2	36.9
37.8	36.6	36.2	36.0	38.1	37.8
35.8	35.8	36.7	35.6	38.9	38.9
38.7	36.3	35.8	36.4	38.3	37.9
36.9	36.0	37.2	36.5	38.4	37.8
38.2	36.2	36.6	36.1	37.9	37.9
37.9	36.5	36.5	36.8	38.1	38.9
36.8	36.1	36.7	35.9	38.3	37.8
38.4	36.0	36.8	36.1	38.6	37.9
36.5	36.2	36.8	35.3	39.0	38.0

Appendix 17: Raw measured data for tea crop height (cm)

	Replication					
	1	2	3	4	5	6
			Clone S15/10			
Irrigation						
I1 (1)	62.13	64.87	65.33	64.93	70.80	68.27
I2 (1)	65.20	63.53	64.87	68.93	69.80	67.73
I3 (1)	64.00	66.67	61.80	68.27	69.67	70.93
I4 (1)	67.60	67.67	62.20	63.87	62.40	67.33
I1 (2)	67.80	67.07	66.40	66.20	61.13	70.27
I4 (2)	68.07	66.80	65.87	66.53	62.07	65.53
			CloneK35			
I1 (1)	58.27	63.13	62.00	63.00	60.47	62.13
I2 (1)	64.53	64.33	59.40	64.47	61.47	63.87
I3 (1)	63.47	61.80	62.60	63.33	64.60	58.73
I4 (1)	59.13	62.20	58.93	56.60	58.73	58.93
I1 (2)	63.93	62.47	58.87	57.80	58.67	58.07
I4 (2)	63.33	61.07	59.80	57.53	58.40	60.47
			Clone PC81			
I1 (1)	68.47	68.07	67.67	67.27	69.73	66.73
I2 (1)	67.33	68.93	66.67	69.60	67.00	68.53
I3 (1)	68.07	68.07	67.00	70.20	70.60	67.67
I4 (1)	67.33	67.53	68.20	66.20	65.60	66.13
I1 (2)	68.73	67.13	67.40	66.13	66.33	67.33
I4 (2)	68.20	106.60	68.67	66.00	67.40	67.33
			Clone 207			
I1 (1)	69.87	71.33	70.60	70.53	72.67	68.47
I2 (1)	68.40	69.33	69.80	72.73	68.87	69.53
I3 (1)	72.00	68.73	70.33	72.60	72.27	69.27
I4 (1)	68.00	68.60	72.27	68.6	71.27	71.80
I1 (2)	71.73	68.60	68.87	69.07	70.47	67.67
I4 (2)	71.00	70.60	68.93	66.67	69.47	71.40

Appendix 18: Raw data for tea crop cover (m^2)

	Replication					
	1	2	3	4	5	6
			Clone S15/10			
Irrigation						
I1 (1)	0.64	0.66	0.65	0.64	0.65	0.64
I2 (1)	0.69	0.63	0.66	0.66	0.66	0.67
I3 (1)	0.60	0.60	0.63	0.65	0.65	0.68
I4 (1)	0.65	0.66	0.63	0.68	0.62	0.69
I1 (2)	0.62	0.62	0.66	0.65	0.64	0.68
I4 (2)	0.62	0.66	0.66	0.70	0.60	0.65
			CloneK35			
I1 (1)	0.61	0.63	0.65	0.62	0.60	0.62
I2 (1)	0.65	0.63	0.61	0.59	0.52	0.65
I3 (1)	0.57	0.59	0.63	0.60	0.60	0.62
I4 (1)	0.55	0.63	0.61	0.60	0.59	0.60
I1 (2)	0.61	0.61	0.60	0.62	0.58	0.59
I4 (2)	0.63	0.62	0.53	0.58	0.62	0.64
			ClonePC81			
I1 (1)	0.66	0.66	0.64	0.66	0.69	0.65
I2 (1)	0.69	0.66	0.66	0.66	0.62	0.65
I3 (1)	0.64	0.63	0.68	0.64	0.65	0.64
I4 (1)	0.66	0.63	0.66	0.66	0.64	0.66
I1 (2)	0.65	0.65	0.63	0.65	0.66	0.64
I4 (2)	0.69	0.66	0.66	0.63	0.67	0.66
			Clone207			
I1 (1)	0.65	0.66	0.67	0.62	0.62	0.64
I2 (1)	0.62	0.65	0.64	0.63	0.65	0.64
I3 (1)	0.61	0.66	0.65	0.63	0.61	0.62
I4 (1)	0.61	0.63	0.64	0.64	0.66	0.65
I1 (2)	0.62	0.59	0.64	0.64	0.63	0.63
I4 (2)	0.63	0.61	0.64	0.64	0.65	0.66

Appendix 19 : Sample calculation for crop ground cover percent

Treatment 1 (Clone K35 irrigation application level 1)

$$mean\ area\ conversion\ for\ square\ count = 0.62\ m^2$$

$$tea\ plant\ root\ zone\ area = (S_r \times S_p)$$

$$tea\ plant\ root\ zone\ area = (1.2\ m \times 0.6\ m)$$

$$tea\ plant\ root\ zone\ area = 0.72\ m^2$$

$$fraction\ of\ root\ zone\ area\ covered\ by\ crop\ canopy = \frac{0.62}{0.72}$$

$$= 0.86$$

$$\Rightarrow 86\ \%$$

$$Ground\ coverage\ per\ ha = ground\ coverage\ per\ bush \times number\ of\ tea\ bushes\ per\ ha$$

$$\Rightarrow 0.62 \times 13\ 888\ tea\ bushes$$

$$\Rightarrow 8610.56\ m^2$$

$$Ground\ coverage\ ha^{-1}\ (\%) = \frac{Ground\ cover\ per\ ha\ (m^2)}{Area\ \ per\ ha\ (m^2)} \times 100$$

$$\Rightarrow Ground\ cover\ ha^{-1}\ (\%) = \frac{8610.56}{10\ 000} \times 100$$

$$\Rightarrow Ground\ cover\ ha^{-1}\ (\%)\ for\ clone\ K35 = 86\ \%$$

Appendix 20: Layout of drip irrigation system on 9 ha field