Irrigation scheduling effects on components of water balance and performance of dry season fadama-grown pepper in an inland-valley ecosystem in a humid tropical environment

Running title: *Responses of pepper evapotranspiration to irrigation and capillary rise*

Abstract

This study examined the contribution of water table via capillary rise and irrigation, to soil moisture storage and water use of pepper (*Capsicum annuum* var.Tatase), grown in an inland valley swamp (flood plain) in the dry season in a humid zone of Nigeria.

The contribution of water table (capillary rise/upflows: Cg) to root zone moisture was quantified based on the soil water balance. Capillary rise was taken as the difference between estimated crop evapotranspiration (ETa) and measured soil water depletion (SWD). Irrigation regimes consisted of water application at weekly (7-day) and fortnight (14-day) interval using gravity-drip system. In the respective 7-day and 14-day irrigation intervals, shoot biomass were 153 and 141 g plant^{-1} while fruit yields were 8.6 and 7.9 t ha^{-1} which constituted about 8.2 % yield reductions were obtained under 14-day compared with 7-day irrigation. Capillary rise ranged from 2.3 to 5.2 mm which amount to 81 and 124 % of pepper evapotranspitaion (ETa) across the sampling periods. The results showed that the weekly and fortnight irrigation intervals produced seasonal ET were 109 and 83 mm, soil moisture contents of 201 and 164 mm within crop root zone and water use efficiencies of 0.14 and 0.19 t/ha/mm. Soil moisture storage and its depletion, Cg, crop evapotranspiration (ETa) and relative water use (ETa/Eo) differed in the growth stages of pepper, were influenced by irrigation regimes, groundwater table depth, and the prevailing weather conditions (vapour pressure deficit, temperature, thermal time) during pepper growth. Seasonal trends of the relative water use indicates the inability of soil moisture storage to satisfy pepper water requirements (ETa). Weekly irrigation offered the best compromise in the circumstance of declining water table depths and high climatic demand of the dry season in the site of study. Results show that irrigation regimes imposed optimized the contribution of groundwater to soil moisture storage and water use of pepper.

Keywords: *Capillary rise, water table, irrigation, evapotranspiration, relative water use, pepper.*

Introduction

Inland valley swamps (flood plains), are characterized by seasonal flooding at the peak of the rainy season, and shallow ground water table depths which enhance residual soil moisture regimes in the dry season via capillary rise (upflows). The floodplains are characterized by shallow but variable water table depths (Ogwu and Babalola, 2002, IWMI, 2002), the declining soil moisture storage *may call* for the use of irrigation (supplementary) for dry season farming in inland flood plains. In sub-Saharan Africa, inland wetlands (fadama schemes) constitutes about 135 million ha of land (IWMI, 2002), a veritable source of water for dry season crop production (mostly vegetables), is a common feature of the farming system of the tropics. However, the vast soil, water and agricultural potentials of inland floodplains have not be fully exploited (Ogwu and Babalola, 2002).

In soils underlain by shallow groundwater table, the presence of water table impacts land surface processes (soil, vegetation and climate) may be impacted either by capillary rise or direct root water uptake (York *et al.*, 2002; Yeh and Eltahir, 2005; Niu *et al*., 2007; Sun *et al*., 2010; McFadyen and Grieve, 2012). Under field conditions in agroecologies (soil and weather conditions), different results had been reported about the effects of groundwater depth on crop water use and satisfaction index and the ratio of actual (ETa) to potential (ETp) evapotranspiration (Liang *et al*., 2003; Chen and Hu, 2004; Fan *et al.*, 2007; Maxwell et al., 2007).

Unlike deep water table conditions, shallow water table maintains elevated soil moistures in crop root zone through capillary rise driven by soil matric potential gradients (Chen and Hu, 2004; McFadyen and Grieve, 2012). Capillary rise to root zone moisture and crop water use (evapotranspiration) are affected by many factors such as rainfall, irrigation, root water uptake, and soil evaporation (Yeh and Eltahir, 2005; Fan *et al*., 2007; Sun *et al*., 2010; McFadyen and Grieve, 2012). The contribution of water table to crop water requirement is assessed based on a number of approaches such as the computation of capillary upward flux from Darcy's Law using changes in water potential gradients (Van Bavel *et al*., 1968; Ragab and Amer, 1986). In approaches based on soil water balance, capillary upward flux is taken as the difference between estimated evapotranspiration and soil water depletion (Stuff and Dale, 1978; Wallender *et al*., 1979; Ragab and Amer, 1986).

Despite the realization that water table contribution to crop water requirement, knowledge on how best to incorporate capillary rise in irrigation scheduling is inadequate (Hurst *et al*, 2004; Sun *et al*., 2010; McFadyen and Grieve, 2012). Moreover, there is scanty information on the irrigation requirements of crops grown on inland floodplains characterized by shallow and variable water table depths. This study was designed to investigate the effects of water fluxes from shallow water table and irrigation regimes on soil water storage and pepper water use in an inland valley swampland (fadama) in a humid zone of Nigeria. Irrigation water was applied once weekly (7-day) and fortnightly (14-day) using drip system in order to optimize contribution of water tables via capillary rise (upflow) for enhanced soil water storage and uptake by pepper.

Materials and Methods

The effects of gravity-drip irrigation system and the contribution of water table to soil moisture storage, water use and fruit yield of pepper grown in the dry season in an inland flood plain (wetland) was examined in the dry season (January to May) of 2009 and 2010. The trials were conducted at the Teaching and Research Farm of the Federal University of Technology, Akure, in the humid rainforest zone of Nigeria. Table 1 presents the results of the laboratory analyses of some physical properties of soil at site of experiment.

Irrigation strategies

Four-weeks old seedlings of pepper, *Capsicum annuum* var. Shombo, raised in the nursery were transplanted into 20 by 10m field plot at 90 by 30 cm spacing in January, 2009. The field was drip-irrigated once per week and fortnight from transplanting to fruit harvest. Irrigation water was applied using the gravity-drip irrigation system which delivered water to plants via point source emitters of 2l/h discharge rate. The emitters were installed on laterals per row of crop and were spaced 90 cm apart. Irrigation buckets were suspended on 1.5 m stakes to provide the required hydraulic heads.

