RESPONSE OF OKRA TO DIFFERENT IRRIGATION AND FERTILIZATION METHODS IN THE KETA SAND SPIT OF SOUTHEAST GHANA

BY

ERIC OPPONG DANSO

(10255903)

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DECLARATION

I declare that this thesis is my original work, done under supervision. It is being submitted for the degree of PhD Soil and Water Engineering at the University of Ghana, Legon, Accra. It has not been submitted for any degree or examination in any university.

Eric Oppong Danso

(Student)

Dr.Stephen Abenney-Mickson

(Principal supervisor)

Dr. Edward Benjamin Sabi

(Supervisor)

Dr. Finn Plauborg

(Supervisor)

Prof. Mark K. Abekoe

(Supervisor)

DEDICATION

I dedicate this write-up with love and affection to my families present and future.

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ABSTRACT

The sandy soil in the Keta Sand Spit, Southeast Ghana is infertile but is used for intensive vegetable cultivation. The vegetable production systems are managed with large amounts of irrigation water and fertilizers on sandy soils with low inherent water and nutrient retention capacities. The long term sustainability of a shallow groundwater lens which is used for irrigation in the area is threatened by several consecutive years of over withdrawal. Also, the shallow groundwater which is the primary irrigation water resource is prone to salinization from the Keta Lagoon, the Atlantic Ocean and brackish water underneath. There is excess input of phosphorus into the soil, through the continuous application of animal manure as the sole plant nutrient over the years. To ensure the sustainability of vegetable production at the Keta Spit, introduction of water saving irrigation systems and improved irrigation and fertilizer management schemes are important. Thus, the main aim of the study was to explore the productivity of drip irrigation compared with sprinkler and the traditional bucket irrigation in the Keta Sand Spit. Okra (Abelmoschus esculentum L) is widely grown in Southeast Ghana including the Keta Sand Spit area and was therefore used as the model crop. The study was conducted to evaluate the effect of different irrigation and fertilization methods on crop evapotranspiration, yield, nitrogen uptake, crop intercepted solar radiation, radiation use efficiency and water productivity of okra grown in a sandy soil. The basal crop coefficient (K_{cb}) was related to spectral reflectance measurements. The basal crop coefficient and soil evaporation coefficient (K_e) for drip and sprinkler irrigation were also estimated using FAO-56 methods. There were four seasons of study to determine the okra crop response to the following treatments: 1. sprinkler irrigation with manure spread on the soil (SSM); 2. sprinkler irrigation with manure placed around the plants (SPM); 3. Bucket irrigation with manure spread on the soil

(BSM) 4. drip irrigation with manure placed around the plants (DPM) and 5. drip irrigation with fertigation (DFT); i.e. nutrient solution added to irrigation water. Fertigation was done only two times (two weeks after germination and immediately after flowering) during the first and second experiments while weekly fertigation (8 times from two weeks after germination) was done during the third and fourth experiments. Results from the experiments showed that the okra crop did not respond well when fertigation was done only twice (two weeks after germination and immediately after flowering) in the first and second experiments, probably due to nitrogen lost through leaching on the extremely sandy soil. However, a significant improvement on the yield response ($P \leq 0.05$) in the fertigated treatment compared to SSM, SPM, BSM and DPM was obtained when fertigation was done weekly for eight weeks. In the third experiment, with similar nitrogen application (89 kg N/ha) for all treatments, the highest yield, N uptake, water productivity (WP) and radiation use efficiency (RUE) were obtained under DFT and these parameters were significantly higher than the other treatments (SSM, SPM, BSM and DPM). Increase in fertilization in the fourth experiment (from 89 kg N ha^{-1} to 140 kg N ha^{-1}) increased yield and WP compared to the three previous seasons, WP for DFT and DPM being significantly higher than for SSM, SPM and BSM. In the four seasons under sprinkler irrigation, yield was higher with manure placed around the plants (SPM) compared with manure evenly spread on the soil (SSM) even though the difference was not significant during the first and last experiments. The optimal crop N-uptake was 125 kg N/ha independent of season and adequate N-supply seemed especially important for ensuring sufficient light interception and radiation use efficiency during the fruiting stage of growth. Simple linear regression equations ($R^2 > 0.9$) were developed to provide an estimate of K_{cb} during any time of the growth period with the fraction of the photosynthetically active radiation (f_{PAR}) data from spectrosense measurements. The dual K_c

values derived from FAO-56 methodology for sprinkler irrigation were $K_{c\ ini}$: 1.10, $K_{c\ mid}$: 0.9 and $K_{c\ end}$: 1.05 whilst for $K_{e\ ini}$: 0.95, $K_{e\ mid}$: 0.05 and $K_{e\ end}$ 0.29, and for $K_{cb\ ini}$: 0.15, $K_{cb\ mid}$: 0.85 and $K_{cb\ end}$: 0.76 respectively. For drip irrigation the initial, mid and late season K_c were 0.48, 0.89 and 0.98 with K_e having 0.33, 0.04 and 0.22, and for K_{cb} 0.15, 0.85 and 0.76 respectively. The K_c data showed that the evaporative component was high during the initial stage of the growing season, due to the high frequency of irrigation. Seasonal crop water use (ET_c) for sprinkler irrigation were 346 mm, 339 mm, 379 mm, and 346 mm for the four experiments. For drip irrigation these were 233 mm, 236 mm, 269 mm and 233 mm. By adopting drip irrigation for okra, the seasonal crop water use could be reduced by nearly 30 %. From the results it is concluded that: 1. on coarse textured sandy soil drip irrigation with weekly fertigation resulted in significant water savings, yield increase and improvement in WP, RUE and nitrogen uptake compared with sprinkler irrigation combined with farm manure 2. The dual crop coefficient which allowed differentiation between crop transpiration (basal crop coefficient, K_{cb}) and evaporation from the soil (evaporation coefficient, K_e) should be used for irrigation scheduling in the Keta Sand Spit.

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LIST OF PRINCIPAL ABBREVIATIONS AND SYMBOLS

Some of the symbols and abbreviations used in this thesis are defined as follows:

Notation	Meaning	Units
ANOVA	Analysis of variance	-
AP	Application efficiency	-
BSM	Bucket irrigation with spread manure	
$Ca(NO_3)_2$	Calcium nitrate	-
Ca	Calcium	-
Cl	Chlorine	-
Con.	Concentrated	-
CR	Capillary rise	mm
D	Accumulated soil moisture deficit	mm
DANIDA	Ministry of Foreign Affairs of Denmark	-
DAS	Days after sowing	-
D_e	Cumulative depth of evaporation from the soil surface layer	mm
DFT	Drip irrigation with fertigation	-
DP	Deep percolation	mm
DP_e	Deep percolation from the evaporation layer	mm
DPM	Drip with placed manure	-
d_r	Inverse relative distance Earth-Sun	-
DS	Developmental growth stage	-
e_a	Actual vapour pressure	kPa
E	Evaporation	mm
Eqn.	Equation	
$e^o(T_{max})$	Saturation vapour pressure at the maximum temperature	kPa
$e^o(T_{min})$	Saturation vapour pressure at the minimum temperature	kPa

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Notation	Meaning	Units
e_s	Saturation vapour pressure for a given time period	
e_s-e_a	Saturation vapour pressure deficit	kPa
ET	Evapotranspiration	mm
ET_c	Crop evapotranspiration	mm
ET_o	Grass reference evapotranspiration	mm
Expt.	Experiment	-
FAO	Food and Agriculture Organization of the United Nations	-
f_c	Fraction of the soil surface covered with vegetation as observed from above	-
f_{ew}	Fraction of soil that is both wetted and exposed to solar radiation	-
Fig.	Figure	-
f_w	Fraction of soil surface wetted by rain or irrigation	-
f_{PAR}	Fraction of intercepted photosynthetically active radiation	MJ m^{-2}
G	soil heat flux density	MJ m^{-2} day^{-1}
GHC	Ghana cedi	-
GPS	Global positioning system	-
G_{sc}	Solar constant (0.0820)	MJ m^{-2} day^{-1}
H	Sensible heat	MJ m^{-2} day^{-1}
ha	Hectare	-
H_2SO_4	Sulphuric acid	-
HCl	Hydrochloric acid	-
HCO_3^-	Bicarbonate	-
I	Irrigation depth	mm
IPAR	Intercepted photosynthetically active radiation	MJ m^{-2}
IS	Initial crop growth stage	-
IWP	Irrigation water productivity	kg m^{-3}

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Notation	Meaning	Units
IWP_{tbm}	Irrigation water productivity at the total above ground biomass level	kg m^{-3}
IWP_y	Irrigation water productivity at the fresh pod yield level	kg m^{-3}
LAI	Leaf area index	m^2 m^{-2}
K	Potassium	-
K_c	Crop coefficient	-
KCl	Potassium Chloride	-
$K_{c\ end}$	Crop coefficient at end of the late season growth stage	-
$K_{c\ ini}$	Crop coefficient during the initial season growth stage	-
$K_{c\ max}$	Maximum value of crop coefficient following rain or irrigation	-
$K_{c\ mid}$	Crop coefficient during the mid-season growth stage	-
K_{cb}	Basal crop coefficient	-
$K_{cb\ end}$	Basal crop coefficient at end of the late season growth stage	-
$K_{cb\ ini}$	Basal crop coefficient during the initial season growth stage	
$K_{cb\ mid}$	Basal crop coefficient during the mid-season growth stage	-
K_e	Soil evaporation coefficient	-
$K_{e\ end}$	Soil evaporation coefficient at the end of the late season growth stage	-
$K_{e\ ini}$	Soil evaporation coefficient during the initial season growth stage	-
$K_{e\ mid}$	Soil evaporation coefficient during the mid-season growth stage	-
K_r	Soil evaporation reduction coefficient	-
K_2SO_4	Potassium sulphate	-
LS	Late season growth stage	-
LSD	Least significant difference	-
Max.	Maximum	-
MS	Mid-season growth stage	-

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Notation	Meaning	Units
N	Nitrogen	-
N/A	Not applicable	-
Na	Sodium	-
NaOH	Sodium hydroxide	-
Na_2SO_4	Sodium sulphate	-
Nap	Nitrogen application amount	kg ha^{-1}
NDVI	Normalized difference vegetation index	-
NH_3	Ammonia	-
NUE	Nitrogen use efficiency	%
Nup	Nitrogen uptake	kg ha^{-1}
PAR	Photosynthetically active radiation	MJ m^{-2}
P	Rainfall	mm
P	Phosphorus	-
Pa	Atmospheric pressure	kPa
PN	Price of nitrogen	GHC/kg N
PO	Price of okra	GHC/ton
PY	Fresh pod yield	10^3x kg ha^{-1}
Q	Global radiation	MJ m^{-2}
R_a	Extraterrestrial radiation	MJ m^{-2}
REW	Readily evaporable water	mm
RH	Relative humidity	%
RH_{max}	Daily maximum relative humidity	%
RH_{min}	Daily minimum relative humidity	%
R_n	Net radiation	MJ m^{-2} day^{-1}
R_{ns}	Net solar or shortwave radiation	MJ m^{-2} day^{-1}
RO	Surface runoff	mm

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Notation	Meaning	Units
R_s	Solar or shortwave radiation	MJ m^{-2} day^{-1}
R_{so}	Clear-sky solar radiation	MJ m^{-2} day^{-1}
RUE	Radiation use efficiency	g MJ^{-1}
RVI	Ratio vegetation index	-
SPM	Sprinkler irrigation with placed manure	-
SPM	Sprinkler irrigation with spread manure	-
TBM	Total above ground biomass	10^3 x kg ha^{-1}
TDS	Total dissolved solids	mg L^{-1}
TEW	Total evaporable water	mm
TIW	Total applied irrigation water	mm
T	Crop transpiration	mm
T_m	Daily mean air temperature	^{0}C
T_{max}	Daily maximum air temperature	^{0}C
T_{min}	Daily minimum air temperature	^{0}C
U_2	Wind speed at 2 m above ground surface	m s^{-1}
Vis	vegetation indices	-
Vol.	Volume	-
WP	Water productivity	kg m^{-3}
WP_{tbm}	Water productivity at the biomass level	kg m^{-3}
WP_y	Water productivity at the fresh pod yield level	kg m^{-3}
WUE	Water use efficiency	kg m^{-3}
λET	Latent heat flux	MJ m^{-2} day^{-1}
Z	Height above mean sea level	m
Z_e	Depth of surface soil layer subjected to drying by evaporation	mm
α	albedo	-

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Notation	Meaning	Units
γ	Psychrometric constant	kPa $^0C^{-1}$
Δ	Slope of saturation vapour pressure curve	kPa $^0C^{-1}$
ΔSF	Change in subsurface flow over a period of time	mm
ΔSW	Change in soil water content over the time period	mm
θ_{fc}	Soil water content at field capacity	$m^3\ m^{-3}$
θ_{wp}	Soil water content at wilting point	$m^3\ m^{-3}$
ρi	Reflection coefficient in the near-infrared region	nm
$\rho i,\infty$	Near-infrared reflectance at peak vegetative growth	nm
$\rho i,s$	Near-infrared reflectance from bare soil	nm
ρr	Reflection coefficient in the red region	nm
$\rho r,\infty$	Red reflectance at peak vegetative growth	nm
$\rho r,s$	Red reflectance from bare soil	nm
ω_s	Sunset hour angle	rad

CHAPTER ONE

1.0 INTRODUCTION

The soils in the Keta Sand Spit, Southeast Ghana are sandy and infertile but have been used for vegetable production since the beginning of the 19th century. The availability of a shallow groundwater lens has made it possible for irrigation to be practised such that vegetable farming can take place all year. The soils are also deficient in N, P and K and because of their coarse-texture, they have low water holding capacity, high infiltration rates, raising the possibility of nutrient leaching. Nitrate in particular is mobile and in sandy soils can move quickly when there is a downward water flow in the soil. Thus, crops cultivated on sandy soil require either large quantities of applied nitrogen or better husbandry, which match the nitrogen supply with the crop nitrogen demands during the season. Cautious irrigation applications should be able to avoid movement of nitrate and other nutrients beyond the root zone (Drost and Koenig 2001; Hanson *et al.* 2006). Since irrigation and nitrogen availability are linked this way, appropriate irrigation and nitrogen management are required to avoid nitrate leaching and groundwater pollution.

Water and nitrogen are necessary ingredients for plant growth and in their desire to increase yield, farmers apply them excessively. Small holder vegetable farmers in the Keta Sand Spit irrigate by hand, using buckets to fetch water from shallow wells. The bucket irrigation method is highly adopted and practiced, although it is water wasting. The farmers in Keta tend to apply excessive amounts of irrigation water at high frequency (daily or twice a day irrigation events) to minimize risk of yield reductions due to the low water holding capacity of the sandy soil in the area. Such intensive and high frequency irrigation is labour intensive and inefficient since about half of the water applied to the field is lost to surface runoff, evaporation and deep percolation

(Batchelor *et al.*, 1996). The trend in recent years in Keta has been towards shifting from bucket to motorized sprinkler irrigation in order to reduce the cumbersome and limited productivity associated with the bucket irrigation method. The introduction of motorized sprinkler irrigation coupled with increasing population has increased groundwater abstraction from the aquifers in the Keta basin during the last decade (Bannerman, 1994; Jorgensen and Banoeng-Yakubo, 2001; Helstrup *et al.*, 2007). Also, increase in the withdrawal of the shallow groundwater has increased the risk for salt water intrusion from the Atlantic Ocean, the Keta lagoon and salt water underneath (Kortatsi and Agyekum, 1999). To ensure the sustainability of vegetable production in the Keta Sand Spit, improved irrigation and fertigation systems and water management schemes need to be developed. Agricultural practices such as drip irrigation and quantitative irrigation scheduling can help to reduce irrigation amounts and thus conserve water resources. The adoption of drip irrigation system for crop production is slowly increasing as water resources become scarce worldwide. Drip irrigation systems save water, have application efficiencies of 90 % compared with 75 % for sprinkler (Simonne *et al.*, 2011; Dworak *et al.*, 2007) when properly managed. However, farmers in Keta are reluctant to convert to drip irrigation because some initial trials of the drip system did not improve productivity. This was probably due to poor management of the drip system on the sandy soil with low water and nutrient holding capacities.

Worldwide, irrigation scheduling is often based on climatic data obtained roughly by calculating accumulated deficit (D) of daily water balance data from evapotranspiration (ET) and rainfall (R). Thus

$$D=\sum(R-ET). \qquad (1.1)$$

During a drying cycle a certain D level will initiate an irrigation event (Hillel, 1998). Availability of weather data allows the use of advanced methods for calculation of ET predictions as reviewed by Allen *et al.* (1998).

Applying the right amount of water at the right time is crucial to make the most efficient use of any irrigation system, as either excessive or inadequate irrigation reduces yield due to leaching of nutrients, and water stress, respectively. On a sandy soil as in Keta frequent irrigation becomes extremely important due to the very small amount of plant available water within the crop root zone. Adopting high-frequency irrigation on sandy soils ensures water availability in the root zone of each plant, maintaining high soil matric potential in the rhizosphere to reduce plant water stress (Singh and Rajput, 2007; Al-Harbi *et al.*, 2008; Zotarelli *et al.*, 2009). Several authors (Bures *et al.*, 1997; Orozco and Marfa, 1995; da Silva *et al.*, 1993; Wallach *et al.*, 1992) have observed that small changes in soil water content of sandy soils cause changes of up to four or five fold in its hydraulic conductivity. The ensuing decrease in water fluxes decrease the acquisition of nutrients by plants (Raviv *et al.*, 1999). This is especially true with drip irrigation systems where the decreased soil volume reduces the storage capacity of the soil for water and nutrients, which in turn raises the chances of stress when an application of water is delayed for even a short period of time (Bar-Yosef, 1977). Therefore, scheduling irrigation with few but large applications on a sandy soil could induce water stress between applications and hence scientific irrigation scheduling to account for actual crop water use is necessary on a sandy soil.

Scheduling high frequency irrigation with the reference evapotranspiration (ET_o) and crop coefficient (K_c) approach needs careful management. Evapotranspiration (ET) during the initial stage for annual crops is predominantly in the form of soil evaporation. Increased soil evaporation can cause K_c values to deviate significantly from the empirically determined K_c values for several days following irrigation or rainfall. It is therefore important to take into account the irrigation frequency when estimate of crop evapotranspiration during the initial is made. The initial K_c ($K_{c\ ini}$) can therefore be very large under high frequency irrigation. However, the K_c reported by Allen *et al.*, (1998) were developed with low irrigation frequency and can introduce substantial errors when used under high frequency irrigation. Allen *et al.*, (1998) recommends an innovative figure (Fig. 30 of Allen et al., 1998) to estimate the initial K_c ($K_{c\ ini}$) according to the magnitude of reference evapotranspiration (ET_o) during the initial period and according to the frequency of soil wetting to calculate crop evapotranspiration (ET_c). Alternatively, ET_c under high frequency irrigation can be estimated accurately using the dual K_c approach which separates crop transpiration coefficient (K_{cb}) from soil evaporation coefficient (K_e) to specify the individual contributions for the two parts of crop evapotranspiration.

Also, scheduling irrigation, using the ET_o and K_c procedure can be cumbersome due to many factors that affect crop development, like climate conditions, water and nutrient management (Hunsaker *et al.*, 2007). The single K_c approach has been used extensively in many irrigation scheduling models (e.g., Smith, 1991; Fox *et al.*, 1992; Bos *et al.*, 1996). The single K_c values used in these models were determined to estimate crop water use under optimal crop growth conditions. However, rigidly applying the empirically determined mean K_c values may introduce errors in irrigation scheduling, if crop growth change from optimal forms (Bausch and Neale, 1989). One way to allow changing irrigation scheduling needs is to use remote sensing information. Several studies have adopted remote sensing technology for ET_c estimation using vegetation indices established on canopy reflectance to estimate and trace crop coefficients (Hunsaker *et al.*, 2005a; Johnson and Scholash, 2005; Tasumi *et al.*, 2005). The studies above suggest that using proxy K_{cb} obtained from using remote sensing can provide a real-time method to successfully alter K_{cb} for real growth conditions as influenced by climate, pest damage, disease, and other effects. Also, Allen *et al.* (1998) strongly recommend that K_c values should be developed locally to reflect local conditions. Allen *et al.* (1998) also explained that the FAO-developed K_c values need to be adjusted locally as they are intended to only describe ET_c for healthy crops grown under standard management practices, having no growth and yield restrictions. Even though irrigated agriculture in the Keta Sand Spit had been taking place since the beginning of the 19th century, literature search showed that there is no locally developed K_c of any of the vegetables grown in the area.

A review of literature has revealed that only scant information is available on irrigated horticultural production and on the shallow groundwater in the Keta Sand Spit. Studies on the evolution of the horticultural system and its sustainability have been carried out by Awadzi et al (2008). Most of the studies in Keta were hydrogeologic and focused on the threat of overexploitation of the shallow groundwater lens (Kortatsi and Agyekum, 1999; Jorgensen and Banoeng-Yakubo, 2001; and Helstrup *et al.*, 2007) rather than on irrigated agriculture in the area. Literature search also indicated that no study has been conducted in the area on the performance of drip irrigation compared to the traditional bucket and sprinkler irrigation. Further search again showed that despite the fact that many farmers in the area have been practicing irrigation for a very long time, no study has been conducted yet to determine local crop coefficient and irrigation water requirements of any of the vegetable crops grown in the area. The comparative effect of drip irrigation with other irrigation methods on vegetable crops has been reported in the literature but with different conclusions (Musick and Dusek, 1980; Howell *et al.*, 1995; Howell *et al.*, 1997). It is therefore important to study how drip irrigation will perform compared with bucket and sprinkler irrigation in the Keta Sand Spit under high frequency irrigation.

The conventional way of applying animal manure, surface spreading and incorporation at the Keta Sand Spit (Awadzi et al., (2008) is fast and cheap. However, broad spread application of manure is usually uneven (Huther, 1988). Broadcast manure may contaminate crops with microorganisms and also enter watercourses through runoff (Anderson and Christie, 1995; Steffens and Lorenz, 1998). Farmers in the Keta Sand Spit use cowdung and poultry manure to augment the fertility of the soil. However, the addition of animal manure as the sole plant nutrient add a lot of P to the soil since animal manure has a high P/N ration. To avoid the current oversupply of P, animal manure may be supplemented by inorganic N and K fertilizer through fertigation (Or and Coelho 1996; Boyhan and Kelley 2001). When introducing drip irrigation it may be necessary to place manure in trenches under each drip line as drip irrigation does not wet the entire soil surface in row crop on sandy soils. There is therefore a need to investigate how manure placed close to the crop will interact with drip irrigation and compare this with the traditional broad-spread manure with sprinkler irrigation, and as well compare to fertigation.

1.1 Objectives

The objectives of the study were to:

1. Determine the yield of okra grown in the Keta Sand Spit under drip, sprinkler and bucket irrigation.
2. Determine the water productivity and irrigation water productivity of okra grown in the Keta Sand Spit under drip, sprinkler and bucket irrigation.
3. Determine the length of growth stages and the basal crop coefficient of okra grown in the Keta Sand Spit.

4. Determine the radiation capture and radiation use efficiency of okra grown in the Keta Sand Spit under drip sprinkler and bucket irrigation.
5. Determine the nitrogen uptake and nitrogen use efficiency of okra grown in the Keta Sand Spit under drip, sprinkler and bucket irrigation.
6. Determine the optimal rate of N-supply to okra grown in the Keta Sand Spit.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definition, importance and drawbacks of irrigation

Irrigation is the practice of supplying water artificially to permit farming in arid regions and to offset drought in semiarid regions (Hillel, 1980). Other authors (Schwab *et al.*, 1987, Seckler, 1993) define irrigation as any process other than precipitation, which supplies water to crops, orchards, grasses or any other cultivated plants. In humid regions of the world, rainfall provides the water need of crops while in arid places, rainfall does not meet the water needs and irrigation either makes up the deficit or provides all the water requirements. In arid and semi arid regions of the world where the amount and timing of rainfall are not sufficient to meet crop water requirement, irrigation becomes a vital tool in raising crops to meet the needs of food and fibre. Even in areas where total rainfall is sufficient, its distribution during the year may be uneven. Consequently, irrigation may make multiple cropping possible in such situations. In fact, the potential productivity of irrigated land can exceed that of non irrigated (rain fed) land four-fold or more, due to both increased yields per season and to the possibility of multiple cropping (Hillel, 1980). It has been estimated that to meet the food security of 8 billion people by 2025, the irrigated area must expand to more than 20 % and irrigated crop yields should improve by 40 % above current yields (Wolters, 1992; Lascano and Sojka, 2007). Thus, irrigation is an extremely important means of providing food security in future. Even though there have been massive experiences in irrigation of crops to maximize performance, efficiency and profitability, the science of irrigation still continues to evolve (Sleper *et al.*, 2007). Thus the importance of irrigation has made national planners to be strongly attracted to irrigation as a means of supporting future food security strategies wherever rainfall is erratic or demographic pressure on rainfed land is rising (Elahi and Kushatani, 1990).

Despite the potential for increased productivity, irrigated agriculture may have certain disadvantages. It is by far the greatest user of fresh water on earth taking up about two thirds of the total fresh water designated to human uses (Fereres and Evans, 2006). In addition to the pressure on freshwater resources is the increased realization of the need for water in the preservation of the environment and ecosystems and the heightened competition for water with other areas of our society. Freshwater is now considered as a limited and overexploited natural resource in many parts of the world (Millennium Ecosystem Assessment, 2005; Rockstrom *et al.*, 2009a). Irrigated agriculture is therefore faced with the challenge of enhancing the use of water resources. It is also faced with a number of difficult problems regarding its future. One main concern is the low efficiency with which water resources have been used for irrigation (Huffaker and Hamilton, 2007). Another issue is that, irrigated agriculture may be a source of pollution through discharge of pollutants and sediments to surface and/or groundwater (Almasri and Kaluarachchi, 2007). If it is not managed efficiently with the provision of adequate drainage, it may cause salinization and water-logging of lands (Hillel 1980). Irrigation should therefore be based on principles of sustainability i.e. socio-economically sound production with little or no negative effect on the environment and human livelihoods.

2.1.1 Groundwater supply and quality in the Keta basin

Groundwater is the main water supply for Ghana’s rural population, which forms about 74 % of the total population of the country (Ghana Statistical Services, 2002). In the Keta basin, there has been growing concern with the increased abstraction of the groundwater from the aquifers during the last decade (Jorgensen and Banoeng-Yakubo, 2001; Helstrup *et al.*, 2007).

This is due to increasing water demands from an expanding population and a rising electrical conductivity especially of the coastal shallow groundwater in the basin (Helstrup *et al.*, 2007). One of the main concerns in water quality and management of water supply in the Keta basin is salinization of groundwater (Helstrup *et al.*, 2007). Many prospective sites for wells were not completed due to salinity problems in the groundwater. Virtually all communities in the basin have depended on groundwater from the shallow aquifers to meet both domestic and irrigation needs over the past several years. Yidana *et al.*, (2010); Kortatsi and Agyekum (1999) conducted assessments of the impact of large scale abstraction on the quality of the shallow groundwater in the Keta basin. Their study was initiated based on the concern raised by Robinson (1998) that construction of several mechanized wells for irrigation in the Keta Sand Spit without adequate monitoring may cause the shallow groundwater to become saline. The concern was based on the fact that the freshwater was sitting on a large mass of saline water and also close to two saline water bodies (the Keta lagoon to the north and the Gulf of Guinea to the south) (Fig. 2.1). Any disturbance of the fragile fresh/saline water interface by uncontrolled large-scale abstraction could erode the fresh water base of the strip.

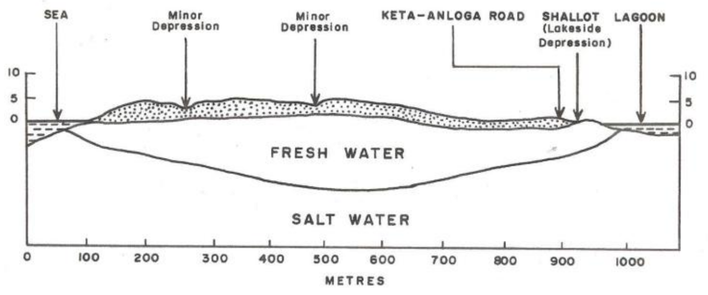

Fig. 2.1 A cross section of the shallow fresh water lens and three saline water bodies
Source: Kortatsi and Agyekum (1999)

The optimum amount of water required for approximately 7 months of irrigation per year in the Keta Sand Spit is estimated to be 2.0 × 10^7 m^3 (Kortatsi and Agyekum 1999). They deduced that abstraction of 2.0 × 10^7 m^3 of water to irrigate would lower the water table by approximately 1.0 m during the dry season. The consequence of this they concluded would be the entry of saline water from both the lagoon and the sea into the fresh water lens making it unsuitable for irrigation. According to Kortatsi and Agyekum (1999), the hypothetical changes in the chemical composition of fresh water when mixed with sea water shown in Table 2.1 indicate that by mixing only 10 % and 20 % of sea water with fresh water (mean concentration) will change the total concentration of the major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, Cl^-, HCO_3^-) from 373 mg/L to 3906 mg/L and 7441 mg/L, respectively. Consequently, significant ingress of sea or brackish water into the fresh water lens as a result of large-scale irrigation will increase the salinity of the fresh water aquifer lenses tremendously. Again, the mixing of only 10 % of sea or brackish water with the fresh groundwater will increase the total dissolved solid content of the fresh water (mixture) by tenfold (Kortatsi and Agyekum, 1999). A spike in the salinization of the fresh water lens will, therefore, lead to increased salinity, and specific ions hazards to vegetable crops currently produced in the Keta Sand Spit.

Table 2.1 Hypothetical mixing of fresh water from the Keta Strip with sea water

Parameter	Fresh water (mg/L)	Sea water (mg/L)	Mixture 1 (mg/L) 90% fresh water & 10% sea water	Mixture 2 (mg/L) 80% fresh water & 20% sea water
Ca	21	425	61	102
Mg	1	1398	140	280
Na	69	10875	1149	2230
K	6	404	45	85
SO_4	26	2796	303	580
Cl	192	19679	2141	4089
HCO_3	58	146	67	75
Total	373	35723	3906	7441

Source: Kortatsi and Agyekum (1999)

Another source of salinization of the shallow fresh water lens envisaged by Kortatsi and Agyekum (1999) is irrigation return water. Irrigation water (especially overhead irrigation methods) is concentrated through evapotranspiration anytime the fresh water moves to the surface and is exposed to the weather. Therefore, as abstracted water infiltrates back to the water table as irrigation return water, its TDS is higher than what it was when it was first pumped out. Bucket and sprinkler irrigation are aggressively practiced whereby farmers irrigate once or twice a day during the growing season. As a result of the haphazard manner in which irrigation is practiced in the Keta Sand Spit, the problem of salinization of the shallow groundwater through over abstraction and irrigation return water is likely to be compounded. Though rainfall after irrigation may just be enough to flush the saline water, once the fresh water lens gets contaminated it becomes extremely difficult to deal with. The shallow groundwater will, therefore, no longer be suitable for irrigation in the area, effectively halting vegetable farming in the Keta Sand Spit. This will be a socio-economic disaster for the Keta Spit, in particular and Ghana in general. Kortatsi and Agyekum (1999) therefore recommended drip irrigation in the Keta Spit as a water saving irrigation method to protect the shallow groundwater from overexploitation. Compared with sprinkler irrigation, drip irrigation saves about 20-30 % water, and by optimizing irrigation scheduling a further 10-20 % more water is saved (Dworak *et al.*, 2007). Assuming 30 % of irrigation water can be saved by adopting drip irrigation in the Keta Spit, then 6.0 x 10^6 m^3 irrigation water will be needed for 7 months per year instead of 2.0 x 10^7 $m^3$for sprinkler. Also, irrigation return water under drip irrigation will be less concentrated as water under drip irrigation is delivered below the crop canopy thereby reducing evaporation.

2.2 Types of Irrigation

Irrigation can generally be grouped into sprinkler, drip (trickle) and surface (gravity) application systems (James 1998). In well developed irrigation areas of the world, irrigation technologies are advanced and almost all irrigation is pressurized and served by sprinkler, mini-sprinkler, and drip systems (Melamed 1988). However, in developing countries, gravity methods of irrigation dominate. Sprinkler irrigation systems use sprinklers operating at pressures ranging from 70 to 700 kPa (James 1998) to form and distribute droplets of water over the land surface. Drip irrigation on the other hand is the frequent, slow application of water either directly onto the land surface or into the root zone of the crop (James, 1998). The main purpose of drip irrigation is wetting only the root zone of the crop (rather than the entire land surface) and also to maintain the soil water content of the crop root zone close to optimum levels. Drip irrigation usually operates using pressures ranging from 15 to 200 kPa to apply water drop by drop into the root zone.

Bucket irrigation is another form of irrigation practiced by small holder farmers especially in developing countries. It is the most adopted and practiced irrigation type in the Keta Sand Spit. In bucket irrigation, water is manually fetched from a shallow well and subsequently sprinkled on the land surface (Fig. 2.2). In line with this, Batchelor *et al.*, (1996) noted that the bucket irrigation method is laborious hence small holder farmers usually cultivate vegetables on small gardens (0.01–0.50 ha).

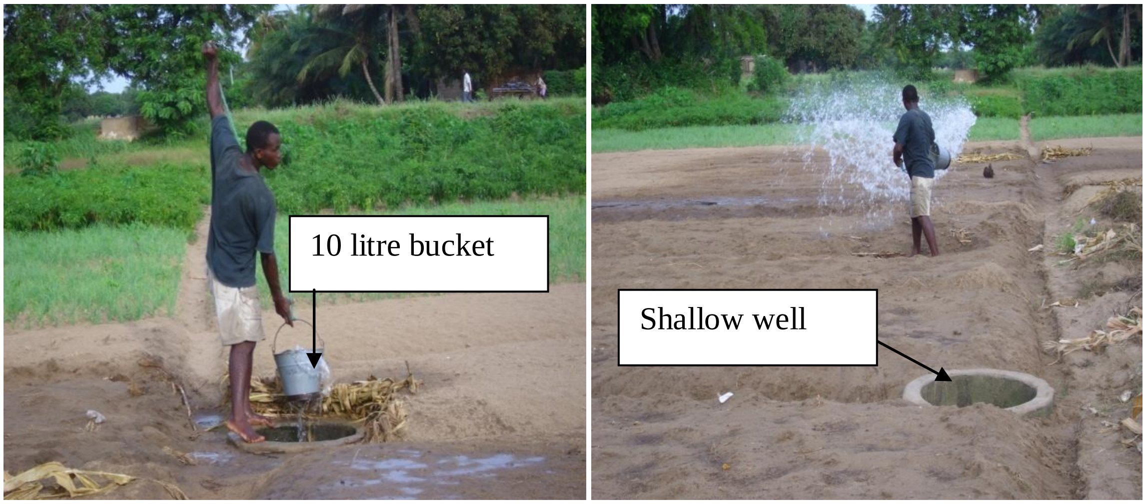

Fig. 2.2 Bucket irrigation from the shallow well in the Keta Sand Spit

Information on water application amounts using bucket irrigation in Keta was collected through surveys. On the average, vegetable farmers in Keta apply as much as 13 mm day^{-1} of water for okra which is above the average ET$_o$ value of 4 mm day^{-1}. Considering the fact that concern has been raised about the over exploitation of the shallow groundwater (Jorgensen and Banoeng-Yakubo, 2001; Helstrup *et al.*, 2007) with the implication of its possible salinization (Kortatsi and Agyekum, 1999) applying about 69 % more irrigation water than the average evapotranspiration is very wasteful. This has increased the importance of implementation of water conservation practices in irrigated agriculture in the Keta Sand Spit.

2.2.1 Advantages of drip irrigation

Drip irrigation save water and of higher productivity compared with other irrigation methods (Hillel 1980). Drip irrigation ensures that water wets the root zone of the crop through an interconnection of pipes and emitters. With drip irrigation it is feasible to get suitable moisture conditions even in soils such as coarse sands and clays which are not suitable for conventional irrigation methods (Goldberg and Shmueli, 1970). Drip irrigation saves water, while providing high yield and exceptional product quality. Also, a drip irrigation set up can readily be used for fertigation, through which the applied fertilizer is placed in the active root zone such that crop nutrient requirements can be provided correctly (Or and Coelho 1996; Boyhan and Kelley 2001). Crops receiving fertilizers applied under sprinkler irrigation generally have low fertilizer use efficiency (Cassel *et al.* 2001; Hebbar *et al.* 2004). A properly designed drip fertigation system delivers water and nutrients at a rate and frequency optimizing crop water and nutrient uptake, while minimizing leaching of nutrients from the root zone (Gardenas *et al.* 2005). On the other hand, it is regarded as eco-friendly (Phene *et al.*, 1994; Waddell *et al.*, 1999) and also ensures substantial water and fertilizer savings (Mmolawa and Or 2000; Patel and Rajput, 2004). As a result, drip irrigation has been found to increase yield by about 50 % over other irrigation techniques (Sivanappan, 1994). Drip irrigation system, when combined with frequent monitoring of plant water requirements, provides what is perhaps the best approach in control of water and nutrient management for crop production (Thompson *et al.*, 2000). There have been many studies comparing drip irrigation with other irrigation methods (Ravelo *et al.*, 1977; Unlu *et al.*, 2006; Garry *et al.*, 2010; Sturm *et al.*, 2010; Woltering *et al.*, 2011). Though information about productivity when comparing drip to other irrigation methods is often conflicting in the literature, (Ravelo *et al.*, 1977; Unlu *et al.*, 2006; Garry *et al.*, 2010; Sturm *et al.*, 2010; Woltering *et al.*, 2011) it is accepted generally that production and water use efficiency are highly enhanced by adopting drip irrigation.

2.3 Irrigation scheduling

Irrigation scheduling is generally based on management skills which usually results in few but excessive applications (Fereres *et al.*, 2003). Scheduling irrigation can however be improved when factors such as plant evaporative demand and soil characteristics are taken into account. Better irrigation scheduling methods are needed in the arid and semi arid parts of the world where water resources are scarce. Scientific irrigation scheduling methods have been available for several decades, and there has been a rise in the use of these methods (Leib *et al.*, 2002). However, as Howell (1996) pointed out, notable improvements in irrigation scheduling are needed to meet the scarce water challenges facing growers today.

Determining irrigation timing and amount traditionally involves selecting a desired allowable soil water depletion target for the given crop/soil system, calculating daily ET_c using the K_c method, and using the soil water balance equation to estimate root zone soil water depletion (George *et al.*, 2004). Therefore, when irrigation scheduling is supported by accurate ET_c estimates, irrigation systems can be operated to provide the appropriate crop water replacement and attain high water application efficiencies with little leaching.

2.3.1 Evapotranspiration measurement methods

Various methods are used to estimate ET_c, which include: energy balance, soil water balance, lysimeters, pan evaporation and meteorological methods. The energy balance method provides an estimate of the evapotranspiration rate by applying the principle of energy conservation (Allen et al., 1998). The energy balance equation for an evaporating surface can be written as:

$$R_n - G - \lambda ET - H = 0 \tag{2.1}$$

where R_n is the net radiation (MJ $m^{-2}day^{-1}$), H the sensible heat (MJ $m^{-2}day^{-1}$), G the soil heat flux (MJ $m^{-2}day^{-1}$), and λET the latent heat flux (MJm^{-2} day^{-1}). The λET representing the ET fraction can be derived from the energy balance equation if all other components are known. R_n and G can be measured or estimated from climatic parameters.

The soil water balance method is also widely used to estimate evapotranspiration. In this method, various components of the soil water balance are assessed by the incoming and outgoing water flow into the crop root zone over a given period of time. Evapotranspiration can thus be deduced from the change in soil water content (ΔSW) over the time period as:

$$ET = I + P - RO - DP + CR \pm \Delta SF \pm \Delta SW \qquad (2.2)$$

Where:

where I is irrigation, P is rainfall, RO is surface runoff, DP is deep percolation, CR is capillary rise, SF is change in subsurface flow and ET is evapotranspiration. Lysimeters are by far the most accurate method of determining evapotranspiration. It works by isolating the crop root zone from its environment and controlling the processes that are difficult to measure (Allen *et al.*, 1998). It measures the different terms in the soil water balance equation with greater accuracy (Allen et al., 1998).

Due to the practical difficulties in obtaining accurate field measurements, evapotranspiration is often computed from weather data. Some of the models for the calculation of evapotranspiration from climatic data are Penman-Monteith, Businger-van Bavel, Priestley Taylor, Jensen-Haise, Hargreaves, Turc and Blaney-Criddle. Indeed, many empirical or semi-empirical models have been developed to predict evapotranspiration from meteorological data, but according to Hossein *et al.* (2004), there is no universal agreement on the appropriateness of any given model for a given climate. More importantly, most models need local calibration before they can be used for the estimation of ET_o (Smith *et al.*, 1996). As a result of the above concerns, many researchers evaluated the performance of the different calculation methods for various locations. From an Expert Consultation meeting held in May 1990, the FAO Penman-Monteith method is now recommended as the accepted method for the computation of ET_o

worldwide. The evapotranspiration from crop surfaces under standard conditions is determined by crop coefficients (K_c) that relate ET_c to ET_o. The FAO Penman-Monteith method requires radiation, air temperature, air humidity and wind speed data. These climatic parameters were recorded by a meteorological station close to the research site and thus used for the ET_o computation.

2.3.2 Crop evapotranspiration and crop coefficient

The most popular and widely used technique to estimate crop evapotranspiration relies on the use of evapotranspiration from a reference surface (ET_o) and crop coefficients (K_c). Doorenbos and Pruitt (1977) and other authors have explored this useful and favourable approach for ET_c estimation. Crop evapotranspiration estimation methods using field measurements are time consuming and need technical facilities and expertise which are not always available in developing countries. The methodology described in Doorenbos and Pruitt (1977) has been improved by Allen *et al.* (1998), with an adjustment in the calculation of ET_o and the presentation of two different methods for the determination of crop evapotranspiration (ET_c). From the two possible calculation procedures to estimate ET_c, the first one uses a single K_c ($ET_c = ET_o \times K_c$), combining crop transpiration and soil evaporation effects. The second, dual K_c ($ET_c = ET_o \times (K_e + K_{cb})$) separates the single K_c into the transpiration and evaporation components of ET_c and it is mainly used to calculate ET_c for frequent periods (daily or two day periods).

2.3.2.1 Crop evapotranspiration using the single K_c approach

Crop evapotranspiration is calculated by multiplying ET_o by crop coefficient (K_c), a coefficient that expresses the difference in evapotranspiration between the cropped and reference grass surface. When the difference between soil evaporation and crop transpiration between the reference and cropped surface is combined into one single coefficient, then the single K_c is used. The single K_c is calculated as:

$$K_c = \frac{ET_c}{ET_o} \qquad (2.3)$$

Where

ET_o is reference evapotranspiration (mm)

ET_c is crop evapotranspiration (mm)

K_c is the dimensionless crop coefficient

Soil evaporation may fluctuate daily as a result of precipitation or irrigation, and as such the single K_c only expresses the time averaged effects of crop evapotranspiration. The time averaged single K_c is used for irrigation systems where the averaged effects of soil wetting are acceptable and relevant. This is particularly true for surface irrigation and sprinkler systems where the time interval between successive irrigations is often several days, usually ten days or more (Allen *et al.*, 1998). Often, fast estimate of ET_o x K_c must be made within a short period of time. These may require using the single K_c method because of the simplicity of its computation procedure. This makes the single K_c method convenient and popular to use than the dual K_c method. As stated earlier, the single K_c method represent only average conditions for soil wetting by irrigation and/or precipitation, so that the potential for error with this method increases when irrigation frequency is high.

Alternatively, initial K_c ($K_{c\ ini}$) under high frequency irrigation can be accurately estimated according to the magnitude of reference ET_o during the initial period and according to how often the soil is wetted to calculate crop evapotranspiration (ET_c). This method of estimating K_c initial is presented in Fig 30 of Allen *et al.* (1998). Though the dual-K_c is preferred to the single-K_c especially for high frequent irrigation events, the single-K_c has gained wide acceptance due to simplicity of the calculation involved. The result is that crop water requirement estimated with the single K_c under high frequent irrigation without considering the irrigation frequency and magnitude of ET_o during the initial period may contain substantial inaccuracies thereby providing erroneous data for agricultural water management.

2.3.2.2 Crop evapotranspiration using the dual K_c approach

In the dual crop coefficient method, the effects of crop transpiration and soil evaporation are separately determined. The two separated coefficients are: the basal crop coefficient (K_{cb}) to account for plant transpiration, and the soil evaporation coefficient (K_e) to describe evaporation from the soil surface. The dual K_c is therefore calculated as:

$$K_c = K_{cb} + K_e \tag{2.4}$$

Since the dual K_c approach separates soil water evaporation from crop transpiration it is expected to provide accurate ET_c estimation especially during the initial crop stage of high frequency irrigation.

Several studies have been conducted to quantify, critique and compare the accuracy of the single-K_c and dual-K_c procedures for estimation of ET_c in crop systems (Liu and Pereira 2000; Tolk and Howell 2001 and ShiZhang *et al.* 2007). All the results showed that the dual-K_c estimated ET_c more accurately than the single-K_c. As a result, the dual K_c is highly recommended when more precise estimates of ET_c are needed for real-time irrigation scheduling. When one is not using the dual K_c approach under high frequency irrigation, Allen *et al.* (1998) recommends that $K_{c\ ini}$ is estimated by considering the magnitude of ET_o and the frequency of irrigation.

2.4 Water use efficiency (WUE) in irrigated agriculture

Agriculture is often characterized by inefficiency and of lower profitability compared with other sectors. Previous evaluation of the efficiency of agricultural water use (e.g., Wallace 2000) has shown that for rain-fed crops, the portion of rainfall used for crop transpiration is low, from 15 to 30 % (Rockstrom and Falkenmark 2000). Comparably, lower values have been reported by Wallace and Gregory (2002) for irrigated agriculture (13–18 % of irrigation water delivered). Future water scarcity is currently considered as the biggest water problem worldwide (Jury and Vaux 2005). World food production may soon be limited by water availability as it will be more difficult to find additional water supplies for agriculture as a result of competition from other sectors. Obviously, the solution to this competition for water resources lies mostly on improving the efficiency of water use for food production.

Efficiency literally means a measure of the output obtained from a given input. Water use efficiency in irrigated agriculture may be defined in several ways, depending on the nature of the inputs and outputs under examination. Water use efficiency is defined as a ratio of biomass accumulation, which is usually expressed as carbon dioxide assimilation (A), total dry matter yield (B), or crop grain yield (G), to water consumed, expressed as transpiration (T), evapotranspiration (ET), or total water input to the system (I). Various strategies are required to enhance water use efficiency in irrigated and rain-fed agriculture. One way is breeding crop varieties that use water efficiently. Others include better management of the water resource and changes in crop management. Water use efficiency can also be enhanced by adopting water saving and efficient irrigation method like drip irrigation (Costa *et al.*, 2007). Wallace and Batchelor (1997) proposed four ways for enhancing water use efficiency in irrigated agriculture (Table 2.2).

Table 2.2 Ways for enhancing water use efficiency in irrigated agriculture

Improvement category	Options
Agronomic	Crop management to enhance precipitation capture or reduce water evaporation (e.g., crop residues, conservation till, and plant spacing); improved varieties; advanced cropping strategies that maximize cropped area during periods of lower water demands and/or periods when rainfall may have greater likelihood of occurrence.
Engineering	Irrigation systems that reduce application losses, improve distribution uniformity, or both; cropping systems that can enhance rainfall capture (e.g., crop residues, deep chiseling or paratilling, furrow diking, and dammer-diker pitting).
Management	Demand-based irrigation scheduling; slight to moderate deficit irrigation to promote deeper soil water extraction; avoiding root zone salinity yield thresholds; preventive equipment maintenance to reduce unexpected equipment failures.
Institutional	User participation in an irrigation district (or scheme) operation and maintenance; water pricing and legal incentives to reduce water use and penalties for inefficient use; training and educational opportunities for learning newer and advanced techniques.

Source: Wallace and Batchelor (1997)

Enhancing the efficient use of water resources by adopting drip irrigation has been reported (Musick and Dusek, 1980; Howell *et al.*, 1995; Howell *et al.*, 1997). Since WUE is the yield divided by the water used by the crop to produce that yield, any factor that increases the crop water requirement without increasing the yield will reduce WUE. Similarly any factor that reduces the water requirement of the crop without reducing the yield will increase WUE. Water requirements of crops are greatest in arid and semiarid regions, while the supply by rainfall is least' (Hillel, 1980). It is the large vapour pressure deficit of the air that forces the large water consumption by crop and the high water use per unit of crop yield. Tanner and Sinclair (1983) presented data that supported the concept of greater WUE in humid regions using corn as the model crop. Their mean WUE was 1.8 kg m^{-3} for several semi arid sites while averaging >2.5 kg m^{-3} in humid sites. The foregoing observation reflects higher vapour pressure deficit and evaporative demand in arid and semi arid regions. The Keta Sand Spit is a semi arid area with mean annual evapotranspiration (1785 mm) exceeding mean annual rainfall (800 mm) (Banoeng-Yakubo *et al.*, 2005). Relative humidity is however, very high and has a value as high as 96 % in the mornings (Banoeng-Yakubo *et al.*, 2005) reflecting low vapour pressure deficit. The high relative humidity is probably due to the fact that the area is sandwiched between two large water bodies (The Keta Lagoon to the north and the Gulf of Guinea to the south). It is therefore necessary to study the water productivity of okra grown in the Keta Sand Spit (semi arid climate but with high relative humidity) hence low irrigation water requirement. It is also important to know the water productivity of drip irrigation and compare with the adopted irrigation methods in the area (bucket and sprinkler).

2.5 Nitrogen uptake by crops

Nitrogen (N) is the most abundant and important mineral nutrient in plants and in their desire to increase production, farmers apply it in large quantities, in the form of nitrogen-based fertilizers. Nitrogen uptake by the aboveground biomass results in crop growth as well as variations in N concentration in plants (Balik *et al.*, 2003; Gastal and Lemaire, 2002). Nitrogen taken up by the plant also affects the quality of the plant (Turan and Sevimli, 2005). Hence, optimal N application methods are important to ensure high and quality yields at the same time (Rahn, 2002). While it is virtually impossible to prevent nitrate leaching, improved management practices resulting in increased fertilizer N use efficiency can reduce the likelihood of nitrate contamination of groundwater (Bijay-Singh *et al.*, 1995; Cassman *et al.*, 2002). The efficient utilization of N can be enhanced by balanced application of N, P and K with lighter but frequent irrigation (Bijay-Singh *et al.*, 1995; Bijay-Singh and Sekhon, 1979).

Most often manure in the form of dried cow dung or poultry droppings is spread as fertilizers on the sandy soils of Keta Spit at sowing or planting of the crops for bucket and sprinkler irrigated crops. However, by the introduction of drip irrigation, fertilizers can also be added through fertigation (Hagin *et al.*, 2003). One of the major essential elements for plant growth is nitrogen. Nitrogen is required in large quantities for plants to grow. Nitrogen is mostly provided in the form of synthetic chemical fertilizer. On the other hand, animal manure has been used for many centuries as fertilizer. Manures have the advantage of releasing plant nutrients slowly thus avoiding nutrient leaching especially on sandy soils. Manure not only provides plant nutrients, but also improves soil physical properties. Unger and Stewart (1974) observed increased water holding capacity and decreased evaporation rate with increased manure applications. Increased water infiltration where manure was used is common in literature (Mathers *et al.* 1977; Mazurak *et al.* 1955; and Swader and Stewart, 1972). Manure is also known to increase soil organic matter and supplied plant nutrients.

For over a century, the vegetable farmers of Keta have been applying a lot of poultry manure and cow dung as fertilizers. In addition, some inorganic fertilizers such as urea, sulphate of ammonia and N-P-K are added to augment the fertility of the soils (Awadzi *et al.*, 2008). The application of organic manure and inorganic fertilizers add a lot of N (in the form of ammonium and nitrate) to the soil. This practice may have contributed large amounts of N to the plough layer, saturating this layer with the nutrient. Because of the sandy nature of the soil, the practice is likely to result in loss of N from the plough layer through leaching.

No study has been conducted to compare N uptake with manure fertilization to N uptake with fertilization from chemical fertilizers in the Keta Sand Spit. By introducing drip irrigation and fertigation in the Keta Sand Spit, N uptake under fertigation can be compared to N uptake under manure applications. Therefore, field comparison of N uptake for different modes of fertilizer application (manure and fertigation) is needed to clarify the optimal growth conditions for okra in the Keta Sand Spit.

2.6 Radiation interception and radiation use efficiency

The transformation of solar energy into biomass is an economical but inefficient process as close to 2 % of the incoming solar energy captured by the crop within the photosynthetically active spectrum of solar radiation is transformed into biomass (Vargas *et al.*, 2002). This efficiency is however, largely dependent on plant cultivar and environmental conditions. In order to identify and select the optimal crop for a certain meteorological condition and to know the basic processes of radiation capture and energy transformation into biomass it is important to measure and describe crop growth over time in detail. When describing yield and growth of crops as influenced by environmental conditions and management, three types of factors can be differentiated (Rabbinge and de Wit 1989). These are: (1) factors that determine potential yield (such as temperature and radiation), (2) factors that limit growth (such as nutrients and water), (3) factors that reduce growth (such as pests and diseases). Based on knowledge about the effect of the above factors on light interception during the growing season, the total biomass may be calculated from Monteith’s equation (Monteith 1977):

$$TBM = IPAR \times RUE \qquad (2.5)$$

where

IPAR is the amount of photosynthetic active radiation intercepted by the crop canopy (MJ m^{-2})

RUE is the radiation use efficiency (g MJ^{-1}).

TBM is the total above ground biomass (kg ha^{-1})

Several authors have observed a good linear relationship between biomass accumulation and IPAR in healthy green crops (Cannell *et al.*,1987; Grace *et al.*, 1987; Dalla-Tea and Jokela 1991; Will *et al.* 2005; Christensen and Goudrian 1993; Legg *et al.*, 1979). The slope of this relationship is called radiation use efficiency given as:

$$RUE = \frac{TBM}{IPAR} \tag{2.6}$$

Various simulation models use the concept behind IPAR and RUE to simulate crop growth and yield (e.g. Amir and Sinclair 1991*a*; Jamieson *et al.* 1998*b*). A lot of these models involve the effect of drought on light interception and radiation use (Amir and Sinclair 1991*b* and Jamieson *et al.* 1998*a*). Several models showing the effect of nitrogen supply on leaf index and RUE also exist (Sinclair and Horie 1989; Sinclair and Amir 1992). Values of RUE are common in literature for many crops, and the differences among crops are significant (Gower *et al.* 1999). Agronomic practices affect the IPAR and RUE in terms of biomass production. Studies of RUE under a combination of different irrigation and fertilization methods are scanty (e.g. Olesen *et al.*, 2000 and Andersen *et al.*, 1996), and there are no studies to date examining RUE under different irrigation and fertilization methods in the Keta Sand Spit. Also the okra crop is less well examined with respect to canopy intercepted radiation and radiation use efficiency under tropical conditions.

On the sandy soil in Keta, nutrient deficiency may occur due to nitrate leaching if irrigation is not managed well. Nutrient deficiency may affect both IPAR and RUE (Salvagiotti and Miralles, 2008). It is therefore important to determine the influence of drip, sprinkler and bucket irrigation with different fertilization on IPAR and RUE in the Keta Sand Spit.

2.7 Crop coefficient from spectral reflectance measurements

A basic need for irrigation scheduling is the determination of daily crop evapotranspiration (ET_c) during the growing period. A widely applied method for estimating ET_c is the crop coefficient (K_c) approach (Doorenbos and Pruitt 1977; Allen *et al.*, 1998; Jensen and Allen 2000), in which empirically determined K_c is multiplied by evapotranspiration from a reference surface (traditionally grass or alfalfa) to calculate ET_c. Crop coefficient values determined for various crops will normally vary with respect to changes in vegetative growth until effective full cover is reached. After full cover, the K_c will likely decline. The amount of the decline is mainly dependent on the particular growth characteristics of the crop (Jensen *et al.* 1990) and how irrigation is managed during the late season (Allen *et al.* 1998).

A lot of irrigation computation models that calculate crop evapotranspiration (ET_c) use the time averaged single K_c. The time averaged single K_c method has been shown to provide ET_c estimation with reasonable accuracy for most applications (Allen *et al.*, 1998). However, for high frequency irrigation, using the dual K_c approach may produce more accurate ET_c values (Allen *et al.*, 2005a; Liu and Pereira 2000; Liu and Luo, 2010). Initial applications of the dual K_c procedure include Allen (2000) and Liu and Pereira (2000). In the former study (Allen, 2000), carried out in Turkey, the dual K_c method was applied to a variety of crops in a study comparing several approaches to estimate crop evapotranspiration. In the later study (Liu and Pereira, 2000) however, the dual K_c approach to estimate ET_c was applied on winter wheat and summer maize in the North China Plain. Both studies showed the suitability of using the dual K_c method and its advantage over the single K_c in showing impacts of wetting frequency on total water consumption. The superiority of the dual K_c method for the winter wheat-summer maize crop sequence has been affirmed through several years of lysimeter data (Liu and Luo, 2010). Further successful applications of the dual K_c method abound in literature: Tolk and Howell (2001) for sorghum, Howell *et al.* (2004) for cotton, Zhao and Nan (2007) for maize, Hunsaker (1999) for cotton, Howell *et al.* (2002) for cotton, and Hunsaker *et al.* (2003) for alfalfa.

The FAO-56 dual K_c method provide a good framework for estimating daily ET_c (Liu and Luo, 2010; Allen, 2000; Allen *et al.*, 2005a; Liu and Pereira, 2000). However, its successful application in providing good ET_c estimates for irrigation scheduling is strongly supported by the ability to determine and construct a K_{cb} curve that tracks the actual crop growth during a given season (Allen *et al.* 1998; Hunsaker *et al.* 2003). The normal application of K_{cb} requires the description of canopy development during the growing season. The parameters that are commonly used in irrigation scheduling include time passed from planting (Doorenbos and Pruitt, 1977; Allen *et al.*, 1998), percentage of time from planting to effective full cover and from effective full cover to harvest (Wright, 1982), and accumulated growing degree days (GDD) from planting (Stegman, 1988). However, when crops are grown under optimum management conditions, K_{cb} curves can shift along any of the above mentioned indicators from season to season. Serious shifts can occur especially during early crop growth when real weather conditions vary from expected conditions (Bausch, 1995). Hunsaker *et al.* (2002) showed in field experiments the need to adjust K_{cb} curves during each cutting cycle of alfalfa to explain the changes in meteorological conditions that occur during the year. Changes in optimum K_{cb} curves can also be widened when cropped fields deviate greatly from the best standard agronomic practices.

Additionally, there is an array of other cultural, managerial, and environmental factors that cause shifts from normal K_{cb} curves. For example, Hunsaker *et al.* (2005a) observed that an increase or decrease in the planting density and fertilizer application rates for cotton greatly changed the seasonal forms of K_{cb} and ET_c during controlled experiments. At the field level, non uniform distribution of applied water and nutrients, differences in soil water retention, crop disease, and several other environmental limitations can introduce substantial variations in basal crop coefficient. When a deviation from normal crop growth is caused by any of the above mentioned factors, the K_{cb} should be adjusted.

Even when management factors and weather conditions are optimal with minimal crop variability, applying K_{cb} values from the literature will likely need some kind of local adjustment, unless the K_{cb} values were locally developed. A widely used approach is to adjust the K_{cb} in relation to observed growth. Allen *et al.* (1998) suggest modifications to K_{cb} values based on observed changes for leaf area index (LAI) or fraction of vegetative cover relative to that for optimum vegetation. The suggested adjustments should provide fairly good results because K_{cb} value varies proportionately to the amount of actively transpiring canopy (Jensen *et al.*, 1990). However, for many commercial farms, adjusting K_{cb} based on LAI or vegetative cover measurements is most likely impractical because of the amount of data to be collected manually over large areas within a relatively short period of time.

Applying remote sensing technology can provide excellent means to get over many of the failings of the conventional K_{cb} curves by providing real-time information on daily crop growth as affected by actual crop growth patterns, local climate, and field spatial variability. Multispectral vegetation indices (VIs), computed as differences, ratios, or linear combinations of reflected light in the visible and near infrared and relative vegetative indices (RVI) have been found to closely match several crop growth parameters such as leaf area index (Moran *et al.*, 1995), crop yield (Plant *et al.*, 2000), and percent crop cover (Heilman *et al.*, 1982). Other authors (Bausch, 1995; Neale *et al.*, 2003; Hunsaker *et al.*, 2005a; Johnson and Scholasch, 2005) have shown that the multispectral VIs can be used as real time substitutes of K_{cb} for many crops. Consequently, VIs from remote sensing information possibly provide a means to infer in real time the spatial distribution of the basal crop coefficient. Such information would considerably reduce laborious crop surveys to obtain suitable basal crop coefficients. The practicality of using multispectral VIs as near real time substitutes for K_{cb} was first suggested over three decades ago by Jackson *et al.* (1980), who showed the similarity between the seasonal distribution of a VI for wheat and that of the wheat crop coefficient. This VI-based K_c concept was further confirmed by Bausch and Neale (1987) and Neale *et al.* (1989) who developed K_{cb} for corn based on several vegetative indices. Bausch and Neale (1989) and Bausch (1995) reported better estimation of ET_c by incorporating VI- based corn K_{cb} in an irrigation scheduling model. Hunsaker *et al.* (2005b) also established a simple model for predicting the K_{cb} of wheat from normalized difference vegetation index (NDVI) data.

Determining daily ET_c with the VI-based K_{cb} would require frequent, but not daily, VI measurements, since the generally smooth shape of the K_{cb} curve over a growing season would enable data to be interpolated between successive measurements. Only limited research has been carried out to develop VI-based K_{cb} for crops other than corn. However, Choudhury *et al.* (1994) showed through simulation studies that VIs could be used to obtain K_{cb} for many other agricultural crops. One of the most important ways of improving the efficient use of water resources for irrigation in the Keta Sand Spit will be determining local K_{cb} values for proper irrigation scheduling. It is therefore important to develop local real time K_{cb} values in the Keta

Sand Spit to improve irrigation scheduling using the fraction of photosynthetically active radiation ($f_{PAR)}$ data from relative vegetative indices.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site Characteristics

The experimental site is located in the coastal savannah zone in the south eastern corner of Ghana (latitude 5^{o} 48' N, longitude 0^{o} 55' E), at an altitude of 8 m above mean sea level. (Fig. 3.1). The site is located within the narrow Keta Sand Spit, separating the Keta lagoon from the Gulf of Guinea. The Sand Spit consists of white medium marine sand forming elongated sandbars with narrow depressions in between (Awadzi *et al.*, 2008). The fresh water lens is superimposed on salty ground water with a thick layer of clay soil sandwiched between the fresh water lens and the salty water (Awadzi *et al.*, 2008).

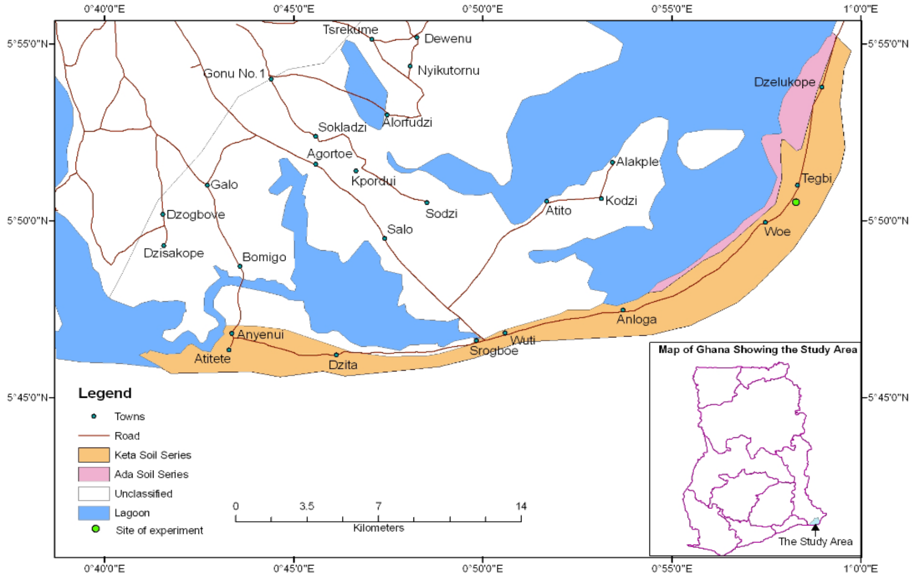

Fig. 3.1 Map of study area showing experimental site.

The site lies within the dry equatorial climatic region, and lies within the driest part of Ghana. Two seasons are clearly defined in this area: the rainy and dry seasons. The months of June and July defines the main rainy season, whilst September and October defines the minor rainy season. June is usually the month with the highest rainfall in the area. Relative humidity is generally high in the mornings and at night but low in the afternoon (Banoeng-Yakubo *et al.*, 2005). Based on climate data from 1913 to 1992, the mean annual precipitation in the area is 801 mm. The highest monthly mean value of 188 mm occurs in June while the minimum mean value of 11 mm occurs in January. Annual evaporation is about 1785 mm. Monthly comparison of rainfall and potential evaporation shows that, rainfall exceeds potential evaporation only in June (Banoeng-Yakubo *et al.*, 2005).

3.2 Soils

The soils at the experimental site belong to the Keta series. They are classified as Quartzipsamments according to Soil Taxonomy as cited by Awadzi *et al.*, (2008). According to FAO (1998), the soil is classified as Arenosols as cited by Awadzi *et al.*, (2008) which was formed from marine sandy deposits. The soils contain more than 96 % sand in the 1.0 m horizon. The soil is low in nitrogen, organic matter and cation exchange capacity that limit nutrient storage ability but very high in phosphorus content due to the continuous application of manure over the years. Table 3.1 shows the physical and chemical properties of the experimental soil.

Table 3.1 Physical and chemical properties of the top soil layer (0-40cm) in the experimental site.

Parameter	**Value**
Physical	
Clay < 2 µm (%)	2.40
Silt 2-20µm (%)	4.00
Fine sand 20-200 µm (%)	9.97
Sand 20-2000 µm (%)	86.58
Coarse sand >2000 µm (%)	0.62
Dry bulk density (g cm^{-3})	1.47
Field capacity (vol. %)	7.00
Wilting point (vol. %)	1.4
Chemical	
pH	7.70
Organic carbon (%)	0.19
Total nitrogen (%)	0.09
Available phosphorus (mg/kg)	105
Total phosphorus (mg/kg)	1246
Potassium (mg/kg)	31.28

3.3 Land use history

By the end of the 19th century, coconut (*Cocus nucifera*) production had been introduced in Keta and served as an important cash crop in the area. In the 1930s however, due to the world economic recession, the collapse of coconut production by Cape-St Paul disease and the expanding population forced the people to give up coconut production and resorted to intensive horticultural system on the Sand Spit. The main cultivated crop became shallot, with pepper, okra and tomatoes as intercrops. The crops are grown with large application of poultry and cowdung manure.

3.4 Experimental treatments

Four experimental treatments were studied during two seasons in 2010 and 2011 while five treatments were studied during two seasons in 2011 and 2012. The additional treatment to make the treatments five was bucket irrigation with spread manure which was not initially part of the treatments. The experiments were conducted outside the main rain season. The first experiment with four treatments was carried out from 16th October, 2010 to 30th December, 2010. The second experiment also with four treatments was conducted during the period 6th July, 2011 to 9th October, 2011 while the third experiment with five treatments was conducted from 21st December, 2011 to 15th March, 2012. Finally, the fourth and final experiment with five treatments was conducted from 3rd August, 2012 to 31st October, 2012.

Experimental treatments were made up of a combination of irrigation and fertilization. Irrigation methods used in the study consisted of bucket, sprinkler and drip irrigation while the fertilization methods used in the study were cow dung manure spread and incorporated into the soil, cow dung manure placed close to the plant and chemical fertilizer supplied through fertigation. The combinations of irrigation and fertilization treatments are given in Table 3.2 and explained as follows:

1. *Drip irrigation with placed manure (DPM)*

Drip irrigation with fertilization using dried cow dung placed in small trenches under each emitter (Fig. 3.2a). Two weeks before seeding, 72 small pits of 15 cm depth by 15 cm diameter were made under each emitter. Afterwards, the soil from each pit was mixed with 0.5 kg of manure and put back in the pits such that the space between emitters was free of cow dung. The local ‘Nyuigzovi’ okra variety seeds were then sown in the pits at a depth of approximately 2.5 cm.

2. *Sprinkler irrigation with placed manure (SPM)*

Sprinkler irrigation with fertilization using dried cow dung but placed at the seeding point. Two weeks before seeding, 72 similar pits as described for DPM were made in the plots. Afterwards, the soil from each pit was mixed with 0.5 kg of manure and put back in the pits leaving the space between plants free of cow dung. The local ‘Nyuigzovi’ variety seeds were then sown in the pits at a depth of approximately 2.5 cm.

3. *Sprinkler irrigation with spread manure (SSM)*

With the SSM treatment (Fig. 3.2b), two weeks before seeding, the soil was manually tilled with a hoe to a depth of about 20 cm. About 34.5 kg of dried cow dung in granulate form was evenly spread on the plot size of 17.28 m^2. The cow dung was then incorporated into the 5 cm upper soil layer using a rake. The local ‘Nyuigzovi’ variety seeds were then sown in small pits at a depth of approximately 2.5 cm

4. *Bucket irrigation with spread manure (BSM)*

Bucket irrigation is the most adopted and practised irrigation method in the Keta Sand Spit. The BSM treatment was therefore added to reflect the local irrigation method in the Keta area. The mode of manure application was same as described for SSM but with bucket irrigation as the irrigation method.

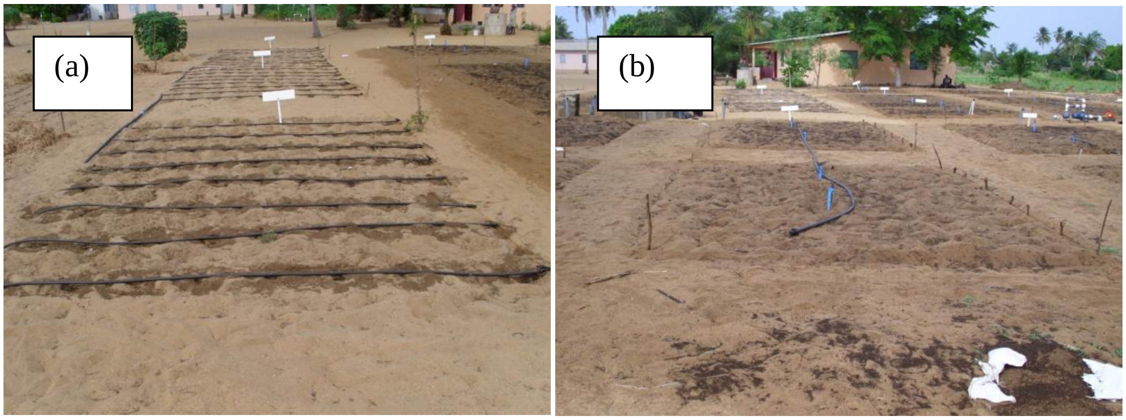

Fig. 3.2 Drip with placed manure (a) and sprinkler with spread manure (b) plots

5. *Drip Irrigation with Fertigation (DFT)*

Drip irrigation with fertigation using Calcium Nitrate ($Ca(NO_3)_2$) and Potassium Chloride (KCl) to avoid over-supply of phosphorus . Fertigation for the first experiment was split into two doses (two weeks after germination and immediately after flowering) while 8 doses of fertigation were applied for the second and third experiments (weekly; starting two weeks after germination). To supply 89 kg N/ha to a plot size of 17.28 m^2, about 0.9 kg of $Ca(NO_3)_2$ was weighed and thoroughly mixed with distilled water. In supplying 120 kg K/ha, about 0.4 kg of KCl was weighed and mixed with distilled water. The two mixtures were mixed in a 9 litre container to obtain the stock solution. A proportional flow injector (Dosatron DI-16, France) (Fig. 3.3) was set to inject 1% of the stock solution into the irrigation flow.

Fig. 3.3 Fertigation with the Dosatron

Nitrogen supply was increased from 89 kg N/ha to 140 kg N/ha during the last experiment. Therefore for the SSM and BSM 54.3 kg was applied as described above. With the SPM and DPM 0.75 kg of the dried cowdung was placed in each pit under each emitter as also described above. Finally for DFT, 1.4 kg of $Ca(NO_3)_2$ and 0.4 kg of KCl were weighed into a 9 litre container and dissolved in distilled water to obtain the stock solution. Fertilizing by broad-spread dried cowdung (SSM) constitutes the usual practice for the Keta area, however excessive amounts of P are supplied when the crop demand for N has to be satisfied. In addition broad-spread manure may not decompose under drip irrigation as only soil near emitters is wetted. As the supply of nutrients was scheduled from both fertilizer and soil analyses and the latter showed high soil P content no cowdung was used in DFT. Thus, assuming that under optimum soil moisture conditions about 80% of N in manure will be available to the plants, all treatments received potentially the same amount of N.

3.4.1 Experimental layout and crop sowing pattern

The combined irrigation and fertilizer treatments were arranged in a randomized complete block design with four replications. Each experimental plot was 3.6 m x 4.8 m (17.28 m^2) in size, with a planting distance of 0.4 m and row distance of 0.6 m which accommodated 72 okra plants of the local ‘Nyuigzovi’ variety. The plots were separated by 2m buffer strips to serve as walk way and more importantly to minimise the chances of moisture drifting from one treatment to another treatment and from one replication to another replication.

Water for the system was pumped from the shallow aquifer, and was filtered using a 51 mm diameter (120 mesh) disc filter (Naandan, Israel). Plots were irrigated using Naandan manufactured microsprinklers with a discharge of 50 L/h and drip tubes with a discharge of 2 L/h. The microsprinklers had a radius of throw of 2m. For the sprinkler irrigated plots, 32 mm diameter polyethylene tubing was connected to the main line such that it passed through the centre of each plot. Two microsprinkler heads were installed in the middle of each plot on 1 m risers and spaced 2 m apart to supply water to the entire plot. For the drip irrigated blocks, 32 mm diameter polyethylene tubing was connected to the main line after which laterals were connected to the 32 mm polyethylene tubing. Each plot was instrumented with manual gate valves to control the flow of water to plots. The drip irrigation system had emitter spacing of 40 cm that fitted the planting distance. Each emitter therefore irrigated one plant.

Table 3.2 Irrigation and fertilization treatments applied to okra during the study

Expt.	Date	Irrigation and fertilization treatments	Code
1	16-10-2010 to 9-1-2011	Sprinkler N-optimal from spread manure 20t/ha, 0.56%N, 0.72%P	SSM
		Sprinkler N-optimal from placed manure 20t/ha, 0.56%N, 0.72%P	SPM
		Drip N-optimal from placed manure 20t/ha, 0.56%N, 0.72%P	DPM
		Drip P-optimal from soil 89 kg N/ha from $Ca(NO3)_2$ and 120 kg K/ha from KCl	DFT
2	16-7-2011	Sprinkler N-optimal from spread manure 20t/ha, 0.56%N, 0.72%P	SSM
	to 9-10-2011	Sprinkler N-optimal from placed manure 20t/ha, 0.56%N, 0.72%P	SPM
		Drip N-optimal from placed manure 20t/ha, 0.56%N, 0.72%P	DPM
		Drip P-optimal from soil 89 kg N/ha from $Ca(NO3)_2$ and 120 kg K/ha from KCl	DFT
3	21-12-2012 to 15-3-2013	Bucket N-optimal from spread manure 20t/ha, 0.56%N, 0.72%P	BSM
		Sprinkler N-optimal from placed manure 20t/ha, 0.56%N, 0.72%P	SSM
		Sprinkler N-optimal from placed manure 20t/ha, 0.56%N, 0.72%P	SPM
		Drip N-optimal from placed manure 20t/ha, 0.56%N, 0.72%P	DPM
		Drip P-optimal from soil 89 kg N/ha from $Ca(NO3)_2$ and 120 kg K/ha from KCl	DFT
4	3-8-2012 to 31-10-2012	Bucket N-optimal from spread manure 31.5t/ha, 0.56%N, 0.72%P	BSM
		SprinklerN-optimal from placed manure 31.5t/ha, 0.56%N, 0.72%P	SSM
		SprinklerN-optimal from placed manure 31.5t/ha, 0.56%N, 0.72%P	SPM
		Drip N-optimal from placed manure 31.5t/ha, 0.56%N, 0.72%P	DPM
		Drip P-optimal from soil 140 kg N/ha from $Ca(NO3)_2$ and 120 kg K/ha from KCl	DFT

3.5 Meteorological data and ET_o computation

Standard meteorological data were obtained from an automatic weather station (Fig. 3.4) (Campbell Scientific, Logan, Utah) located at the research site, within a distance of 1 km and included daily maximum and minimum air temperature, relative humidity, wind speed, rainfall, and solar radiation.

Figure 3.4 A Campbell Scientific meteorological station close to the study site.

The daily weather data were used to compute daily ET_o by the most widely accepted FAO-56 Penman-Monteith mathematical model for reference grass surface (Allen et al., 1998). The FAO-56 Penman-Monteith model for evapotranspiration estimation from weather data is given as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (3.1)$$

Where: ET_o is reference grass evapotranspiration (mm day^{-1}); R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}); G is soil heat flux density (MJ m^{-2} day^{-1}); T is mean daily air temperature at 2 m height (°C); u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa); e_a is actual vapour pressure (kPa), $e_s - e_a$ is saturation vapour pressure deficit (kPa), Δ is slope of vapour pressure curve (kPa $°C^{-1}$), γ is psychrometric constant (kPa $°C^{-1}$). The spreadsheets for the ET_o computations are shown in Appendix A.

3.5.1 Procedures for computing ET_o using the FAO56-PM equation

The FAO-56 model for computing grass reference ET_o requires measured weather parameters of air temperature (T), relative humidity (RH), wind speed ($U_{2)}$ and solar radiation (R_s). The computation procedure is explained in detail in Allen *et al.*, (1998) publication. The computation procedure is summarized below.

The soil heat flux, G is taken as zero for daily ET_o computation because G is small for daily ET_o computation and may be ignored (Allen *et al.*, 1998).

The following equations were used for computing the needed parameters for the daily ET_o computation:

Slope of the saturation vapour pressure versus temperature curve, Δ (kPa $^oC^{-1}$) was computed with the equation:

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T_m}{T_m + 237.3}\right)\right]}{(T_m + 237.3)^2} \tag{3.2}$$

where T_m (^oC) is average temperature and calculated as:

$$T_m = \frac{T_{min} + T_{max}}{2} \tag{3.3}$$

The psychrometric constant, γ (kPa $^oC^{-1}$) was calculated from the equation:

$$\gamma = 0.665 \times 10^{-3}\text{Pa} \tag{3.4}$$

where Pa (kPa), the atmospheric pressure, was calculated using the equation:

$$\text{Pa} = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26} \tag{3.5}$$

z is altitude of site for the meteorological station in meters. The altitude was measured with an Etrex handheld GPS (10m above mean sea level). The atmospheric pressure was therefore constant in the computation. The psychrometric constant was therefore calculated as:

$$\gamma = 0.665 \times 10^{-3} \left[101.3 \left(\frac{293 - 0.0065 \times 10}{293}\right)^{5.26}\right] \quad (3.6)$$

The saturation vapour pressure at the minimum temperature, $e^o(T_{min})$ (kPa) was calculated using the equation:

$$e^o(T_{min}) = 0.6108 \exp\left(\frac{17.27 T_{min}}{T_{min} + 237.3}\right) \quad (3.7)$$

The saturation vapour pressure at the maximum temperature, $e^o(T_{max})$ (kPa) from the equation:

$$e^o(T_{max}) = 0.6108 \exp\left(\frac{17.27 T_{max}}{T_{max} + 237.3}\right) \quad (3.8)$$

The mean saturation vapour pressure, e_s (kPa) was then calculated as:

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \quad (3.9)$$

The actual vapour pressure which is derived from RH_{max} and RH_{min}, e_a (kPa) was computed using the equation:

$$e_a = \frac{e^o(T_{min}) \frac{RH_{max}}{100} + e^o(T_{max}) \frac{RH_{min}}{100}}{2} \quad (3.10)$$

Clear-sky radiation, R_{so} ($MJm^{-2}day^{-1}$) was calculated as:

$$R_{so} = (0.75 + 2 \times 10^{-5} z) R_a \quad (3.11)$$

where Ra ($MJm^{-2}day^{-1}$) the extraterrestrial radiation was computed using the equation:

$$R_a = \frac{24 \times 60}{\pi} G_{sc} d_r [\omega_s \sin(\phi) \sin(\delta) + \cos(\phi) \cos(\delta) \sin(\omega_s)] \quad (3.12)$$

where $G_{sc} = 0.082$ MJ m^{-2} min^{-1}

Net shortwave radiation, R_{ns} ($MJm^{-2}day^{-1}$) was calculated as:

$$R_{ns} = (1 - \alpha) R_S \quad (3.13)$$

where the albedo, $\alpha = 0.23$

Net longwave radiation, R_{nl} ($MJm^{-2}day^{-1}$) was computed from the model:

$$R_{nl} = \sigma\left(\frac{T_{max},K^4 + T_{min},K^4}{2}\right)(0.34 - 0.14 \times {e_a}^{0.5})\left(1.35\frac{R_S}{R_{so}} - 0.35\right) \qquad (3.14)$$

where Stefan-Boltzmann constant, $\sigma = 4.903 \text{ X } 10^{-9}$ MJ K^{-4} m^{-2} day^{-1} ,

maximum absolute temperature, T_{max}, K = T_{max} + 273.16, (3.15)

minimum absolute temperature, T_{min}, K = T_{min} + 273.16 (3.16)

Finally net radiation, R_n (MJ $m^{-2}day^{-1}$) was computed as:

$$R_n = R_{ns} - R_{nl} \qquad (3.17)$$

3.6 Irrigation scheduling using the single K_c approach

Irrigation scheduling (timing and amount) during the first three seasons was based on daily crop evapotranspiration (ET_c). Daily ET_c was estimated using reference evapotranspiration (ET_o, Eq. 3.1) and the single crop coefficient (K_c) approach presented in FAO-56 (Allen *et al.* 1998). Crop evapotranspiration was computed as the product of reference evapotranspiration and crop coefficient, K_c:

$$ET_c = ET_o \ x \ K_c \qquad (3.18)$$

Due to the high irrigation frequency in the study area (daily or twice a day events), K_c for the initial stage was estimated from Allen *et al.*, (1998) (Fig. 3.5) and adjusted for the fraction of soil surface wetted (100% for sprinkler, 31% for drip irrigation (Allen *et al.* 1998)). The K_c values for sprinkler and drip as well as the length of the growth stages for the first three experiments are given in Table 3.3.