Tensiometers were placed in the soil at depths of 20 and 60 cm to measure hydraulic gradient from the irrigated plots. Prior to use, the tensiometers were saturated by pre-pressurizing with distilled water at high pressure, and were calibrated in the positive pressure range while the calibration curve in the negative pressures was extrapolated. All the calibration tests were performed under controlled laboratory conditions at constant pressure and temperature of 29 °C.

The tensiometers were installed in the field bored by pushing a PVC tube into in auger-drilled holes equipped with metallic leading edge, in the soil.

Soil moisture storage and its depletion

Soil moisture depletion (SWD) was obtained from the differences in soil moisture contents measured between two measurement period. Soil moisture contents were determined weekly at incremental depths of 20 cm taken with augers and core samplers and measured by gravimetric method (oven-dried moist soil samples at 105 ^{o}C for 24 hours). Ten samples were collected from each soil layer.

Data on the changes in ground water table depths of the site of study were obtained from the Benin-Owena River Basin Development Authority (BORBDA), Akure, Nigeria. BORBDA takes records of water table depths from observation wells and Piezometers and via the use of the FAO method which calculates potential capillary rise from ground water table below the root zone according to the graphical relationships (Doorenbos and Pruitt, 1975; Sepaskhah *et al.*, 2003). Observation wells were made with a porous casing (constructed with a 10 cm diameter PVC pipe, buried vertically in the ground which permits the groundwater level to rise and fall inside it as the water level in the adjacent soils. The observation wells were installed with a simple float indicator which provides rapid evaluation of shallow water table depths. The float indicator assembly was lowered into the well. The float indicator moves with the water table thus allowing above ground indication of the water level.

Pepper growth and fruit yield

Data were collected on pattern of soil moisture storage and depletion, and agronomic parameters of root and shoot biomass, leaf area and fruit yield characters of pepper. The dry weights of root and shoot biomass were obtained from their respective fresh weights oven-dried at 80 ^{o}C for 48

h. The effective root zone depth was estimated by excavating the root system (Agele *et al.*, 2002). Plant leaf area was measured at 50% flowering date using a leaf area meter (Delta T, UK). Pepper fruits were harvested weekly from ten plants sampled per plot starting from physiological maturity. Harvested fruits per plant were counted and summed over all fruit harvests in order to arrive t the total fruit yield per plant

Water table contribution to soil moisture storage and crop water use (evapotranspiration)

In estimating ground water table contribution was estimated via capillary rise (upflow) to soil moisture storage, direct estimates can be made by measuring soil water potential and interpreting an effective unsaturated conductivity between the measurement points using the steady state analysis of Gardner (1958) and Talsma (1963). Estimates of upflows are also derivable as the error term of the soil water balance after other components (total evaporation, rainfall, irrigation, soil storage change, and drainage) are measured or estimated.

Quantifying capillary upward flux from soil water balance

Capillary rise (upflow) from water table to the soil surface can be estimated using the Darcy's Law:

$$Q = k\left(\frac{d\text{Ü}}{dz} - 1\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where Q is the capillary rise (cm/day), k is the hydraulic conductivity (mm/day), $d\text{Ü}$ is the soil matric suction (cm), and z is the distance from soil surface to the bottom of the root zone.

Solving equation 1 for z:

$$\int dz = \int \frac{K}{K+Q} = dw \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots2$$

Water table contribution to root zone soil moisture can also be estimated based on the soil water balance in which capillary rise is taken as the difference between crop evapotranspiration (ET) and soil water depletion (SWD). Thus, using the water balance equation, the individual components which govern the net soil water changes (ΔS) in the crop root zone can therefore be obtained:

$$P = \Delta S - ET + L - Rs + W - Dp \ldots\ldots\ldots\ldots\ldots\ldots..3$$

where P is precipitation, ET actual evapotranspiration, L lateral inflow, Rs lateral outflow, W is capillary rise from the water table, and Dp deep percolation and ΔS is changes in soil moisture storage.

For soils under the influence of shallow water tables, equation 3 can be rewritten in the form:

$$ET = P + I + Cg - Dp - Rs - \Delta S\ldots\ldots\ldots\ldots4$$

where ET crop evapotranspiration, P is precipitation, I is irrigation water applied, Dp is deep percolation, Rs is surface runoff, Cg is water table contribution and ΔS is changes in soil water storage.

During pepper growth in the dry season, P, Dp, and Rs components of the water balance equation in Equation 4 were assumed zero except for periods when irrigation occurred. This means that there are periods when P, Dp and Rs are zero between irrigation. During the rainless dry months and for soils under the influence of shallow water tables, equations 3 and 4 were simplified to account for crop evapotranspiration in the form:

$$ET = Cg - \Delta S\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots5$$

Solving equation 5 for Cg:

$Cg = -\Delta S - ET$……………………………..……6

Actual evapotranspiration (ETa) was calculated by means of a water balance equation as:

$SW1 + P + Ir = Rs + Dp - ETa + SW2$…………7

where Sw_1 and Sw_2 are initial and final moisture contents of soil profile, P is precipitation received, Ir is irrigation water applied, ETa is actual evapotranspiration, Rs is surface runoff and Dp, was assumed capillary rise from water table to crop root zone. Both P and Rs are assumed negligible. Equations 6 and 7 were therefore employed in the calculation of capillary rise from water table to crop root zone. Actual evapotranspiration (ETa) was obtained by direct measurement as the error term in the water balance equation (Equations 3 and 4). Estimate the groundwater contributions to ET was obtained from the calculated actual ET using the real Kc based on the canopy size and soil moisture conditions.

Potential evapotranpiration (ETp) was estimated using the FAO method (Doorenbos and Pruitt, 1975; Allen *et al*., 1998) in the form:

$ETp = KcETo$…………………….8

where ETo is reference evapotranspiration and kc is the crop coefficient (Doorenbos and Pruitt, 1975; Allen *et al*., 1998). Potential ET for the crop was calculated using the reference ET (ETo) multiplied by crop coefficient, Kc corrected with the soil moisture conditions. Crop coefficient (Kc) for pepper in the tropics: initial (0.3), rapid development phase (0.6), mid season/peak vegetative growth (1.15), maturity (0.8) were obtained from Allen *et al*. (1998). The reference evapotranspiration (ETo) values for the months of December - April were computed.