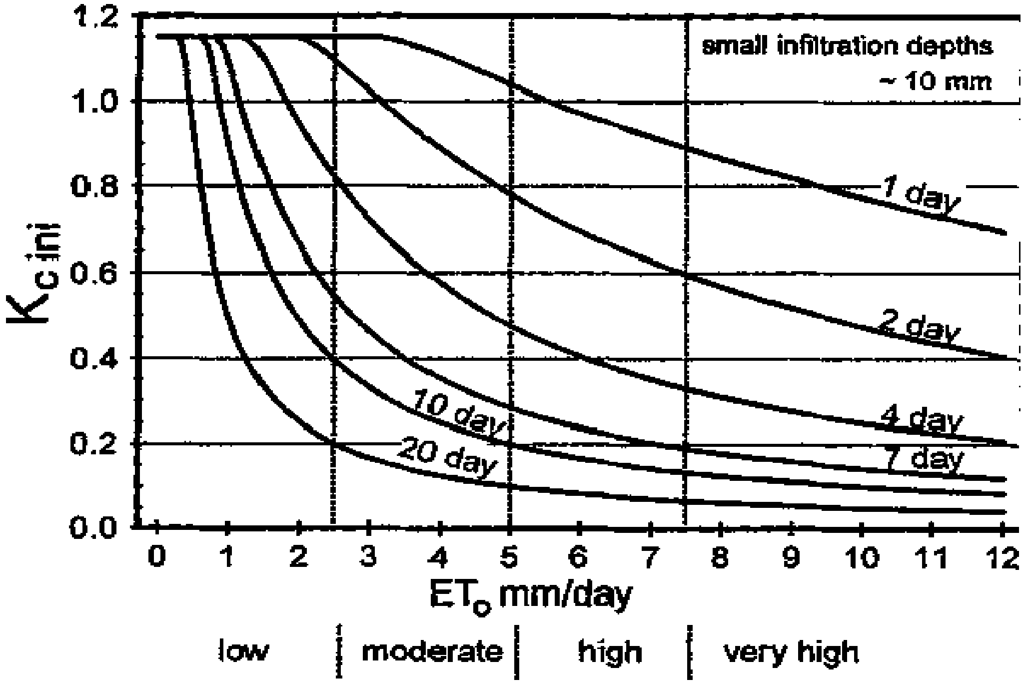

Fig. 3.5 Average K_c initial as related to the level of ET_o and the interval between irrigations and/or significant rain during the initial growth stage for all soil types
Source: Allen *et al.*, (1998)

Crop coefficient for the mid season ($K_{c\ mid}$) and late season ($K_{c\ end}$) were obtained from Kisekka *et al.*, (2010). The $K_{c\ mid}$ and $K_{c\ end}$ values were then adjusted for the effect of relative humidity and wind speed using Equations 3.19a and 3.19b as outlined in the FAO-56 publication (Allen *et al.* 1998).

$$K_{c\,mid\,adj} = K_{c\,mid} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (3.19a)$$

$$K_{c\,end\,adj} = K_{c\,end} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (3.19b)$$

Where $K_{c\ mid\ adj}$ and $K_{c\ end\ adj}$ are the adjusted $K_{c\ mid}$ and $K_{c\ end}$ values; $K_{c\ mid}$ and $K_{c\ end}$ are K_c values during the mid and late seasons respectively; u_2 is the mean value of wind speed recorded in a day during the mid and late season growth stage (m s^{-1}) for $1 \leq u_2 \leq 6$; RH_{min} mean value for daily minimum relative humidity during the mid and late season growth stages (%), for $20 \leq RH_{min} \leq 80$; h is the mean plant height during the mid and late season stages (m) for $0.1 < h < 10$.

Table 3.3 Crop coefficients and length of growth stages for okra during the first three experiments

Growth stage	Length of growth stages[a]	Crop coefficient (K_c)	
		Sprinkler	Drip
Initial	25	1.06[b]	0.33[b]
Development	25	Linearly interpolated	Linearly interpolated
Mi-season	25	0.95[c]	0.95[c]
Late season	11	Linearly interpolated	Linearly interpolated
End of season	N/A[d]	0.84[c]	0.84[c]
Total	86		

[a] The length of growth stages was obtained from the current experiment. [b] K_c initial was estimated from Allen et al., (1998). [c] K_c mid and K_c end were obtained from Kisseka et al., (2010). [d] Not applicable, since there is no growth length at the end of the season.

The irrigation amount I (l) in this study was determined by:

$$I = A\ x\ ET_o\ x\ K_c\ x\ \left(\frac{1}{AP}\right) \tag{3.20}$$

Where:

A is plot area (m^2), ET_o is daily reference crop evapotranspiration amount (mm), K_c is crop coefficient in the initial, mid and late stage, AP is application efficiency (90 % for drip and 75 % for sprinkler (Simonne *et al.*, 2011; Dworak *et al.*, 2007). Daily time of operation of the irrigation system was worked out on the basis of:

1. Discharge of the drip tube (2 L h^{-1}) and that of sprinklers (50 L h^{-1}).
2. Application efficiency of 75 % for sprinkler and 90 % for drip

3. Wetted area of a plot of the irrigation system during the initial stage of the crop growth (100 % for sprinkler and 31 % for drip)

Accordingly, duration of operating of the irrigation system was worked out for the different methods of irrigation (drip and sprinkler). The spread sheet for calculating the irrigation amounts and duration of operation of drip and sprinkler irrigation systems is shown in Appendix B. The duration of delivery of water to each plot was controlled with the help of gate valves. Water saved under drip irrigation compared to sprinkler irrigation was primarily a reduction in soil evaporation between rows which were not wetted by emitters during the initial stage of the okra crop growth.

3.7 Irrigation scheduling using the dual K_c approach

Irrigation scheduling during the last season was also based on daily crop evapotranspiration (ET_c). However, daily ET_c was estimated using the dual K_c approach as described in Allen *et al.* (1998). The dual K_c method which separates soil evaporation (K_e) from crop transpiration (K_{cb}) is given as:

$$K_c = K_e + K_{cb} \tag{3.21}$$

Where K_{cb} is the basal crop coefficient and K_e is the soil evaporation coefficient. Crop evapotranspiration (ET_c) is then computed as:

$$ET_c = (K_e + K_{cb})\ x\ ET_o \tag{3.22}$$

The K_{cb} for the initial, middle and late seasons were obtained by following the guidelines outlined in Table 18 of the FAO-56 publication (Allen *et al.*, 1998). The K_{cb} for the initial stage of the okra crop growth was 0.15. The $K_{cb\ mid}$ and $K_{cb\ end}$ were 0.85 and 0.75, respectively, after adjusting for the effect of relative humidity and wind speed by substituting K_c with K_{cb} in equations 3.19a and 3.19b

The calculation procedure for K_e was also based on the guideline in the FAO-56 publication Allen *et al.*, (1998). The daily K_e which is mainly the soil evaporation component of the dual K_c was adjusted for the soil surface wetness using the following equation:

$$K_e = K_r\,(K_{c\,max} - K_{cb}) \leq f_{ew}\,K_{c\,max} \qquad (3.23)$$

Where K_e = evaporation coefficient; K_{cb} = basal crop coefficient; $K_{c\ max}$ = maximum value of K_c following rain or irrigation; K_r = dimensionless soil evaporating reduction coefficient dependent on the cumulated depth of water evaporated from the top soil; f_{ew} = fraction of the soil that is wetted and exposed to solar radiation.

The sum of K_{cb} and K_e in Equation (3.21) cannot exceed some maximum value ($K_{c\ max}$) which defines an upper limit on the evaporation and transpiration from any cropped surface based on the available latent energy. $K_{c\ max}$ was calculated as:

$$K_{cmax} = max\left(\left\{1.2 + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3}\right\}, \{K_{cb} + 0.05\}\right) \qquad (3.24)$$

Where h = mean plant height during the time of calculation; K_{cb} as defined previously. K_r from equation 3.23 was calculated as:

$$K_r = \frac{TEW - D_{e,i-1}}{TEW - REW} \qquad (3.25)$$

and

$$TEW = 1000(\theta_{FC} - 0.5\theta_{WP})Z_e \qquad (3.26)$$

where TEW = total evaporable water defined as the maximum depth of water that can be evaporated from the soil when the top soil has initially been wetted completely (mm), $D_{e,\ i-1}$ = cumulative depth of evaporation from the soil surface layer at the end of day i − 1 (mm), Z_e = depth of the surface soil layer that is drying by evaporation (m), and REW = readily evaporable water (mm). Average typical values of Z_e and REW for sandy soil (Z_e = 0.1 m and REW = 2 mm) were used (Allen *et al.*, 1998). The effective fraction of the soil surface covered by crop canopy was estimated as:

$$f_c = \left(\frac{K_{cb} - K_{c\,min}}{K_{c\,max} - K_{c\,min}}\right)^{(1+0.5h)} \tag{3.27}$$

where f_c = effective fraction of the soil surface covered by crop canopy, $K_{c\ min}$ = minimum K_c for bare soil with no ground cover (≈0.15), and h = mean plant height. Therefore, the fraction of the soil that is exposed to solar radiation and air ventilation and from which the majority of evaporation occurs is expressed as $(1 - f_c)$.

The estimation of K_e requires a daily water balance computation for the exposed and wetted fraction of the surface soil layer to determine D_e:

$$D_{e,i} = D_{e,i-1} - (P_i - RO_i) - \frac{I_i}{f_w} + \frac{E_i}{f_{ew}} + T_{ew,i} + DP_{e,i} \tag{3.28}$$

where $D_{e,i-1}$ and $D_{e,i}$ are cumulative depletion depth at the end of days i-1 and i (mm), P_i and RO_i are precipitation and precipitation runoff from the soil surface on day i (mm), i_i is the irrigation depth on day i that infiltrates the soil (mm), E_i is evaporation on day i (i.e., $E_i = K_e\ x\ ET_o$) (mm), $T_{ew,\ i}$ is the depth of transpiration from the exposed and wetted fraction of the soil surface layer on day i (mm), and $DP_{e,\ i}$ is the deep percolation loss from the topsoil layer on day i if soil water content exceeds field capacity (mm), f_w is the fraction of soil surface wetted by irrigation, f_{ew} is the exposed and wetted soil fraction. The irrigation depth is divided by f_w to approximate the infiltration depth to the f_w portion of the soil surface. Similarly, E_i is divided by f_{ew} since it is assumed that all E_i (besides a small amount of evaporation that is implicit to the K_{cb} coefficient) is taken from the f_{ew} fraction of the surface layer. $DP_{e,\ i}$ is the downward drainage of water from the topsoil layer on day i if soil water content exceeds field capacity (mm).

3.8 Yield, above ground biomass and water productivity

Fresh pod yields (PY, kg ha^{-1}) of all treatments were determined from 28 plants when green pods were matured by harvesting the crop from 8-m^2 area at the centre of each plot to avoid border effects. Pods were harvested every two days from start of harvest. An electronic scale was used to weigh the harvested pods of each plot. The weight of total above ground dry biomass (TBM), which includes the dry weights of shoot, was recorded at the end of harvest (86 DAS). The shoot (leaf, stem and pod) portion of all the plots was recorded after drying in an oven at 80 ^{o}C to a constant weight. Five plants from small sampling plots of 1m^2 were selected in each plot for the determination of above ground biomass and were also reported in kg ha^{-1}.

Water productivity of the fresh pod yield (WP_y) is defined as the crop yield per unit volume of water used. The latter was obtained from Equations 3.18 and 3.22. Irrigation water productivity (IWP) is also defined as crop yield per unit volume of irrigation water applied using Equation 3.20. Finally, WP_y, $WP_{tbm,}$ IWP_y and IWP_{tbm} were calculated as:

$$WP_y = \frac{PY}{\sum ETc} \tag{3.29}$$

$$WP_{tbm} = \frac{TBM}{\sum ETc} \tag{3.30}$$

$$IWP_y = \frac{PY}{TIW} \tag{3.31}$$

$$IWP_{tbm} = \frac{TBM}{TIW} \tag{3.32}$$

Where WP_y is the water productivity at the fresh pod yield level (kg m^{-3}), WP_{tbm} is the water productivity at the total above ground biomass level (kg m^{-3}), IWP_y is the irrigation water productivity at the fresh pod yield level (kg m^{-3}), IWP_{tbm} is the irrigation water productivity at the total above ground biomass level (kg m^{-3}), ET_c is total crop evapotranspiration (mm) and TIW is the total amount of irrigation water applied (m^3).

3.9 Plant nutrient analysis, nitrogen uptake and nitrogen use efficiency

Oven dried plant samples of stem, leaves and pod were ground separately into fine powder in a mill and 0.1 g of each plant sample was weighed into a 250 ml Kjeldahl flask. 0.2 g of digestion accelerator powder (K_2SO_4 and Na_2SO_4 mixture), selenium catalyst, was added and was followed by 5 ml conc. H_2SO_4. The mixture was heated until the digest became clear. The flask was then cooled and its content transferred into a 100 ml volumetric flask with distilled water and made to volume. An aliquot of 10 ml of the digest was taken into a Markham distillation apparatus. Five millilitres of 40 % NaOH solution was added to the aliquot and the mixture distilled. The distillate was collected into 5 ml of 2 % boric acid. Three drops of mixed indicator containing methyl red and methylene blue were added to the distillate in a 50 ml Erlemeyer flask and then titrated against 0.01M hydrochloric acid (HCl) solution (Bremner, 1965). The % nitrogen was calculated as:

$$\%N = \frac{\text{Molarity of HCl x titre volume x } 10^{-3}\text{x 14 x volume of extractant x 100}}{\text{weight of sampe x volume of aliquot}} \quad (3.33)$$

Nitrogen uptake (Nup) was calculated at final harvest as:

$$\text{Nup} = \frac{\text{N x TBM}}{100} \quad (3.34)$$

Finally, nitrogen use efficiency (NUE) was calculated as:

$$NUE\ (\%) = \frac{Nup}{Nap} \quad (3.35)$$

Where Nup is the nitrogen uptake (kg ha^{-1}), TBM is the total above ground dry biomass yield (kg ha^{-1}), N is the total nitrogen (%), NUE is the nitrogen use efficiency (%), Nap is the rate of nitrogen application (kg ha^{-1})

3.10 Optimal nitrogen supply

Yield response to nitrogen (N) was described by a second degree polynomial:

$$PY = aN_{up^2} + bN_{up} + \mathrm{c} \tag{3.36}$$

and the optimal Nup was found by differentiating Eq. 3.36 with respect to Nup:

$$\frac{\partial PY}{\partial Nup} = 2aNup + b \tag{3.37}$$

and equating the incremental income from an extra kg of Nup with the price of N (PN, GHC/kg N):

$$PO \times \frac{\partial PY}{\partial Nup} = PO \times (2aNup + b) = PN \tag{3.38}$$

where PO is the price of okra (GHC/ton).

By solving the resulting equation (3.38) with respect to Nup, the economic optimum Nup (where expenses exactly outweigh extra income) is found. However, to find the economic optimal rate of N application, Nup in Equation (3.38) should be divided with average NUE (Equation 3.35).

3.11 Spectral reflectance measurements and radiation use efficiency

Spectral reflectance data from the crop canopy was measured every week (Fig. 3.6) in each plot from 8 DAS onwards using an SDL 1800, two-band sensor (Skye Instruments, Powys, Wales, UK) in the wavelength intervals of 640–660 nm (red) and 790–810 nm (infrared). The measurements were taken at 3 PM (at high solar inclination) from the south-western side of the plots to avoid shadowing from the person performing the measurement.

Fig. 3.6 Spectrosense measurement in a plot of okra

The ratio vegetation index (RVI) was calculated from the ratio of the reflection coefficient in the near-infrared region (ρi, 790–810 nm) to the reflection coefficient in the red region (ρr, 640–660 nm) as follows:

$$\mathrm{RVI} = \frac{\rho \mathrm{i}}{\rho \mathrm{r}} \tag{3.39}$$

Daily values for RVI were calculated by interpolating between two contiguous measurements of RVI in a plot. The function given by Christensen and Goudrian (1993) was used to calculate the RVI for the fraction of intercepted photosynthetically active radiation (f_{PAR}) between 0 and 1.0 (Equations (3.40) – (3.42)):

$$RVI = \frac{\{\rho_{i,\infty}+(\eta_i/\rho_{i,\infty})(1-f_{PAR})\}}{\{\rho_{r,\infty}+(\eta_r/\rho_{r,\infty})(1-f_{PAR})^2\}} \times \frac{\{1+\eta_r(1-f_{PAR})^2\}}{\{1+\eta_i(1-f_{PAR})\}} \tag{3.40}$$

$$\eta_r = \frac{\rho_{r,\infty}-\rho_{r,s}}{\rho_{r,s}-1/\rho_{r,\infty}} \tag{3.41}$$

$$\eta_i = \frac{\rho_{i,\infty}-\rho_{i,s}}{\rho_{i,s}-1/\rho_{i,\infty}} \tag{3.42}$$

where $\rho i,\infty$ is the near-infrared reflectance at maximum RVI; $\rho r,\infty$ is the red reflectance at maximum RVI; $\rho i,s$ is the near-infrared reflectance from the bare soil where RVI was the lowest and $\rho r,s$ is the red reflectance from the bare soil where RVI was the lowest.

A polynomial function was then fitted to data pairs of f_{PAR} (Fig 3.7) and RVI by minimizing the sum of squares between assumed and model values of f_{PAR} using the solver function in Microsoft Excel. The function was then used to calculate the daily f_{PAR} for each plot from the interpolated RVI values.

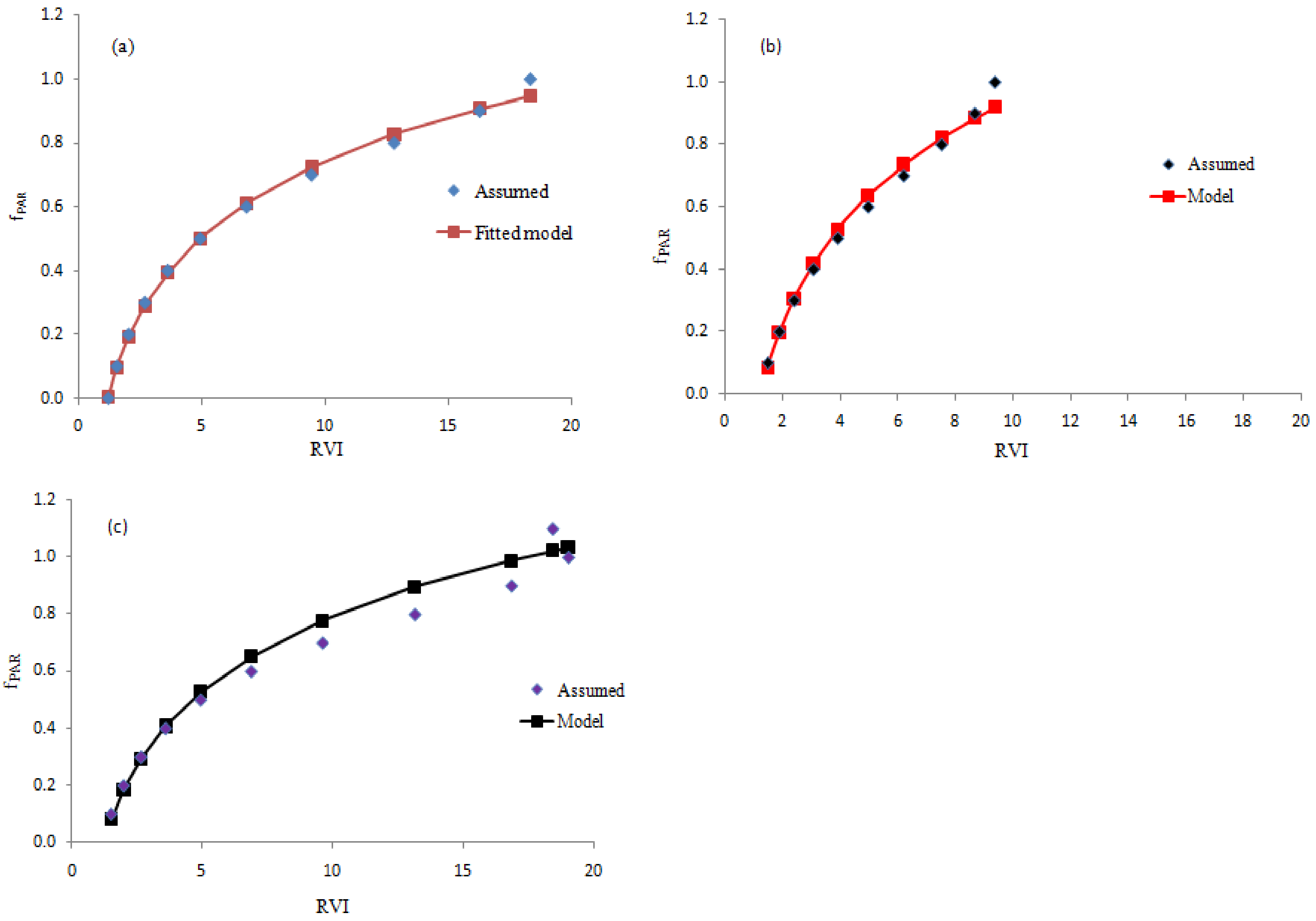

Fig 3.7 Model fitted to f_{PAR} data for the second (a), third (b) and fourth (c) experiments

The model function for the second, third and fourth experiments are given as:

$$f_{PAR} = 21.02 - 21.07 \times RVI^{-0.017} \tag{3.43}$$

$$f_{PAR} = 21.17 - 21.27 \times RVI^{-0.022} \tag{3.44}$$

$$f_{PAR} = 38.09 - 38.17 \times RVI^{-0.010} \tag{3.45}$$

Daily f_{PAR} was used to calculate the accumulated intercepted photosynthetically active radiation (IPAR, MJ m^{-2}) using the following relation:

$$\text{IPAR} = \sum_{7}^{83} 0.5 \text{ x Q x } f_{PAR} \tag{3.46}$$

where Q is the daily global radiation (MJ m^{-2}), and assuming that half of this energy is in the visible band (Monteith and Unsworth, 1990). The IPAR accumulation started from 7 DAS to 84 DAS (3 days before end of harvest). Finally, radiation use efficiency (RUE, g MJ^{-1}) was calculated as:

$$\text{RUE} = \frac{TBM}{IPAR} \tag{3.47}$$

3.12 Crop coefficient

The basal crop coefficient value changes in proportion with the amount of actively transpiring canopy (Jensen *et al.*, 1990). It strongly correlates with the amount of vegetation. The dual crop coefficient (K_c), basal crop coefficient (K_{cb}) and evaporation coefficient (K_e) were determined according to the FAO-56 description (Allen *et al.*, 1998) as outlined under section 3.8.

The interception of photosynthetically active radiation by a crop can be described in terms of the total amount of incident photosynthetically active radiation (PAR) on the crop, and the fraction of this radiation which is intercepted by the canopy (f_{PAR}). The fraction of incident PAR intercepted (f_{PAR}) is a function of LAI (leaf area index) and the light extinction coefficient, k

(Monteith, 1965). Monteith, (1965**)**, found a way of providing a good estimate of either LAI or f_{PAR} by assuming a Beer's law relationship between LAI and f_{PAR}. The relationship is given as:

$$f_{PAR} = 1 - e^{(-k\ x\ LAI)} \tag{3.48}$$

Where k is the canopy extinction coefficient. The canopy extinction coefficient, k depends on the angle distribution of the leaves in the canopy and the angle of radiation (zenith solar angle) and has been reported to be similar for crops which belong to the same family of crops (Gourdiaan, 1988). The canopy extinction coefficient for cotton which belong to the same family as okra (malvaceae family) has been established from unstressed field experiments (0.56 - 0.87) (Constable, 1986; Rosenthal and Gerik, 1991; Sadras and Wilson, 1997). Equation 3.48 was therefore used to calculate LAI by assuming k value of 0.8 for okra. The relation given by Ritchie and Burnett (1971) was then used to determine the basal K_{cb}. The relation is given as:

$$K_{cb} = \frac{T}{ET_o} = -0.21 + 0.7\ x\ (LAI)^{0.5} \tag{3.49}$$

A simple linear regression relationship to predict K_{cb} was then established between f_{PAR} and K_{cb}

3.13 Data analysis

Analysis of variance (ANOVA) was conducted to evaluate the effects of the treatments on WP, IWP, RUE, yield, TBM, crop Nup and NUE. The statistical package GenStat 9th Edition was used to calculate F probabilities, and differences were considered significant at $P \leq 0.05$ according to LSD test.

CHAPTER FOUR

4.0 RESULTS

4.1 Climate data

The climate data during the experimental seasons were similar except that there was no rainfall during the second experiment (Table 4.1). The third experiment compared with the second and fourth experiments was characterized by relatively high temperature and ET_o but with low relative humidity (Table 4.1). There was no functional meteorological station during the first experiment and as such, irrigation was scheduled with average ET_o of 4 mm day-1

Table 4.1 Climate data during the growing seasons in 2011 and 2012

Month	Experiment	Temp. (^{0}C)		Relative humidity	Wind speed	Radiation	Rainfall	ET_o
		Min.	Max.	(%)	(ms^{-1})	($MJ\ m^{-2}day^{-1}$)	(mm)	($mm\ day^{-1}$)
Jul.	2nd	23.3	26.2	86.5	3.4	18.1	0.0	3.7
Aug.		23.6	26.3	85.6	3.5	16.6	0.0	3.5
Sept.		24.5	27.5	83.7	3.5	19.7	0.0	4.2
Oct.		25.1	29.0	80.4	2.8	21.7	0.0	4.6
Dec.	3rd	26.0	30.6	78.7	1.8	15.0	0.0	3.7
Jan.		24.8	30.3	76.7	1.8	16.4	27.0	4.0
Feb.		25.3	29.6	72.8	2.5	18.6	56.0	4.7
Mar.		26.9	30.6	74.9	2.5	21.4	0.0	5.2
Aug.	4th	22.7	25.9	84.9	3.4	20.0	29.4	3.9
Sep.		24.0	27.7	81.8	3.1	21.2	37.8	4.4
Oct.		24.6	29.3	78.8	2.4	11.6	17.8	3.2

4.2 Fresh pod yield and dry matter yield

There was no significant difference in okra fresh pod yield for sprinkler (SSM and SPM) treatments, but there was a significant difference between drip (DPM was significantly higher than DFT) treatments during the first experiment (Table 4.2). The DFT treatment which received fertigation two times during the season had the lowest yield (9.8 t ha^{-1}) and this was significantly lower than DPM (13.1 t ha^{-1}) and SPM (12.5 t ha^{-1}) but insignificant compared with SSM (11.2 t ha^{-1}). Dry matter yield levels in the first experiment were similar to the fresh pod yield except that there was no significant difference between SSM and SPM (Table 4.2).

The yield pattern of the different treatments during the second experiment was similar to the first experiment with the second experiment having higher values (Table 4.2). Drip with two fertigations (DFT) again had the lowest fresh pod yield and this yield was significantly lower than SSM, SPM and DPM. In the second experiment however, there were significant differences between same irrigation methods: SPM was significantly higher than SSM with DPM being significantly higher than DFT. Drip with fertigation again had the lowest above ground biomass and this was significantly lower than SSM and SPM but insignificant compared with DPM.

In the third experiment, the bucket irrigation with spread manure (BSM) was added to the treatments. Fertigation for the third experiment was given weekly for eight weeks; as a result, both fresh pod and above ground biomass were significantly higher in the DFT treatment than SSM, SPM, BSM and DPM. Fresh pod yield of SPM (13.7 t ha^{-1}) was higher than both SSM (11.2 t ha^{-1}) and BSM (11.6 t ha^{-1}) but differences were not significant. Total above ground biomass of SPM was significantly higher than SSM and BSM.

Table 4.2 Okra fresh pod yield (PY), total aboveground biomass (TBM), accumulated crop evapotranspiration (∑ETc), total amount of applied irrigation water (TIW), WPy and WP_{tbm} of the experiments.

Experiment	Treatment	PY (10^3kg ha^{-1})	TBM (10^3kg ha^{-1})	∑ETc (mm)	TIW (mm)	WP_y (kg m^{-3})	WP_{tbm} (kg m^{-3})
1st	SSM	11.2ab	2.6b	346.4	461.8	3.2c	1.4a
	SPM	12.5a	3.6a	346.4	461.8	3.4c	1.5a
	DPM	13.1a	3.6a	233.1	259.0	5.6a	1.6a
	DFT	9.8b	2.5b	233.1	259.0	4.2b	1.5a
$LSD_{0.05}$		**2.4**	**0.3**			**0.6**	**0.3**
2nd	SSM	18.4b	4.7ab	338.9	451.9	5.4b	1.4a
	SPM	21.1a	5.1a	338.9	451.9	6.2a	1.6a
	DPM	14.6c	3.8bc	235.6	262.8	6.2a	1.6a
	DFT	11.3d	3.5c	235.6	262.8	4.8b	1.5a
$LSD_{0.05}$		**2.2**	**1.0**			**0.7**	**0.3**
3rd	SSM	11.2b	2.8c	379.0	464.0	2.9c	0.7d
	SPM	13.7b	3.8b	379.0	464.0	3.6c	1.0c
	BSM	11.6b	2.8c	379.0	1184.8	3.1c	0.7d
	DPM	13.9b	3.8b	268.8	266.4	5.2b	1.4b
	DFT	17.5a	5.5a	268.8	266.4	6.5a	2.1a
$LSD_{0.05}$		**3.1**	**0.7**			**0.9**	**0.2**
4th	SSM	22.4a	6.1a	368.4	491.2	6.1b	1.6b
	SPM	22.9a	6.3a	368.4	491.2	6.2b	1.7b
	BSM	17.0c	4.7c	346.6	1139.6	4.6c	1.3c
	DPM	23.8a	6.6a	257.3	285.9	9.2a	2.6a
	DFT	24.2a	6.7a	257.3	285.9	9.4a	2.6a
$LSD_{0.05}$		**3.1**	**0.8**			**1.0**	**0.3**

Values, which have no letters in common, are significantly different at $P \leq 0.05$ according to LSD test

In the fourth experiment where there was an increase in fertilization (Table 3.2) with fertigation procedure again weekly, DFT had the highest yield and it was significantly higher than BSM but insignificant compared with SSM, SPM and DPM (Table 4.2). Fresh pod and above ground biomass of SPM was higher than SSM and BSM even though the difference was not significant .Bucket irrigation with spread manure had the lowest fresh pod and dry matter yield compared with the other treatments.

4.3 Effect of irrigation type on ET_c, irrigation water and water productivity

Figure 4.1 shows the appearance of the okra crop at 9, 22, 42, 63 and 90 days after sowing (DAS) represented by (a), (b), (c), (d) and (e) respectively during the last experiment. This appearance shows that there was incomplete ground cover at 9, 22 and 42 DAS which define the initial and crop development stages while effective full cover were at 63 and 90 DAS. Evapotranspiration was therefore mainly in the form of soil evaporation at 9 and 22 DAS, partly evaporation and partly transpiration at 42 DAS and substantial crop transpiration during 63 and 90 DAS. Water saved under drip irrigation compared to sprinkler was a reduction in soil evaporation during 9, 22, and 42 DAS as only sand near emitters is wetted in drip irrigation as against complete wetting by sprinkler.

The highest estimated accumulated evapotranspiration ($\sum ET_c$) and total amount of irrigation water (TIW) was obtained for sprinkler treatments followed by drip (Table 4.2) during the four experiments, results of which are embedded in the Equations 3.18 and 3.20. The use of drip irrigation reduced crop water use by 33 % during the first experiment compared with sprinkler irrigation (compare ETc in Table 4.2). Drip irrigation again saved 30 %, 29 % and 30 % water compared with sprinkler during the second, third and fourth experiments respectively. The water saved by adopting drip irrigation was primarily as a result of a reduction in soil evaporation during the initial and crop development stages (Fig. 4.2).

Drip irrigation also reduced the total amount of applied irrigation water. Drip irrigation treatments used 41 – 44 % less total applied irrigation water compared with sprinkler for the four experiments (compare TIW in Table 4.2). These findings confirm the water saving potential of drip irrigation. Both sprinkler and drip irrigation used less irrigation water compared with bucket irrigation (Table 4.2). Sprinkler irrigation used 57 – 61 % less applied irrigation water while drip irrigation used 75 – 78 % less applied irrigation water compared with bucket irrigation.

Fig. 4.1 The appearance of the okra crop during different growth stages (a = 9 DAS, b = 22 DAS, c = 42 DAS, d = 63 DAS and e = 90 DAS).

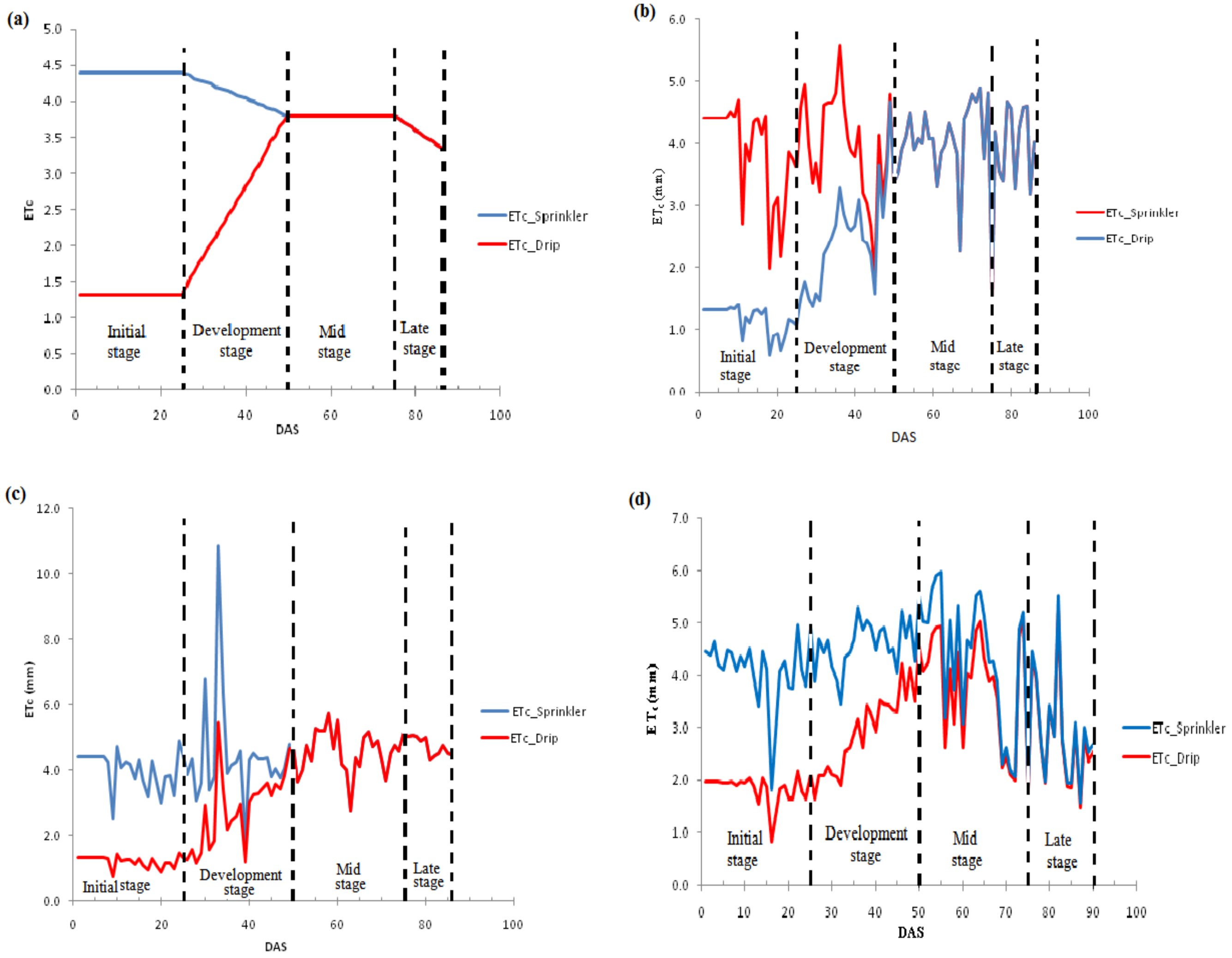

Fig. 4.2 Crop evapotranspiration of drip and sprinkler for the first (a), second (b), third (c) and fourth (e) experiments during initial, development, mid season and late season stages of okra growth.

In the first experiment, WP_y and IWP_y of the crop in the drip treatments (DPM and DFT) were significantly higher than sprinkler treatments (SSM and SPM). Within the same irrigation methods however WP_y and IWP_y, of DPM was significantly higher than DFT but SPM was insignificant compared with SSM (Table 4.2 and Fig. 4.3). There was no significant difference in WP_{tbm} between all the treatments (Table 4.2) However, IWP_{tbm} of DPM and DFT were significantly higher than SSM and SPM (Fig. 4.4). In the second experiment, WP_y of DFT was significantly lower than DPM and SPM but insignificant compared with SSM. The IWP_y was highest in DPM and significantly higher than SSM, SPM and DFT (Fig. 4.3). There was no significant difference in WP_{tbm} between all treatments during the second experiment. Irrigation water productivity at the dry matter level (IWP_{tbm}) was highest in DPM and significant compared with SSM and SPM but insignificant compared with DFT.

Increase in yield in the drip treatments in the third experiment enhanced both WP_y and WP_{tbm}. The drip treatments (DPM and DFT) were significantly higher in both WP_y and WP_{tbm} compared with sprinkler and bucket treatments (SSM, SPM and BSM). Irrigation water productivity was also enhanced in the third experiment. The drip treatments were again significantly higher in both IWP_y and IWP_{tbm} when compared with sprinkler and bucket treatments (Fig. 4.3 and 4.4). The fertigated treatment (DFT) had the highest WP_y (6.5 kg m^{-3}) and WP_{tbm} (2.0 kg m^{-3}) while BSM had the lowest WP_y (3.1 kg m^{-3}) and WP_{tbm} (0.7 kg m^{-3}). Irrigation water productivity was also highest in DFT (IWP_y = 6.6 kg m^{-3} and IWP_{tbm} = 2.1 kg m^{-3}) with BSM recording the lowest: IWP_y = 0.9 kg m^{-3} and IWP_{tbm} = 0.2 kg m^{-3}.

In the final experiment where there was an increase in fertilization, there was no significant difference in WPy and WP_{tbm} within the same irrigation method: DPM was statistically the same as DFT and SSM was not significant from SPM. Bucket irrigation with spread manure had the lowest WP_y (4.6 kg m^{-3} and WP_{tbm} (1.3 kg m^{-3}) and these values were significantly lower than SSM, SPM, DPM and DFT. On the other hand, water saved by adopting drip irrigation (ET_c in Table 4.2) enhanced both WP_y and WP_{tbm} of DFT and DPM such that WP_y and WP_{tbm} of DFT and DPM were significantly higher than SSM, SPM and BSM.