Data for computing reference evapotranspiration (ETo) was computed by the Penman-Monteith combination equation (Doorenbos and Pruitt, 1977; Allen *et al*., 1998) using data obtained from the agrometeorological station of the University.

The second year experiment which followed the procedures and treatments as in 2009 experiment, were sown on January 2010. The results for the two years experiments were separately analyzed, and were not significantly different from one year to the other. Therefore, data collected o for the two-years of study were averaged and means of the two year (2009 and 2010) field experiments are presented in Tables and Figures in the text.

Results

Weather condition of the study site

The trends in weather conditions at site of study is presented in Fig.1. November marks the unset of the dry season which span December of a year to April of another. The period of experiment (January to early May) falls within the dry season, low amount of rainfall (79 mm) was received from transplanting to fruit filling (1 - 10 weeks after transplanting;WAT), average minimum and maximum temperatures during period of experiment were 21 and 29 ^{o}C with high air vapour pressure deficits.

Pepper growth and yield.

Irrigation regimes produced differences in growth and yield characters of pepper (Table 2a). For weekly irrigation, values of roots and shoot dry weights and leaf areas were higher and the onset of flowering was delayed and this appeared to have translated to fruiting advantages under this treatment. Higher efficiency of water use for fruit production was obtained for pepper plants that were irrigated weekly in addition to higher. The growth and yield characters of irrigated and un-irrigated pepper are presented in Table 2b. The effect of irrigation was pronounced on root and shoot biomass, leaf area, growth duration, fruit yield, harvest index and the efficiency of water use of pepper. Consistently, values of these parameters were significantly lower for un-irrigated pepper over the irrigated crop.

Components of soil water balance and crop water deficits.

The time course in water table depths at various sampling points at the site of study (an inland swamp/flood plain) is shown in Fig.1. Capillary rise was high between January to mid February which coincides with establishment and development stages of pepper (when cop root zone depth was under the influence of the upper threshold of water table depth). The pattern of soil water suction sampled at 20 and 60 cm soil depth during pepper growth are presented in Fig.2a and b. Soil moisture tension ranged from -2 to -10 and -9 to -2 bars -5 to -3 and -11 to –7 bars at transplanting to establishment/mid season (15 and 45 DOY: 1 to 6 WAT) and -3 to -13 and -17 to -9 bars at mid season (45 DOY: 6 WAT). In general, soil water suction ranged between -7 to -13 and -3 to –9 bar at the surface (0 – 20 cm) and subsoil depths (20 – 60 cm) respectively.

Capillary rise from water table (Cg) was taken as the difference between the crop evapotranspiration (ETa) and soil water depletion (SWD) (Equation 5 and 6). Using these equations, the estimated capillary rise (Cg) from 2 weeks after transplanting (WAT) to termination of experiment (16 WAT) for each irrigation interval (weekly and fortnight intervals), were summed up to determine Cg for each sampling period (Table 2). The estimated capillary upflow from a water table, as a percentage of total water use by (Cg/ETa) values differed for the different growth stages of pepper as a function of soil moisture contents and atmospheric factors (Tables 3 and 4). The results show that Cg/ETa is affected by the water table depth and atmospheric conditions and the irrigation regimes. For the irrigation treatments, the estimated water table contribution via capillary rise to crop evapotarnspiration (ETa) varied during pepper growth according to the soil water balance which amount to 43 to 88 % of pepper ET (Table 3). Although, trends in irrigation regimes were similar: as frequency of irrigation increased from fortnightly to weekly irrigation intervals, values of Cg varied from 0.66 and 1.24 to 0.63 and 1.23 and respectively which translated to 65 and 124 % of crop evapotranspiration. About 8.2 % yield reductions were obtained under fortnight compared with weekly irrigation this translated to 24 % water savings (reduced water use). The results showed that actual evapotranspiration was higher in the various growth stages of pepper (Fig. 3), which amounted to seasonal ETa of 109 and 83 mm and soil moisture storage of 201 and 164 mm within crop root zone for the respective weekly and fortnightly irrigations (Table 3).

The ratio of seasonal actual to potential evapotranspiration (ETa/ETp) and the relative water use (ETa/Eo) which varied during pepper growth, were used as indices crop water deficits. The values of ETa/ETp ranged from 0.7 to 1.1 during pepper establishment/mid season and at reproductive growth phases and maximum values which were 0.61 to 1.8 for weekly and fortnight irrigation treatments (Table 2). The relative water use is defined as the ratio of actual evapotranspiration (ETa) to open water evaporation (Eo), this parameter is dependent on soil moisture status. The range of values of the relative water use were similar between establishment (4.3 &5.2) and at reproductive growth phases (4.1 & 4.8) for the respective weekly and fortnight irrigation intervals. Seasonal ratios of ETa/Eo which ranged from 0.77 to 0.80 were reported for rainfed tomato in south western Nigeria (Agele et al., 2002; Agele et al., 2011).

The temporal pattern of water fluxes from the ground water table via capillary rise (upflow: Cg), soil moisture storage and its depletion, pepper evapotranspiration (ETa) and relative water use (ETa/Eo) were related with the prevailing weather conditions (evaporative demand, thermal time accumulation,) under the weekly and fortnight irrigation regime (Fig. 4). The ETa/ETp ratio, soil moisture depletion (SWD) and relative water use closely associated with thermal time requirement (TT^{o}Cd) and R^2 values obtained ranged from 0.5 to 0.9 (Fig. 4). In particular, maximum temperatures were more closely associated with relative water use (R^{2} : 0.9) (Fig. 4). The high temperatures and evaporative demand during pepper growth in the dry season affected its water use (evapotranspiration). However, the contribution from the ground water table via upflows was not adequate in meeting pepper water requirement of the growing environmental conditions of the dry season and hence the magnitude of relative water use obtained. The time dynamics of capillary upflow (Cg), Cg/ETa and relative water use as affected by irrigation frequency is presented in Fig. 5a and b. Weekly irrigation offered the best compromise in the circumstance of the declining contribution from the ground water table depths and high climatic demand of the dry season at the site of study.

Discussion

The root zone moisture and pepper and use (evapotranspiration) were affected by the irrigation regimes imposed and possibly the contribution of water table via capillary rise (upflow).
presence of variable ground water table depths. There were interactions among capillary fluxes of water from the water table, irrigation, soil moisture storage and pepper water use with the prevailing weather conditions (vpd, temperature, thermal time/heat accumulation) of the dry season during pepper growth.

Capillary upflow (Cg) contributed about 60% to pepper water use (ETa) and the contribution decreased as water table depth declined (less than 0.7 m at planting (January) to a little over 1.5m at crop maturity (April/May). However, capillary rise was not able to fully satisfy pepper evapotranspiration possibly due to inadequate root densities to enhance access to water from the per fringe of the water table. The estimated capillary upflow from the ground water table as a percentage of total water use (Cg/ETa) differed during the growth stages of pepper and were affected by water table depth, irrigation regimes, soil moisture contents and prevailing weather conditions. As frequency of irrigation increased from fortnightly to weekly irrigation intervals, Cg values ranged from 0.66 - 1.24 to 0.63 - 1.23 which averagely amounts to 65 and 124 % of crop evapotranspiration. Increasing the frequency of irrigation from fortnight to weekly intervals improves root zone soil water storage, but the effects of this on capillary contribution to crop ET was not profound. As the water table deepens and water content in the upper layers declines, so water table contribution to the crop evapotranspiration (Cg/ETa) declines. The decline in Cg may possibly be due to deepening of the depth to water table in addition to increases in soil water evaporation, temperatures and climatic/ evaporative demand. Kruse *et al*. (1993) reported that the proportions of daily Cg to daily ET were different for different periods within the year and were affected by fluctuations in water table depths. Changes in Cg/ETa ratios with declining ground water table depths means declining contribution of water table to crop evapotranspiration (ETa).

As the water table depth deepens and the upper surface of the soil dries out so its contribution to crop root zone moisture and crop water use declined. Our results were consistent with those of Ragab and Amer (1986) and Ayars *et al*. (2006). Yang *et al*. (2007) among other studies confirmed the variations of contribution of capillary rise to soil water storage as function of ground water table depths. High capillary rise is obtainable when water table depth is within the upper threshold of capillary rise during which crop evapotranspiration may be sourced entirely from water table (Beverly *et al*., 1999). Conversely, during mid season to fruiting and fruit harvest (Mid February to April) of pepper, capillary rise from the water table becomes negligible (the lower threshold of water table depth): (Beverly *et al.,* 1999). In this situation, large fraction of crop evapotranspiration would come from water storage in the unsaturated zone (Beverly *et al.,* 1999). Inverse relationships had been found between capillary rise and depth-to-groundwater table (Kollet and Maxwell, 2008). Crop evapotranspiration is strongly influenced by changes in water table depth. Yang *et al*. (2007) observed water movement upward and downward from the water table using trends of water potential in the soil profile.

The magnitude of relative water use indicates the inability of soil moisture storage (replenishment trends by irrigation and capillary upflow from the ground water table) to satisfy pepper water requirements (ETa). Sepaskhah *et al*. (2003) attributed time-course changes in ETa/ETo ratio to the influence of water table and irrigation. Although, capillary flux enhanced soil moisture storage in the unsaturated layer (crop root zone) above the ground water table, the magnitude of crop evapotranspiration (ETa), Cg/ETa ratio and relative water use indicate that upflows from water tables was not adequate to satisfy pepper evapotranspiration and that pepper appeared not to be adequately adapted to a drying soil profile even in the presence of unsaturated fringe within 1m GWT depth. Thorburn et al. (1995) observed that root growth (biomass and root length densities) increased with declining capillary upward flux above ground water table. The authors concluded from their conductance simulation models of root, soil and water, that water should have been readily available from the near saturated conditions above the water table given the magnitudes of root length densities. Pepper has a well adapted dicotyledonus root system with small axial resistance, this attribute would have enhanced soil moisture extraction within crop rootzone depths (from the near saturated conditions above the water table). An exclusive reliance on upflows from water tables will subject pepper crop to soil moisture deficit stress. Since upflows from water table was not adequate to meet pepper water requirement, irrigation is required in addition in order to recharge soil moisture in crop rootzone. This observation is interpreted to mean that despite the presence of a shallow water table in the profile (unsaturated fringe within crop root zone), water was extracted preferentially from soil storage presumably from the irrigation enhanced soil moisture replenishment within crop root zone) and not necessarily the supplies from the ground water table via upflows. Numerous studies have demonstrated the importance of incorporating capillary flux from ground water tables into irrigation scheduling strategies in soils affected by variable but shallow ground water table depths such as inland valley swamps of the humid tropics.

The temporal pattern of water fluxes from the ground water table via capillary rise (upflow: Cg), soil moisture storage and its depletion, pepper water use (ETa) and relative water use closely associated with thermal time requirement (TT^{o}Cd) with medium to high regression coefficients (R^2) and maximum temperatures and were closely associated with ETa/Eo (R^{2} : 0.9) in particular (Fig. 4). The high temperatures and evaporative demand during pepper growth in the dry season affected its water use (evapotranspiration). There were strong influences of irrigation frequency on the time dynamics of capillary upflow (Cg), Cg/ETa (crop evapotranspiration) and crop water stress index. The equations generated from the regression analysis of Cg/ETa, ETa/ETp and soil moisture storage and ground water contribution (Cg) are possible indicators of stress tolerance and ability of the tested crop to effectively use soil moisture as fed by ground water contribution and irrigation.

Conclusion

The changes in root zone soil moisture storage and crop evapotranspiration for pepper grown in the dry season in an inland swamp (fadama) affected by irrigation scheduling in the presence of ground water table were examined in a humid tropical zone of Nigeria. Irrigation regimes and capillary upflow affected soil moisture storage and pepper water use (ETa). Capillary flux contributed to replenishment of root zone soil moisture following depletion by soil evaporation and pepper water use (ETa) from the unsaturated root zone layer above the ground water table. Water table contribution (capillary flux) was taken as the difference between estimated evapotranspiration (ET) and measured soil water depletion. Capillary upflow (Cg) ranged from 0.03 to 0.50 which is 60 % on the average, of pepper water use (ETa) over the sampling period decreased as water table depth declined. There were interactions among capillary fluxes of water from the water table, irrigation, soil moisture storage and pepper water use with the prevailing weather conditions (vpd, temperature, thermal time/heat accumulation). Capillary flux from ground water tables should be incorporated into irrigation scheduling strategies for soils under the influence of water table such as inland valley swamps. It is concluded that in the presence of shallow water tables, irrigation management should be modified to optimize the contribution from water table to rootzone moisture storage and crop evapotranspiration.