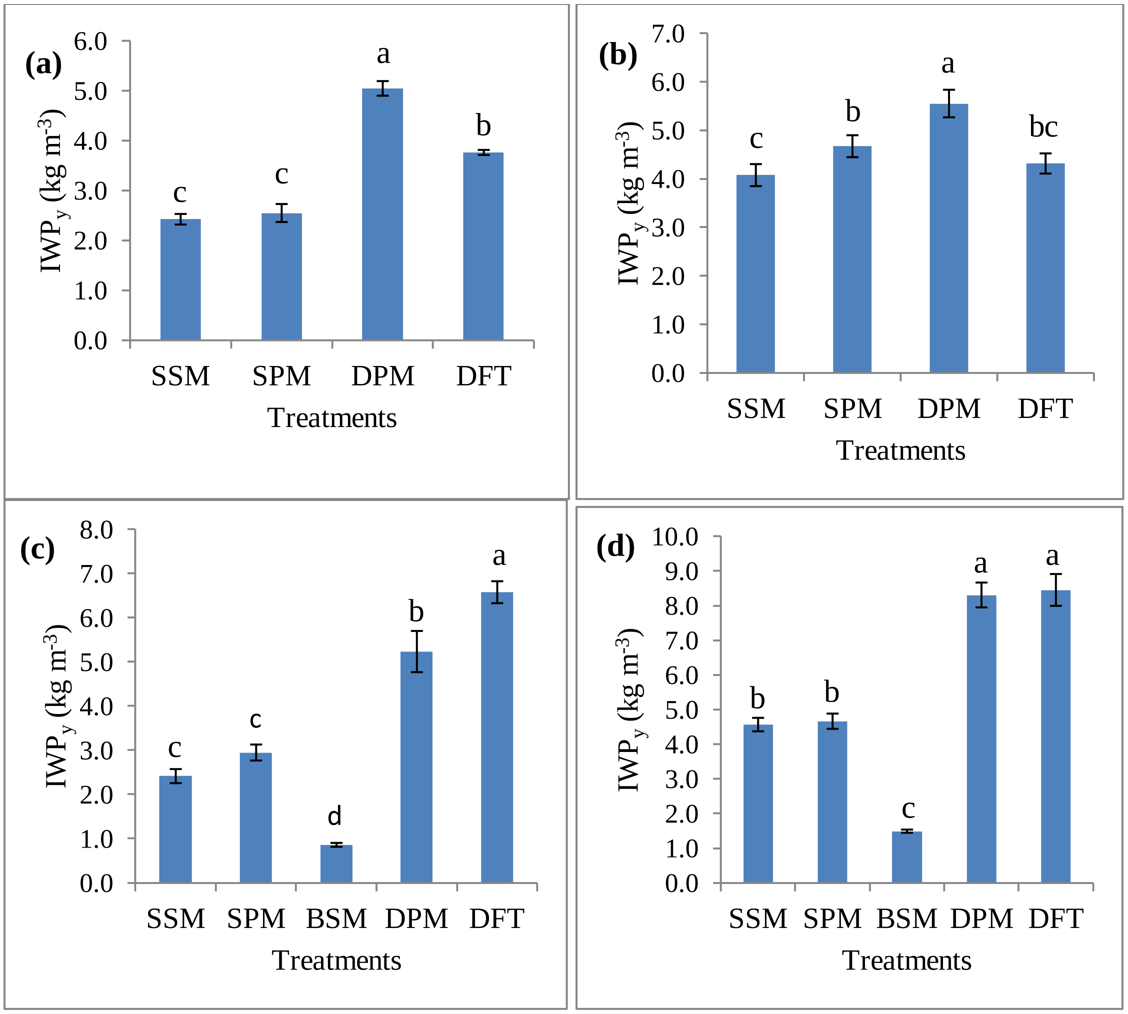

Fig. 4.3 Irrigation water productivity for the fresh pod yield during the first (a), second (b), third (c) and fourth (d) experiments. Error bars indicate standard error of the mean (n=4). Columns which have no letters in common are significantly different at P ≤ 0.05 according to LSD test.

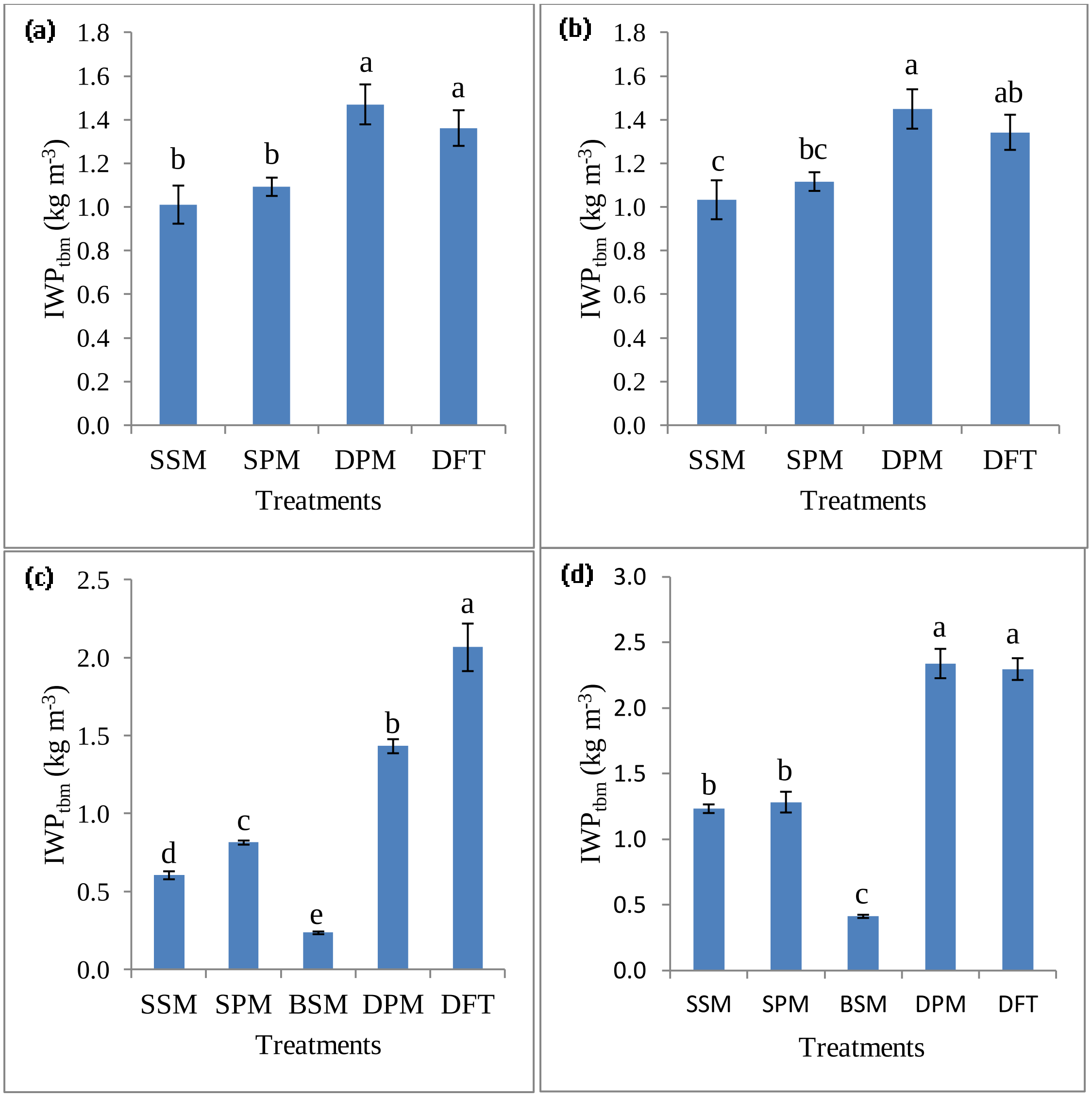

Fig. 4.4 Irrigation water productivity for the total above ground biomass during the first (a), second (b), third (c) and fourth (d) experiments. Error bars indicate standard error of the mean (n=4). Columns which have no letters in common are significantly different at P ≤ 0.05 according to LSD test

4.4 Length of growth stages and K$_c$ from the experiments

The growth stages considered in this study were the initial, crop development mid season and late season as defined in Allen *et al.*, (1998). Weekly values of the fraction of the intercepted photosynthetically active radiation (f$_{PAR}$) calculated from spectral reflectance measurements for the first, second and third experiments are shown in Fig. 4.5. The figure also shows the crop growth stages as delineated from f_{PAR} data (thick line) and tabulated values (dashed line) from Kisekka *et al.*, (2010). Note that the positions of the lines on the x-axis are different from one another (compare positions of thick lines to dashed lines on the x-axis in Fig. 4.5).

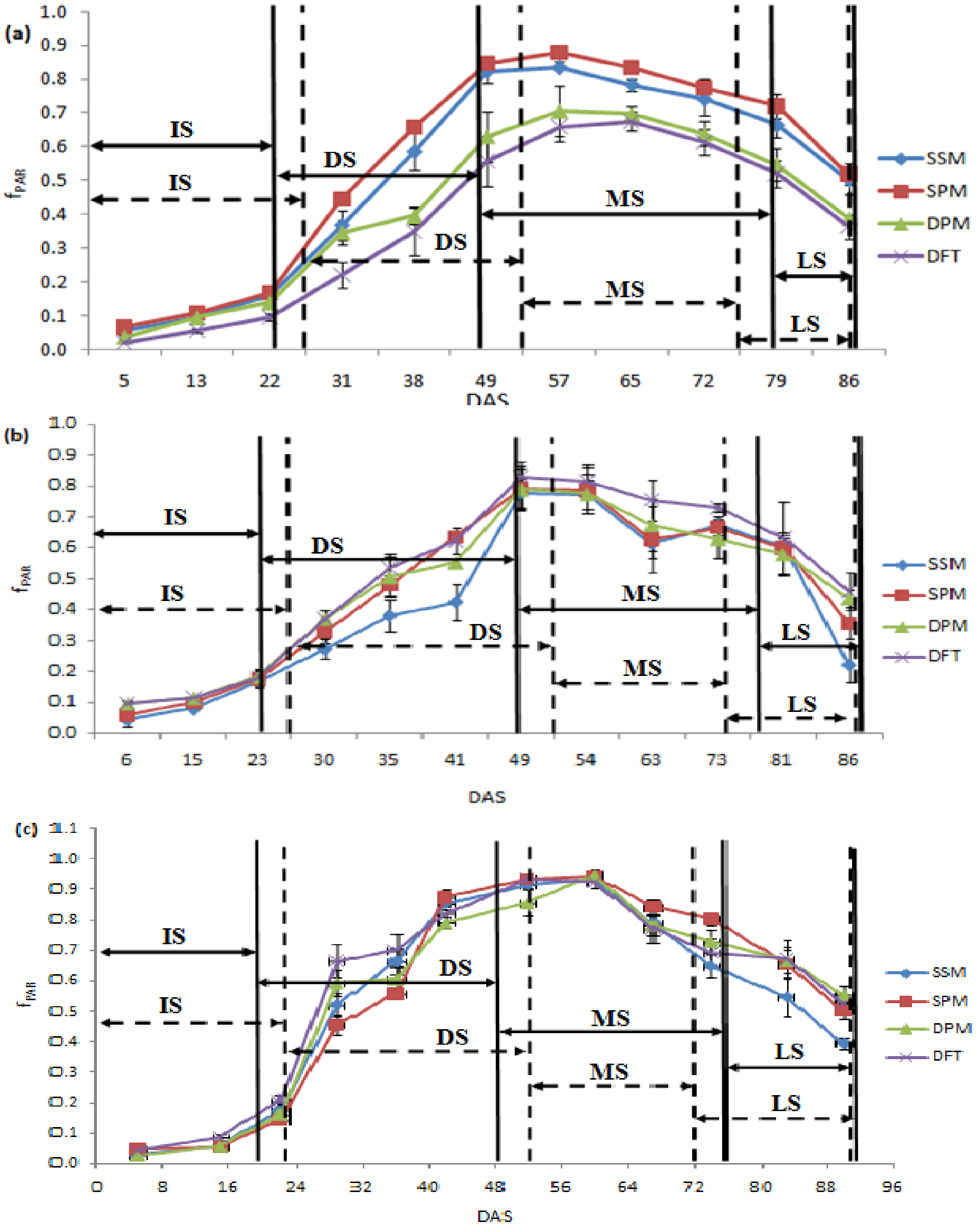

Fig. 4.5 Variation of photosythetically active radiation (f_{PAR}) for the second (a), third (b) and fourth (c) experiments during growth period (days after sowing (DAS). The thick line represents actual growth stage from f_{PAR} data while the dashed line shows tabulated growth stages. IS, initial stage; DS, development stage; MS, mid season stage; LS, late season stage. DAS, days after sowing

The default growth stages (Kisekka *et al.*, (2010)) had 25 days for the initial stage, 25 days for the development stage, 25 days for the mid season stage and 15 days for the late stage (dashed line in Fig. 4.5). The actual growth stages determined from f_{PAR} data for the first experiment were 23 days for the initial stage, 26 days for the development stage, 30 days for the mid season stage and only 7 days for the late season (thick line in Fig. 4.5). For the third experiment, growth stages from f_{PAR} data were 23 days for the initial stage, 26 days for development stage, 32 days for mid season stage and only 5 days for the late season stage. Finally for the last experiment, f_{PAR} growth stages were 22 days for the initial stage, 20 days for the development stage, 41 days for the mid season stage and 7 days for the late season. This shows that the tabulated lengths of the growth stages can differ from actually determined field growth lengths.

Fig. 4.6 shows the relationship between K_{cb} derived from equation 3.49 (Ritchie and Burnett (1971)) and f_{PAR} for the second, third and fourth experiments respectively. Both f_{PAR} and K_{cb} values were average for the four treatments. The relationship between K_{cb} and f_{PAR} for each of the four treatments is given in Appendix D. The linear regression line fitted between K_{cb} and f_{PAR} could be used to derive the K_{cb}, during any time of the growing season assuming that irrigated okra for the different treatments in the Keta Sand Spit represents such a crop with f_{PAR} as shown in Fig 4.5.

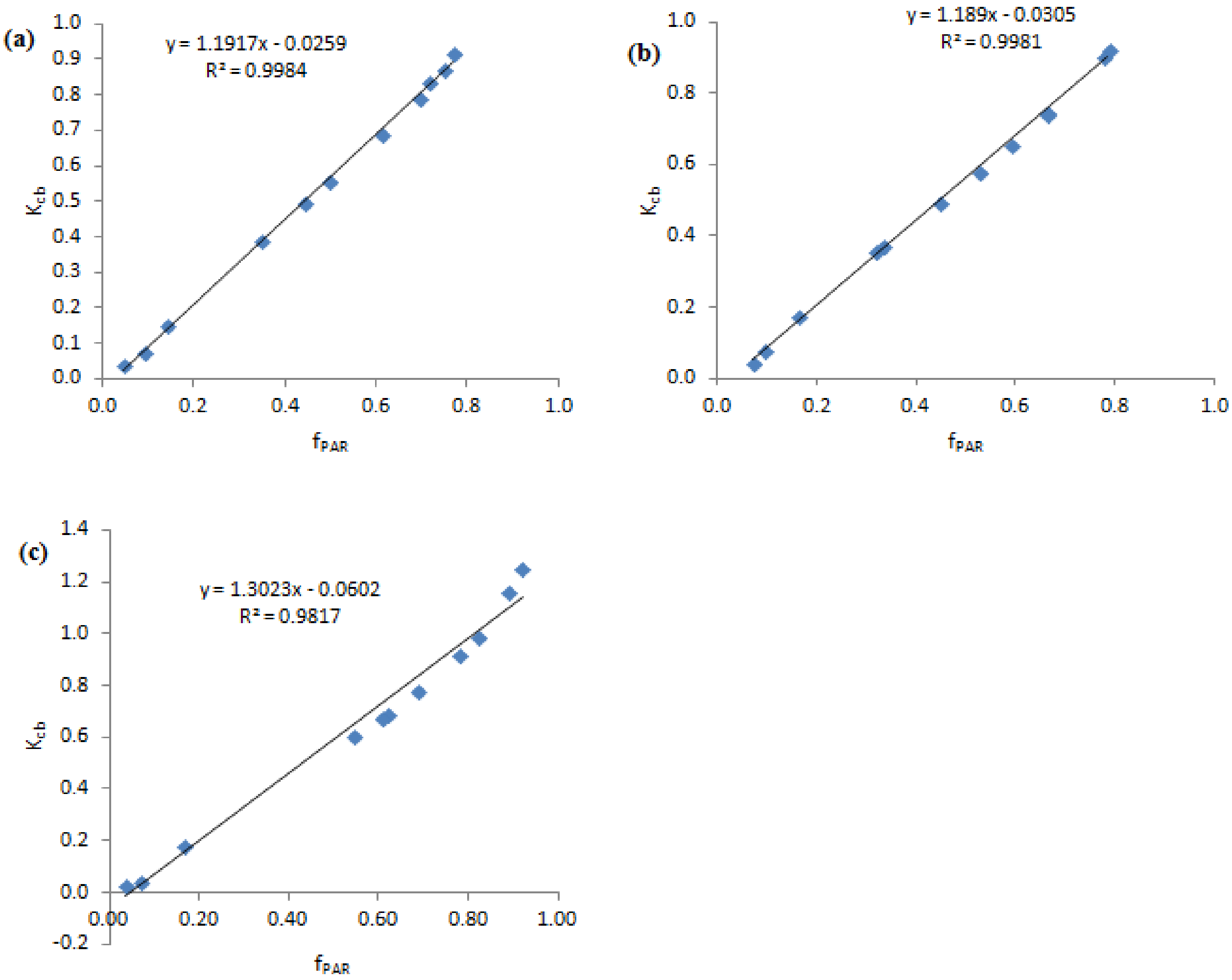

Fig. 4.6 Relationship between basal crop coefficient (K_{cb}) and fraction of photosynthetically active radiation (f_{PAR}) for second (a), third (b) and fourth (c) experiments.

The initial K_c values of the first, second and third experiments were estimated from Allen *et al.*, (1998) and as such, they will be separated from the K_c of the final experiment where the dual K_c approach was used. The crop coefficient values for first, second and third experiments are shown in Fig. 4.7 which indicates that a high value of evaporative component existed for sprinkler irrigation during the initial growth stage, due to high frequency of irrigation. The K_c of drip during the initial stage was low compared to sprinkler (compare K_c of drip and sprinkler in Fig. 4.7). The empirically tabulated K_c values are usually developed with sprinkler irrigation under low irrigation frequency (weekly or ten day events). The tabulated crop coefficient

(Kisekka *et al.*, (2010)) values were different from sprinkler crop coefficients (Fig 4.7). The initial K_c of sprinkler for the first, second and third experiments was 1.06 as against a tabulated value of 0.4. The initial K_c of drip for the first, second and third experiments was 0.3 as a result of drip irrigation wetting only a fraction of the soil surface

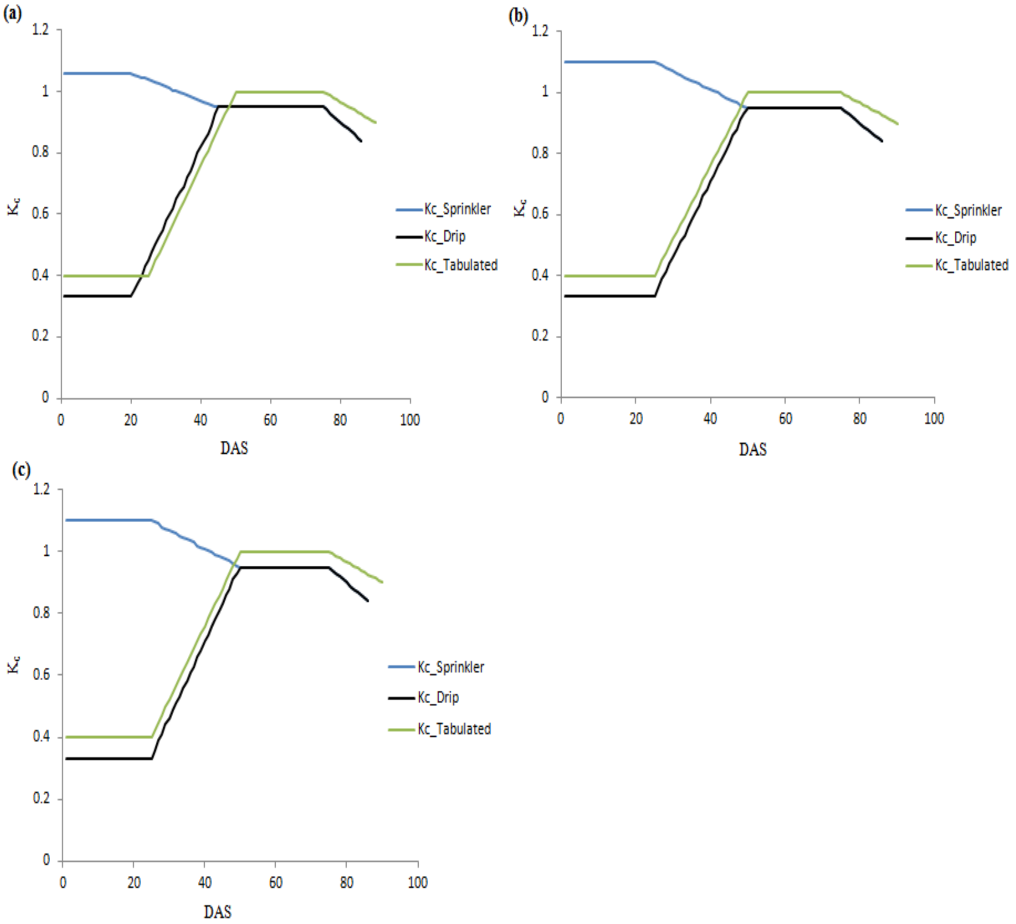

Fig. 4.7 Crop coefficient curves for the first (a), second (b) and third (c) experiments. Tabulated values were obtained from Kisekka *et al.*, (2010)

In the final experiment the dual crop coefficient approach was used to estimate soil evaporation and crop transpiration using the methodologies of Allen *et al.*, (1998). The dual crop coefficient approach also showed that a high value of evaporative component existed during the initial growth stage (Fig. 4.8). Therefore, it is worthwhile to estimate dual crop coefficient which allows differentiation between crop transpiration (basal crop coefficient, K_{cb}) and evaporation from the soil (evaporation coefficient, K_e). Maximum K_e values were reached during the initial stage, when ground cover was small and irrigation frequent. Later, as the vegetative cover increased, the K_{cb} value increased rapidly; K_e values decreased to the minimum during the mid season growth stage, when K_{cb} reached its maximum value. The K_c values during initial, mid and late stages for sprinkler irrigation were 1.10, 0.9 and 1.05 whilst for K_e these were 0.95, 0.05 and 0.29, and for K_{cb} 0.15, 0.85 and 0.76 respectively. For drip irrigation the initial, mid and late season K_c were 0.48, 0.89 and 0.98 with K_e having 0.33, 0.04 and 0.22, and for K_{cb} 0.15, 0.85 and 0.76 respectively. The difference in K_c between sprinkler and drip accounted for the water saving under drip irrigation during the initial stage of the okra crop growth.

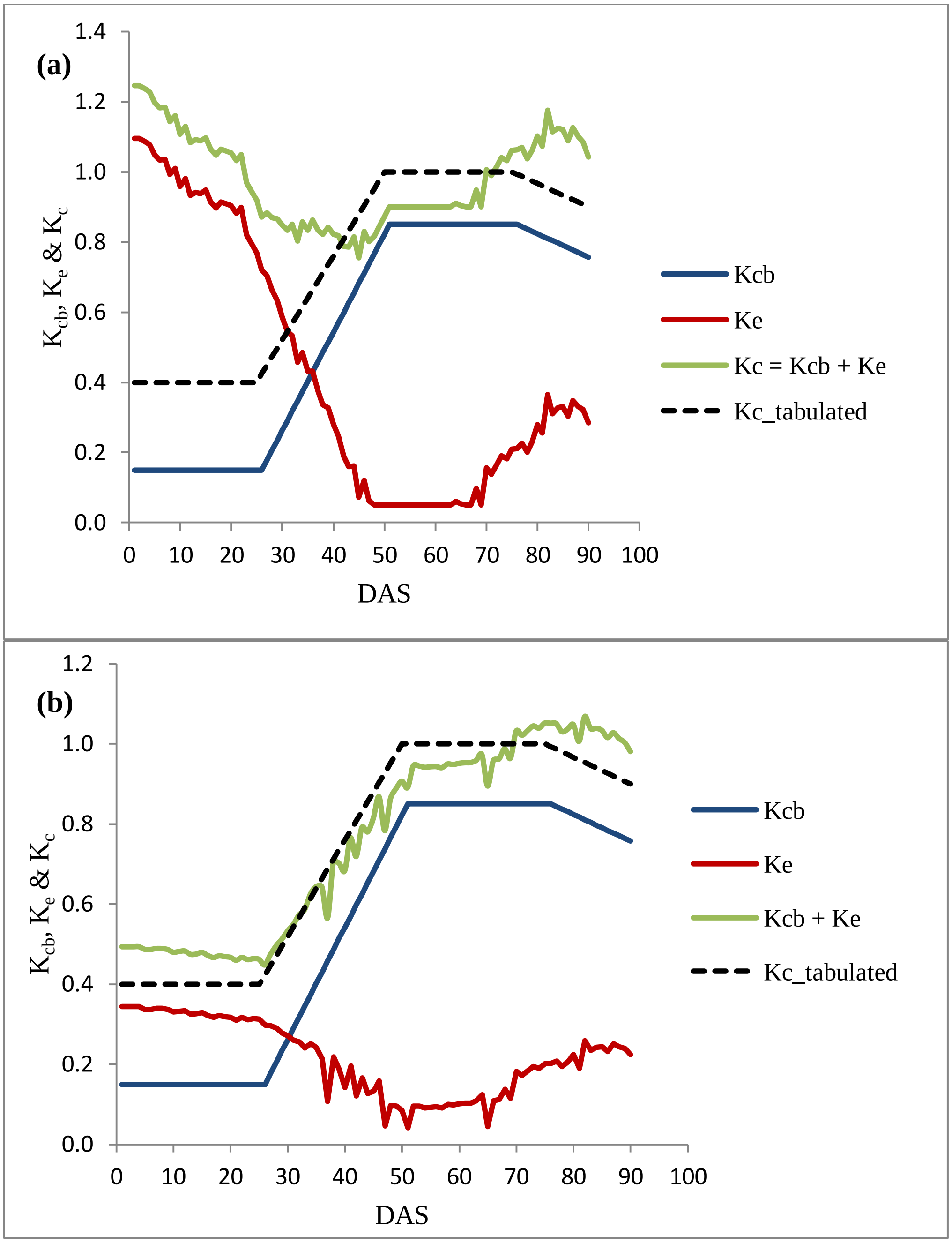

Fig. 4.8 Dual crop coefficient (K_c), basal crop coefficient (K_{cb}) and evaporation coefficient (K_e) variations of (a) sprinkler and (b) drip irrigated okra according to FAO-56 guideline. Dashed curve represents tabulated K_c values (Kisekka *et al.*, (2010)). DAS, days after sowing

4.5 Intercepted radiation and radiation use efficiency (RUE)

Figure 4.5 shows values of the fraction of the intercepted photosynthetically active radiation (f_{PAR}) calculated from spectral reflectance measurements for the second, third and fourth experiments. Generally, f_{PAR} values of sprinkler treatments (SSM and SPM) were higher compared with drip treatments (DPM and DFT) during the second experiment. At the start of the growth period during the second experiment (5 DAS) the value of f_{PAR} was 0.07 for SPM, 0.05 for SSM, 0.04 for DPM and 0.02 for DFT. The f_{PAR} of SPM increased to 0.84 at 49 DAS and declined to 0.52 at the end of harvest, but the f_{PAR} was approximately constant between 49 DAS and 79 DAS. The f_{PAR} of SSM showed a similar trend as that of SPM, reaching a maximum value of 0.82 at 49 DAS, remained constant for about 30 days, and then decreased to 0.5 at end of harvest (86 DAS). The f_{PAR} of DPM in the minor rain season in 2011 was similar in trend to those of SPM and SSM but values were low from those of SPM and SSM peaking at 0.63 at 49 DAS remained fairly constant for about 30 days and came down to 0.39 at the end of harvest (86 DAS). A similar trend of f_{PAR} peaking at 49 DAS and remaining constant for about 30 days and dropping sharply to 0.36 at end of harvest (86 DAS) was realized for DFT.

Unlike the second experiment where f_{PAR} of sprinkler treatments (SSM and SPM) were higher than drip treatments (DPM and DFT), the third experiment had drip treatments (DPM and DFT) recording higher values of f_{PAR} compared to sprinkler and bucket treatments (SSM, SPM and BSM). At the initial stage of the crop growth (6 DAS), the f_{PAR} value was 0.10 for both DFT (with weekly fertigation), and DPM, 0.06 for SPM and 0.05 for both SSM and BSM. At the middle of the season, the f_{PAR} of DFT reached a maximum value of 0.83 at 49 DAS and fell to 0.46 at end of harvest 86 DAS. The f_{PAR} of DPM rose steadily and peaked at 0.79 at 49 DAS remained fairly constant for 32 days before falling to 0.44 at 86 DAS. The f_{PAR} of SPM and SSM also followed a similar trend; increasing steadily from 6 DAS to peak at 0.79 and 0.78 at 49 DAS and remaining approximately constant for about 32 days before decreasing to 0.36 and 0.22 at 86 DAS at end of harvest respectively. Finally, f_{PAR} of BSM reached a maximum value of 0.74 at 49 DAS, remained fairly constant for 32 days and finally decreased to 0.35 at end of harvest.

The f_{PAR} values for the final experiment were generally higher than those of the first and second experiments. The f_{PAR} at the start of measurement (5 DAS), were 0.05 for SPM, and 0.04 for DFT and 0.03 for BSM, SSM and DPM respectively. At the peak growth stage (42 DAS), the f_{PAR} of SPM reached a maximum value of 0.87 and declined to 0.50 at end of harvest 90 DAS. The f_{PAR} of SSM peaked at 0.85 at 42 DAS and was fairly constant for 40 days before falling to 0.39 at 90 DAS. The f_{PAR} of DFT also increased from 0.04 at 5 DAS peaking at 0.82 at 42 DAS before falling to 0.53 at end of season 90 DAS. For BSM f_{PAR} was 0.76 during peak period (42 DAS) before dropping to 0.47 at 90 DAS (end of harvest). Finally, f_{PAR} of DPM reached a value of 0.79 at 42 DAS, remained almost the same for 40 days and finally fell to 0.55 at end of harvest.

Table 4.3. Intercepted photosythetically active radiation (IPAR), Radiation use efficiency (RUE), nitrogen uptake (Nup) and nitrogen use efficiency (NUE) for the different treatments.

Experiment	Treatment	IPAR (MJ m^{-2})	RUE (g MJ^{-1})	Nup (kg ha^{-1})	NUE (%)
1st	SSM	-	-	37.3ab	33.2ab
	SPM	-	-	43.6a	38.3a
	DPM	-	-	45.0a	41.6a
	DFT	-	-	29.5b	26.8b
$LSD_{0.05}$				**9.3**	**9.5**
2nd	SSM	416.3b	1.12a	72.4a	81.3a
	SPM	446.3a	1.13a	73.4a	82.4a
	DPM	344.9c	1.12a	50.0b	56.1b
	DFT	311.3d	1.13a	44.8b	50.3b
$LSD_{0.05}$		**26.9**	**0.26**	**18.0**	**20.2**
3rd	SSM	337.5bc	0.83b	40.8b	45.9bc
	SPM	366.8ab	1.04b	47.3b	53.2b
	BSM	309.2c	0.91b	36.3b	33.7c
	DPM	370.1ab	1.04b	48.0b	53.9b
	DFT	400.2a	1.38a	66.7a	75.0a
$LSD_{0.05}$		**37.5**	**0.24**	**13.6**	**15.2**
4th	SSM	428.8a	1.42a	88.6a	63.3a
	SPM	434.5a	1.45a	94.2a	67.3a
	BSM	389.1b	1.21b	59.0b	42.2b
	DPM	428.5a	1.48a	104.1a	74.3a
	DFT	452.7a	1.53a	104.6a	74.7a
$LSD_{0.05}$		**28.2**	**0.19**	**18.8a**	**12.8**

Values, which have no letters in common, are significantly different at $P \leq 0.05$ according to LSD test

The IPAR for the second experiment had SPM and SSM being significantly higher than DPM and DFT treatments. Comparing treatments with the same irrigation method, SPM was significantly higher than SSM while DPM was significantly higher than DFT. There was no significant difference between all treatments for RUE.

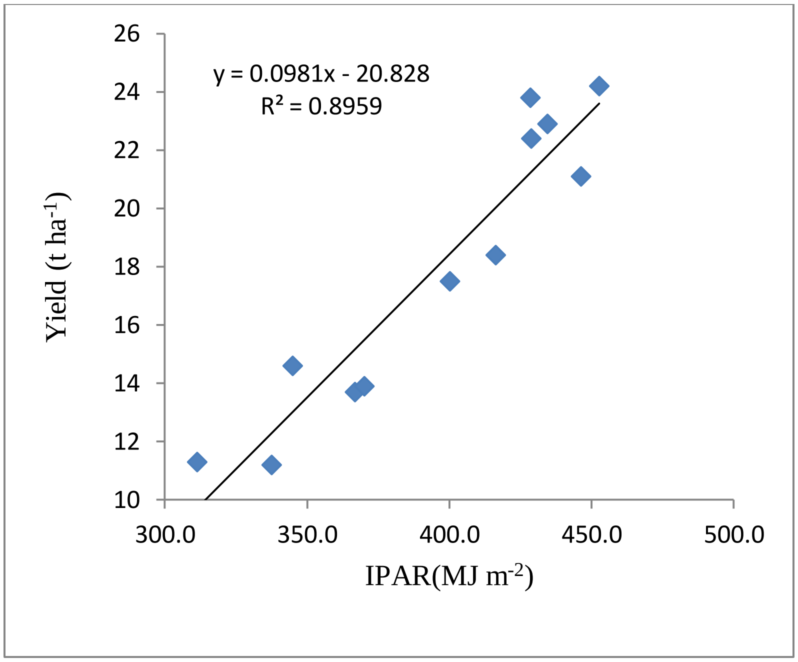

Fig. 4.9 The relationship between okra pod fresh yield and IPAR of the crop over second, third and fourth experiments

The IPAR and RUE of sprinkler treatments were higher than drip treatments during the second experiment but during the third experiment, drip treatments recorded higher values compared to sprinkler and bucket treatments (SSM, SPM and BSM). In the third experiment, the IPAR of DFT was significantly higher than SSM and BSM (Table 4.3) but insignificant compared to SPM and DPM. The IPAR of BSM was significantly lower than SPM, DPM and DFT but insignificant compared with SSM. Drip with weekly fertigation recorded the highest value of RUE and this was significantly higher than DPM, SPM, SSM and BSM. In the final experiment where there was an increase in fertilization the f_{PAR} and IPAR values were generally higher than those of the second and third experiments but with less variability between different treatments (Table 4.3 and Fig. 4.5). The different treatments did not have any effect on IPAR and RUE except BSM which was significantly lowest compared with SSM, SPM, DPM and DFT. By cross-examining the data from the second, third and fourth experiments, pod yield appeared to be strongly related to IPAR (Fig. 4.9) independent of season. The crop yield is therefore dependent on its ability to capture the photosynthetically active radiation.

4.6 Nitrogen uptake and nitrogen use efficiency of the experiments

Nitrogen uptake and NUE for the first and second experiments showed DFT with the lowest values (Table 4.3). In the first experiment, DPM had the highest Nup and NUE and this was significantly higher than DFT but insignificant compared with SSM and SPM. Nitrogen uptake in the second experiment showed no significant difference within the same irrigation method (SSM same as SPM; DPM same as DFT). SPM had a significantly higher Nup (73.4 kg ha^{-1}) than DPM (50.0 kg ha^{-1}) and DFT (44.8 kg ha^{-1}), implying that SPM captured 82.4 % of applied N whilst SSM, DPM and DFT had NUE values of 81.3 %, 56.1 % and 50.3 % respectively (Table 4.3). Nitrogen uptake and NUE of drip treatments were significantly higher than sprinkler treatment (Table 4.3).

The Nup and NUE in the third experiment were generally lower than those of the second experiment (Table 4.3). Nitrogen uptake of DFT in the third experiment was the highest and significantly higher than DPM, SPM SSM and BSM. Table 4.3 shows that DFT in the third experiment took up 75.0 % of applied N, with DPM, SPM, SSM and BSM capturing values of 53.9 %, 53.2 %, 45.9 % and 33.7 % respectively. Again in the third experiment, there was no significant difference between Nup of DPM, SPM, SSM and BSM.

Increase in fertilization during the last experiment increased the Nup compared to the other experiments. Nitrogen uptake and NUE were again highest in DFT but these values were not significant compared with SSM, SPM and DPM. Bucket irrigation with spread manure had the lowest Nup and NUE and these values were significantly lower than SSM, SPM, DPM and DFT.

When cross-examining the data from the second, third and fourth experiments, it appears that fresh pod yield was strongly related to crop Nup (Fig. 4.10) independent of season. Applying the yield response coefficients from Fig. 4.10 in Eqn. (3.37), it is first observed that this is a linearly declining function. Assuming that the net-economic income (PO) is 1.5 GHC per kg okra harvested, while the price of nitrogen (PN) is 3.0 GHC per kg N in urea (Edward Ahiabor, personal communication), solving Eq. (3.38) resulted in a figure for the optimal N-uptake near to 125 kg/ha. Assuming an average NUE of 0.75 an optimal rate of N application of around 165 kg N/ha was found.

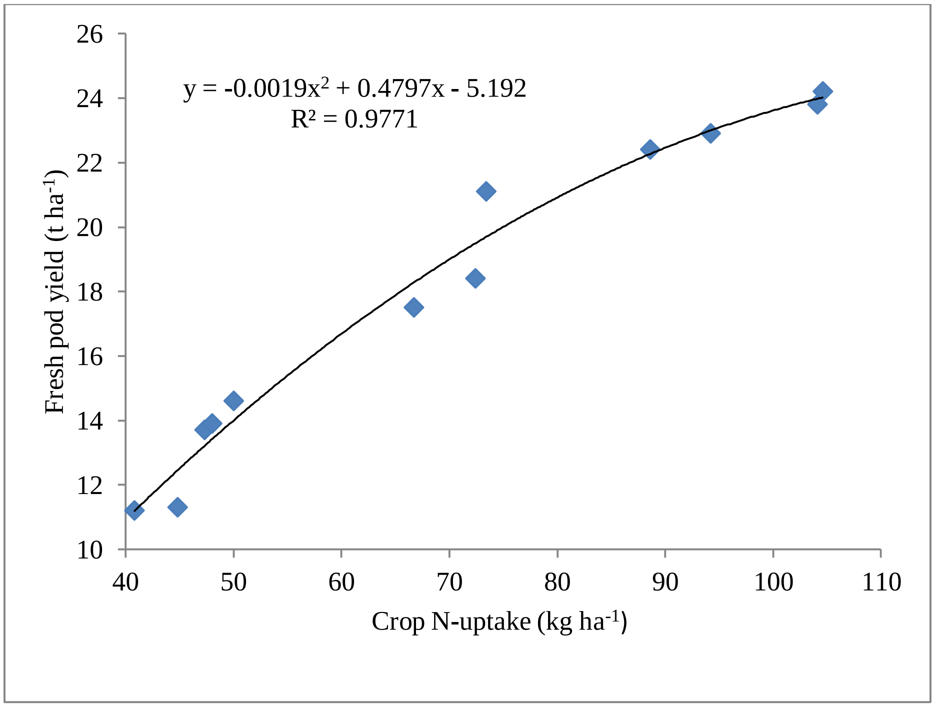

Fig. 4.10. The relationship between okra pod fresh yield and nitrogen uptake of the crop for second, third and fourth experiments

CHAPTER FIVE

5.0 DISCUSSION

5.1 Yield, N uptake and NUE as affected by irrigation and fertilization method

As stated earlier in the introduction, drip irrigation enhances plant growth, yield, water and nutrient use efficiency compared to other irrigation methods. However, it can be difficult to manage on sandy soils due to the tendency of leaching of nutrients when fertilization is not managed well which may ultimately result in yield reductions. Fertigation during the first and second experiments were done only two times (two weeks after germination and immediately after flowering). The yield and Nup were highest in manure treatments (SPM and DPM) and lowest with the DFT treatment (two fertigations). Due to the low yield in the DFT treatment for the first and second experiments, fertigation strategy for the third and fourth experiments was changed from twice events to weekly doses; and this resulted in higher yield and Nup for the DFT treatment compared with SSM, BSM, SPM and DPM (Table 4.2 and 4.3). The positive effect of high fertigation frequency on yield and Nup has also been found by Silber et al., (2003) and Badr and Abou El-Yazied (2007). Dangler and Locascio (1990) and Locascio et al. (1997) affirmed the observation above by reporting that when plants are given pre-plant fertilizer followed by one or two side dressings, they initially get a higher dosage of fertilizer than they require while between applications, soil nitrogen concentration may become low and plant nutrient deficiency could develop. It therefore suggests that ccontinuous application of nutrients at, frequent application rates ensures that the root surface and its vicinity are well supplied with fresh nutrient solution during fertigation events. Espousing this observation, Silber et al., (2005) noted that frequent fertigation improved the uptake of nutrients through two main mechanisms:

"continuous replenishment of nutrients in the depletion zone at the vicinity of root interface and enhanced transport of dissolved nutrients by mass flow, due to the higher averaged water content in the medium". With weekly applications the N supply probably matched plant N requirements with only short period of depletion between applications, leading to enhanced Nup and positive effect on yield on a soil inherently low in organic carbon, N and mineralization potential (Table 3.1). During the first and second experiments where fertigation was done only two times, nitrogen deficiency might have occurred between applications and resulted in low Nup and yield in DFT compared with DPM, SPM and SSM. Also, excess nitrogen not used after application in DFT of the first and second experiments with only two applications might have been leached below the root zone thereby reducing the Nup and consequently yield.