References

Agele, S.O., Olufayo, A & Iremiren, G.O. (2002). Effects of season of sowing on water use and yield of tomato in the humid south of Nigeria. *African Crop Science Journal* 10 (3), 231-237.

Agele, S.O., Iremiren, G.O. & Ojeniyi, S.O. 2011. Evapotranspiration, wáter use efficiency and yield of rainfed and irrigated tomato in the dry seaosn in a humid rainforest zone of Nigeria. *International Journal of Biology & Agricultural Sciences* 13, 469-476.

Ahmad M.D., Bastiaanssen, W.G.M & Feddes, R. 2002. Sustainable use of ground water for irrigation: a numerical analysis of the subsoil water fluxes. *ICID Journal of Irrigation and Drainage* 51(43) 227-241.

Allen, R.G., Pereira, L.S., Raes, D & Smith, M. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56 Food and Agriculture Organization of the United Nations Rome, 1998

Ayars, J.E.,Christen, E.W. Soppe, R.W.O & Meyer, M.S. 2006. Resource potential of shallow groundwater for crop water use-A review. *Irrigation Science* 24: 147 -160.

Beverly, C.R. Nathan, R.J., Malafant, K.W.J. & Fordham, D.P. 1999. Development of a simplified unsaturated module for providing recharge estimates to saturated groundwater models. *Hydrological Processes* 13:653–675.

Brolsma, R. J. & Bierkens, M. F. P. 2007 Groundwater-soil water-vegetation dynamics in a temperate forest ecosystem along a slope. *Water Resources Research* 43, W01414,

Chen, X. & Hu, Q. 2004 Groundwater influences on soil moisture and surface evaporation. *Journal of Hydrology* 297, 285–300.

Chow, F. K. Weigel, A. P. Street, R. L. Rotach, M. W. & Xue, M. 2006. High resolution large-eddy simulations of flow in a steep Alpine valley. Part I: methodology, verification, and sensitivity studies. *Journal of Applied Meteorology and Climatology* 45, 63–86.

Doorenbos, J. & Pruitt, W. O. 1975. Crop water requirements. *Irrigation and Drainage Paper No. 24.* FAO, Rome, Italy. 149 p.

Fan, Y. Miguez-Macho, G. Weaver, C. P. Walko, R. & Robock, A.2007 Incorporating water table dynamics in climate modeling: 1. Water table observations and equilibrium water table 30 simulations. *Journal of Geophysical Research* 112, D10125.

Gardner, W. R. 1958. Some steady state solutions of the unsaturated moisture flow equation with application to evaporation from a water table. *Soil Science* 85, 244–249.

Hurst, C.A. Thorburn, P.J. Lockington, D. & Bristow, K.L. 2004 Sugarcane water use from shallow water tables: implications for improving irrigation water use efficiency. *Agricultural Water Management* 65,1-19.

International Water management Institute (IWMI) (2002). Annual Reports, IWMI Thailand. 135pp.

Kollet, S. J. & Maxwell, R. M. 2008. Capturing the influence of groundwater dynamics on land surface processes using an integrated, distributed watershed model. *Water Resources Research* 44, W02402.

Kruse, E.G. Young, D.A. & Champion, D.F. 1993. Effect of saline water table on corn irrigation In: *Development and management aspects of irrigation and drainage systems* (Keyes, C.G. Ward, T.J. eds.). ASCE Specialty Conference. New York. Pp 444 – 453.

Liang, X., Xie, Z., & Huang, M. 2003. A new parameterization for surface and groundwater interactions and its impact on water budgets with the variable infiltration capacity (VIC) land surface model. *Journal of Geophysical Research* 108(D16), 8613.

Maxwell, R. M., Chow, F. K., & Kollet, S. J. 2007. The groundwater-land-surface-atmosphere connection: Soil moisture effects on the atmospheric boundary layer in fully-coupled simulations. *Advances in Water Resources* 30, 2447–2466.

McFadyen, L & Grieve, A.M. 2012. Effects of irrigation management and watertable depth on growth and yield of field-grown Sultana grapevines in south eastern Australia. Agric Water Manage.11, Pages 20-26

Niu, G.-Y., Yang, Z.-L., Dickinson, R. E., Gulden, L. E. & Su, H. 2007. Development of a simple groundwater model for use in climate models and evaluation with Gravity Recovery and Climate Experiment data. J. Geophys. Res., 112, D07103, doi:10.1029/2006JD007522, 2007

Ogwu, L. & Babalola, A. (2002). Effects of seedbed type and mulching on the performance of early season yam grown in inland valley bottom in south western Nigeria. Agricultural Water Management 54, 25-34

Ragab, R.A. & Amer, F. 1986. Estimating Water Table Contribution to the Water Supply of Maize. *Agricultural Water Management* 11 (1986) 221-230 221

Sepaskhah , A.R., Kanooni, A. & Ghasemi, M.M. 2003. Estimating water table contributions to corn and sorghum water use. *Agricultural Water Management* 58(1), 67-79.

Sezen, A.M., Yazar, A & Eker, S. 2006. Effect of irrigation regimes on yield and quality of field grown bell pepper. *Agricultural Water Management* 81(1-2)115-131.

Sun, H., Shen, Y., Yu, Q., Flerchinger, G.N., Zhang, Y., Liu, C. & Zhang, X. 2010. Effect of precipitation change on water balance and WUE of the winter wheat–summer maize rotation in the North China Plain. *Agricultural Water Management* 97(8), 117-1125

Stuff, R.G. & Dale, R.F. 1978. A soil moisture budget model accounting for water table influence. *Soil Science Society of America Journal* 65, 292-495.

Talsma. T. 1963. The control of saline groundwater. Meded Landouwhogeschool, Wageningen 63(10):1–68

Thorburn, P.J. Walker, G.R. & Jolly, I.D. 1995. Uptake of saline groundwater by plants: an analytical model for semi-arid and arid areas. *Plant Soil* 175:1–11

Van Bavel, C.H.M., Stark, B.G. & Brust, K.J. 1968. Hydraulic properties of a clay loam soil and the field measurements of water uptake by the roots. 1. Interpretation of water content and pressure profile. *Soil Science Society of America Proceeding* 32, 310-317.