Organic manures have been reported to improve soil biological activity which ultimately results in higher yield (Worthington, 2001). Higher yields of lettuce have been reported with chicken manure, compared with inorganic fertilizer (Masarirambi et al., 2010). In comparing the yield levels of rice and sorghum, in Brazil using manure and chemical fertilizers, Fearnside et al., (2001) reported higher yields for manure treatments compared with chemical fertilizer treatments. Yanar et al., (2011) and Ogunlela et al., (2005) also reported higher yields for tomato and okra when using organic fertilizer compared with inorganic fertilizer. However, the chemical fertilizers in these studies were given as pre-plant with one or two side dressings during the season. It therefore seems that organic manure is the superior method of fertilization when the fertilizer need of the crop is given at pre-plant. This is probably so because manure releases nutrients slowly to the plants, which may avoid leaching of nitrogen, hence enhance yield and consequently higher nitrogen use efficiency. All the same, looking at Table 4.3 it appears that the NUE of treatments receiving manure was highly variable over the four seasons perhaps due to the complex interaction between root zone extension, soil moisture pattern and breakdown rate as function of temperature. Notably, placed manure in all four experiments achieved a higher NUE than broad-spread in the two sprinkler irrigated treatments and although this was not significant it resulted in a significantly higher yield in the first three experiments, when N was more limiting than in the last. It is clear that soil P status in the experiments did not place a limitation on yield since DFT, with no supply of P, had the highest yield in the last two experiments. Nevertheless, from the above considerations and the present practise of utilizing locally available manure as a valuable resource, a fertilization strategy covering the crop P demand, as well as part of the demand for other nutrients, by use of animal manure, and supplying the remaining part of the N-demand through high frequency fertigation may be the most sustainable solution for the Keta area.

5.2 Evapotranspiration and water productivity of okra during the experiments

Crop water use is generally classified as water lost by the crop through crop transpiration and soil evaporation (crop evapotranspiration; ET_c). A good knowledge of ET_c therefore helps to determine water productivity (WP) to improve agricultural water management. By the definition of WP and IWP (Equations 3.29 – 3.31), higher yield and less water will enhance both WP and IWP. The fresh pod yield of DPM was numerically highest in the first experiment reflecting in the highest WP_y and IWP_y of DPM compared with the other treatments (Table 4.2, Fig 4.3 and Fig. 4.4). Even though the fresh pod yield of DFT was the lowest numerically, it's WP_y and IWP_y were significantly higher than sprinkler treatments due to water saved under drip irrigation. In the second experiment too, water saved under drip irrigation had an effect on WP and IWP. Water productivity of the fresh pod yield (WP_y), WP_{dm}, IWP_y and IWP_{dm} of DFT were insignificant compared with those of SSM though fresh pod yield and above ground biomass were lowest in DFT. This result again indicated the effect of water saved under drip irrigation on water productivity. Irrigation water productivity was lowest in the BSM treatment for the third and last experiments due to low yields and excessive amount of applied irrigation water. The excessive volume of applied irrigation water might have again leached some nutrients thereby reducing the yield and consequently irrigation water productivity. Woltering *et al.*, (2011) also found low irrigation water application efficiency for okra and eggplant in Niamey using traditional bucket irrigation due to excessive amount of applied irrigation water. Again in the third and fourth experiments during which fertigation was weekly for DFT; WP_y, WP_{tbm}, IWP_y and IWP_{tbm} of DFT was improved by the combined effect of increased yield and water saving (Table 4.2). Considering Equations 3.18 and 3.20, $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$, water saving of up to 30 % was achieved with drip caused mainly by the lower evapotranspiration during the initial and developmental stages of the crop growth. This finding is consistent with other authors who found higher WP of drip compared to other irrigation methods (Batchelor *et al.* 1996; Simonne *et al.*, 2011; Dworak *et al.*, 2007). The dual K_c method was used for the last experiment. It is important to note that the dual K_c approach did not have an effect on water saved. Water saved by drip in the last experiment was close to 30 % as was the case for the first, second and third experiments when the single K_c was used. It is also important to note that when using the single K_c method during the first, second and third experiments, $K_{c\ ini}$ was estimated by the methodology of Allen *et al.*, (1998) to account for the effect of frequency of wetting. In the last experiment, though there was no significant difference in yield and total dry matter, WP_y, IWP_y WP_{tbm} and IWP_{tbm} of DFT and DPM were significantly higher than SSM and SPM which was again caused by water saved under drip irrigation.

5.3 Crop coefficient (K_c) of okra from the experiments

5.3.1 Lengths of growth stages and f_{PAR}-K_{cb} model

Crop coefficient (K_c) values are usually based on the length of a particular growth stage of the crop. The lengths have been grouped into the initial, crop development, middle and late season stages and usually determined from the fraction of ground cover (Fig. 4.1) and or the leaf area index. The fraction of ground cover (f_c) is strongly correlated with leaf area index (LAI) (Allen *et al.*, 1998). The LAI too is highly correlated with the fraction of intercepted photosynthetically active radiation (f_{PAR}) and thus the f_{PAR} could be used to provide real time delineation of different growth stages. The length of the crop growth stages may substantially differ from region to region, with climate, and cropping conditions, and with crop variety (Allen *et al.*, 1998). The lengths of growth stages from the experiments were not the same as reported with tabular K_c (Fig. 4.5). There were differences in all the growth stages when the tabulated lengths are compared with lengths delineated with f_{PAR} data (Fig. 4.5). The observed differences could probably be attributed to varietal differences between the tabulated variety and the one used for our experiment. Crop growth can be affected by management practices such as fertilization, crop density, pest control and sowing dates. Also, climatic factors like temperature and solar radiation can affect crop growth thereby impacting on the growth stages. The tabulated growth stages are usually given while stating the location and planting date to show that the lengths of the growth stages could change with climate and planting date (Allen *et al.*, 1998). The differences in the tabulated growth stages and one from our experiments could also be attributed to differences in climate and management practices during the growth period.

The experiments, established that the basal crop coefficient (K_{cb}) was related nearly and strongly to f_{PAR} (Fig. 4.6) following the methodologies of Ritchie and Burnett (1971) who related transpiration to LAI in cotton and sorghum. The strong correlation between f_{PAR} and K_{cb} has also been reported by other authors (Ayars *et al.*, 2003; Ritchie, 1972; de Medeiros *et al.*, 2001). The basal crop coefficient during any stage of the growth period can therefore be estimated with the relationship between f_{PAR} and K_{cb} as shown in Fig.4.6.

5.3.2 Crop coefficients

The plotted K_c curve for sprinkler irrigation from the experiments does not follow the conventional shape of the crop coefficient curve recommended for okra (Kisekka *et al.*, 2010) (Fig. 4.7). For high frequency irrigation, the initial K_c must be high to account for the frequency of irrigation and the evaporative demand. The K_c thereafter, drops (mid season stage from Kisekka *et al.*, 2010) and drops further, at harvest (late season stage again from Kisekka *et al.*, 2010). Crop coefficient for drip irrigation was low during the initial stage (Fig 4.7). This results from the fact that soil evaporation during the initial stage of drip is low as only a fraction of the soil surface (f_c) is wetted. In this work the f_c was only 0.3 (Allen *et al.*, 1998) as vertical movement of water is higher than lateral movement of water on a sandy soil. The lower K_c increase in the crop development and mid season periods (Fig. 4.7) as the limited soil evaporation gives way to crop transpiration over the entire cropped surface.

A high evaporation component of evapotranspiration existed during mainly the initial stage and partly the crop development stage of the crop growth (Fig. 4.8). K_e was maximum during the initial stage, when ground cover was small with high irrigation frequency. As the crop grew and shaded much of the ground (Fig. 4.1) the K_{cb} value increased steadily with a corresponding decrease in the K_e values (Fig. 4.8). The K_{cb} reached maximum value at effective full cover corresponding with a decrease in K_e values to the minimum value. Soil evaporation gradually gives way to crop transpiration as more of soil surface is covered with vegetation explaining why K_e was maximum during the initial stage with K_{cb} highest during complete ground cover stage. The soil evaporation component of ET (K_e) for sprinkler was 65 %, 20 % and 24 % higher compared to drip during the initial, mid and late season stages which reflect limited soil evaporation under drip irrigation. The dual K_c calculated for sprinkler was 56 %, only 1 % and 7 % higher compared to drip for $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$. The estimated low K_c values for drip reflect the effect of practicing drip irrigation. These results are considered reasonable since it supports the reported conclusions of many studies regarding the significant reduction in crop water requirement when localized irrigation systems are practiced (Amayreh and Al-Abed, 2005; Allen *et al.*, 1998).

5.4 Radiation use as affected by N uptake and irrigation

Crop growth in the open field is largely dependent on the capacity of the canopy to capture solar radiation, which is a function of LAI and canopy architecture (Gifford *et al.*, 1984). Several studies have showed an association of higher crop Nup with denser crop canopies with high LAI values that intercept more light and eventually produce higher yields (Andersen *et al.* 1996, Ferreira and Carr 2002; Shahnazari *et al.* 2007). In fact, higher Nup seems to increase mainly the light interception via an increased LAI while RUE may be relatively unaffected (e.g. Andersen *et al.*, 1996; Olesen *et al.*, 2000). This is in accordance with the result found in the present study as the fresh pod yield (Table 4.2) correlated strongly with IPAR (Table 4.3) with an R^2 value of 0.9 (Fig. 4.9).

The f_{PAR} results for SPM and SSM were higher than for DPM and DFT in the second experiment, while results from the third and fourth experiments showed that peak f_{PAR} values (DAS 42 and 49) in DFT and DPM were higher than in SPM and SSM, indicating a higher LAI and a longer period of leaf greenness (Fig.4.5) in accordance with the results on crop N uptake

(Table 4.3). Thus, the significantly higher IPAR of SSM and SPM compared with DPM and DFT in the second experiment and significantly higher IPAR of DFT and DPM compared with SSM and SPM in the third experiment were mainly due to larger leaf area and longer periods of greenness. The low N uptake in the second experiment in DFT and DPM probably induced nitrogen stress, negatively affecting the values IPAR. During the last experiment however, there was no significant difference in IPAR between drip and sprinkler treatments, which indicated similar LAI and length of greenness for SSM, SPM, DPM and DFT (Table 4.3). The N-supply (140 kg ha^{-1}) seemed to be closed to optimal for all treatments and no significant differences in IPAR and RUE developed between drip and sprinkler treatments, although DFT again had the highest values and yield. It therefore seems that fertigation was the superior method of fertilization in the case where yield was slightly limited by N-supply near the economic optimum, which we calculated to be 165 kg N/ha based on results from the second, third and fourth experiments. However, fertigation on sandy soil needs to be done frequently with approximately weekly dosing to ensure optimal crop development.

It is evident from Fig. 4.5b that DFT distinguished itself from the other treatments by having a higher f_{PAR} during the mid and late season stages of growth. Fruiting of the okra crop for the experiments occurred during the mid and late season stages of growth. Thus, adequate N supply and perhaps late season N availability seemed especially important for fruit set. Also, looking at Table 4.1 there was no rainfall during the second experiment but 83 mm of rainfall was recorded during the third experiment. It could therefore be argued that in the third experiment with inadequate N supply (89 kg ha^{-1}); rainfall of 83 mm leached some N in SSM and SPM in a soil whose field capacity water content is only 28 mm (Table 3.1). Again, about 56 mm of the total rainfall in the third experiment occurred during the late season and when comparing Tables 4.1 and Fig. 4.5b it is evident that the high rainfall leached some N in SSM and SPM. This is so because DFT in Fig. 4.5b during the mid and late seasons distinguished itself well compared with SSM, SPM and DPM as the weekly fertigation strategy probably ensured adequate N was available in DFT after the rainfall. The importance of high f_{PAR} during the late season stage may also be noticed by comparing SSM and SPM treatments during the second experiment (Fig. 4.5a) versus yields shown in Table 4.2. Comparing Tables 4.1, 4.2, 4.3 and Figure 4.5 suggest that N and irrigation/fertigation management in okra should aim at ensuring adequate N-status of the crop during the mid and late season stages. In the present experiments this seemed to be equivalent to a crop Nup of about 125 kg N per ha, considering that okra is a high value crop. This corresponds to optimal rate of N application of around 165 kg N per ha, which is quite robust with respect to price-relations (PO/PN), but of course can be lowered if higher NUE than 0.75 can be attained by better N and irrigation management.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of contributions

1. Simple linear regression equations were developed to estimate the seasonal distribution of K_{cb} with the fraction of the photosynthetically active radiation data from spectrosense measurements for three growing seasons in the Keta Sand Spit, South East Ghana. The f_{PAR} derived K_{cb} functions can be used together with K_e computed with the FAO-56 method thus, providing a means to apply spectral reflectance information for real-time okra irrigation scheduling using the dual K_c approach. Since the spectral reflectance derived K_{cb} are expected to track the real time growth of the crop, field observation and other procedures required to adjust empirical K_{cb} curves for conditions other than optimum are eliminated as well.
2. The fraction of the photosynthetically active radiation (f_{PAR}) data from spectrosense measurements was used to delineate and determine the lengths of real time growth stages of okra crop for three cropping seasons. The main advantages expected for using real-time f_{PAR} derived lengths of growth stages in place of conventional growth stages lengths are the elimination of the need to predict the time-scale crop growth stages and future climatic conditions for a given growing season.
3. At the Keta Sand Spit drip irrigation with about 30 % less water as used with sprinkler irrigation could produce similar or higher yield of okra. Water saved with drip irrigation compared with sprinkler irrigation was mainly through a reduction in soil evaporation during the initial and development stages of the okra crop growth. Reducing the

abstraction of irrigation water would help to protect the shallow aquifer from possible salinization resulting from over-exploiting the fresh water lens.

4. The optimal rate of N-supply to okra was found to be about 165 kg N ha^{-1} at a NUE of 0.75 i.e. a crop uptake of 125 kg N ha^{-1} seemed to be optimal independent of season.

6.2 Conclusions

From the results of the study the following conclusions are drawn:

1. Empirically developed single K_c for okra was different from K_c estimated from the experiment with the dual K_c approach by separating soil evaporation from crop transpiration using the FAO-56 methodology. This was due to the sandy soil and resultant high frequency irrigation. Therefore the dual K_c approach should be used in determining crop water requirement of okra grown in the Keta Sand Spit
2. $K_{c\ ini}$ estimated from Fig. 30, of Allen *et al.*, (1998) during the first, second and third experiments (1.06) was close to $K_{c\ ini}$ determined using the dual K_c approach (1.10). Therefore, in the absence of expertise to handle the computationally driven dual K_c method, $K_{c\ ini}$ can be estimated from Fig. 30 of Allen *et al.*, (1998)
3. Drip irrigation with weekly doses of fertigation significantly improved yield, nitrogen uptake and intercepted photosynthetically active radiation as compared with drip irrigation with two doses and with sprinkler irrigation with traditional fertilization by animal manure. Compared to the latter method the drip irrigation reduced the excess application of phosphorus.
4. The study also revealed that yield of sprinkler with placed manure for the four experiments were higher than yields of sprinkler with spread manure and may be

recommended for farmers in the Keta Sand Spit in the absence of water saving drip irrigation.

6.3 Recommendations for future research

The following recommendations are made based on the results and findings of this work:

1. Drip irrigation with weekly fertigation had a positive effect on yield and enhanced resource use efficiency (water, nitrogen and radiation) in this study. In other studies more frequent fertigation (daily, 2, 3, 4, 5 and 6 day events) proved productive compared with weekly fertigation events (Badr and Abou El-Yazied, 2007). Therefore, further field experiments with more frequent fertigation treatments should be performed.
2. The okra was harvested fresh for its fresh pods and thus the late season stage of its growth was short implying ground cover was high during the late season and as such water saved under drip irrigation mainly occurred during the initial and developmental stages of the crop growth. Further, drip and sprinkler comparative studies are needed for crops that are allowed to senescence and thus have a long late season so that water saved under drip as a result of soil evaporation during the late season could be captured such that drip compared to sprinkler irrigation could save more than 30% irrigation water.
3. Relative humidity is very high in the Keta Sand Spit which resulted in low ET_c values by using the FAO-56 model for ET_o computation. Other ET_c measurement methods that deal with actual soil water depletions by crop roots (e.g lysimeters) should be used in further studies and compared with the FAO-56 method.
4. The study estimated LAI using Beer’s law by assuming extinction coefficient of 0.8 for okra. However, deviation for the assumed values will affect the LAI value and

subsequently the f_{PAR}-K_{cb} relation. Further studies can establish the extinction coefficient of okra such that LAI of okra is calculated based on measured extinction coefficient.

5. In further research, sap flow sensors could be installed to measure crop transpiration such that K_{cb} could be obtained directly. The K_{cb} obtained could be compared with the one calculated using the Richie and Bennet function as was done in this study.

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APPENDICES

Appendix A

SPREAD SHEET FOR ET$_o$ COMPUTATION FOR THE EXPERIMENTS

A1. The spread sheet for the ET_o computation for the second experiment

Julien Day	Date	T_{min}	T_{max}	RH_{min}	RH_{max}	u_2	R_s	dr	δ	ωs	R_a	T_m	Δ	γ	e?(T_{min})	e?(T_{max})	e_s	e_a	e_s-e_a	R_{so}	R_{ns}	R_{nl}	R_n	ET_o
197	7/16/2011	24.06	27.21	76.8	91.1	2.80	19.09	0.97	0.37	1.61	35.85	25.64	0.19	0.07	2.99	3.61	3.30	2.75	0.55	26.89	14.70	2.56	12.13	3.92
198	7/17/2011	23.94	27.33	78	92.1	2.92	18.96	0.97	0.37	1.61	35.88	25.64	0.19	0.07	2.97	3.63	3.30	2.79	0.52	26.91	14.60	2.50	12.10	3.86
199	7/18/2011	24.43	27.06	79.6	91.7	3.10	18.13	0.97	0.37	1.61	35.90	25.75	0.20	0.07	3.06	3.58	3.32	2.83	0.49	26.94	13.96	2.29	11.67	3.72
200	7/19/2011	24.37	27.21	79.1	90.6	3.81	22.04	0.97	0.36	1.61	35.93	25.79	0.20	0.07	3.05	3.61	3.33	2.81	0.52	26.96	16.97	3.11	13.86	4.31
201	7/20/2011	24.71	26.99	81.2	90.8	4.31	20.90	0.97	0.36	1.61	35.96	25.85	0.20	0.07	3.11	3.56	3.34	2.86	0.48	26.98	16.09	2.82	13.28	4.09
202	7/21/2011	23.66	26.19	74.4	89.6	4.28	14.11	0.97	0.36	1.61	36.00	24.93	0.19	0.07	2.92	3.40	3.16	2.57	0.59	27.00	10.86	1.59	9.28	3.46
203	7/22/2011	23.97	26.69	81	91.4	3.00	18.61	0.97	0.35	1.61	36.03	25.33	0.19	0.07	2.98	3.50	3.24	2.78	0.46	27.03	14.33	2.40	11.92	3.70
204	7/23/2011	23.66	26.97	77	91.8	3.06	20.76	0.97	0.35	1.61	36.06	25.32	0.19	0.07	2.92	3.56	3.24	2.71	0.53	27.05	15.98	2.92	13.06	4.10
205	7/24/2011	23.71	26.6	77.6	91.4	4.07	20.07	0.97	0.34	1.61	36.09	25.16	0.19	0.07	2.93	3.48	3.21	2.69	0.52	27.08	15.45	2.79	12.66	4.02
206	7/25/2011	23.39	26.5	76.9	90.7	4.03	21.89	0.97	0.34	1.61	36.13	24.95	0.19	0.07	2.88	3.46	3.17	2.64	0.53	27.10	16.86	3.23	13.62	4.27
207	7/26/2011	23.23	24.92	79.8	90.8	3.38	9.22	0.97	0.34	1.61	36.16	24.08	0.18	0.07	2.85	3.15	3.00	2.55	0.45	27.13	7.10	0.49	6.62	2.45
208	7/27/2011	22.75	25.71	78.7	90.6	3.45	18.04	0.97	0.33	1.61	36.19	24.23	0.18	0.07	2.77	3.30	3.04	2.55	0.48	27.15	13.89	2.44	11.45	3.62
209	7/28/2011	22.86	25.8	80.2	91.3	3.21	16.65	0.97	0.33	1.61	36.23	24.33	0.18	0.07	2.79	3.32	3.05	2.60	0.45	27.18	12.82	2.09	10.73	3.38
210	7/29/2011	22.77	26.37	78.4	92	3.24	20.48	0.97	0.32	1.60	36.26	24.57	0.18	0.07	2.77	3.44	3.10	2.62	0.48	27.21	15.77	2.91	12.86	3.95
211	7/30/2011	22.86	26	79.3	92	2.81	21.34	0.97	0.32	1.60	36.30	24.43	0.18	0.07	2.79	3.36	3.07	2.61	0.46	27.23	16.43	3.09	13.34	4.00
212	7/31/2011	23.25	26.25	76	90.1	3.18	18.02	0.97	0.32	1.60	36.34	24.75	0.19	0.07	2.85	3.41	3.13	2.58	0.55	27.26	13.88	2.41	11.46	3.76
213	8/1/2011	23.51	26.21	81.4	90.8	3.68	21.40	0.97	0.31	1.60	36.37	24.86	0.19	0.07	2.90	3.40	3.15	2.70	0.45	27.29	16.48	3.01	13.46	4.03
214	8/2/2011	23.77	25.09	87.9	91.4	2.43	6.83	0.97	0.31	1.60	36.41	24.43	0.18	0.07	2.94	3.18	3.06	2.74	0.32	27.31	5.26	-0.05	5.31	1.81
215	8/3/2011	23.85	26.26	83.1	92.2	2.79	12.10	0.97	0.30	1.60	36.44	25.06	0.19	0.07	2.96	3.41	3.19	2.78	0.40	27.34	9.32	1.02	8.30	2.71
216	8/4/2011	23.74	25.98	82.7	91.3	3.24	12.68	0.97	0.30	1.60	36.48	24.86	0.19	0.07	2.94	3.36	3.15	2.73	0.42	27.37	9.77	1.16	8.61	2.84
217	8/5/2011	23.41	24.81	83.5	91.3	3.67	6.34	0.97	0.29	1.60	36.51	24.11	0.18	0.07	2.88	3.13	3.01	2.62	0.38	27.39	4.88	-0.16	5.04	1.98
218	8/6/2011	23.41	25.38	84.4	91.6	3.59	11.72	0.97	0.29	1.60	36.55	24.40	0.18	0.07	2.88	3.24	3.06	2.69	0.37	27.42	9.03	0.97	8.06	2.63
219	8/7/2011	23.41	26.12	80.8	91.7	3.55	17.36	0.97	0.28	1.60	36.59	24.77	0.19	0.07	2.88	3.39	3.13	2.69	0.44	27.45	13.37	2.15	11.22	3.51
220	8/8/2011	23.38	26.11	79.8	89.9	3.08	16.11	0.97	0.28	1.60	36.62	24.75	0.19	0.07	2.87	3.38	3.13	2.64	0.49	27.47	12.41	1.92	10.49	3.40
221	8/9/2011	23.32	26.15	79.1	90.3	2.93	15.42	0.97	0.27	1.60	36.66	24.74	0.19	0.07	2.86	3.39	3.13	2.63	0.49	27.50	11.87	1.77	10.10	3.31
222	8/10/2011	23.52	26.44	78	89.7	3.91	21.73	0.97	0.27	1.60	36.69	24.98	0.19	0.07	2.90	3.45	3.17	2.65	0.53	27.52	16.73	3.11	13.62	4.25
223	8/11/2011	23.91	26.66	75.9	87.4	3.80	23.18	0.97	0.26	1.60	36.72	25.29	0.19	0.07	2.97	3.49	3.23	2.62	0.61	27.55	17.85	3.46	14.39	4.61
224	8/12/2011	24.29	26.5	77.4	86.2	4.17	15.86	0.98	0.26	1.60	36.76	25.40	0.19	0.07	3.04	3.46	3.25	2.65	0.60	27.58	12.21	1.86	10.35	3.72
225	8/13/2011	24.37	26.21	79.3	88.6	4.47	12.09	0.98	0.25	1.60	36.79	25.29	0.19	0.07	3.05	3.40	3.23	2.70	0.53	27.60	9.31	1.03	8.28	3.11
226	8/14/2011	24.19	26.87	75.4	86.6	3.94	13.16	0.98	0.24	1.60	36.82	25.53	0.19	0.07	3.02	3.54	3.28	2.64	0.64	27.62	10.14	1.29	8.85	3.44
227	8/15/2011	24.19	26.01	77.8	85.8	3.63	11.07	0.98	0.24	1.60	36.85	25.10	0.19	0.07	3.02	3.36	3.19	2.60	0.59	27.65	8.53	0.84	7.68	3.02
228	8/16/2011	24.37	26.91	75.4	86.7	3.61	20.52	0.98	0.23	1.59	36.89	25.64	0.20	0.07	3.05	3.55	3.30	2.66	0.64	27.67	15.80	2.84	12.96	4.35
229	8/17/2011	24.1	26.78	75.5	85.5	3.47	21.14	0.98	0.23	1.59	36.92	25.44	0.19	0.07	3.00	3.52	3.26	2.61	0.65	27.69	16.28	3.02	13.26	4.42
230	8/18/2011	24.04	26.73	75.2	85.2	3.78	21.07	0.98	0.22	1.59	36.95	25.39	0.19	0.07	2.99	3.51	3.25	2.59	0.66	27.72	16.22	3.02	13.21	4.45
231	8/19/2011	23.55	27.13	71	86.9	3.61	21.69	0.98	0.22	1.59	36.97	25.34	0.19	0.07	2.90	3.59	3.25	2.54	0.71	27.74	16.70	3.22	13.49	4.62
232	8/20/2011	23.16	28.05	57.58	86.5	3.51	23.77	0.98	0.21	1.59	37.00	25.61	0.19	0.07	2.84	3.79	3.31	2.32	1.00	27.76	18.30	3.99	14.31	5.39
233	8/21/2011	23.25	26.5	73.2	89	4.29	22.12	0.98	0.20	1.59	37.03	24.88	0.19	0.07	2.85	3.46	3.16	2.54	0.62	27.78	17.03	3.28	13.75	4.51
234	8/22/2011	23.47	26.37	78.8	90.5	4.33	19.98	0.98	0.20	1.59	37.05	24.92	0.19	0.07	2.89	3.44	3.16	2.66	0.50	27.80	15.39	2.68	12.70	4.00
235	8/23/2011	23.63	26.29	79.2	90.5	3.00	19.02	0.98	0.19	1.59	37.08	24.96	0.19	0.07	2.92	3.42	3.17	2.67	0.49	27.82	14.65	2.46	12.18	3.82
236	8/24/2011	23.3	26.14	81.3	92.4	3.32	19.52	0.98	0.18	1.59	37.10	24.72	0.19	0.07	2.86	3.39	3.13	2.70	0.43	27.83	15.03	2.53	12.50	3.75

Table A1 continued...

Julien Day	Date	T_{min}	T_{max}	RH_{min}	RH_{max}	u_2	R_s	dr	δ	ωs	R_a	T_m	Δ	γ	$e(T_{min})$	$e(T_{max})$	e_s	e_a	e_s-e_a	R_{so}	R_{ns}	R_{nl}	R_n	ET_o
237	8/25/2011	23.2	26.58	78.9	92	3.86	22.44	0.98	0.18	1.59	37.12	24.88	0.19	0.07	2.84	3.48	3.16	2.68	0.48	27.85	17.28	3.17	14.11	4.25
238	8/26/2011	23.9	26.4	82	90.3	3.50	14.63	0.98	0.17	1.59	37.15	25.13	0.19	0.07	2.96	3.44	3.20	2.75	0.45	27.87	11.26	1.50	9.76	3.20
239	8/27/2011	23.7	25.92	82.5	91.3	3.00	14.42	0.98	0.17	1.59	37.17	24.80	0.19	0.07	2.93	3.35	3.14	2.72	0.42	27.88	11.11	1.47	9.64	3.07
240	8/28/2011	23.4	25.46	82.6	90.9	2.76	12.01	0.98	0.16	1.59	37.18	24.42	0.18	0.07	2.87	3.26	3.07	2.65	0.41	27.90	9.25	1.00	8.25	2.71
241	8/29/2011	23.3	25.01	84.2	91.6	2.58	6.68	0.98	0.15	1.59	37.20	24.17	0.18	0.07	2.87	3.17	3.02	2.65	0.37	27.91	5.14	-0.12	5.26	1.90
242	8/30/2011	23.4	26.63	78.4	91.8	3.46	22.02	0.98	0.15	1.59	37.22	25.01	0.19	0.07	2.88	3.49	3.18	2.69	0.49	27.92	16.96	3.06	13.90	4.23
243	8/31/2011	23.2	26.11	82.3	91.4	3.90	15.04	0.98	0.14	1.59	37.23	24.64	0.19	0.07	2.84	3.38	3.11	2.69	0.42	27.93	11.58	1.61	9.98	3.18
244	9/1/2011	23.1	26.71	78.2	91.5	2.77	19.79	0.98	0.13	1.58	37.25	24.93	0.19	0.07	2.83	3.51	3.17	2.67	0.50	27.94	15.23	2.61	12.62	3.93
245	9/2/2011	23.9	27.15	71.4	88.7	3.53	25.13	0.98	0.13	1.58	37.26	25.51	0.19	0.07	2.96	3.60	3.28	2.60	0.68	27.95	19.35	3.86	15.50	5.01
246	9/3/2011	24.1	26.49	79	87.8	4.04	15.50	0.98	0.12	1.58	37.27	25.30	0.19	0.07	3.00	3.46	3.23	2.69	0.55	27.96	11.93	1.71	10.22	3.55
247	9/4/2011	23.9	26.47	78.2	90.2	3.84	17.33	0.99	0.11	1.58	37.27	25.19	0.19	0.07	2.97	3.46	3.21	2.69	0.52	27.96	13.34	2.09	11.26	3.71
248	9/5/2011	24	26.78	77.8	89.5	3.42	20.32	0.99	0.11	1.58	37.28	25.40	0.19	0.07	2.99	3.52	3.25	2.71	0.55	27.97	15.64	2.70	12.95	4.13
249	9/6/2011	24.3	27.19	79.2	89.5	3.11	21.88	0.99	0.10	1.58	37.29	25.75	0.20	0.07	3.04	3.61	3.32	2.79	0.53	27.97	16.85	2.94	13.91	4.33
250	9/7/2011	24.7	27.48	77.6	89.5	3.52	24.04	0.99	0.09	1.58	37.29	26.08	0.20	0.07	3.11	3.67	3.39	2.81	0.57	27.98	18.51	3.35	15.16	4.73
251	9/8/2011	24.6	27.13	78.8	88	4.28	19.06	0.99	0.09	1.58	37.29	25.85	0.20	0.07	3.09	3.59	3.34	2.77	0.57	27.98	14.68	2.39	12.29	4.08
252	9/9/2011	24.3	27.41	77.3	89.3	3.46	20.81	0.99	0.08	1.58	37.29	25.86	0.20	0.07	3.04	3.65	3.35	2.77	0.58	27.98	16.03	2.75	13.28	4.29
253	9/10/2011	24.4	27.37	75.9	89.6	2.51	20.50	0.99	0.07	1.58	37.29	25.89	0.20	0.07	3.06	3.64	3.35	2.75	0.60	27.98	15.78	2.70	13.08	4.22
254	9/11/2011	24.1	27.53	75.7	90.2	2.89	24.17	0.99	0.06	1.58	37.29	25.80	0.20	0.07	2.99	3.68	3.34	2.74	0.59	27.97	18.61	3.46	15.15	4.74
255	9/12/2011	24.8	27.5	79.1	89	3.56	20.91	0.99	0.06	1.58	37.28	26.15	0.20	0.07	3.13	3.67	3.40	2.84	0.56	27.97	16.10	2.70	13.41	4.29
256	9/13/2011	24.8	27.48	77.5	88.6	3.82	20.34	0.99	0.05	1.58	37.28	26.16	0.20	0.07	3.14	3.67	3.40	2.81	0.59	27.96	15.66	2.62	13.04	4.29
257	9/14/2011	24.3	26.99	80	89.7	3.73	15.52	0.99	0.04	1.58	37.27	25.63	0.19	0.07	3.03	3.56	3.30	2.78	0.51	27.96	11.95	1.66	10.29	3.47
258	9/15/2011	24.3	27.34	75.7	88.5	3.71	18.24	0.99	0.04	1.57	37.26	25.80	0.20	0.07	3.03	3.64	3.33	2.72	0.62	27.95	14.04	2.27	11.77	4.04
259	9/16/2011	24.6	27.2	78.3	88.2	4.16	19.89	0.99	0.03	1.57	37.24	25.89	0.20	0.07	3.09	3.61	3.35	2.77	0.57	27.94	15.32	2.56	12.76	4.20
260	9/17/2011	24.6	27.39	76.9	87.9	4.25	21.91	0.99	0.02	1.57	37.23	25.97	0.20	0.07	3.08	3.65	3.37	2.76	0.61	27.93	16.87	2.99	13.88	4.54
261	9/18/2011	24.6	27.39	76.2	88.3	3.00	20.62	0.99	0.02	1.57	37.21	26.00	0.20	0.07	3.09	3.65	3.37	2.76	0.62	27.92	15.88	2.74	13.14	4.30
262	9/19/2011	24.8	27.68	75	88.2	2.72	18.33	0.99	0.01	1.57	37.20	26.22	0.20	0.07	3.12	3.71	3.42	2.77	0.65	27.91	14.11	2.26	11.85	4.02
263	9/20/2011	24.8	26.51	81.8	89	2.69	8.60	0.99	0.00	1.57	37.18	25.63	0.19	0.07	3.12	3.46	3.29	2.81	0.49	27.89	6.62	0.27	6.35	2.38
264	9/21/2011	24.1	28.18	75.5	89.6	2.52	22.94	0.99	-0.01	1.57	37.16	26.15	0.20	0.07	3.01	3.82	3.41	2.79	0.62	27.87	17.66	3.18	14.48	4.62
265	9/22/2011	25.1	28.52	72.5	86.8	2.90	22.36	1.00	-0.01	1.57	37.13	26.82	0.21	0.07	3.19	3.90	3.54	2.80	0.75	27.86	17.22	3.08	14.14	4.79
266	9/23/2011	24.9	28.29	72.3	87.6	3.28	24.23	1.00	-0.02	1.57	37.11	26.60	0.20	0.07	3.15	3.84	3.50	2.77	0.73	27.84	18.66	3.50	15.16	5.04
267	9/24/2011	25.1	28.53	74.3	87.4	3.10	23.51	1.00	-0.03	1.57	37.08	26.80	0.21	0.07	3.18	3.90	3.54	2.84	0.70	27.82	18.10	3.27	14.83	4.90
268	9/25/2011	25.2	28.55	73.3	85.9	3.06	24.73	1.00	-0.03	1.57	37.05	26.87	0.21	0.07	3.20	3.90	3.55	2.81	0.75	27.80	19.04	3.57	15.48	5.14
269	9/26/2011	25.3	28.17	72.5	86.5	2.89	16.42	1.00	-0.04	1.57	37.02	26.71	0.21	0.07	3.22	3.82	3.52	2.77	0.74	27.77	12.64	1.90	10.74	3.94
270	9/27/2011	24.7	28.64	69.8	87	3.31	23.54	1.00	-0.05	1.57	36.99	26.65	0.21	0.07	3.10	3.92	3.51	2.72	0.79	27.75	18.13	3.44	14.69	5.06
271	9/28/2011	24.6	25.95	82.9	89.3	1.95	4.53	1.00	-0.05	1.57	36.96	25.27	0.19	0.07	3.09	3.35	3.22	2.77	0.45	27.73	3.49	-0.54	4.03	1.63
272	9/29/2011	24.7	28.4	72.1	88.2	2.92	20.32	1.00	-0.06	1.56	36.92	26.56	0.20	0.07	3.12	3.87	3.49	2.77	0.72	27.70	15.65	2.71	12.93	4.45
273	9/30/2011	24.4	28.6	70.3	89.7	3.14	15.45	1.00	-0.07	1.56	36.89	26.50	0.20	0.07	3.06	3.91	3.49	2.75	0.74	27.67	11.90	1.72	10.17	3.83
274	10/1/2011	24.3	29.19	70.5	87.1	2.67	14.32	1.00	-0.08	1.56	36.85	26.76	0.21	0.07	3.04	4.05	3.55	2.75	0.79	27.64	11.03	1.49	9.53	3.68
275	10/2/2011	24.8	28.71	70.5	87.7	2.09	25.18	1.00	-0.08	1.56	36.81	26.77	0.21	0.07	3.14	3.94	3.54	2.76	0.77	27.61	19.39	3.75	15.64	5.11
276	10/3/2011	25	28.77	71.3	87.7	2.37	24.63	1.00	-0.09	1.56	36.76	26.88	0.21	0.07	3.17	3.95	3.56	2.80	0.76	27.58	18.96	3.60	15.36	5.06
277	10/4/2011	25.1	28.94	71.6	88.4	2.51	14.88	1.00	-0.10	1.56	36.72	27.03	0.21	0.07	3.19	3.99	3.59	2.84	0.75	27.55	11.46	1.57	9.89	3.67
278	10/5/2011	25.4	29.1	72.2	87.5	2.98	22.07	1.00	-0.10	1.56	36.68	27.26	0.21	0.07	3.25	4.03	3.64	2.88	0.76	27.51	16.99	3.00	13.99	4.80
279	10/6/2011	25.3	28.89	72.3	86.9	3.37	25.18	1.00	-0.11	1.56	36.63	27.12	0.21	0.07	3.23	3.98	3.61	2.84	0.76	27.48	19.39	3.68	15.71	5.26
280	10/7/2011	25.6	29.11	70.8	84.4	3.46	24.63	1.00	-0.12	1.56	36.58	27.36	0.21	0.07	3.28	4.03	3.66	2.81	0.84	27.44	18.96	3.62	15.34	5.35
281	10/8/2011	25.7	28.48	74.9	85.6	3.09	14.88	1.00	-0.12	1.56	36.53	27.07	0.21	0.07	3.29	3.89	3.59	2.86	0.72	27.41	11.46	1.57	9.89	3.73
282	10/9/2011	25.2	29.12	72.6	86.8	3.04	22.07	1.00	-0.13	1.56	36.48	27.17	0.21	0.07	3.21	4.03	3.62	2.86	0.76	27.37	16.99	3.05	13.94	4.80

Table A2. The spread sheet for the ET_o computation for the third experiment

Julien Day	Date	T_{min}	T_{max}	RH_{min}	RH_{max}	u_2	R_s	dr	δ	ωs	R_a	T_m	Δ	γ	$e(T_{min})$	$e(T_{max})$	e_s	e_a	e_s-e_a	R_{so}	R_{ns}	R_{nl}	R_n	ET_o
355	12/21/2011	25.9	30.34	61.28	88.1	2.06	15.69	1.03	-0.41	1.53	33.01	28.10	0.22	0.07	3.33	4.33	3.83	2.79	1.04	24.77	12.08	2.16	9.92	3.95
356	12/22/2011	26.3	30.85	67.93	88.1	1.39	16.31	1.03	-0.41	1.53	33.02	28.57	0.23	0.07	3.42	4.45	3.94	3.02	0.92	24.77	12.56	2.12	10.44	3.75
357	12/23/2011	26	30.81	64.71	88.4	1.53	16.87	1.03	-0.41	1.53	33.03	28.42	0.22	0.07	3.37	4.44	3.90	2.93	0.98	24.78	12.99	2.32	10.67	3.91
358	12/24/2011	26.8	31.16	62.58	85	2.03	16.72	1.03	-0.41	1.53	33.04	29.00	0.23	0.07	3.53	4.53	4.03	2.92	1.11	24.78	12.87	2.31	10.56	4.20
359	12/25/2011	26.9	30.89	63.51	86.5	1.93	13.56	1.03	-0.41	1.53	33.05	28.91	0.23	0.07	3.55	4.46	4.01	2.95	1.05	24.79	10.44	1.58	8.86	3.63
360	12/26/2011	26.3	30.79	67.58	88	1.73	15.82	1.03	-0.41	1.53	33.06	28.55	0.23	0.07	3.42	4.44	3.93	3.01	0.92	24.80	12.18	2.02	10.16	3.78
361	12/27/2011	26.9	30.85	67.9	87.2	1.94	15.69	1.03	-0.41	1.53	33.08	28.85	0.23	0.07	3.53	4.45	3.99	3.05	0.94	24.82	12.08	1.96	10.12	3.85
362	12/28/2011	26.4	30.34	71.1	88	2.28	16.09	1.03	-0.41	1.53	33.10	28.35	0.22	0.07	3.43	4.33	3.88	3.05	0.83	24.83	12.39	2.03	10.36	3.86
363	12/29/2011	25.7	28.94	72.5	86.2	2.05	6.33	1.03	-0.40	1.53	33.12	27.30	0.21	0.07	3.29	3.99	3.64	2.87	0.78	24.85	4.88	-0.02	4.90	2.28
364	12/30/2011	25.1	31.72	35.6	88.8	1.67	15.50	1.03	-0.40	1.53	33.14	28.39	0.22	0.07	3.18	4.68	3.93	2.24	1.68	24.86	11.93	2.60	9.34	4.31
365	12/31/2011	24.2	29.56	64.83	90.1	1.70	16.28	1.03	-0.40	1.53	33.17	26.89	0.21	0.07	3.02	4.14	3.58	2.70	0.88	24.88	12.54	2.33	10.21	3.72
1	1/1/2012	24.4	30.19	57.49	89.4	1.95	15.24	1.03	-0.40	1.53	33.19	27.27	0.21	0.07	3.05	4.29	3.67	2.60	1.07	24.90	11.74	2.18	9.56	3.85
2	1/2/2012	25.1	30.53	61.97	90.7	1.61	16.07	1.03	-0.40	1.53	33.22	27.81	0.22	0.07	3.18	4.37	3.78	2.80	0.98	24.92	12.38	2.22	10.16	3.79
3	1/3/2012	25.4	30.11	69.27	91.3	1.35	14.99	1.03	-0.40	1.53	33.26	27.78	0.22	0.07	3.25	4.27	3.76	2.96	0.80	24.95	11.54	1.84	9.70	3.41
4	1/4/2012	25.1	31.56	51.49	90.8	1.41	15.91	1.03	-0.40	1.53	33.29	28.34	0.22	0.07	3.19	4.64	3.91	2.64	1.27	24.97	12.25	2.33	9.93	3.92
5	1/5/2012	24.7	30.09	65.04	91.4	1.30	14.34	1.03	-0.39	1.53	33.32	27.39	0.21	0.07	3.11	4.27	3.69	2.81	0.88	25.00	11.04	1.79	9.25	3.34
6	1/6/2012	24.6	29.78	65.01	90.7	1.03	12.20	1.03	-0.39	1.53	33.36	27.21	0.21	0.07	3.10	4.19	3.65	2.77	0.88	25.03	9.40	1.32	8.08	2.91
7	1/7/2012	25.6	31.95	30.53	90.4	1.32	13.72	1.03	-0.39	1.53	33.40	28.75	0.23	0.07	3.27	4.74	4.01	2.20	1.80	25.06	10.57	2.10	8.47	3.89
8	1/8/2012	24.6	30.38	63.81	92	1.36	13.40	1.03	-0.39	1.53	33.44	27.47	0.21	0.07	3.09	4.34	3.71	2.80	0.91	25.09	10.32	1.57	8.75	3.24
9	1/9/2012	25.3	30.15	68.26	91.7	1.01	11.12	1.03	-0.39	1.53	33.48	27.71	0.22	0.07	3.22	4.28	3.75	2.94	0.81	25.12	8.56	1.00	7.57	2.72
10	1/10/2012	25.8	30.63	67.01	90.2	1.24	14.90	1.03	-0.38	1.53	33.53	28.20	0.22	0.07	3.32	4.40	3.86	2.97	0.89	25.15	11.48	1.80	9.68	3.46
11	1/11/2012	25.8	30.82	66.06	89.7	1.27	14.83	1.03	-0.38	1.53	33.57	28.31	0.22	0.07	3.32	4.45	3.88	2.96	0.93	25.19	11.42	1.79	9.63	3.49
12	1/12/2012	25.7	32.39	44.42	90.8	1.28	8.68	1.03	-0.38	1.53	33.62	29.04	0.23	0.07	3.30	4.86	4.08	2.58	1.50	25.22	6.68	0.54	6.14	2.94
13	1/13/2012	24.6	31.8	28.25	90.8	1.42	17.10	1.03	-0.38	1.53	33.67	28.18	0.22	0.07	3.08	4.70	3.89	2.06	1.83	25.26	13.17	3.17	10.00	4.44
14	1/14/2012	23.8	30.7	21.6	86.4	2.14	7.96	1.03	-0.37	1.53	33.72	27.25	0.21	0.07	2.95	4.42	3.68	1.75	1.93	25.30	6.13	0.46	5.67	4.03
15	1/15/2012	22.9	30.89	25.42	81.4	1.71	7.18	1.03	-0.37	1.53	33.78	26.91	0.21	0.07	2.80	4.46	3.63	1.71	1.92	25.34	5.53	0.20	5.33	3.55
16	1/16/2012	21.7	30.88	17.82	86.1	1.51	11.90	1.03	-0.37	1.53	33.83	26.28	0.20	0.07	2.59	4.46	3.53	1.51	2.01	25.38	9.16	1.87	7.29	4.00
17	1/17/2012	21.4	30.6	53.57	83	1.44	8.37	1.03	-0.36	1.53	33.89	26.01	0.20	0.07	2.55	4.39	3.47	2.24	1.24	25.42	6.44	0.49	5.96	2.82
18	1/18/2012	23.4	29.58	65.3	88	2.16	12.60	1.03	-0.36	1.53	33.94	26.50	0.20	0.07	2.88	4.14	3.51	2.62	0.89	25.47	9.70	1.43	8.28	3.36
19	1/19/2012	25.4	29.34	71.5	85.8	2.33	33.68	1.03	-0.36	1.53	34.00	27.36	0.21	0.07	3.24	4.09	3.66	2.85	0.81	25.51	25.93	5.94	19.99	6.35
20	1/20/2012	24.9	29.66	71.5	89.1	1.75	12.97	1.03	-0.35	1.53	34.06	27.29	0.21	0.07	3.15	4.16	3.66	2.89	0.76	25.55	9.98	1.36	8.62	3.18
21	1/21/2012	26.1	29.8	68.13	87.2	2.44	13.46	1.03	-0.35	1.53	34.12	27.93	0.22	0.07	3.37	4.19	3.78	2.90	0.88	25.60	10.37	1.47	8.89	3.59
22	1/22/2012	23.6	30.2	63.4	90.8	1.57	61.11	1.03	-0.35	1.53	34.19	26.90	0.21	0.07	2.91	4.29	3.60	2.68	0.92	25.65	47.06	12.62	34.43	10.33
23	1/23/2012	25.4	29.87	67.6	90.1	1.50	31.68	1.03	-0.34	1.53	34.25	27.63	0.22	0.07	3.24	4.21	3.73	2.88	0.84	25.69	24.39	5.40	19.00	6.07
24	1/24/2012	25.5	29.46	74.7	90.8	1.80	17.23	1.03	-0.34	1.54	34.32	27.46	0.21	0.07	3.25	4.11	3.68	3.01	0.67	25.74	13.26	2.15	11.12	3.76
25	1/25/2012	26.3	29.68	71	87.8	2.91	16.23	1.03	-0.33	1.54	34.38	27.99	0.22	0.07	3.42	4.17	3.79	2.98	0.81	25.79	12.49	1.98	10.51	4.01
26	1/26/2012	26.8	29.84	72.2	83.2	2.73	16.51	1.03	-0.33	1.54	34.45	28.31	0.22	0.07	3.52	4.20	3.86	2.98	0.88	25.84	12.71	2.04	10.67	4.12
27	1/27/2012	27.1	30.32	67.58	82.5	2.75	17.72	1.03	-0.33	1.54	34.52	28.72	0.23	0.07	3.59	4.32	3.95	2.94	1.01	25.89	13.64	2.34	11.31	4.50
28	1/28/2012	21.5	28.68	72.8	91.1	1.83	4.05	1.03	-0.32	1.54	34.58	25.10	0.19	0.07	2.57	3.93	3.25	2.60	0.65	25.94	3.12	-0.62	3.74	1.77
29	1/29/2012	24.3	29.46	61.91	90.5	2.53	17.88	1.03	-0.32	1.54	34.65	26.88	0.21	0.07	3.04	4.11	3.58	2.65	0.93	26.00	13.77	2.58	11.19	4.27

Table A2 continued...

33	2/2/2012	25.9	29.69	69.62	90	2.70	19.61	1.03	-0.30	1.54	34.93	27.77	0.22	0.07	3.33	4.17	3.75	2.95	0.80	26.21	15.10	2.64	12.45	4.44	44
34	2/3/2012	26.1	29.7	74	89.6	2.08	17.22	1.03	-0.29	1.54	35.01	27.89	0.22	0.07	3.38	4.17	3.77	3.06	0.72	26.26	13.26	2.05	11.21	3.90	45
35	2/4/2012	26.2	29.61	71.6	89.9	1.97	18.66	1.03	-0.29	1.54	35.08	27.88	0.22	0.07	3.39	4.15	3.77	3.01	0.76	26.32	14.37	2.38	11.99	4.14	46
36	2/5/2012	26.1	30.12	67.9	89.2	2.39	15.56	1.03	-0.28	1.54	35.15	28.11	0.22	0.07	3.38	4.27	3.83	2.96	0.87	26.37	11.98	1.79	10.19	3.90	47
37	2/6/2012	21.3	29.92	62.8	87.7	2.48	17.51	1.03	-0.28	1.54	35.22	25.61	0.19	0.07	2.53	4.22	3.38	2.44	0.94	26.42	13.49	2.59	10.90	4.20	48
38	2/7/2012	25.5	32.65	15.47	86.8	2.05	13.57	1.03	-0.27	1.54	35.29	29.10	0.23	0.07	3.27	4.93	4.10	1.80	2.30	26.48	10.45	2.13	8.32	5.01	49
39	2/8/2012	24.4	30.95	25.36	76	2.14	14.20	1.03	-0.27	1.54	35.37	27.69	0.22	0.07	3.06	4.48	3.77	1.73	2.04	26.53	10.93	2.33	8.60	4.92	50
40	2/9/2012	23.3	29.02	51.57	84.3	2.03	13.47	1.03	-0.26	1.54	35.44	26.18	0.20	0.07	2.87	4.01	3.44	2.24	1.20	26.59	10.37	1.71	8.66	3.82	51
41	2/10/2012	26	28.77	55.08	81.3	2.86	13.45	1.03	-0.26	1.54	35.51	27.36	0.21	0.07	3.35	3.95	3.65	2.45	1.20	26.64	10.35	1.60	8.75	4.21	52
42	2/11/2012	26.4	29.71	61.13	83.6	2.97	20.05	1.02	-0.25	1.54	35.58	28.05	0.22	0.07	3.44	4.17	3.81	2.71	1.09	26.70	15.44	2.93	12.51	5.00	53
43	2/12/2012	26.2	29.18	55.08	81.3	2.05	17.92	1.02	-0.25	1.55	35.66	27.68	0.22	0.07	3.40	4.05	3.72	2.50	1.23	26.75	13.80	2.65	11.15	4.51	54
44	2/13/2012	21.5	28.68	25.36	76	2.14	22.12	1.02	-0.24	1.55	35.73	25.10	0.19	0.07	2.57	3.93	3.25	1.47	1.78	26.80	17.03	5.04	11.99	5.55	55
45	2/14/2012	27.1	30.08	55.08	81.3	2.86	21.56	1.02	-0.24	1.55	35.80	28.59	0.23	0.07	3.58	4.26	3.92	2.63	1.29	26.86	16.60	3.37	13.24	5.47	56
46	2/15/2012	26.4	29.07	51.57	84.3	2.97	22.12	1.02	-0.23	1.55	35.87	27.72	0.22	0.07	3.44	4.02	3.73	2.49	1.24	26.91	17.03	3.64	13.39	5.48	57
47	2/16/2012	27.1	30.08	25.36	76	2.39	21.56	1.02	-0.22	1.55	35.94	28.59	0.23	0.07	3.58	4.26	3.92	1.90	2.02	26.96	16.60	4.36	12.25	6.03	58
48	2/17/2012	26.8	29.85	55.08	81.3	2.05	20.05	1.02	-0.22	1.55	36.01	28.31	0.22	0.07	3.52	4.21	3.86	2.59	1.27	27.02	15.44	3.03	12.41	4.91	59
49	2/18/2012	26.4	29.07	25.36	76	2.05	22.96	1.02	-0.21	1.55	36.08	27.72	0.22	0.07	3.44	4.02	3.73	1.82	1.91	27.07	17.68	4.84	12.84	5.82	60
50	2/19/2012	21.9	28.47	55.08	81.3	2.14	18.24	1.02	-0.21	1.55	36.15	25.19	0.19	0.07	2.63	3.88	3.26	2.14	1.12	27.12	14.04	2.93	11.11	4.40	61
51	2/20/2012	25.1	29.04	69.6	88.1	2.78	17.94	1.02	-0.20	1.55	36.22	27.09	0.21	0.07	3.19	4.01	3.60	2.80	0.80	27.17	13.81	2.28	11.53	4.22	62
52	2/21/2012	21.6	29.44	61.68	91	2.18	8.77	1.02	-0.19	1.55	36.28	25.52	0.19	0.07	2.58	4.11	3.34	2.44	0.90	27.22	6.75	0.40	6.35	2.90	63
53	2/22/2012	24.3	29.16	64.54	89.5	2.26	20.86	1.02	-0.19	1.55	36.35	26.72	0.21	0.07	3.03	4.04	3.54	2.66	0.88	27.27	16.06	3.02	13.04	4.60	64
54	2/23/2012	26.4	29.07	73.4	84.6	3.00	18.24	1.02	-0.18	1.55	36.41	27.72	0.22	0.07	3.44	4.02	3.73	2.93	0.80	27.32	14.04	2.22	11.82	4.33	65
55	2/24/2012	25.8	29.39	64.46	83.6	2.94	22.76	1.02	-0.18	1.55	36.48	27.60	0.22	0.07	3.32	4.10	3.71	2.71	1.00	27.37	17.53	3.40	14.13	5.24	66
56	2/25/2012	26.8	29.85	67.16	81.4	3.35	22.96	1.02	-0.17	1.55	36.54	28.31	0.22	0.07	3.52	4.21	3.86	2.84	1.02	27.41	17.68	3.29	14.39	5.44	67
57	2/26/2012	26.9	30.13	68.05	82.5	3.22	20.05	1.02	-0.16	1.55	36.60	28.54	0.23	0.07	3.55	4.27	3.91	2.92	0.99	27.46	15.44	2.60	12.84	4.98	68
58	2/27/2012	27.1	30.08	70.1	82.9	3.30	21.57	1.02	-0.16	1.55	36.66	28.59	0.23	0.07	3.58	4.26	3.92	2.98	0.94	27.50	16.61	2.83	13.77	5.14	69
59	2/28/2012	27	29.58	72.8	83	3.56	17.92	1.02	-0.15	1.56	36.72	28.29	0.22	0.07	3.57	4.14	3.85	2.99	0.87	27.55	13.80	2.10	11.70	4.53	70
60	2/29/2012	21.9	28.47	67.04	91.5	2.09	17.44	1.02	-0.14	1.56	36.78	25.19	0.19	0.07	2.63	3.88	3.26	2.51	0.75	27.59	13.43	2.32	11.11	3.87	71
61	3/1/2012	26.2	29.54	73.4	81.8	3.06	20.29	1.02	-0.14	1.56	36.84	27.85	0.22	0.07	3.39	4.13	3.76	2.90	0.86	27.63	15.62	2.62	13.01	4.74	72
62	3/2/2012	26.7	29.5	66.36	85	2.43	21.91	1.02	-0.13	1.56	36.89	28.08	0.22	0.07	3.49	4.12	3.81	2.85	0.96	27.68	16.87	3.01	13.87	4.99	73
63	3/3/2012	25	29.71	69.95	88.1	2.57	21.94	1.02	-0.12	1.56	36.94	27.36	0.21	0.07	3.17	4.17	3.67	2.86	0.82	27.72	16.89	2.97	13.92	4.81	74
64	3/4/2012	27.3	30.26	67.21	80.8	3.19	22.48	1.01	-0.12	1.56	37.00	28.80	0.23	0.07	3.64	4.31	3.97	2.92	1.06	27.76	17.31	3.06	14.25	5.44	75
65	3/5/2012	27.3	30.36	63.92	79	2.90	21.42	1.01	-0.11	1.56	37.05	28.84	0.23	0.07	3.63	4.33	3.98	2.82	1.16	27.79	16.49	2.95	13.54	5.35	76
66	3/6/2012	26.9	30.39	63.04	82.1	2.86	22.44	1.01	-0.10	1.56	37.10	28.67	0.23	0.07	3.55	4.34	3.95	2.83	1.12	27.83	17.28	3.14	14.13	5.43	77
67	3/7/2012	26.5	30.34	63.66	83.9	3.53	22.04	1.01	-0.10	1.56	37.14	28.43	0.22	0.07	3.46	4.33	3.90	2.83	1.06	27.87	16.97	3.04	13.93	5.45	78
68	3/8/2012	27.5	30.46	69.92	80.7	3.81	21.43	1.01	-0.09	1.56	37.19	28.96	0.23	0.07	3.66	4.36	4.01	3.00	1.01	27.90	16.50	2.74	13.76	5.37	79
69	3/9/2012	27.6	30.95	65.05	80.6	3.44	21.56	1.01	-0.08	1.56	37.23	29.30	0.23	0.07	3.70	4.48	4.09	2.95	1.14	27.93	16.60	2.83	13.78	5.53	80
70	3/10/2012	27.1	31.07	61.86	83.2	2.70	18.33	1.01	-0.08	1.56	37.28	29.09	0.23	0.07	3.59	4.51	4.05	2.89	1.16	27.97	14.11	2.23	11.88	4.85	81
71	3/11/2012	25.2	30.98	63.66	84.9	2.10	22.12	1.01	-0.07	1.56	37.32	28.08	0.22	0.07	3.20	4.49	3.84	2.79	1.06	28.00	17.03	3.08	13.95	5.07	82
72	3/12/2012	27.4	30.95	65.24	81.5	2.49	21.22	1.01	-0.06	1.56	37.36	29.17	0.23	0.07	3.65	4.48	4.06	2.95	1.12	28.02	16.34	2.75	13.60	5.18	83
73	3/13/2012	27.6	31.28	64.66	79.1	2.85	22.01	1.01	-0.05	1.57	37.39	29.43	0.24	0.07	3.69	4.56	4.13	2.93	1.19	28.05	16.95	2.92	14.03	5.51	84
74	3/14/2012	27	31.25	63.92	80.3	2.50	21.56	1.01	-0.05	1.57	37.43	29.14	0.23	0.07	3.57	4.56	4.06	2.89	1.17	28.08	16.60	2.87	13.73	5.30	85
75	3/15/2012	27.9	31.67	63.8	77.8	2.89	19.92	1.01	-0.04	1.57	37.46	29.78	0.24	0.07	3.75	4.67	4.21	2.95	1.26	28.10	15.34	2.50	12.84	5.32	86

Table A3. The spread sheet for the ET_o computation for the fourth experiment

Julien Day	Date	T_{min}	T_{max}	RH_{min}	RH_{max}	u_2	R_s	dr	δ	ωs	R_a	T_m	Δ	γ	$e(T_{min})$	$e(T_{max})$	e_s	e_a	e_s-e_a	R_{so}	R_{ns}	R_{nl}	R_n	ET_o
216	8/3/2012	23.4	25.9	76.8	87.6	4.21	19.60	0.97	0.30	1.60	36.48	24.67	0.19	0.07	2.88	3.35	3.11	2.55	0.57	27.37	15.09	2.77	12.31	4.06
217	8/4/2012	23.43	26	77.8	86.6	4.54	18.81	0.97	0.29	1.60	36.51	24.72	0.19	0.07	2.88	3.36	3.12	2.56	0.57	27.39	14.48	2.59	11.89	3.99
218	8/5/2012	23.53	26.2	76.5	88.7	3.59	21.11	0.97	0.29	1.60	36.55	24.88	0.19	0.07	2.90	3.41	3.15	2.59	0.56	27.42	16.25	3.06	13.19	4.22
219	8/6/2012	23.22	25.8	75	89.4	4.11	17.71	0.97	0.28	1.60	36.59	24.49	0.18	0.07	2.85	3.31	3.08	2.51	0.56	27.45	13.64	2.37	11.27	3.82
220	8/7/2012	23.25	25.9	78.2	88.6	3.91	18.33	0.97	0.28	1.60	36.62	24.57	0.18	0.07	2.85	3.34	3.09	2.57	0.53	27.47	14.12	2.45	11.66	3.80
221	8/8/2012	23.51	26	77.1	89.4	3.46	21.37	0.97	0.27	1.60	36.66	24.78	0.19	0.07	2.90	3.37	3.13	2.59	0.54	27.50	16.46	3.09	13.36	4.19
222	8/9/2012	22.7	25.7	76.4	89.7	4.27	20.74	0.97	0.27	1.60	36.69	24.20	0.18	0.07	2.76	3.30	3.03	2.50	0.53	27.52	15.97	3.04	12.93	4.10
223	8/10/2012	22.38	25.4	74.8	90	4.10	18.77	0.97	0.26	1.60	36.72	23.90	0.18	0.07	2.71	3.25	2.98	2.43	0.54	27.55	14.46	2.65	11.81	3.87
224	8/11/2012	22.41	25.7	77.2	91.3	3.94	21.22	0.98	0.26	1.60	36.76	24.08	0.18	0.07	2.71	3.31	3.01	2.52	0.50	27.58	16.34	3.11	13.23	4.06
225	8/12/2012	22.63	25.4	79.8	91.7	2.59	22.04	0.98	0.25	1.60	36.79	24.02	0.18	0.07	2.75	3.25	3.00	2.55	0.44	27.60	16.97	3.24	13.74	4.05
226	8/13/2012	22.09	25.4	75	91.5	2.87	22.88	0.98	0.24	1.60	36.82	23.76	0.18	0.07	2.66	3.25	2.95	2.43	0.52	27.62	17.62	3.56	14.06	4.26
227	8/14/2012	21.6	25.1	78.7	92.6	3.82	21.45	0.98	0.24	1.60	36.85	23.34	0.17	0.07	2.58	3.18	2.88	2.45	0.43	27.65	16.52	3.20	13.32	3.90
228	8/15/2012	22.27	25.6	78.3	90.9	1.97	16.18	0.98	0.23	1.59	36.89	23.92	0.18	0.07	2.69	3.28	2.98	2.50	0.48	27.67	12.46	1.99	10.47	3.28
229	8/16/2012	21.72	25.6	77	92.8	2.21	23.58	0.98	0.23	1.59	36.92	23.68	0.18	0.07	2.60	3.29	2.94	2.47	0.47	27.69	18.16	3.65	14.51	4.27
230	8/17/2012	21.56	24.8	79.6	93.2	3.74	21.86	0.98	0.22	1.59	36.95	23.17	0.17	0.07	2.57	3.13	2.85	2.44	0.41	27.72	16.83	3.27	13.56	3.88
231	8/18/2012	22.02	23.7	89.8	93	3.36	7.11	0.98	0.22	1.59	36.97	22.84	0.17	0.07	2.65	2.92	2.79	2.54	0.24	27.74	5.48	-0.02	5.49	1.74
232	8/19/2012	22.64	25.3	86.8	93	2.54	14.31	0.98	0.21	1.59	37.00	23.99	0.18	0.07	2.75	3.23	2.99	2.68	0.31	27.76	11.02	1.46	9.55	2.82
233	8/20/2012	22.7	26.4	75.2	92.1	2.88	19.03	0.98	0.20	1.59	37.03	24.53	0.18	0.07	2.76	3.43	3.10	2.56	0.53	27.78	14.65	2.57	12.08	3.85
234	8/21/2012	22.67	25.7	80.7	91.7	3.80	21.90	0.98	0.20	1.59	37.05	24.21	0.18	0.07	2.75	3.31	3.03	2.60	0.43	27.80	16.86	3.13	13.73	4.03
235	8/22/2012	22.96	25.6	85.5	92.8	3.87	17.40	0.98	0.19	1.59	37.08	24.26	0.18	0.07	2.80	3.27	3.04	2.70	0.34	27.82	13.40	2.09	11.31	3.27
236	8/23/2012	22.94	25.6	82.7	92.1	3.30	18.33	0.98	0.18	1.59	37.10	24.27	0.18	0.07	2.80	3.28	3.04	2.65	0.39	27.83	14.11	2.32	11.79	3.51
237	8/24/2012	22.93	26.3	78.8	90.6	3.25	17.40	0.98	0.18	1.59	37.12	24.62	0.18	0.07	2.80	3.42	3.11	2.62	0.49	27.85	13.40	2.16	11.24	3.60
238	8/25/2012	22.78	26.1	80.2	92.5	2.40	18.33	0.98	0.17	1.59	37.15	24.44	0.18	0.07	2.77	3.38	3.08	2.64	0.44	27.87	14.11	2.33	11.78	3.59
239	8/26/2012	22.81	26.1	80.3	92	2.42	25.48	0.98	0.17	1.59	37.17	24.48	0.18	0.07	2.78	3.39	3.08	2.64	0.44	27.88	19.62	3.83	15.79	4.58
240	8/27/2012	23.19	26.3	75.6	91.2	3.53	20.29	0.98	0.16	1.59	37.18	24.74	0.19	0.07	2.84	3.42	3.13	2.59	0.54	27.90	15.62	2.80	12.82	4.08
241	8/28/2012	23.66	26.7	78.2	91.3	3.56	18.10	0.98	0.15	1.59	37.20	25.18	0.19	0.07	2.92	3.50	3.21	2.70	0.51	27.91	13.94	2.24	11.70	3.76
242	8/29/2012	22.79	26.1	80.5	92.8	3.03	24.43	0.98	0.15	1.59	37.22	24.43	0.18	0.07	2.77	3.37	3.07	2.64	0.43	27.92	18.81	3.59	15.22	4.38
243	8/30/2012	23.15	26.4	80.1	91.8	2.52	17.78	0.98	0.14	1.59	37.23	24.77	0.19	0.07	2.84	3.44	3.14	2.68	0.46	27.93	13.69	2.18	11.51	3.57
244	8/31/2012	23.11	26.2	79.2	92	3.61	23.74	0.98	0.13	1.58	37.25	24.66	0.19	0.07	2.83	3.40	3.12	2.65	0.47	27.94	18.28	3.45	14.83	4.37
245	9/1/2012	23.77	26.4	76.5	89.1	4.54	22.49	0.98	0.13	1.58	37.26	25.11	0.19	0.07	2.94	3.45	3.20	2.63	0.57	27.95	17.31	3.23	14.09	4.47
246	9/2/2012	23.69	26.3	77.9	88.4	4.64	23.53	0.98	0.12	1.58	37.27	24.98	0.19	0.07	2.93	3.41	3.17	2.62	0.55	27.96	18.12	3.45	14.67	4.54
247	9/3/2012	23.79	25.8	80.8	88.5	4.01	16.78	0.99	0.11	1.58	37.27	24.79	0.19	0.07	2.95	3.32	3.13	2.64	0.49	27.96	12.92	2.00	10.92	3.56
248	9/4/2012	23.61	26.5	79.2	89.2	3.55	17.07	0.99	0.11	1.58	37.28	25.07	0.19	0.07	2.91	3.47	3.19	2.67	0.52	27.97	13.15	2.04	11.10	3.64
249	9/5/2012	23.99	26.5	78.6	89.9	3.39	13.94	0.99	0.10	1.58	37.29	25.26	0.19	0.07	2.98	3.47	3.23	2.70	0.52	27.97	10.73	1.38	9.35	3.24
250	9/6/2012	23.82	26.6	78.9	90.4	2.90	21.82	0.99	0.09	1.58	37.29	25.21	0.19	0.07	2.95	3.48	3.22	2.71	0.51	27.98	16.80	2.99	13.81	4.24
251	9/7/2012	23.77	27.5	70.5	89.6	3.57	20.61	0.99	0.09	1.58	37.29	25.65	0.20	0.07	2.94	3.68	3.31	2.61	0.70	27.98	15.87	2.86	13.01	4.47
252	9/8/2012	23.25	26.5	73.2	89	4.29	22.12	0.99	0.08	1.58	37.29	24.88	0.19	0.07	2.85	3.46	3.16	2.54	0.62	27.98	17.03	3.25	13.78	4.52
253	9/9/2012	23.47	26.4	78.8	90.5	4.33	19.98	0.99	0.07	1.58	37.29	24.92	0.19	0.07	2.89	3.44	3.16	2.66	0.50	27.98	15.39	2.65	12.73	4.00
254	9/10/2012	23.63	26.3	79.2	90.5	3.00	19.02	0.99	0.06	1.58	37.29	24.96	0.19	0.07	2.92	3.42	3.17	2.67	0.49	27.97	14.65	2.44	12.20	3.82
255	9/11/2012	23.3	26.1	81.3	92.4	3.32	19.52	0.99	0.06	1.58	37.28	24.72	0.19	0.07	2.86	3.39	3.13	2.70	0.43	27.97	15.03	2.51	12.51	3.76
256	9/12/2012	23.17	26.6	78.9	92	3.86	22.44	0.99	0.05	1.58	37.28	24.88	0.19	0.07	2.84	3.48	3.16	2.68	0.48	27.96	17.28	3.15	14.13	4.25
257	9/13/2012	23.86	26.4	82	90.3	3.50	14.63	0.99	0.04	1.58	37.27	25.13	0.19	0.07	2.96	3.44	3.20	2.75	0.45	27.96	11.26	1.49	9.77	3.20
258	9/14/2012	23.67	25.9	82.5	91.3	3.00	14.42	0.99	0.04	1.57	37.26	24.80	0.19	0.07	2.93	3.35	3.14	2.72	0.42	27.95	11.11	1.46	9.64	3.07
259	9/15/2012	23.38	25.5	82.6	90.9	2.76	12.01	0.99	0.03	1.57	37.24	24.42	0.18	0.07	2.87	3.26	3.07	2.65	0.41	27.94	9.25	0.99	8.26	2.71
260	9/16/2012	23.33	25	84.2	91.6	2.58	6.68	0.99	0.02	1.57	37.23	24.17	0.18	0.07	2.87	3.17	3.02	2.65	0.37	27.93	5.14	-0.12	5.26	1.90

Table A3 continued...

261	9/17/2012	23.39	26.6	78.4	91.8	3.46	22.02	0.99	0.02	1.57	37.21	25.01	0.19	0.07	2.88	3.49	3.18	2.69	0.49	27.92	16.96	3.06	13.90	4.23
262	9/18/2012	23.16	26.1	82.3	91.4	3.90	15.04	0.99	0.01	1.57	37.20	24.64	0.19	0.07	2.84	3.38	3.11	2.69	0.42	27.91	11.58	1.61	9.97	3.18
263	9/19/2012	23.14	26.7	78.2	91.5	2.77	19.79	0.99	0.00	1.57	37.18	24.93	0.19	0.07	2.83	3.51	3.17	2.67	0.50	27.89	15.23	2.62	12.61	3.92
264	9/20/2012	23.86	27.2	71.4	88.7	3.53	25.13	0.99	-0.01	1.57	37.16	25.51	0.19	0.07	2.96	3.60	3.28	2.60	0.68	27.87	19.35	3.87	15.48	5.01
265	9/21/2012	24.11	26.5	79	87.8	4.04	15.50	1.00	-0.01	1.57	37.13	25.30	0.19	0.07	3.00	3.46	3.23	2.69	0.55	27.86	11.93	1.73	10.21	3.55
266	9/22/2012	23.9	26.5	78.2	90.2	3.84	17.33	1.00	-0.02	1.57	37.11	25.19	0.19	0.07	2.97	3.46	3.21	2.69	0.52	27.84	13.34	2.10	11.24	3.71
267	9/23/2012	24.01	26.8	77.8	89.5	3.42	20.32	1.00	-0.03	1.57	37.08	25.40	0.19	0.07	2.99	3.52	3.25	2.71	0.55	27.82	15.64	2.72	12.92	4.13
268	9/24/2012	24.31	27.2	79.2	89.5	3.11	21.88	1.00	-0.03	1.57	37.05	25.75	0.20	0.07	3.04	3.61	3.32	2.79	0.53	27.80	16.85	2.96	13.89	4.33
269	9/25/2012	24.67	27.5	77.6	89.5	3.52	24.04	1.00	-0.04	1.57	37.02	26.08	0.20	0.07	3.11	3.67	3.39	2.81	0.57	27.77	18.51	3.39	15.13	4.72
270	9/26/2012	24.57	27.1	78.8	88	4.28	19.06	1.00	-0.05	1.57	36.99	25.85	0.20	0.07	3.09	3.59	3.34	2.77	0.57	27.75	14.68	2.42	12.26	4.08
271	9/27/2012	24.31	27.4	77.3	89.3	3.46	20.81	1.00	-0.05	1.57	36.96	25.86	0.20	0.07	3.04	3.65	3.35	2.77	0.58	27.73	16.03	2.78	13.24	4.28
272	9/28/2012	24.41	27.4	75.9	89.6	2.51	20.50	1.00	-0.06	1.56	36.92	25.89	0.20	0.07	3.06	3.64	3.35	2.75	0.60	27.70	15.78	2.74	13.04	4.21
273	9/29/2012	24.06	27.5	75.7	90.2	2.89	24.17	1.00	-0.07	1.56	36.89	25.80	0.20	0.07	2.99	3.68	3.34	2.74	0.59	27.67	18.61	3.51	15.10	4.72
274	9/30/2012	24.8	27.5	79.1	89	3.56	20.91	1.00	-0.08	1.56	36.85	26.15	0.20	0.07	3.13	3.67	3.40	2.84	0.56	27.64	16.10	2.74	13.36	4.28
275	10/1/2012	24.84	27.5	77.5	88.6	3.82	20.34	1.00	-0.08	1.56	36.81	26.16	0.20	0.07	3.14	3.67	3.40	2.81	0.59	27.61	15.66	2.67	12.99	4.28
276	10/2/2012	24.26	27	80	89.7	3.73	15.52	1.00	-0.09	1.56	36.76	25.63	0.19	0.07	3.03	3.56	3.30	2.78	0.51	27.58	11.95	1.70	10.24	3.46
277	10/3/2012	24.26	27.3	75.7	88.5	3.71	18.24	1.00	-0.10	1.56	36.72	25.80	0.20	0.07	3.03	3.64	3.33	2.72	0.62	27.55	14.04	2.33	11.72	4.02
278	10/4/2012	24.57	27.2	78.3	88.2	4.16	19.89	1.00	-0.10	1.56	36.68	25.89	0.20	0.07	3.09	3.61	3.35	2.77	0.57	27.51	15.32	2.62	12.69	4.18
279	10/5/2012	24.55	27.4	76.9	87.9	4.25	21.91	1.00	-0.11	1.56	36.63	25.97	0.20	0.07	3.08	3.65	3.37	2.76	0.61	27.48	16.87	3.07	13.81	4.52
280	10/6/2012	24.6	27.4	76.2	88.3	3.00	20.62	1.00	-0.12	1.56	36.58	26.00	0.20	0.07	3.09	3.65	3.37	2.76	0.62	27.44	15.88	2.81	13.07	4.28
281	10/7/2012	24.76	27.7	75	88.2	2.72	18.33	1.00	-0.12	1.56	36.53	26.22	0.20	0.07	3.12	3.71	3.42	2.77	0.65	27.41	14.11	2.33	11.78	4.00
282	10/8/2012	24.75	26.5	81.8	89	2.69	8.60	1.00	-0.13	1.56	36.48	25.63	0.19	0.07	3.12	3.46	3.29	2.81	0.49	27.37	6.62	0.31	6.32	2.37
283	10/9/2012	24.12	28.2	75.5	89.6	2.52	22.94	1.01	-0.14	1.56	36.43	26.15	0.20	0.07	3.01	3.82	3.41	2.79	0.62	27.33	17.66	3.27	14.39	4.59
284	10/10/2012	25.12	28.5	72.5	86.8	2.90	22.36	1.01	-0.14	1.56	36.38	26.82	0.21	0.07	3.19	3.90	3.54	2.80	0.75	27.29	17.22	3.18	14.04	4.77
285	10/11/2012	24.91	28.3	72.3	87.6	3.28	24.23	1.01	-0.15	1.56	36.32	26.60	0.20	0.07	3.15	3.84	3.50	2.77	0.73	27.25	18.66	3.60	15.06	5.01
286	10/12/2012	25.07	28.5	74.3	87.4	3.10	23.51	1.01	-0.16	1.55	36.27	26.80	0.21	0.07	3.18	3.90	3.54	2.84	0.70	27.21	18.10	3.38	14.72	4.87
287	10/13/2012	25.19	28.6	73.3	85.9	3.06	24.73	1.01	-0.16	1.55	36.21	26.87	0.21	0.07	3.20	3.90	3.55	2.81	0.75	27.16	19.04	3.68	15.36	5.11
288	10/14/2012	25.25	28.2	72.5	86.5	2.89	16.42	1.01	-0.17	1.55	36.15	26.71	0.21	0.07	3.22	3.82	3.52	2.77	0.74	27.12	12.64	1.98	10.66	3.92
289	10/15/2012	24.65	28.6	69.82	87	3.31	23.54	1.01	-0.18	1.55	36.09	26.65	0.21	0.07	3.10	3.92	3.51	2.72	0.79	27.08	18.13	3.56	14.56	5.03
290	10/16/2012	24.59	26	82.9	89.3	1.95	4.53	1.01	-0.18	1.55	36.03	25.27	0.19	0.07	3.09	3.35	3.22	2.77	0.45	27.03	3.49	-0.52	4.00	1.62
291	10/17/2012	24.72	28.4	72.1	88.2	2.92	20.32	1.01	-0.19	1.55	35.97	26.56	0.20	0.07	3.12	3.87	3.49	2.77	0.72	26.99	15.65	2.82	12.82	4.42
292	10/18/2012	24.4	28.6	70.3	89.7	3.14	15.45	1.01	-0.19	1.55	35.91	26.50	0.20	0.07	3.06	3.91	3.49	2.75	0.74	26.94	11.90	1.81	10.09	3.81
293	10/19/2012	24.32	29.2	70.5	87.1	2.67	14.32	1.01	-0.20	1.55	35.85	26.76	0.21	0.07	3.04	4.05	3.55	2.75	0.79	26.89	11.03	1.58	9.45	3.65
294	10/20/2012	24.83	28.7	70.5	87.7	2.09	25.18	1.01	-0.21	1.55	35.79	26.77	0.21	0.07	3.14	3.94	3.54	2.76	0.77	26.85	19.39	3.90	15.49	5.07
295	10/21/2012	24.99	28.8	71.3	87.7	2.37	24.63	1.01	-0.21	1.55	35.72	26.88	0.21	0.07	3.17	3.95	3.56	2.80	0.76	26.80	18.96	3.75	15.22	5.02
296	10/22/2012	25.11	28.9	71.6	88.4	2.51	14.88	1.01	-0.22	1.55	35.66	27.03	0.21	0.07	3.19	3.99	3.59	2.84	0.75	26.75	11.46	1.66	9.80	3.64
297	10/23/2012	25.42	29.1	72.2	87.5	2.98	22.07	1.01	-0.22	1.55	35.59	27.26	0.21	0.07	3.25	4.03	3.64	2.88	0.76	26.70	16.99	3.14	13.85	4.77
298	10/24/2012	25.34	28.9	72.3	86.9	3.37	25.18	1.01	-0.23	1.55	35.53	27.12	0.21	0.07	3.23	3.98	3.61	2.84	0.76	26.65	19.39	3.83	15.56	5.23
299	10/25/2012	25.61	29.1	70.8	84.4	3.46	24.63	1.01	-0.24	1.55	35.46	27.36	0.21	0.07	3.28	4.03	3.66	2.81	0.84	26.60	18.96	3.79	15.18	5.31
300	10/26/2012	25.65	28.5	74.9	85.6	3.09	14.88	1.01	-0.24	1.55	35.39	27.07	0.21	0.07	3.29	3.89	3.59	2.86	0.72	26.55	11.46	1.67	9.79	3.71
301	10/27/2012	25.21	29.1	72.6	86.8	3.04	22.07	1.01	-0.25	1.55	35.33	27.17	0.21	0.07	3.21	4.03	3.62	2.86	0.76	26.50	16.99	3.19	13.80	4.76
302	10/28/2012	25.38	28.1	74.4	87.1	2.92	13.23	1.02	-0.25	1.54	35.26	26.76	0.21	0.07	3.24	3.81	3.53	2.83	0.70	26.45	10.19	1.35	8.84	3.39
303	10/29/2012	24.96	28.9	72.9	87.2	2.88	20.22	1.02	-0.26	1.54	35.19	26.91	0.21	0.07	3.16	3.97	3.57	2.83	0.74	26.40	15.57	2.85	12.72	4.43
304	10/30/2012	22.23	28	71.4	91.1	2.06	18.95	1.02	-0.26	1.54	35.13	25.11	0.19	0.07	2.68	3.78	3.23	2.57	0.66	26.35	14.59	2.79	11.81	3.91
305	10/31/2012	25.18	29.1	71.6	89.1	2.72	24.59	1.02	-0.27	1.54	35.06	27.14	0.21	0.07	3.20	4.03	3.62	2.87	0.75	26.30	18.93	3.74	15.19	5.04

Appendix B

SPREAD SHEET FOR CALCULATIING TIME OF OPERATING THE IRRIGATION SYSTEMS

Table B1. The spread sheet for time of operation of sprinkler irrigation for first experiment

Date	Vol_plot (l) per 1 hr	Time (Mins)	Plot area (m^2)	ET_0 (mm)	K_c	ETc (mm)	AP	Irrig Need (L)	Operation time (mins)
10/16/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/17/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/18/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/19/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/20/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/21/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/22/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/23/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/24/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/25/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/26/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/27/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/28/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/29/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/30/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
10/31/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
11/1/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
11/2/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
11/3/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
11/4/2010	100	60	17.28	4	1.06	4.24	0.75	97.69	58.61
11/5/2010	100	60	17.28	4	1.055	4.22	0.75	97.23	58.34
11/6/2010	100	60	17.28	4	1.05	4.2	0.75	96.77	58.06
11/7/2010	100	60	17.28	4	1.045	4.18	0.75	96.31	57.78
11/8/2010	100	60	17.28	4	1.047	4.188	0.75	96.49	57.89
11/9/2010	100	60	17.28	4	1.04	4.16	0.75	95.85	57.51
11/10/2010	100	60	17.28	4	1.035	4.14	0.75	95.39	57.23
11/11/2010	100	60	17.28	4	1.03	4.12	0.75	94.92	56.95
11/12/2010	100	60	17.28	4	1.025	4.1	0.75	94.46	56.68
11/13/2010	100	60	17.28	4	1.02	4.08	0.75	94.00	56.40
11/14/2010	100	60	17.28	4	1.015	4.06	0.75	93.54	56.13
11/15/2010	100	60	17.28	4	1.01	4.04	0.75	93.08	55.85
11/16/2010	100	60	17.28	4	1.005	4.02	0.75	92.62	55.57
11/17/2010	100	60	17.28	4	1.005	4.02	0.75	92.62	55.57
11/18/2010	100	60	17.28	4	1.00	4	0.75	92.16	55.30
11/19/2010	100	60	17.28	4	0.995	3.98	0.75	91.70	55.02
11/20/2010	100	60	17.28	4	0.99	3.96	0.75	91.24	54.74
11/21/2010	100	60	17.28	4	0.985	3.94	0.75	90.78	54.47
11/22/2010	100	60	17.28	4	0.98	3.92	0.75	90.32	54.19
11/23/2010	100	60	17.28	4	0.975	3.9	0.75	89.86	53.91
11/24/2010	100	60	17.28	4	0.97	3.88	0.75	89.40	53.64
11/25/2010	100	60	17.28	4	0.965	3.86	0.75	88.93	53.36
11/26/2010	100	60	17.28	4	0.96	3.84	0.75	88.47	53.08
11/27/2010	100	60	17.28	4	0.955	3.82	0.75	88.01	52.81

Table B1 continued...