Yang, S. Wei, D. & Guangxin, Z. 2007. Water fluxes at a fluctuating water table and groundwater contributions to wheat water use in the lower Yellow River flood plain, China. *Hydrological Processes*. 21, 717–724

Yeh, P. J.-F. & Eltahir, E. A. B. 2005. Representation of water table dynamics in a land surface scheme, part I: Model development. *Journal of Climatology* 18, 1861–1880.

York, J. P., Person, M., Gutowski, W. J. & Winter, T. C. 2002. Putting aquifers into atmospheric simulation models: an example from Mill Creek Watershed, Northeastern Kansas. *Advances in Water Resources* 25, 221–238.

Table 1. Physical and chemical properties of soil at site of experiment

Soil properties	
Sand (%)	40.9
Silt (%)	30.8
Clay (%)	28.3
Textural class	Sandy clay loam
Bulk density (g.cm^{-3})	1.24
Porosity (%)	51
Infiltration rate (mm.s^{-1})	3.18
Saturation (%)	40.1
Field capacity moisture (%)	27.9
1500 KPa moisture (%)	17.2
Water holding capacity (%)	21
Organic matter content ((mg g^{-1})	4.23

Table 2a. Effects of irrigation regimes on the growth and yield characters of pepper*.

Irrigation regimes	Root length (cm)	Root dry weight ($g.plant^{-1}$)	Shoot dry weight ($g\ plant^{-1}$)	Leaf area (cm^2)	50% flowering (days)	Fruit yield (t/ha)	Irrigation applied (mm)	Water use efficiency (t/ha/mm)	Harvest index
Weekly	17.8	67.5	153.2	6.4	72	8.6	59.88	0.14	0.54
Fortnightly	19.3	73.4	140.7	6.0	68	7.9	39.92	0.19	0.50
LSD (0.05)	3.4	4. 0	5.1	2.3	4.1	1.8	----	0.03	0.03

**Data presented in the Table are means of the two-year (January to May of 2009 and 2010) field experiments.*

Table 2b. Growth and yield parameters taken on rainfed and irrigated (dry season) pepper*.

Treatments	Root length (cm)	Root dry weight (g)	Shoot dry weight (g)	Leaf area (cm^2)	50% flowering (days)	Fruit y ield	Water use efficiency (t/ha)	Harvest index (t/ha/mm)
Irrigated	18.8	70.3	150.1	6.2	67	8.2	0.16	0.52
Non-Irrigated	21.2	82.7	128.4	5.4	61	6.3	0.21	0.48
LSD(0.05)	4.6	2.7	9.7	0.2	2.3	1.9	ns	0.13

**Data presented in the Table are means of the two-year (January to May of 2009 and 2010) field experiments.*

Table 3. Effects of irrigation regimes on water table contribution (Cg: estimated from the soil water balance), crop evapotranspiration and relative water use

DOY	Irrigation regimes	ETp	ETa (mm)	Relative water use (ETa/Eo)	SWD	Cg (mm)	Cg/ETa
05	Weekly	4.3	4.3	1.91	1.05	2.29	0.83
	Fortnightly		3.3	1.91	0.98	2.36	0.89
015	Weekly	4.7	3.7	1.90	0.94	2.95	0.88
	Fortnightly		5.2	1.92	0.90	2.58	0.83
030	Weekly	4.9	4.7	1.90	0.90	2.92	0.84
	Fortnightly		3.9	1.92	0.82	2.73	0.87
045	Weekly	5.1	5.5	1.86	0.84	2.89	0.85
	Fortnightly		3.1	1.88	0.73	2.80	0.88
060	Weekly	5.0	5.1	1.83	0.78	4.73	0.84
	Fortnightly		4.6	1.86	0.87	4.43	0.85
075	Weekly	5.3	6.5	1.80	0.72	5.16	0.79
	Fortnightly		4.7	1.83	0.62	5.13	0.85
090	Weekly	5.5	7.9	1.73	0.67	4.93	0.74
	Fortnightly		6.5	1.80	0.58	4.77	0.78
105	Weekly	5.2	9.1	1.70	0.63	5.03	0.69
	Fortnightly		7.8	1.77	0.53	4.95	0.73
120	Weekly	5.4	9	1.68	0.58	4.04	0.67
	Fortnightly		8.2	1.73	0.48	3.95	0.72
135	Weekly	5.3	9.3	1.63	0.55	3.96	0.69
	Fortnightly		7.7	1.70	0.39	3.72	0.75
150	Weekly	5.0	8.4	1.60	0.50	3.32	0.67
	Fortnightly		7.3	1.65	0.34	3.15	0.77
165	Weekly	5.3	8.3	1.56	0.48	3.69	0.70
	Fortnightly		6.4	1.61	0.30	3.33	0.79
180	Weekly	5.2	9.5	1.52	0.43	3.55	0.66
	Fortnightly		5.8	1.57	0.28	3.27	0.82

ETo is calculated from Penman-Monteith combination equation while ETa was obtained as As error term in the water balance equation. SWD: soil water depletion.
**Data presented in the Table are means of the two-year (January to May of 2009 and 2010 field experiments.*

Table 4. Seasonal sums of the components of soil water balance (swb): soil moisture storage, capillary rise (Cg) and actual evapotranspiration and relative water use

Growth phases	Irrigation regimes	ETp (mm) (Allen et al., 1998)	ETa (mm) (swb)	Cg (mm) (swb)	Soil moisture storage (mm)	Relative water use (ETa/Eo)
Establishment	***Weekly***	16.3	27.23	15.4	85.3	4.30
	Fortnight	19.6	26.0	17.7	82.8	5.20
Mid season (Onset of flowering)	***Weekly***	20.8	36.6	12.4	108.6	2.90
	Fortnight	39.0	32.6	17.1	103.5	3.10
Reproductive (Fruiting and fruit harvest)	***Weekly***	29.3	39.2	28.2	107.5	4.10
	Fortnight	58.9	27.6	54.7	77.6	4.80
Cumulative Total	***Weekly***	66.9	108.9	56.0	201.4	11.24
	Fortnight	106.8	82.8	89.2	163.7	12.17

Growth stages from planting to maturity: establishment (2-7weeks); mid season/flowering (7-12 weeks); fruiting/harvest (12-18 weeks)
**Data presented in the Table are means of the two-year (January to May of 2009 and 2010 field experiments.*

Caption to Figures

Fig. 1. Yearly trends in ground water table depths, rainfall and open water evaporation at the site of study

Fig.2a. Trends in soil water potential for irrigated and non-irrigated conditions @ DOY 15

Fig.2b. Trends in soil water potential for irrigated and non-irrigated conditions @ DOY 45

Fig. 3. Crop evapotranspiration calculated from soil water balance as affected by irrigation regimes during pepper growth.