11/28/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
11/29/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
11/30/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/1/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/2/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/3/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/4/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/5/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/6/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/7/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/8/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/9/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/10/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/11/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/12/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/13/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/14/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/15/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/16/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/17/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/18/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/19/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/20/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/21/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/22/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/23/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/24/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/25/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/26/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/27/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/28/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/29/2010	100	60	17.28	4	0.95	3.8	0.75	87.55	52.53
12/30/2010	100	60	17.28	4	0.94	3.76	0.75	86.63	51.98
12/31/2010	100	60	17.28	4	0.93	3.72	0.75	85.71	51.43
1/1/2011	100	60	17.28	4	0.92	3.68	0.75	84.79	50.87
1/2/2011	100	60	17.28	4	0.91	3.64	0.75	83.87	50.32
1/3/2011	100	60	17.28	4	0.9	3.6	0.75	82.94	49.77
1/4/2011	100	60	17.28	4	0.89	3.56	0.75	82.02	49.21
1/5/2011	100	60	17.28	4	0.88	3.52	0.75	81.10	48.66
1/6/2011	100	60	17.28	4	0.87	3.48	0.75	80.18	48.11
1/7/2011	100	60	17.28	4	0.86	3.44	0.75	79.26	47.55
1/8/2011	100	60	17.28	4	0.85	3.4	0.75	78.34	47.00
1/9/2011	100	60	17.28	4	0.84	3.36	0.75	77.41	46.45

Table B2. The spread sheet for time of operation of drip irrigation for first experiment

Date	Vol_plot (l) per 1 hr	Time (mins)	Plot area (m2)	ET_o (mm)	K_c	ET_c (mm)	AP	Irrig Need (l)	Operation time (mins)
10/16/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/17/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/18/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/19/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/20/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/21/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/22/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/23/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/24/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/25/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/26/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/27/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/28/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/29/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/30/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
10/31/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
11/1/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
11/2/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
11/3/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
11/4/2010	144	60	17.28	4	0.33	1.33	0.9	25.44	10.6
11/5/2010	144	60	17.28	4	0.35	1.40	0.9	26.88	11.2
11/6/2010	144	60	17.28	4	0.38	1.52	0.9	29.184	12.16
11/7/2010	144	60	17.28	4	0.4	1.60	0.9	30.72	12.8
11/8/2010	144	60	17.28	4	0.43	1.72	0.9	33.024	13.76
11/9/2010	144	60	17.28	4	0.45	1.80	0.9	34.56	14.4
11/10/2010	144	60	17.28	4	0.48	1.92	0.9	36.864	15.36
11/11/2010	144	60	17.28	4	0.5	2.00	0.9	38.4	16
11/12/2010	144	60	17.28	4	0.53	2.12	0.9	40.704	16.96
11/13/2010	144	60	17.28	4	0.55	2.20	0.9	42.24	17.6
11/14/2010	144	60	17.28	4	0.58	2.32	0.9	44.544	18.56
11/15/2010	144	60	17.28	4	0.6	2.40	0.9	46.08	19.2
11/16/2010	144	60	17.28	4	0.62	2.48	0.9	47.616	19.84
11/17/2010	144	60	17.28	4	0.65	2.60	0.9	49.92	20.8
11/18/2010	144	60	17.28	4	0.67	2.68	0.9	51.456	21.44
11/19/2010	144	60	17.28	4	0.69	2.76	0.9	52.992	22.08
11/20/2010	144	60	17.28	4	0.72	2.88	0.9	55.296	23.04
11/21/2010	144	60	17.28	4	0.74	2.96	0.9	56.832	23.68
11/22/2010	144	60	17.28	4	0.77	3.08	0.9	59.136	24.64
11/23/2010	144	60	17.28	4	0.8	3.20	0.9	61.44	25.6
11/24/2010	144	60	17.28	4	0.82	3.28	0.9	62.976	26.24
11/25/2010	144	60	17.28	4	0.84	3.36	0.9	64.512	26.88
11/26/2010	144	60	17.28	4	0.86	3.44	0.9	66.048	27.52
11/27/2010	144	60	17.28	4	0.89	3.56	0.9	68.352	28.48

Table B2 continued...

11/28/2010	144	60	17.28	4	0.93	3.72	0.9	71.424	29.76
11/29/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
11/30/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/1/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/2/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/3/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/4/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/5/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/6/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/7/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/8/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/9/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/10/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/11/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/12/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/13/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/14/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/15/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/16/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/17/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/18/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/19/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/20/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/21/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/22/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/23/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/24/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/25/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/26/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/27/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/28/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/29/2010	144	60	17.28	4	0.95	3.80	0.9	72.96	30.4
12/30/2010	144	60	17.28	4	0.94	3.76	0.9	72.192	30.08
12/31/2010	144	60	17.28	4	0.93	3.72	0.9	71.424	29.76
1/1/2011	144	60	17.28	4	0.92	3.68	0.9	70.656	29.44
1/2/2011	144	60	17.28	4	0.91	3.64	0.9	69.888	29.12
1/3/2011	144	60	17.28	4	0.9	3.60	0.9	69.12	28.8
1/4/2011	144	60	17.28	4	0.89	3.56	0.9	68.352	28.48
1/5/2011	144	60	17.28	4	0.88	3.52	0.9	67.584	28.16
1/6/2011	144	60	17.28	4	0.87	3.48	0.9	66.816	27.84
1/7/2011	144	60	17.28	4	0.86	3.44	0.9	66.048	27.52
1/8/2011	144	60	17.28	4	0.85	3.40	0.9	65.28	27.2
1/9/2011	144	60	17.28	4	0.84	3.36	0.9	64.512	26.88

Table B3. The spread sheet for time of operation of sprinkler irrigation for second experiment

Date	Vol_plot (l) per 1 hr	Time (Mins)	Plot area (m^2)	ET_o (mm)	K_c	ET_c (mm)	AP	Irrig Need (l)	Operation time (mins)
7/16/2011	100	60	17.28	4	1.1	4.4	0.75	101.4	60.8
7/17/2011	100	60	17.28	4	1.1	4.4	0.75	101.4	60.8
7/18/2011	100	60	17.28	4	1.1	4.4	0.75	101.4	60.8
7/19/2011	100	60	17.28	4	1.1	4.4	0.75	101.4	60.8
7/20/2011	100	60	17.28	4	1.1	4.4	0.75	101.4	60.8
7/21/2011	100	60	17.28	4	1.1	4.4	0.75	101.4	60.8
7/22/2011	100	60	17.28	4	1.1	4.4	0.75	101.4	60.8
7/23/2011	100	60	17.28	4.1	1.1	4.5	0.75	104.0	62.4
7/24/2011	100	60	17.28	4.0	1.1	4.4	0.75	101.9	61.1
7/25/2011	100	60	17.28	4.3	1.1	4.7	0.75	108.1	64.9
7/26/2011	100	60	17.28	2.5	1.1	2.7	0.75	62.1	37.3
7/27/2011	100	60	17.28	3.6	1.1	4.0	0.75	91.8	55.1
7/28/2011	100	60	17.28	3.4	1.1	3.7	0.75	85.7	51.4
7/29/2011	100	60	17.28	3.9	1.1	4.3	0.75	100.0	60.0
7/30/2011	100	60	17.28	4.0	1.1	4.4	0.75	101.4	60.9
7/31/2011	100	60	17.28	3.8	1.1	4.1	0.75	95.3	57.2
8/1/2011	100	60	17.28	4.0	1.1	4.4	0.75	102.1	61.3
8/2/2011	100	60	17.28	1.8	1.1	2.0	0.75	45.9	27.6
8/3/2011	100	60	17.28	2.7	1.1	3.0	0.75	68.8	41.3
8/4/2011	100	60	17.28	2.8	1.1	3.1	0.75	71.9	43.2
8/5/2011	100	60	17.28	2.0	1.1	2.2	0.75	50.3	30.2
8/6/2011	100	60	17.28	2.6	1.1	2.9	0.75	66.7	40.0
8/7/2011	100	60	17.28	3.5	1.1	3.9	0.75	88.8	53.3
8/8/2011	100	60	17.28	3.4	1.1	3.7	0.75	86.2	51.7
8/9/2011	100	60	17.28	3.3	1.1	3.6	0.75	82.6	49.6
8/10/2011	100	60	17.28	4.2	1.095	4.6	0.75	105.6	63.3
8/11/2011	100	60	17.28	4.5	1.09	5.0	0.75	114.3	68.6
8/12/2011	100	60	17.28	3.7	1.08	4.0	0.75	91.5	54.9
8/13/2011	100	60	17.28	3.1	1.075	3.3	0.75	77.1	46.3
8/14/2011	100	60	17.28	3.4	1.07	3.7	0.75	84.9	50.9
8/15/2011	100	60	17.28	3.0	1.065	3.2	0.75	74.2	44.5
8/16/2011	100	60	17.28	4.3	1.06	4.6	0.75	106.1	63.7
8/17/2011	100	60	17.28	4.4	1.05	4.6	0.75	106.9	64.1
8/18/2011	100	60	17.28	4.4	1.045	4.7	0.75	107.1	64.3
8/19/2011	100	60	17.28	4.6	1.04	4.8	0.75	110.6	66.4
8/20/2011	100	60	17.28	5.4	1.035	5.6	0.75	128.5	77.1
8/21/2011	100	60	17.28	4.5	1.03	4.6	0.75	107.1	64.3
8/22/2011	100	60	17.28	4.0	1.02	4.1	0.75	93.9	56.3
8/23/2011	100	60	17.28	3.8	1.015	3.9	0.75	89.2	53.5
8/24/2011	100	60	17.28	3.8	1.01	3.8	0.75	87.3	52.4
8/25/2011	100	60	17.28	4.2	1.005	4.3	0.75	98.3	59.0
8/26/2011	100	60	17.28	3.2	1	3.2	0.75	73.7	44.2
8/27/2011	100	60	17.28	3.1	0.99	3.0	0.75	70.0	42.0

TableB3 continued...

8/28/2011	100	60	17.28	2.7	0.985	2.7	0.75	61.5	36.9
8/29/2011	100	60	17.28	1.9	0.98	1.9	0.75	42.9	25.7
8/30/2011	100	60	17.28	4.2	0.975	4.1	0.75	95.0	57.0
8/31/2011	100	60	17.28	3.2	0.97	3.1	0.75	71.2	42.7
9/1/2011	100	60	17.28	3.9	0.96	3.8	0.75	86.8	52.1
9/2/2011	100	60	17.28	5.0	0.955	4.8	0.75	110.3	66.2
9/3/2011	100	60	17.28	3.5	0.95	3.4	0.75	77.7	46.6
9/4/2011	100	60	17.28	3.7	0.95	3.5	0.75	81.2	48.7
9/5/2011	100	60	17.28	4.1	0.95	3.9	0.75	90.5	54.3
9/6/2011	100	60	17.28	4.3	0.95	4.1	0.75	94.9	56.9
9/7/2011	100	60	17.28	4.7	0.95	4.5	0.75	103.5	62.1
9/8/2011	100	60	17.28	4.1	0.95	3.9	0.75	89.4	53.6
9/9/2011	100	60	17.28	4.3	0.95	4.1	0.75	93.8	56.3
9/10/2011	100	60	17.28	4.2	0.95	4.0	0.75	92.3	55.4
9/11/2011	100	60	17.28	4.7	0.95	4.5	0.75	103.7	62.2
9/12/2011	100	60	17.28	4.3	0.95	4.1	0.75	93.8	56.3
9/13/2011	100	60	17.28	4.3	0.95	4.1	0.75	93.9	56.4
9/14/2011	100	60	17.28	3.5	0.95	3.3	0.75	75.9	45.6
9/15/2011	100	60	17.28	4.0	0.95	3.8	0.75	88.3	53.0
9/16/2011	100	60	17.28	4.2	0.95	4.0	0.75	91.9	55.1
9/17/2011	100	60	17.28	4.5	0.95	4.3	0.75	99.3	59.6
9/18/2011	100	60	17.28	4.3	0.95	4.1	0.75	94.2	56.5
9/19/2011	100	60	17.28	4.0	0.95	3.8	0.75	88.0	52.8
9/20/2011	100	60	17.28	2.4	0.95	2.3	0.75	52.1	31.3
9/21/2011	100	60	17.28	4.6	0.95	4.4	0.75	101.1	60.6
9/22/2011	100	60	17.28	4.8	0.95	4.5	0.75	104.8	62.9
9/23/2011	100	60	17.28	5.0	0.95	4.8	0.75	110.3	66.2
9/24/2011	100	60	17.28	4.9	0.95	4.7	0.75	107.3	64.4
9/25/2011	100	60	17.28	5.1	0.95	4.9	0.75	112.5	67.5
9/26/2011	100	60	17.28	3.9	0.95	3.7	0.75	86.2	51.7
9/27/2011	100	60	17.28	5.1	0.95	4.8	0.75	110.7	66.4
9/28/2011	100	60	17.28	1.6	0.95	1.5	0.75	35.6	21.4
9/29/2011	100	60	17.28	4.4	0.94	4.2	0.75	96.4	57.8
9/30/2011	100	60	17.28	3.8	0.93	3.6	0.75	82.2	49.3
10/1/2011	100	60	17.28	3.7	0.92	3.4	0.75	77.9	46.7
10/2/2011	100	60	17.28	5.1	0.91	4.7	0.75	107.2	64.3
10/3/2011	100	60	17.28	5.1	0.9	4.6	0.75	105.0	63.0
10/4/2011	100	60	17.28	3.7	0.89	3.3	0.75	75.2	45.1
10/5/2011	100	60	17.28	4.8	0.88	4.2	0.75	97.4	58.4
10/6/2011	100	60	17.28	5.3	0.87	4.6	0.75	105.5	63.3
10/7/2011	100	60	17.28	5.3	0.86	4.6	0.75	106.0	63.6
10/8/2011	100	60	17.28	3.7	0.85	3.2	0.75	73.1	43.9
10/9/2011	100	60	17.28	4.8	0.84	4.0	0.75	92.9	55.7

Table B4. The spread sheet for time of operation of drip irrigation for second experiment

Date	Vol_plot (l) per 1 hr	Time (mins)	Plot area (m2)	ET_o (mm)	K_c	ET_c (mm)	AP	Irrig Need (l)	Operation time (mins)
7/16/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.6
7/17/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.6
7/18/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.6
7/19/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.6
7/20/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.6
7/21/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.6
7/22/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.6
7/23/2011	144	60	17.28	4.10	0.33	1.36	0.9	26.10	10.88
7/24/2011	144	60	17.28	4.02	0.33	1.33	0.9	25.57	10.65
7/25/2011	144	60	17.28	4.27	0.33	1.41	0.9	27.13	11.30
7/26/2011	144	60	17.28	2.45	0.33	0.81	0.9	15.59	6.50
7/27/2011	144	60	17.28	3.62	0.33	1.20	0.9	23.03	9.60
7/28/2011	144	60	17.28	3.38	0.33	1.12	0.9	21.50	8.96
7/29/2011	144	60	17.28	3.95	0.33	1.31	0.9	25.09	10.46
7/30/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.45	10.60
7/31/2011	144	60	17.28	3.76	0.33	1.25	0.9	23.92	9.97
8/1/2011	144	60	17.28	4.03	0.33	1.34	0.9	25.63	10.68
8/2/2011	144	60	17.28	1.81	0.33	0.60	0.9	11.53	4.80
8/3/2011	144	60	17.28	2.71	0.33	0.90	0.9	17.26	7.19
8/4/2011	144	60	17.28	2.84	0.33	0.94	0.9	18.06	7.52
8/5/2011	144	60	17.28	1.98	0.33	0.66	0.9	12.62	5.26
8/6/2011	144	60	17.28	2.63	0.33	0.87	0.9	16.74	6.98
8/7/2011	144	60	17.28	3.51	0.33	1.16	0.9	22.29	9.29
8/8/2011	144	60	17.28	3.40	0.33	1.13	0.9	21.63	9.01
8/9/2011	144	60	17.28	3.26	0.33	1.08	0.9	20.74	8.64
8/10/2011	144	60	17.28	4.18	0.36	1.51	0.9	28.93	12.05
8/11/2011	144	60	17.28	4.55	0.39	1.77	0.9	34.07	14.19
8/12/2011	144	60	17.28	3.68	0.41	1.51	0.9	28.95	12.06
8/13/2011	144	60	17.28	3.11	0.44	1.37	0.9	26.31	10.96
8/14/2011	144	60	17.28	3.44	0.46	1.58	0.9	30.40	12.67
8/15/2011	144	60	17.28	3.02	0.49	1.48	0.9	28.44	11.85
8/16/2011	144	60	17.28	4.35	0.51	2.22	0.9	42.56	17.73
8/17/2011	144	60	17.28	4.42	0.53	2.34	0.9	44.97	18.74
8/18/2011	144	60	17.28	4.45	0.56	2.49	0.9	47.85	19.94
8/19/2011	144	60	17.28	4.62	0.58	2.68	0.9	51.40	21.42
8/20/2011	144	60	17.28	5.39	0.61	3.29	0.9	63.12	26.30
8/21/2011	144	60	17.28	4.51	0.63	2.84	0.9	54.60	22.75
8/22/2011	144	60	17.28	4.00	0.66	2.64	0.9	50.63	21.10
8/23/2011	144	60	17.28	3.82	0.68	2.59	0.9	49.82	20.76
8/24/2011	144	60	17.28	3.75	0.71	2.66	0.9	51.16	21.32
8/25/2011	144	60	17.28	4.25	0.73	3.10	0.9	59.51	24.80
8/26/2011	144	60	17.28	3.20	0.76	2.43	0.9	46.66	19.44
8/27/2011	144	60	17.28	3.07	0.78	2.39	0.9	45.96	19.15

TableB4 continued...

8/28/2011	144	60	17.28	2.71	0.81	2.19	0.9	42.12	17.55
8/29/2011	144	60	17.28	1.90	0.83	1.58	0.9	30.25	12.60
8/30/2011	144	60	17.28	4.23	0.86	3.64	0.9	69.85	29.11
8/31/2011	144	60	17.28	3.18	0.88	2.80	0.9	53.80	22.42
9/1/2011	144	60	17.28	3.93	0.91	3.57	0.9	68.59	28.58
9/2/2011	144	60	17.28	5.01	0.93	4.66	0.9	89.49	37.29
9/3/2011	144	60	17.28	3.55	0.95	3.37	0.9	64.75	26.98
9/4/2011	144	60	17.28	3.71	0.95	3.52	0.9	67.65	28.19
9/5/2011	144	60	17.28	4.13	0.95	3.93	0.9	75.38	31.41
9/6/2011	144	60	17.28	4.33	0.95	4.12	0.9	79.07	32.95
9/7/2011	144	60	17.28	4.73	0.95	4.49	0.9	86.29	35.95
9/8/2011	144	60	17.28	4.08	0.95	3.88	0.9	74.48	31.03
9/9/2011	144	60	17.28	4.29	0.95	4.07	0.9	78.20	32.58
9/10/2011	144	60	17.28	4.22	0.95	4.01	0.9	76.90	32.04
9/11/2011	144	60	17.28	4.74	0.95	4.50	0.9	86.39	35.99
9/12/2011	144	60	17.28	4.29	0.95	4.07	0.9	78.19	32.58
9/13/2011	144	60	17.28	4.29	0.95	4.08	0.9	78.27	32.61
9/14/2011	144	60	17.28	3.47	0.95	3.30	0.9	63.28	26.37
9/15/2011	144	60	17.28	4.04	0.95	3.83	0.9	73.62	30.67
9/16/2011	144	60	17.28	4.20	0.95	3.99	0.9	76.59	31.91
9/17/2011	144	60	17.28	4.54	0.95	4.31	0.9	82.76	34.48
9/18/2011	144	60	17.28	4.30	0.95	4.09	0.9	78.46	32.69
9/19/2011	144	60	17.28	4.02	0.95	3.82	0.9	73.31	30.54
9/20/2011	144	60	17.28	2.38	0.95	2.26	0.9	43.42	18.09
9/21/2011	144	60	17.28	4.62	0.95	4.39	0.9	84.21	35.09
9/22/2011	144	60	17.28	4.79	0.95	4.55	0.9	87.35	36.40
9/23/2011	144	60	17.28	5.04	0.95	4.79	0.9	91.94	38.31
9/24/2011	144	60	17.28	4.90	0.95	4.66	0.9	89.39	37.25
9/25/2011	144	60	17.28	5.14	0.95	4.88	0.9	93.75	39.06
9/26/2011	144	60	17.28	3.94	0.95	3.74	0.9	71.81	29.92
9/27/2011	144	60	17.28	5.06	0.95	4.80	0.9	92.24	38.43
9/28/2011	144	60	17.28	1.63	0.95	1.54	0.9	29.66	12.36
9/29/2011	144	60	17.28	4.45	0.94	4.18	0.9	80.30	33.46
9/30/2011	144	60	17.28	3.83	0.93	3.57	0.9	68.47	28.53
10/1/2011	144	60	17.28	3.68	0.92	3.38	0.9	64.93	27.05
10/2/2011	144	60	17.28	5.11	0.91	4.65	0.9	89.34	37.23
10/3/2011	144	60	17.28	5.06	0.9	4.56	0.9	87.48	36.45
10/4/2011	144	60	17.28	3.67	0.89	3.26	0.9	62.66	26.11
10/5/2011	144	60	17.28	4.80	0.88	4.23	0.9	81.13	33.80
10/6/2011	144	60	17.28	5.26	0.87	4.58	0.9	87.94	36.64
10/7/2011	144	60	17.28	5.35	0.86	4.60	0.9	88.31	36.80
10/8/2011	144	60	17.28	3.73	0.85	3.17	0.9	60.93	25.39
10/9/2011	144	60	17.28	4.80	0.84	4.03	0.9	77.40	32.25

Table B5. The spread sheet for time of operation of sprinkler irrigation for third experiment

Date	Vol_plot (l) per 1 hr	Time (Mins)	Plot area (m^2)	ETo (mm)	K_C	ET_c (mm)	AP	Irrig Need (l)	Operation time (mins)
12/21/2011	100	60	17.28	4	1.1	4.4	0.75	101.38	60.83
12/22/2011	100	60	17.28	4	1.1	4.4	0.75	101.38	60.83
12/23/2011	100	60	17.28	4	1.1	4.4	0.75	101.38	60.83
12/24/2011	100	60	17.28	4	1.1	4.4	0.75	101.38	60.83
12/25/2011	100	60	17.28	4	1.1	4.4	0.75	101.38	60.83
12/26/2011	100	60	17.28	4	1.1	4.4	0.75	101.38	60.83
12/27/2011	100	60	17.28	4	1.1	4.4	0.75	101.38	60.83
12/28/2011	100	60	17.28	3.86	1.1	4.25	0.75	97.93	58.76
12/29/2011	100	60	17.28	2.28	1.1	2.51	0.75	57.87	34.72
12/30/2011	100	60	17.28	4.31	1.1	4.74	0.75	109.13	65.48
12/31/2011	100	60	17.28	3.72	1.1	4.09	0.75	94.18	56.51
1/1/2012	100	60	17.28	3.85	1.1	4.24	0.75	97.69	58.62
1/2/2012	100	60	17.28	3.79	1.1	4.17	0.75	96.07	57.64
1/3/2012	100	60	17.28	3.41	1.1	3.75	0.75	86.51	51.91
1/4/2012	100	60	17.28	3.92	1.1	4.31	0.75	99.28	59.57
1/5/2012	100	60	17.28	3.34	1.1	3.67	0.75	84.54	50.72
1/6/2012	100	60	17.28	2.91	1.1	3.20	0.75	73.67	44.20
1/7/2012	100	60	17.28	3.89	1.1	4.28	0.75	98.61	59.17
1/8/2012	100	60	17.28	3.24	1.1	3.57	0.75	82.19	49.32
1/9/2012	100	60	17.28	2.72	1.1	2.99	0.75	68.88	41.33
1/10/2012	100	60	17.28	3.46	1.1	3.80	0.75	87.60	52.56
1/11/2012	100	60	17.28	3.49	1.1	3.83	0.75	88.35	53.01
1/12/2012	100	60	17.28	2.94	1.1	3.24	0.75	74.61	44.77
1/13/2012	100	60	17.28	4.44	1.1	4.88	0.75	112.48	67.49
1/14/2012	100	60	17.28	4.03	1.1	4.44	0.75	102.24	61.35
1/15/2012	100	60	17.28	3.55	1.095	3.89	0.75	89.63	53.78
1/16/2012	100	60	17.28	4.00	1.09	4.36	0.75	100.55	60.33
1/17/2012	100	60	17.28	2.82	1.08	3.05	0.75	70.29	42.17
1/18/2012	100	60	17.28	3.36	1.075	3.61	0.75	83.25	49.95
1/19/2012	100	60	17.28	6.35	1.07	6.80	0.75	156.61	93.97
1/20/2012	100	60	17.28	3.18	1.065	3.39	0.75	78.04	46.82
1/21/2012	100	60	17.28	3.59	1.06	3.81	0.75	87.70	52.62
1/22/2012	100	60	17.28	10.33	1.05	10.84	0.75	249.84	149.90
1/23/2012	100	60	17.28	6.07	1.045	6.35	0.75	146.24	87.74
1/24/2012	100	60	17.28	3.76	1.04	3.91	0.75	90.17	54.10
1/25/2012	100	60	17.28	4.01	1.035	4.15	0.75	95.66	57.40
1/26/2012	100	60	17.28	4.12	1.03	4.25	0.75	97.83	58.70
1/27/2012	100	60	17.28	4.50	1.02	4.59	0.75	105.77	63.46
1/28/2012	100	60	17.28	1.77	1.015	1.80	0.75	0.00	0.00
1/29/2012	100	60	17.28	4.27	1.01	4.31	0.75	0.00	0.00
1/30/2012	100	60	17.28	4.48	1.005	4.50	0.75	103.78	62.27
1/31/2012	100	60	17.28	4.35	1	4.35	0.75	100.33	60.20
2/1/2012	100	60	17.28	4.41	0.99	4.36	0.75	100.53	60.32

Table B5 continued...

2/2/2012	100	60	17.28	4.44	0.985	4.38	0.75	100.85	60.51
2/3/2012	100	60	17.28	3.90	0.98	3.82	0.75	88.04	52.82
2/4/2012	100	60	17.28	4.14	0.975	4.04	0.75	93.10	55.86
2/5/2012	100	60	17.28	3.90	0.97	3.78	0.75	87.10	52.26
2/6/2012	100	60	17.28	4.20	0.96	4.03	0.75	92.93	55.76
2/7/2012	100	60	17.28	5.01	0.955	4.78	0.75	110.18	66.11
2/8/2012	100	60	17.28	4.92	0.95	4.68	0.75	107.77	64.66
2/9/2012	100	60	17.28	3.82	0.95	3.63	0.75	83.57	50.14
2/10/2012	100	60	17.28	4.21	0.95	3.99	0.75	92.04	55.22
2/11/2012	100	60	17.28	5.00	0.95	4.75	0.75	109.43	65.66
2/12/2012	100	60	17.28	4.51	0.95	4.29	0.75	98.79	59.27
2/13/2012	100	60	17.28	5.55	0.95	5.28	0.75	121.58	72.95
2/14/2012	100	60	17.28	5.47	0.95	5.20	0.75	119.79	71.87
2/15/2012	100	60	17.28	5.48	0.95	5.20	0.75	119.90	71.94
2/16/2012	100	60	17.28	6.03	0.95	5.73	0.75	132.06	79.23
2/17/2012	100	60	17.28	4.91	0.95	4.66	0.75	107.39	64.43
2/18/2012	100	60	17.28	5.82	0.95	5.53	0.75	127.42	76.45
2/19/2012	100	60	17.28	4.40	0.95	4.18	0.75	0.00	0.00
2/20/2012	100	60	17.28	4.22	0.95	4.01	0.75	0.00	0.00
2/21/2012	100	60	17.28	2.90	0.95	2.75	0.75	63.45	38.07
2/22/2012	100	60	17.28	4.60	0.95	4.37	0.75	0.00	0.00
2/23/2012	100	60	17.28	4.33	0.95	4.12	0.75	0.00	0.00
2/24/2012	100	60	17.28	5.24	0.95	4.98	0.75	114.72	68.83
2/25/2012	100	60	17.28	5.44	0.95	5.17	0.75	119.01	71.41
2/26/2012	100	60	17.28	4.98	0.95	4.73	0.75	108.92	65.35
2/27/2012	100	60	17.28	5.14	0.95	4.88	0.75	112.50	67.50
2/28/2012	100	60	17.28	4.53	0.95	4.31	0.75	99.22	59.53
2/29/2012	100	60	17.28	3.87	0.95	3.68	0.75	0.00	0.00
3/1/2012	100	60	17.28	4.74	0.95	4.51	0.75	0.00	0.00
3/2/2012	100	60	17.28	4.99	0.95	4.74	0.75	109.32	65.59
3/3/2012	100	60	17.28	4.81	0.95	4.57	0.75	105.37	63.22
3/4/2012	100	60	17.28	5.44	0.95	5.16	0.75	118.97	71.38
3/5/2012	100	60	17.28	5.35	0.94	5.03	0.75	115.94	69.57
3/6/2012	100	60	17.28	5.43	0.93	5.05	0.75	116.26	69.76
3/7/2012	100	60	17.28	5.45	0.92	5.02	0.75	115.57	69.34
3/8/2012	100	60	17.28	5.37	0.91	4.88	0.75	112.49	67.49
3/9/2012	100	60	17.28	5.53	0.9	4.98	0.75	114.75	68.85
3/10/2012	100	60	17.28	4.85	0.89	4.32	0.75	99.53	59.72
3/11/2012	100	60	17.28	5.07	0.88	4.46	0.75	102.75	61.65
3/12/2012	100	60	17.28	5.18	0.87	4.50	0.75	103.75	62.25
3/13/2012	100	60	17.28	5.51	0.86	4.74	0.75	109.20	65.52
3/14/2012	100	60	17.28	5.30	0.85	4.50	0.75	103.76	62.26
3/15/2012	100	60	17.28	5.32	0.84	4.47	0.75	102.95	61.77

Table B6. The spread sheet for time of operation of drip irrigation for third experiment

Date	Vol_plot (l) per 1 hr	Time (Mins)	Plot area (m^2)	ET$_0$ (mm)	K$_c$	ETc	AP	Irrig Need (l)	Operation time (mins)
12/21/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.60
12/22/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.60
12/23/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.60
12/24/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.60
12/25/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.60
12/26/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.60
12/27/2011	144	60	17.28	4.00	0.33	1.33	0.9	25.44	10.60
12/28/2011	144	60	17.28	3.86	0.33	1.28	0.9	24.58	10.24
12/29/2011	144	60	17.28	2.28	0.33	0.76	0.9	14.52	6.05
12/30/2011	144	60	17.28	4.31	0.33	1.43	0.9	27.39	11.41
12/31/2011	144	60	17.28	3.72	0.33	1.23	0.9	23.63	9.85
1/1/2012	144	60	17.28	3.85	0.33	1.28	0.9	24.52	10.21
1/2/2012	144	60	17.28	3.79	0.33	1.26	0.9	24.11	10.05
1/3/2012	144	60	17.28	3.41	0.33	1.13	0.9	21.71	9.05
1/4/2012	144	60	17.28	3.92	0.33	1.30	0.9	24.91	10.38
1/5/2012	144	60	17.28	3.34	0.33	1.10	0.9	21.22	8.84
1/6/2012	144	60	17.28	2.91	0.33	0.96	0.9	18.49	7.70
1/7/2012	144	60	17.28	3.89	0.33	1.29	0.9	24.75	10.31
1/8/2012	144	60	17.28	3.24	0.33	1.07	0.9	20.63	8.59
1/9/2012	144	60	17.28	2.72	0.33	0.90	0.9	17.29	7.20
1/10/2012	144	60	17.28	3.46	0.33	1.14	0.9	21.98	9.16
1/11/2012	144	60	17.28	3.49	0.33	1.15	0.9	22.17	9.24
1/12/2012	144	60	17.28	2.94	0.33	0.98	0.9	18.72	7.80
1/13/2012	144	60	17.28	4.44	0.33	1.47	0.9	28.23	11.76
1/14/2012	144	60	17.28	4.03	0.33	1.34	0.9	25.66	10.69
1/15/2012	144	60	17.28	3.55	0.36	1.28	0.9	24.56	10.23
1/16/2012	144	60	17.28	4.00	0.39	1.56	0.9	29.98	12.49
1/17/2012	144	60	17.28	2.82	0.41	1.16	0.9	22.24	9.27
1/18/2012	144	60	17.28	3.36	0.44	1.48	0.9	28.39	11.83
1/19/2012	144	60	17.28	6.35	0.46	2.92	0.9	56.11	23.38
1/20/2012	144	60	17.28	3.18	0.49	1.56	0.9	29.92	12.47
1/21/2012	144	60	17.28	3.59	0.51	1.83	0.9	35.16	14.65
1/22/2012	144	60	17.28	10.33	0.53	5.47	0.9	105.09	43.79
1/23/2012	144	60	17.28	6.07	0.56	3.40	0.9	65.30	27.21
1/24/2012	144	60	17.28	3.76	0.58	2.18	0.9	41.91	17.46
1/25/2012	144	60	17.28	4.01	0.61	2.45	0.9	46.98	19.58
1/26/2012	144	60	17.28	4.12	0.63	2.60	0.9	49.86	20.78
1/27/2012	144	60	17.28	4.50	0.66	2.97	0.9	57.03	23.76
1/28/2012	144	60	17.28	1.77	0.68	1.21	0.9	23.17	9.66
1/29/2012	144	60	17.28	4.27	0.71	3.03	0.9	58.23	24.26
1/30/2012	144	60	17.28	4.48	0.73	3.27	0.9	62.82	26.17
1/31/2012	144	60	17.28	4.35	0.76	3.31	0.9	63.54	26.47
2/1/2012	144	60	17.28	4.41	0.78	3.44	0.9	66.00	27.50

Table B6 continued...

2/2/2012	144	60	17.28	4.44	0.81	3.60	0.9	69.11	28.80
2/3/2012	144	60	17.28	3.90	0.83	3.24	0.9	62.14	25.89
2/4/2012	144	60	17.28	4.14	0.86	3.56	0.9	68.43	28.51
2/5/2012	144	60	17.28	3.90	0.88	3.43	0.9	65.85	27.44
2/6/2012	144	60	17.28	4.20	0.91	3.82	0.9	73.41	30.59
2/7/2012	144	60	17.28	5.01	0.93	4.66	0.9	89.41	37.25
2/8/2012	144	60	17.28	4.92	0.95	4.68	0.9	89.81	37.42
2/9/2012	144	60	17.28	3.82	0.95	3.63	0.9	69.64	29.02
2/10/2012	144	60	17.28	4.21	0.95	3.99	0.9	76.70	31.96
2/11/2012	144	60	17.28	5.00	0.95	4.75	0.9	91.19	38.00
2/12/2012	144	60	17.28	4.51	0.95	4.29	0.9	82.32	34.30
2/13/2012	144	60	17.28	5.55	0.95	5.28	0.9	101.31	42.21
2/14/2012	144	60	17.28	5.47	0.95	5.20	0.9	99.82	41.59
2/15/2012	144	60	17.28	5.48	0.95	5.20	0.9	99.91	41.63
2/16/2012	144	60	17.28	6.03	0.95	5.73	0.9	110.05	45.85
2/17/2012	144	60	17.28	4.91	0.95	4.66	0.9	89.49	37.29
2/18/2012	144	60	17.28	5.82	0.95	5.53	0.9	106.18	44.24
2/19/2012	144	60	17.28	4.40	0.95	4.18	0.9	80.24	33.43
2/20/2012	144	60	17.28	4.22	0.95	4.01	0.9	76.90	32.04
2/21/2012	144	60	17.28	2.90	0.95	2.75	0.9	52.88	22.03
2/22/2012	144	60	17.28	4.60	0.95	4.37	0.9	83.99	34.99
2/23/2012	144	60	17.28	4.33	0.95	4.12	0.9	79.05	32.94
2/24/2012	144	60	17.28	5.24	0.95	4.98	0.9	95.60	39.83
2/25/2012	144	60	17.28	5.44	0.95	5.17	0.9	99.18	41.32
2/26/2012	144	60	17.28	4.98	0.95	4.73	0.9	90.77	37.82
2/27/2012	144	60	17.28	5.14	0.95	4.88	0.9	93.75	39.06
2/28/2012	144	60	17.28	4.53	0.95	4.31	0.9	82.68	34.45
2/29/2012	144	60	17.28	3.87	0.95	3.68	0.9	70.61	29.42
3/1/2012	144	60	17.28	4.74	0.95	4.51	0.9	86.54	36.06
3/2/2012	144	60	17.28	4.99	0.95	4.74	0.9	91.10	37.96
3/3/2012	144	60	17.28	4.81	0.95	4.57	0.9	87.81	36.59
3/4/2012	144	60	17.28	5.44	0.95	5.16	0.9	99.15	41.31
3/5/2012	144	60	17.28	5.35	0.94	5.03	0.9	96.62	40.26
3/6/2012	144	60	17.28	5.43	0.93	5.05	0.9	96.89	40.37
3/7/2012	144	60	17.28	5.45	0.92	5.02	0.9	96.31	40.13
3/8/2012	144	60	17.28	5.37	0.91	4.88	0.9	93.74	39.06
3/9/2012	144	60	17.28	5.53	0.9	4.98	0.9	95.62	39.84
3/10/2012	144	60	17.28	4.85	0.89	4.32	0.9	82.94	34.56
3/11/2012	144	60	17.28	5.07	0.88	4.46	0.9	85.63	35.68
3/12/2012	144	60	17.28	5.18	0.87	4.50	0.9	86.46	36.02
3/13/2012	144	60	17.28	5.51	0.86	4.74	0.9	91.00	37.92
3/14/2012	144	60	17.28	5.30	0.85	4.50	0.9	86.47	36.03
3/15/2012	144	60	17.28	5.32	0.84	4.47	0.9	85.79	35.75

Table B7. The spread sheet for time of operation of sprinkler irrigation for fourth experiment

Date	Vol_plot (l) per 1 hr	Time (Mins)	Plot area (m^2)	ETo (mm)	K_{cb}	K_e	K_C	ET_c (mm)	AP	Irrig Need (l)	Operation time (mins)
8/3/2012	100	60	17.28	4.00	0.0043	1.10	1.10	4.4	0.75	101.38	60.83
8/4/2012	100	60	17.28	4.00	0.0043	1.10	1.10	4.4	0.75	101.38	60.83
8/5/2012	100	60	17.28	4.00	0.0129	1.09	1.10	4.4	0.75	101.38	60.83
8/6/2012	100	60	17.28	4.00	0.0215	1.08	1.10	4.4	0.75	101.38	60.83
8/7/2012	100	60	17.28	4.00	0.0301	1.05	1.08	4.31	0.75	99.25	59.55
8/8/2012	100	60	17.28	4.00	0.0387	1.03	1.07	4.29	0.75	98.77	59.26
8/9/2012	100	60	17.28	4.00	0.0473	1.03	1.08	4.33	0.75	99.70	59.82
8/10/2012	100	60	17.28	3.87	0.0559	0.99	1.05	4.06	0.75	93.53	56.12
8/11/2012	100	60	17.28	4.06	0.0645	1.01	1.07	4.36	0.75	100.48	60.29
8/12/2012	100	60	17.28	4.05	0.0731	0.96	1.03	4.17	0.75	96.17	57.70
8/13/2012	100	60	17.28	4.26	0.0817	0.98	1.06	4.52	0.75	104.09	62.46
8/14/2012	100	60	17.28	3.90	0.0903	0.93	1.02	4.00	0.75	92.08	55.25
8/15/2012	100	60	17.28	3.28	0.0989	0.94	1.04	3.41	0.75	78.68	47.21
8/16/2012	100	60	17.28	4.27	0.1075	0.94	1.05	4.46	0.75	102.83	61.70
8/17/2012	100	60	17.28	3.88	0.1161	0.95	1.06	4.13	0.75	95.14	57.09
8/18/2012	100	60	17.28	1.74	0.1247	0.91	1.04	1.81	0.75	41.64	24.98
8/19/2012	100	60	17.28	2.82	0.1333	0.90	1.03	2.90	0.75	66.87	40.12
8/20/2012	100	60	17.28	3.85	0.1419	0.91	1.06	4.06	0.75	93.60	56.16
8/21/2012	100	60	17.28	4.03	0.1505	0.91	1.06	4.27	0.75	98.36	59.02
8/22/2012	100	60	17.28	3.54	0.1591	0.90	1.06	3.76	0.75	86.70	52.02
8/23/2012	100	60	17.28	3.58	0.1677	0.88	1.05	3.76	0.75	86.59	51.95
8/24/2012	100	60	17.28	4.62	0.1763	0.90	1.07	4.97	0.75	114.49	68.70
8/25/2012	100	60	17.28	3.88	0.2351	0.82	1.05	4.09	0.75	94.21	56.53
8/26/2012	100	60	17.28	3.58	0.2666	0.80	1.06	3.80	0.75	87.45	52.47
8/27/2012	100	60	17.28	4.59	0.2981	0.77	1.07	4.90	0.75	112.93	67.76
8/28/2012	100	60	17.28	3.68	0.3296	0.72	1.05	3.86	0.75	88.96	53.38
8/29/2012	100	60	17.28	4.40	0.3611	0.70	1.07	4.68	0.75	107.94	64.76
8/30/2012	100	60	17.28	4.21	0.3926	0.66	1.06	4.45	0.75	102.42	61.45
8/31/2012	100	60	17.28	4.42	0.4241	0.63	1.06	4.67	0.75	107.62	64.57
9/1/2012	100	60	17.28	3.99	0.4556	0.59	1.04	4.16	0.75	95.91	57.55
9/2/2012	100	60	17.28	3.77	0.4871	0.54	1.03	3.89	0.75	89.63	53.78
9/3/2012	100	60	17.28	3.28	0.5186	0.53	1.05	3.45	0.75	79.52	47.71
9/4/2012	100	60	17.28	4.31	0.5501	0.46	1.01	4.34	0.75	100.02	60.01
9/5/2012	100	60	17.28	4.16	0.5816	0.48	1.07	4.43	0.75	102.10	61.26
9/6/2012	100	60	17.28	4.47	0.6131	0.43	1.04	4.67	0.75	107.59	64.55
9/7/2012	100	60	17.28	4.92	0.6446	0.43	1.08	5.29	0.75	121.96	73.17
9/8/2012	100	60	17.28	4.61	0.6761	0.38	1.05	4.85	0.75	111.80	67.08
9/9/2012	100	60	17.28	4.85	0.7076	0.34	1.04	5.07	0.75	116.70	70.02
9/10/2012	100	60	17.28	4.64	0.7391	0.33	1.07	4.95	0.75	0.00	0.00
9/11/2012	100	60	17.28	4.29	0.7706	0.28	1.05	4.50	0.75	0.00	0.00
9/12/2012	100	60	17.28	4.62	0.8021	0.25	1.05	4.84	0.75	111.59	66.95
9/13/2012	100	60	17.28	4.81	0.8336	0.19	1.02	4.92	0.75	113.24	67.95
9/14/2012	100	60	17.28	4.34	0.8651	0.16	1.02	4.45	0.75	102.43	61.46
9/15/2012	100	60	17.28	4.26	0.8966	0.16	1.06	4.50	0.75	103.79	62.27
9/16/2012	100	60	17.28	4.06	0.9281	0.07	1.00	4.06	0.75	93.47	56.08

Table B7 continued...