Fig. 4. Relations of thermal time with Cg/ETa, ETa/ETo and ETa/Eo (relative water use) during pepper growth

Fig. 5a. Time trends in capillary upflux (Cg), Cg/ETa and relative water use (ETa/Eo) for weekly irrigation

Fig. 5b. Time trends in capillary upflux (Cg), Cg/ETa and relative water use (ETa/Eo) for fortnight irrigation

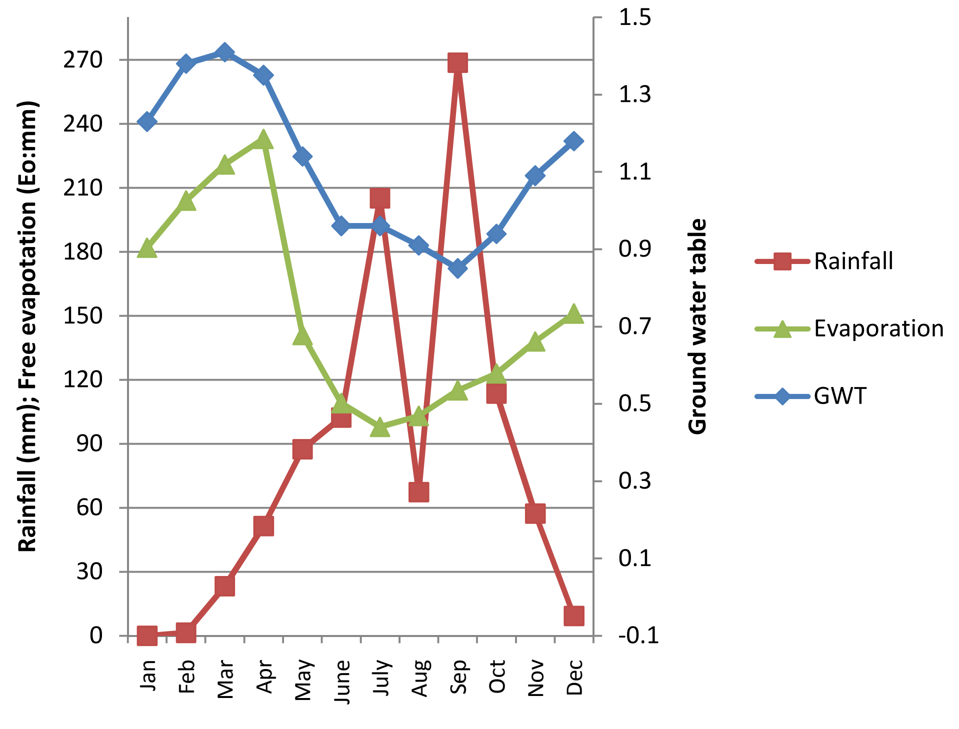

Fig. 1.Yearly trends of ground water table, rainfall and open water evaporation at site of study

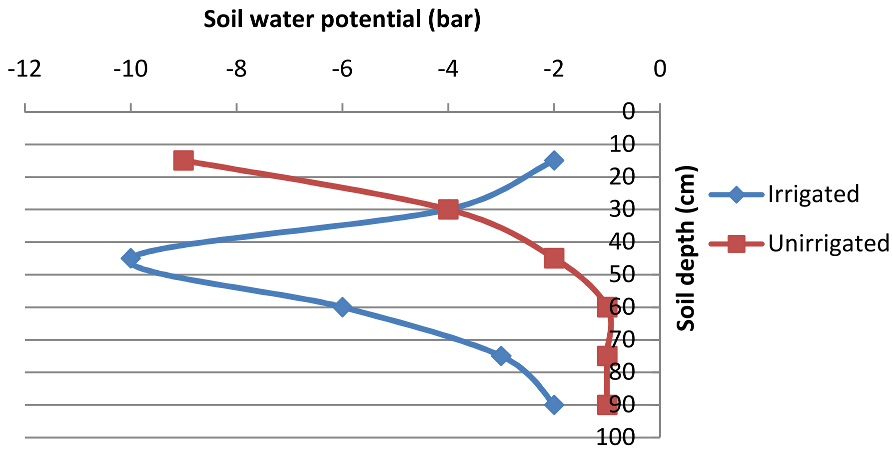

Fig. 2a. Trends in soil water potential for irigated and non irrigated soil conditions @ DOY 15

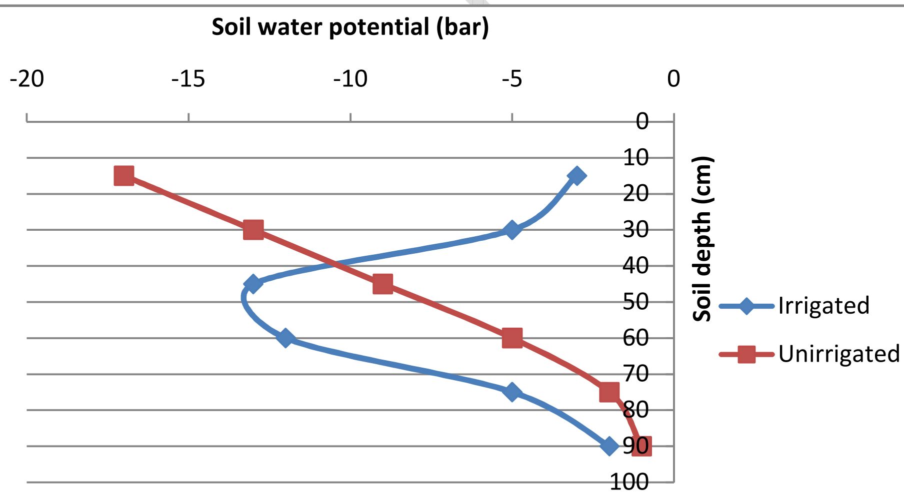

Fig. 2b. Trends in soil water potential for irigated and non irrigated soil conditions @ DOY 45