9/17/2012	100	60	17.28	4.85	0.9596	0.12	1.08	5.23	0.75	120.58	72.35
9/18/2012	100	60	17.28	4.49	0.9911	0.06	1.05	4.73	0.75	108.88	65.33
9/19/2012	100	60	17.28	4.80	1.0226	0.05	1.07	5.14	0.75	118.50	71.10
9/20/2012	100	60	17.28	3.93	1.0348	0.05	1.08	4.26	0.75	98.18	58.91
9/21/2012	100	60	17.28	5.04	1.0442	0.05	1.09	5.51	0.75	127.04	76.22
9/22/2012	100	60	17.28	4.57	1.0536	0.05	1.10	5.05	0.75	116.30	69.78
9/23/2012	100	60	17.28	4.49	1.0630	0.05	1.11	5.00	0.75	115.22	69.13
9/24/2012	100	60	17.28	5.03	1.07	0.05	1.12	5.65	0.75	130.16	78.10
9/25/2012	100	60	17.28	5.21	1.08	0.05	1.13	5.89	0.75	135.74	81.45
9/26/2012	100	60	17.28	5.23	1.09	0.05	1.14	5.97	0.75	137.57	82.54
9/27/2012	100	60	17.28	2.77	1.10	0.05	1.15	3.19	0.75	73.48	44.09
9/28/2012	100	60	17.28	4.37	1.11	0.05	1.16	5.07	0.75	116.87	70.12
9/29/2012	100	60	17.28	3.24	1.10	0.05	1.15	3.72	0.75	85.67	51.40
9/30/2012	100	60	17.28	4.68	1.08	0.05	1.13	5.31	0.75	122.38	73.43
10/1/2012	100	60	17.28	2.75	1.07	0.05	1.12	3.08	0.75	71.01	42.60
10/2/2012	100	60	17.28	4.21	1.06	0.05	1.11	4.67	0.75	0.00	0.00
10/3/2012	100	60	17.28	4.15	1.05	0.05	1.10	4.55	0.75	0.00	0.00
10/4/2012	100	60	17.28	5.06	1.04	0.05	1.09	5.49	0.75	126.60	75.96
10/5/2012	100	60	17.28	5.17	1.02	0.06	1.08	5.60	0.75	0.00	0.00
10/6/2012	100	60	17.28	4.82	1.01	0.05	1.06	5.13	0.75	0.00	0.00
10/7/2012	100	60	17.28	4.04	1.00	0.05	1.05	4.23	0.75	97.57	58.54
10/8/2012	100	60	17.28	4.13	0.98	0.05	1.03	4.27	0.75	98.34	59.01
10/9/2012	100	60	17.28	3.63	0.97	0.10	1.07	3.87	0.75	89.15	53.49
10/10/2012	100	60	17.28	2.32	0.95	0.05	1.00	2.32	0.75	53.43	32.06
10/11/2012	100	60	17.28	2.40	0.93	0.16	1.09	2.61	0.75	60.23	36.14
10/12/2012	100	60	17.28	2.07	0.92	0.14	1.06	2.19	0.75	0.00	0.00
10/13/2012	100	60	17.28	1.93	0.90	0.16	1.07	2.06	0.75	0.00	0.00
10/14/2012	100	60	17.28	4.52	0.89	0.19	1.08	4.89	0.75	112.74	67.64
10/15/2012	100	60	17.28	4.92	0.88	0.18	1.06	5.22	0.75	120.22	72.13
10/16/2012	100	60	17.28	1.75	0.87	0.21	1.08	1.88	0.75	43.35	26.01
10/17/2012	100	60	17.28	4.18	0.86	0.21	1.07	4.47	0.75	102.94	61.76
10/18/2012	100	60	17.28	3.72	0.85	0.23	1.07	3.99	0.75	91.94	55.17
10/19/2012	100	60	17.28	2.57	0.83	0.20	1.03	2.65	0.75	61.11	36.67
10/20/2012	100	60	17.28	1.88	0.82	0.23	1.05	1.98	0.75	45.52	27.31
10/21/2012	100	60	17.28	3.21	0.79	0.28	1.06	3.42	0.75	78.71	47.22
10/22/2012	100	60	17.28	2.81	0.75	0.26	1.01	2.83	0.75	65.12	39.07
10/23/2012	100	60	17.28	4.94	0.75	0.37	1.12	5.51	0.75	126.98	76.19
10/24/2012	100	60	17.28	2.63	0.75	0.31	1.06	2.79	0.75	64.31	38.58
10/25/2012	100	60	17.28	1.80	0.75	0.33	1.08	1.94	0.75	44.59	26.76
10/26/2012	100	60	17.28	1.79	0.75	0.33	1.08	1.93	0.75	44.54	26.72
10/27/2012	100	60	17.28	2.93	0.75	0.30	1.05	3.09	0.75	71.23	42.74
10/28/2012	100	60	17.28	1.44	0.75	0.35	1.10	1.58	0.75	36.47	21.88
10/29/2012	100	60	17.28	2.79	0.75	0.33	1.08	3.01	0.75	69.37	41.62
10/30/2012	100	60	17.28	2.37	0.75	0.32	1.07	2.54	0.75	58.46	35.07
10/31/2012	100	60	17.28	2.58	0.75	0.29	1.04	2.68	0.75	61.67	37.00

Table B8. The spread sheet for time of operation of drip irrigation for fourth experiment

Date	Vol_plot (l) per 1 hr	Time (Mins)	Plot area (m^2)	ET_o (mm)	K_{cb}	K_e	K_c	ET_c	AP	Irrig Need (l)	Operation time (mins)
8/3/2012	144	60	17.28	4.00	0.15	0.34	0.49	1.98	0.9	37.92	15.80
8/4/2012	144	60	17.28	4.00	0.15	0.34	0.49	1.98	0.9	37.92	15.80
8/5/2012	144	60	17.28	4.00	0.15	0.34	0.49	1.98	0.9	37.92	15.80
8/6/2012	144	60	17.28	4.00	0.15	0.34	0.49	1.98	0.9	37.92	15.80
8/7/2012	144	60	17.28	4.00	0.15	0.34	0.49	1.95	0.9	37.42	15.59
8/8/2012	144	60	17.28	4.00	0.15	0.34	0.49	1.95	0.9	37.39	15.58
8/9/2012	144	60	17.28	4.00	0.15	0.34	0.49	1.96	0.9	37.57	15.65
8/10/2012	144	60	17.28	3.87	0.15	0.34	0.49	1.89	0.9	36.35	15.15
8/11/2012	144	60	17.28	4.06	0.15	0.34	0.49	1.98	0.9	37.92	15.80
8/12/2012	144	60	17.28	4.05	0.15	0.33	0.48	1.94	0.9	37.31	15.54
8/13/2012	144	60	17.28	4.26	0.15	0.33	0.48	2.05	0.9	39.38	16.41
8/14/2012	144	60	17.28	3.90	0.15	0.33	0.48	1.89	0.9	36.20	15.09
8/15/2012	144	60	17.28	3.28	0.15	0.32	0.47	1.56	0.9	29.92	12.47
8/16/2012	144	60	17.28	4.27	0.15	0.33	0.48	2.03	0.9	38.97	16.24
8/17/2012	144	60	17.28	3.88	0.15	0.33	0.48	1.86	0.9	35.76	14.90
8/18/2012	144	60	17.28	1.74	0.15	0.32	0.47	0.82	0.9	15.78	6.57
8/19/2012	144	60	17.28	2.82	0.15	0.32	0.47	1.32	0.9	25.26	10.52
8/20/2012	144	60	17.28	3.85	0.15	0.32	0.47	1.81	0.9	34.80	14.50
8/21/2012	144	60	17.28	4.03	0.15	0.32	0.47	1.89	0.9	36.27	15.11
8/22/2012	144	60	17.28	3.54	0.15	0.32	0.47	1.65	0.9	31.73	13.22
8/23/2012	144	60	17.28	3.58	0.15	0.31	0.46	1.65	0.9	31.65	13.19
8/24/2012	144	60	17.28	4.62	0.15	0.32	0.47	2.16	0.9	41.46	17.27
8/25/2012	144	60	17.28	3.88	0.15	0.31	0.46	1.79	0.9	34.38	14.32
8/26/2012	144	60	17.28	3.58	0.15	0.31	0.46	1.66	0.9	31.84	13.27
8/27/2012	144	60	17.28	4.59	0.15	0.31	0.46	2.12	0.9	40.78	16.99
8/28/2012	144	60	17.28	3.68	0.15	0.30	0.45	1.65	0.9	31.64	13.18
8/29/2012	144	60	17.28	4.40	0.18	0.30	0.47	2.09	0.9	40.07	16.69
8/30/2012	144	60	17.28	4.21	0.21	0.29	0.50	2.09	0.9	40.07	16.70
8/31/2012	144	60	17.28	4.42	0.23	0.28	0.51	2.27	0.9	43.52	18.13
9/1/2012	144	60	17.28	3.99	0.26	0.27	0.53	2.13	0.9	40.87	17.03
9/2/2012	144	60	17.28	3.77	0.29	0.26	0.55	2.07	0.9	39.81	16.59
9/3/2012	144	60	17.28	3.28	0.32	0.25	0.57	1.88	0.9	36.13	15.05
9/4/2012	144	60	17.28	4.31	0.35	0.24	0.59	2.53	0.9	48.60	20.25
9/5/2012	144	60	17.28	4.16	0.37	0.25	0.63	2.60	0.9	49.93	20.80
9/6/2012	144	60	17.28	4.47	0.40	0.24	0.64	2.88	0.9	55.28	23.04
9/7/2012	144	60	17.28	4.92	0.43	0.21	0.64	3.16	0.9	60.75	25.31
9/8/2012	144	60	17.28	4.61	0.46	0.11	0.57	2.61	0.9	50.10	20.87
9/9/2012	144	60	17.28	4.85	0.49	0.22	0.71	3.42	0.9	65.72	27.38
9/10/2012	144	60	17.28	4.64	0.51	0.19	0.70	3.26	0.9	62.54	26.06
9/11/2012	144	60	17.28	4.29	0.54	0.14	0.68	2.93	0.9	56.26	23.44
9/12/2012	144	60	17.28	4.62	0.57	0.20	0.77	3.53	0.9	67.86	28.28
9/13/2012	144	60	17.28	4.81	0.60	0.12	0.72	3.46	0.9	66.40	27.67
9/14/2012	144	60	17.28	4.34	0.63	0.17	0.79	3.44	0.9	65.99	27.50
9/15/2012	144	60	17.28	4.26	0.65	0.13	0.78	3.32	0.9	63.83	26.59
9/16/2012	144	60	17.28	4.06	0.68	0.13	0.81	3.31	0.9	63.46	26.44

Table B8 continued...

9/17/2012	144	60	17.28	4.85	0.71	0.16	0.87	4.21	0.9	80.83	33.68	46
9/18/2012	144	60	17.28	4.49	0.74	0.05	0.78	3.52	0.9	67.50	28.12	47
9/19/2012	144	60	17.28	4.80	0.77	0.10	0.86	4.14	0.9	79.49	33.12	48
9/20/2012	144	60	17.28	3.93	0.79	0.09	0.89	3.49	0.9	67.06	27.94	49
9/21/2012	144	60	17.28	5.04	0.82	0.08	0.91	4.57	0.9	87.79	36.58	50
9/22/2012	144	60	17.28	4.57	0.85	0.04	0.89	4.08	0.9	78.28	32.62	51
9/23/2012	144	60	17.28	4.49	0.85	0.10	0.95	4.25	0.9	81.61	34.00	52
9/24/2012	144	60	17.28	5.03	0.85	0.09	0.95	4.76	0.9	91.34	38.06	53
9/25/2012	144	60	17.28	5.21	0.85	0.09	0.94	4.90	0.9	94.13	39.22	54
9/26/2012	144	60	17.28	5.23	0.85	0.09	0.94	4.93	0.9	94.74	39.48	55
9/27/2012	144	60	17.28	2.77	0.85	0.09	0.94	2.62	0.9	50.22	20.92	56
9/28/2012	144	60	17.28	4.37	0.85	0.09	0.94	4.11	0.9	79.00	32.92	57
9/29/2012	144	60	17.28	3.24	0.85	0.10	0.95	3.08	0.9	59.17	24.65	58
9/30/2012	144	60	17.28	4.68	0.85	0.10	0.95	4.44	0.9	85.32	35.55	59
10/1/2012	144	60	17.28	2.75	0.85	0.10	0.95	2.61	0.9	50.20	20.92	60
10/2/2012	144	60	17.28	4.21	0.85	0.10	0.95	4.01	0.9	76.99	32.08	61
10/3/2012	144	60	17.28	4.15	0.85	0.10	0.95	3.96	0.9	75.97	31.65	62
10/4/2012	144	60	17.28	5.06	0.85	0.11	0.96	4.86	0.9	93.23	38.85	63
10/5/2012	144	60	17.28	5.17	0.85	0.12	0.97	5.04	0.9	96.72	40.30	64
10/6/2012	144	60	17.28	4.82	0.85	0.04	0.90	4.32	0.9	82.89	34.54	65
10/7/2012	144	60	17.28	4.04	0.85	0.11	0.96	3.87	0.9	74.28	30.95	66
10/8/2012	144	60	17.28	4.13	0.85	0.11	0.96	3.98	0.9	76.35	31.81	67
10/9/2012	144	60	17.28	3.63	0.85	0.14	0.99	3.59	0.9	68.89	28.71	68
10/10/2012	144	60	17.28	2.32	0.85	0.11	0.96	2.23	0.9	42.90	17.88	69
10/11/2012	144	60	17.28	2.40	0.85	0.18	1.03	2.47	0.9	47.50	19.79	70
10/12/2012	144	60	17.28	2.07	0.85	0.17	1.02	2.12	0.9	40.64	16.93	71
10/13/2012	144	60	17.28	1.93	0.85	0.18	1.03	1.99	0.9	38.29	15.96	72
10/14/2012	144	60	17.28	4.52	0.85	0.19	1.05	4.73	0.9	90.78	37.83	73
10/15/2012	144	60	17.28	4.92	0.85	0.19	1.04	5.11	0.9	98.14	40.89	74
10/16/2012	144	60	17.28	1.75	0.85	0.20	1.05	1.84	0.9	35.26	14.69	75
10/17/2012	144	60	17.28	4.18	0.85	0.20	1.05	4.40	0.9	84.46	35.19	76
10/18/2012	144	60	17.28	3.72	0.84	0.21	1.05	3.91	0.9	75.15	31.31	77
10/19/2012	144	60	17.28	2.57	0.84	0.19	1.03	2.64	0.9	50.77	21.15	78
10/20/2012	144	60	17.28	1.88	0.83	0.21	1.04	1.95	0.9	37.39	15.58	79
10/21/2012	144	60	17.28	3.21	0.82	0.22	1.05	3.37	0.9	64.63	26.93	80
10/22/2012	144	60	17.28	2.81	0.82	0.19	1.01	2.83	0.9	54.27	22.61	81
10/23/2012	144	60	17.28	4.94	0.81	0.26	1.07	5.28	0.9	101.40	42.25	82
10/24/2012	144	60	17.28	2.63	0.80	0.24	1.04	2.73	0.9	52.48	21.87	83
10/25/2012	144	60	17.28	1.80	0.80	0.24	1.04	1.87	0.9	35.85	14.94	84
10/26/2012	144	60	17.28	1.79	0.79	0.24	1.03	1.85	0.9	35.52	14.80	85
10/27/2012	144	60	17.28	2.93	0.78	0.23	1.02	2.98	0.9	57.20	23.83	86
10/28/2012	144	60	17.28	1.44	0.78	0.25	1.03	1.48	0.9	28.45	11.85	87
10/29/2012	144	60	17.28	2.79	0.77	0.24	1.01	2.83	0.9	54.26	22.61	88
10/30/2012	144	60	17.28	2.37	0.76	0.24	1.00	2.38	0.9	45.61	19.00	89
10/31/2012	144	60	17.28	2.58	0.76	0.22	0.98	2.54	0.9	48.69	20.29	90

Appendix C

Relationship between f_{PAR} and basal crop coefficient (K_{cb}) for the experiments

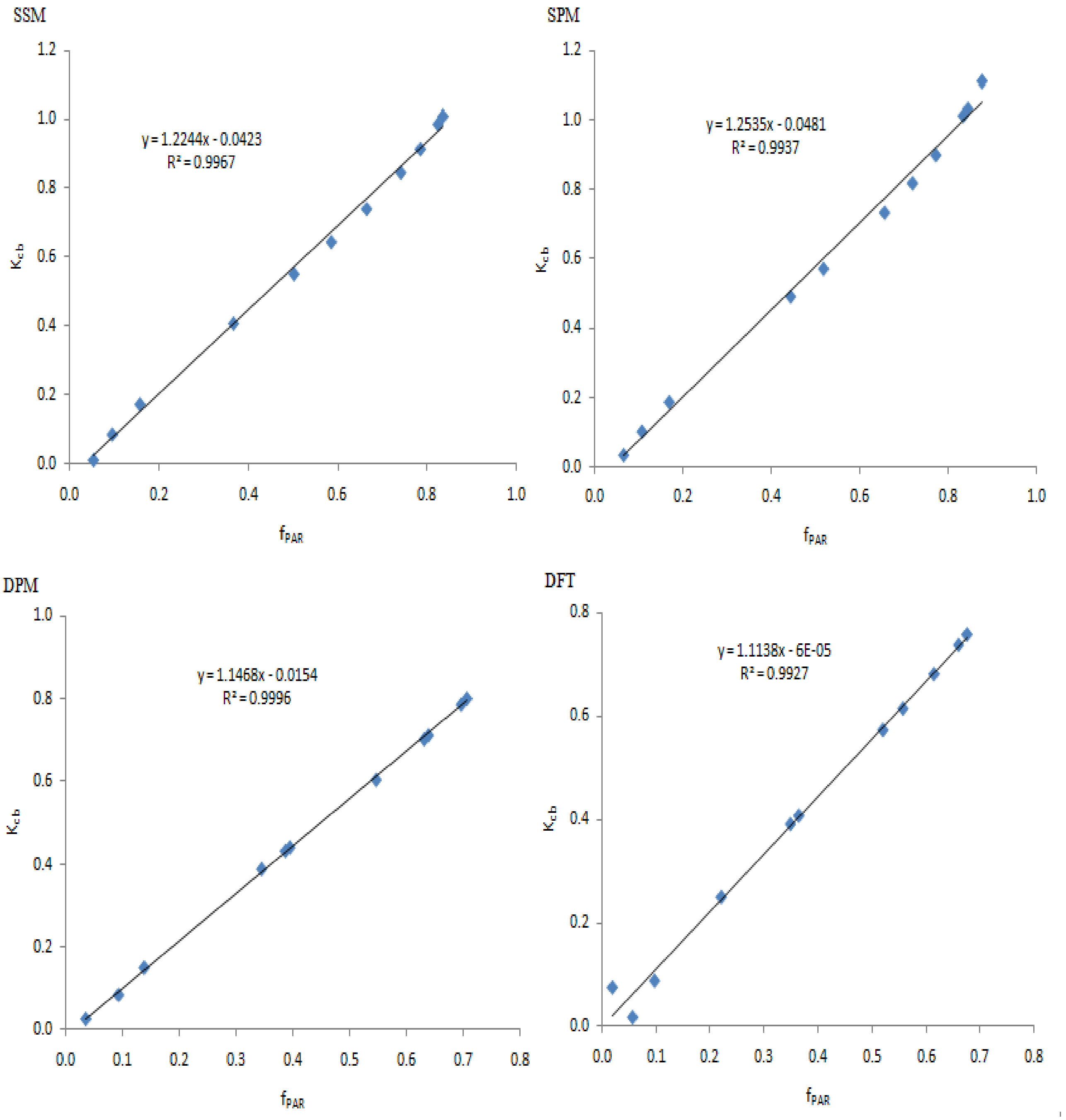

Fig C1 Relationship between f_{PAR} and basal crop coefficient (K_{cb}) for the different treatments for the second experiment

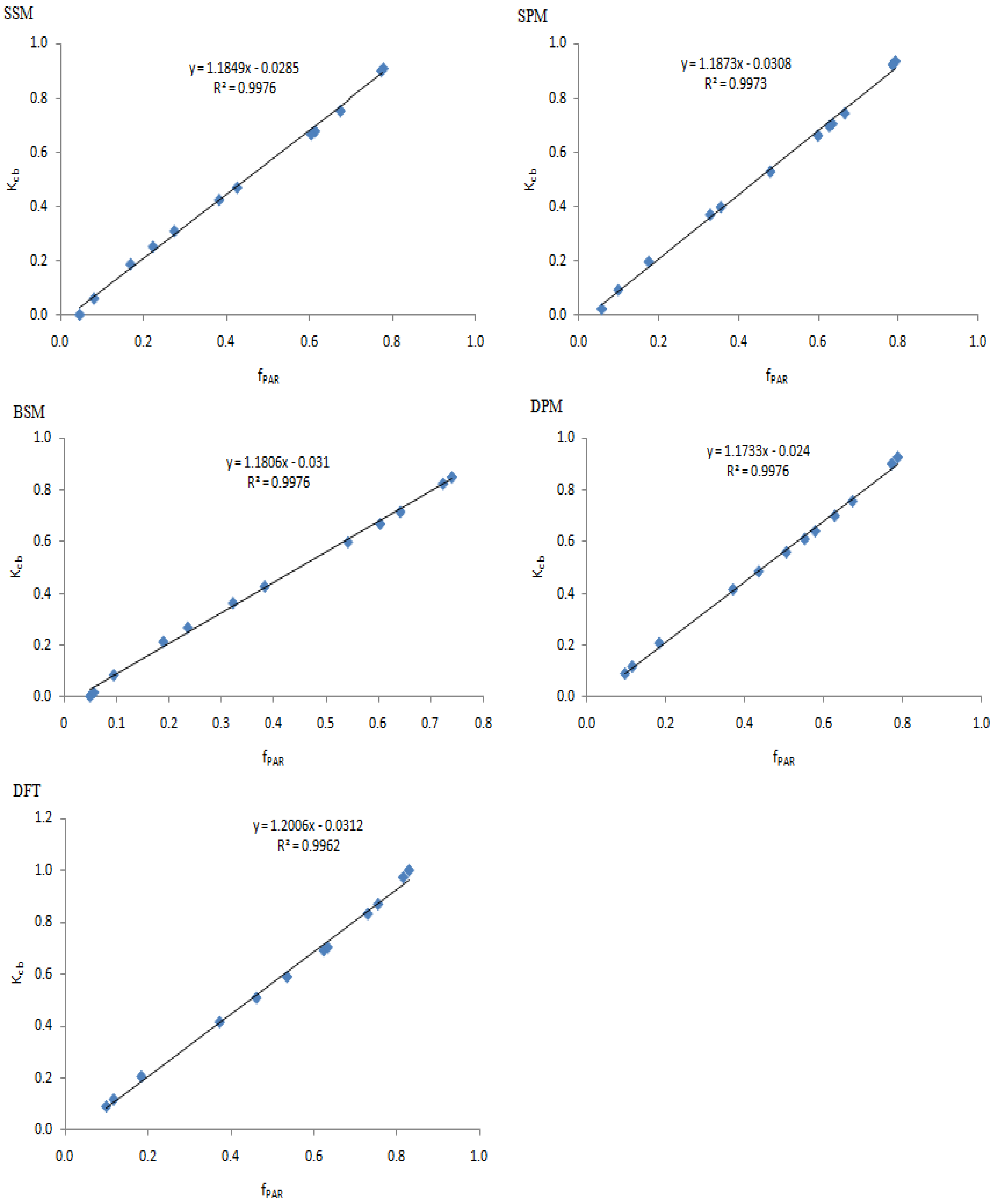

Fig C2 Relationship between f_{PAR} and basal crop coefficient (K_{cb}) for the different treatments for the third experiment

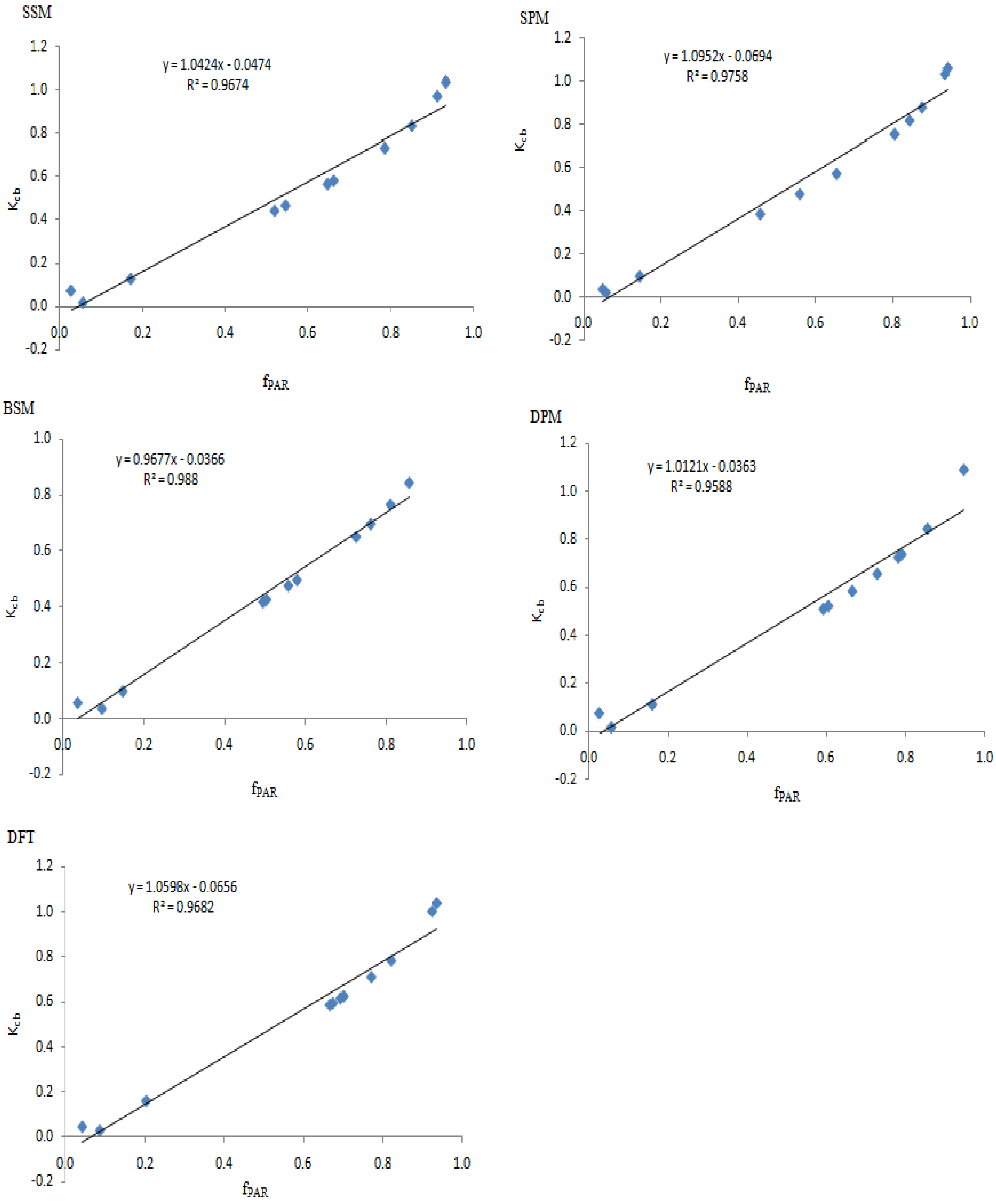

Fig C3 Relationship between f_{PAR} and basal crop coefficient (K_{cb}) for the different treatments for the fourth experiment

Appendix D

Analysis of variance tables (ANOVA) Tables

Table D1 Analysis of Variance (ANOVA) for fresh pod yield for first experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	7.820	2.607	1.21	0.044
Treatment	3	26.376	8.792	4.07	
Residual	9	19.421	2.158		
Total	15	53.618			
Lsd	2.4				

Table D2 Analysis of Variance (ANOVA) for dry matter yield for first experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.088	0.029	0.93	<0.001
Treatment	3	4.265	1.422	45.25	
Residual	9	0.283	0.031		
Total	15	4.636			
Lsd	0.28				

Table D3 Analysis of Variance (ANOVA) for fresh pod yield for second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	19.064	6.355	3.49	<0.001
Treatment	3	220.704	73.568	40.45	
Residual	9	16.368	1.819		
Total	15	256.136			
Lsd	2.16				

Table D4 Analysis of Variance (ANOVA) for dry matter yield for second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.147	0.049	0.13	0.022
Treatment	3	6.100	2.033	5.28	
Residual	9	3.465	0.385		
Total	15	9.712			
Lsd	0.99				

Table D5 Analysis of Variance (ANOVA) for fresh pod yield for third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	13.273	4.424	1.10	0.006
Treatment	4	100.474	25.119	6.23	
Residual	12	48.366	4.030		
Total	19	162.113			
Lsd	3.09				

Table D6 Analysis of Variance (ANOVA) for dry matter yield for third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.124	0.041	0.18	<0.001
Treatment	4	21.650	5.413	23.77	
Residual	12	2.733	0.228		
Total	5	24.507			
Lsd	0.74				

Table D7 Analysis of Variance (ANOVA) for fresh pod yield for fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	12.214	4.071	0.99	0.002
Treatment	4	136.629	34.157	8.32	
Residual	12	49.266	4.106		
Total	19	198.109			
Lsd	3.09				

Table D8 Analysis of Variance (ANOVA) for dry matter yield for fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.124	0.041	0.18	<0.001
Treatment	3	21.650	5.413	23.77	
Residual	9	2.733	0.228		
Total	19	24.507			
Lsd	0.74				

Table D9 Analysis of Variance (ANOVA) for WP_y for the first experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.185	0.062	0.50	<0.001
Treatment	3	14.107	4.702	38.31	
Residual	9	1.105	0.123		
Total	15	15.397			
Lsd	0.56				

Table D10 Analysis of Variance (ANOVA) for WP_{tbm} for the first experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.022	0.007	0.16	0.342
Treatment	3	0.170	0.057	1.27	
Residual	9	0.401	0.045		
Total	15	0.593			
Lsd	0.34				

Table D11 Analysis of Variance (ANOVA) for WP_y for the second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	2.155	0.718	3.43	0.005
Treatment	3	5.497	1.832	8.75	
Residual	9	1.885	0.209		
Total	15	9.537			
Lsd	0.73				

Table D12 Analysis of Variance (ANOVA) for WP_{tbm} for the second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.022	0.007	0.16	0.503
Treatment	3	0.114	0.038	0.85	
Residual	9	0.406	0.045		
Total	15	0.542			
Lsd	0.34				

Table D13 Analysis of Variance (ANOVA) for WP_y for the third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	1.554	0.518	1.42	<0.001
Treatment	4	37.989	9.497	26.06	
Residual	12	4.373	0.364		
Total	19	43.917			
Lsd	0.93				

Table D14 Analysis of Variance (ANOVA) for WP_{tbm} for the third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.033	0.011	0.45	<0.001
Treatment	3	4.944	1.236	51.26	
Residual	9	0.289	0.024		
Total	15	5.266			
Lsd	0.24				

Table D15 Analysis of Variance (ANOVA) for WP_y for the fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	1.865	0.622	1.42	<0.001
Treatment	4	71.298	17.824	40.84	
Residual	12	5.237	0.436		
Total	19	78.400			
Lsd	1.02				

Table D16 Analysis of Variance (ANOVA) for WP_{tbm} for the fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.120	0.040	1.41	<0.001
Treatment	3	5.561	1.390	49.00	
Residual	9	0.341	0.028		
Total	15	6.022			
Lsd	0.26				

Table D17Analysis of Variance (ANOVA) for IWP$_y$ for the first experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.09	0.031	0.39	<0.001
Treatment	3	18.059	6.020	75.31	
Residual	9	0.719	0.080		
Total	15	18.873			
Lsd	0.45				

Table D18 Analysis of Variance (ANOVA) for IWP$_{tbm}$ for the first experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.018	0.006	0.20	0.014
Treatment	3	0.567	0.189	6.19	
Residual	9	0.275	0.031		
Total	15	0.860			
Lsd	0.28				

Table D19Analysis of Variance (ANOVA) for IWP$_y$ for the second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	1.415	0.472	3.26	0.002
Treatment	3	5.020	1.673	11.56	
Residual	9	1.303	0.145		
Total	15	7.738			
Lsd	0.61				

Table D20 Analysis of Variance (ANOVA) for IWP$_{tbm}$ for the second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.018	0.006	0.19	0.028
Treatment	3	0.449	0.150	4.89	
Residual	9	0.275	0.031		
Total	15	0.742			
Lsd	0.28				

Table D21 Analysis of Variance (ANOVA) for IWP_y for the third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	2.078	0.693	4.16	<0.001
Treatment	4	83.147	20.787	124.95	
Residual	12	1.996	0.166		
Total	19	87.222			
Lsd	0.63				

Table D22 Analysis of Variance (ANOVA) for IWP_{tbm} for the third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.033	0.011	0.47	<0.001
Treatment	4	8.355	2.089	89.13	
Residual	12	0.281	0.023		
Total	19	8.669			
Lsd	0.24				

Table D23 Analysis of Variance (ANOVA) for IWP_y for the fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	1.729	0.576	2.04	<0.001
Treatment	4	137.026	34.256	121.00	
Residual	12	3.397	0.283		
Total	19	142.153			
Lsd	0.82				

Table D24 Analysis of Variance (ANOVA) for IWP_{tbm} for the fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.106	0.035	1.95	<0.001
Treatment	4	10.559	2.640	146.35	
Residual	12	0.216	0.018		
Total	19	10.881			
Lsd	0.21				

Table D25 Analysis of Variance (ANOVA) for PAR for the second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	5953.3	1984.4	7.010	<0.001
Treatment	3	46686.4	15562.1	55.01	
Residual	9	2546.0	282.9		
Total	15	55185.7			
Lsd	26.90				

Table D26 Analysis of Variance (ANOVA) for PAR for the third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	3162.3	1054.1	1.78	0.002
Treatment	4	19198.9	4799.7	8.10	
Residual	12	7111.5	592.6		
Total	19	29472.7			
Lsd	37.51				

Table D27 Analysis of Variance (ANOVA) for PAR for the fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	2286.8	762.3	2.28	0.005
Treatment	4	8622.0	2155.5	6.45	
Residual	12	4010.3	334.2		
Total	19	14919.1			
Lsd	28.16				

Table D28 Analysis of Variance (ANOVA) for RUE for the second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.026	0.009	0.33	0.999
Treatment	3	0.001	0.000	0.01	
Residual	9	0.238	0.026		
Total	15	0.265			
Lsd	0.26				

Table D29 Analysis of Variance (ANOVA) for RUE for the third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.019	0.006	0.27	0.003
Treatment	4	0.696	0.174	7.42	
Residual	12	0.281	0.023		
Total	19	0.204			
Lsd	0.24				

Table D30 Analysis of Variance (ANOVA) for RUE for the fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	0.043	0.014	0.92	0.028
Treatment	4	0.246	0.061	3.96	
Residual	12	0.186	0.016		
Total	19	0.475			
Lsd	0.19				

Table D31 Analysis of Variance (ANOVA) for nitrogen uptake for the first experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	37.95	12.65	0.37	0.016
Treatment	3	602.16	200.72	5.91	
Residual	9	305.85	33.98		
Total	15	945.96			
Lsd	9.33				

Table D32 Analysis of Variance (ANOVA) for NUE for the first experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	85.64	28.55	0.8	0.031
Treatment	3	496.58	165.53	4.66	
Residual	9	319.87	35.54		
Total	15	902.09			
Lsd	9.54				

Table D33 Analysis of Variance (ANOVA) for nitrogen uptake for the second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	39.8	13.3	0.11	0.010
Treatment	3	2658.4	886.1	7.03	
Residual	9	1133.9	126.0		
Total	15	3832.1			
Lsd	17.95				

Table D34 Analysis of Variance (ANOVA) for NUE for the second experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	50.3	16.8	0.11	0.010
Treatment	3	3356.2	1118.7	7.03	
Residual	9	1431.5	159.1		
Total	15	4837.9			
Lsd	20.17				

Table D35 Analysis of Variance (ANOVA) for nitrogen uptake for the third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	79.36	26.45	0.34	0.004
Treatment	4	2157.71	539.43	6.91	
Residual	12	936.20	78.02		
Total	19	3173.27			
Lsd	13.61				

Table D36 Analysis of Variance (ANOVA) for NUE for the third experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	103.57	34.52	0.35	0.001
Treatment	4	3623.00	905.75	9.26	
Residual	12	1173.21	97.77		
Total	19	4899.78			
Lsd	15.23				

Table D37 Analysis of Variance (ANOVA) for nitrogen uptake for the fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	983.00	327.7	2.2	0.001
Treatment	4	5553.00	1388.2	9.33	
Residual	12	1786.00	148.8		
Total	19	8322.00			
Lsd	18.80				

Table D38 Analysis of Variance (ANOVA) for NUE for the fourth experiment

Source of variation	Degress of Freedom	Sum of Squares	Mean Square	V.r	F Probality
Block	3	501.52	167.17	2.2	0.001
Treatment	4	2833.15	708.29	9.33	
Residual	12	911.24	75.94		
Total	19	4245.91			
Lsd	13.43				