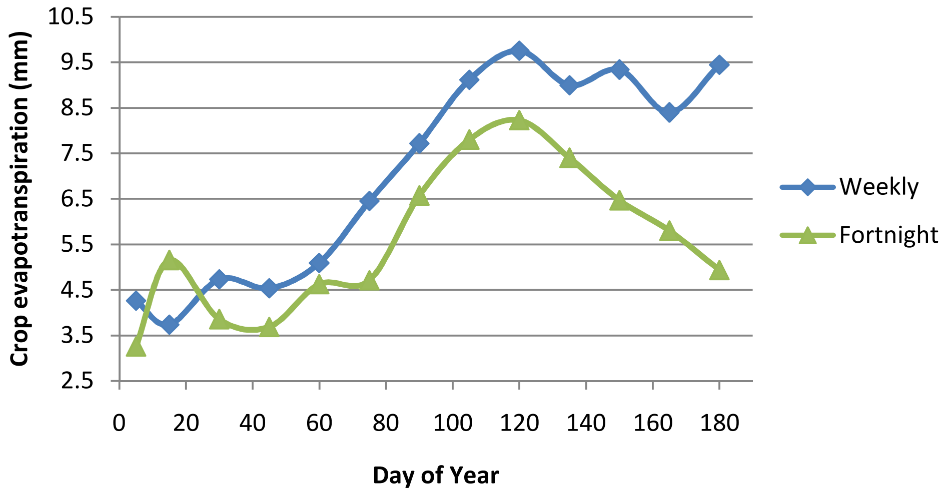

Fig. 3. Crop evapotranspiration (ETa) calculated from soil water balance as affected by irigation regimes during pepper growth

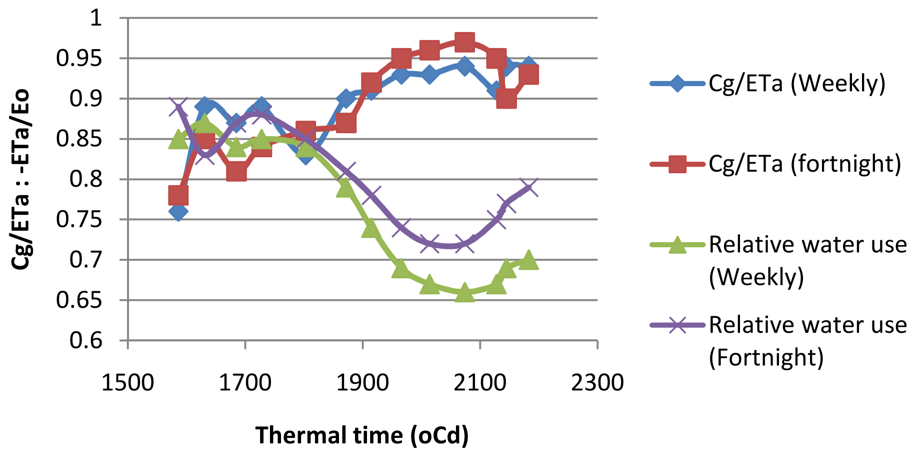

Fig. 4. Relations of thermal time with Cg/ETa and ETa/Eo

for weekly and fortnight irrigation

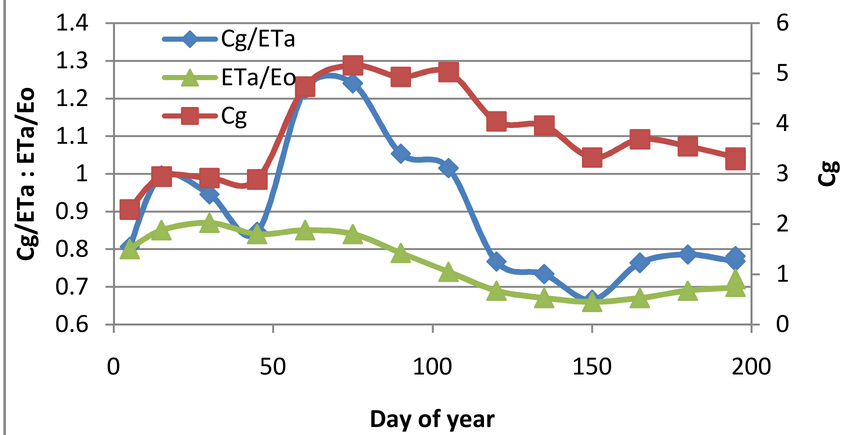

Fig. 5a. Trends in cappilary upflux (Cg) , Cg/ETc and ETa/Eo (Weekly irrigation)

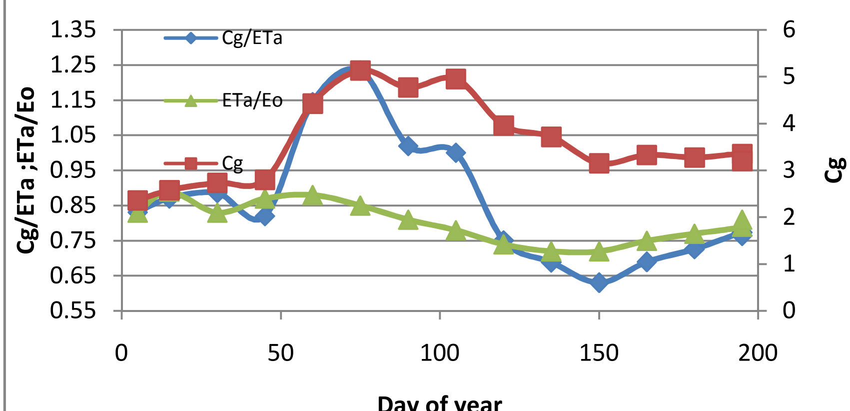

Fig. 5b. Trends in cappilary upflux (Cg) , Cg/ETc and ETa/Eo (fortnight irrigation)