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SHOOT WATER CONTENT AND REFERENCE EVAPOTRANSPIRATION FOR DETERMINATION OF CROP EVAPOTRANSPIRATION

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ABSTRACT

Determination of water requirement for crops in resource limited areas is challenging, yet worsened by the common assumption that all crop varieties within a species have similar water requirements. The objective of the study was to indirectly determine crop evapotranspiration of soybean varieties, using reference evapotranspiration and shoot water content under tillage and no tillage cultivation. The treatments were no tillage and conventional tillage as main plots, and soybean varieties Nyala, SB19, and SB20 as sub-plots, replicated three times. Crop evapotranspiration (ET_C) and crop coefficient (K_C) were different among varieties, and increased during growth period. SB20 had the highest K_C (0.8437 at 87 days after planting - DAP); followed by SB19 (0.7888 at 70 DAP), and Nyala (0.7026 at 66 DAP). Conversely,water use efficiency (WUE) was 0.58 in SB19, 0.52 in Nyala, and 0.47 in SB20.Validation of the calculated ET_C using a crop production function showed a correlation of r = 0.97 between the observed and predicted yields of the three varieties. Furthermore, the normalised root mean square error (NRMSE) and the index of agreement (d) were 0.14 and 0.87, respectively indicating accurate fit. Calculated crop coefficient strongly correlated with observed shoot water content of Nyala ($R^2 = 1$), SB19 ($R^2 = 1$), and SB20 ($R^2 = 1$).

Key Words: Crop coefficient, evaporation, *Glycine max*, shoot, soybean, transpiration

RÉSUMÉ

La détermination du besoin en eau de la plante dans des milieux à ressources limitées est un défi, encore aggravé par l'hypothèse commune qui stipule que toutes les variétés d'une espèce ont les mêmes besoins en eau. L'objectif de cette étude était de déterminer indirectement l'évapotranspiration de la culture des variétés de soja, en utilisant l'évapotranspiration de référence et la teneur en eau de la pousse sous labour et sans labour. Les traitements étaient sans labour et avec labour conventionnel comme parcelles principales, et les variétés de soja Nyala, SB19, et SB20 comme sous parcelles, répliquées trois fois. L'évapotranspiration des cultures (ET_c) et le coefficient de culture (K_c) étaient différents entre les variétés, et augmentaient durant la période de croissance. SB20 avait la valeur la plus élevée de K_c (0,8437 à 87 jours après plantation - DAP) ; suivie de SB19 (0,7888 à 70 DAP), et Nyala (0,7026 à 66 DAP). Inversement, l'efficience d'utilisation de l'eau (WUE) était 0,58 dans SB19, 0,52 dans Nyala, et 0,47 dans SB20. La validation de l'ET_c calculée en utilisant la fonction de production de la culture a montré une corrélation r= 0.97 entre les rendements observés et prédits des trois variétés. De plus, la racine des carrées moyens normalisés de l'erreur (NRMSE) et l'index d'accord (d) étaient 0,14 et 087, respectivement indiquant une concordance précise. La valeur calculée du coefficient de culture était fortement corrélée avec la valeur observée de la teneur en eau de la pousse de Nyala (R^2 = 1), SB19 (R^2 = 1), et SB20 (R^2= 1).

Mots Clés : Coefficient de culture, évapotranspiration, *Glycine max*, pousse, soja, transpiration

INTRODUCTION

Crop coefficient is an important determinant of crop evapotranspiration (Allen *et al*., 1998; Pereira *et al*., 2015); yet, crop evapotranspiration is fundamental in irrigation schedules under atmospheric conditions. Additionally, the amount and distribution of rainfall received in a region influences the irrigation scheduling. This is because the amount of rainfall influences soil water content. In situations where soil-based irrigation scheduling methods (Soulis *et al*., 2015; Valdés *et al*., 2015) are used, direct soil water measurement affects irrigation amount, while in the atmospheric-based methods, the soil water content affects evapotranspiration. Most regions in Sub-Saharan Africa are dependant on rainfall for successful crop production (Foeken, 1994; Herrero *et al*., 2010). However, these regions are increasingly experiencing erratic rainfall amounts and distribution (Kisaka *et al*., 2015; Ngetich *et al*., 2014; Thornton, 2010). This has led to mid-season drought (Kisaka *et al*., 2015; Ngetich *et al*., 2014), and thus the need to understand and manage water requirement of crops through evapotranspiration.

Soybean (*Glycine max* L. Merril), a crop whose production is being promoted in Sub-Saharan Africa (Chianu *et al*., 2009) is adversely affected by mid-season drought. This is due to the continuous erratic rainfall distribution and amount which mostly occur at the important stages of soybean growth; flowering, pod filling and seed filling stages (Mahasi *et al*., 2011; Daryanto *et al*., 2015; Omondi *et al*., 2015). Cover cropping, conservation tillage and mulching are some soil water management techniques (Wakindiki *et al*., 2007; Itabari *et al*., 2011) practised during mid-season drought. Moreover, the major strategy is sowing of drought tolerant and early maturing varieties of soybean (Mahasi *et al*., 2011). These varieties have different crop coefficients (Pereira *et al*., 2015), although, determination of crop coefficient for individual varieties is yet to be conducted, owing to the sensitivity, accuracy and, huge equipment investment required for such experiments (Irmak *et al*., 2013; Majidi *et al*., 2015; Ruiz-Peñalver *et al*., 2015). Therefore, more efficient, effective, but also low-cost procedures for determining crop coefficient of these varieties is required. This could be achieved by borrowing the ideas behind irrigation scheduling methodologies as they input the amount of water required by a plant.

Methods used in irrigation scheduling are evolving from atmospheric-based (Lamm and Rogers, 2015), to soil-based (Soulis *et al*., 2015; Valdés *et al*., 2015), and now plant-based (De la Rosa *et al*., 2015; Shi *et al*., 2015). However, it could be a combination of soil and atmospheric conditions (Paraskevopoulos and Singels, 2014) or the three methods involving soil-plant-atmosphere continuum. Plant based methods, if well monitored, have been commended as the best option (Fernández, 2014) as they measure the 'patient'. Such methods as daily maximum stem diameter shrinkage (De la Rosa *et al*., 2015), leaf water potential (Unlu *et al*., 2014), stem water potential (Gonzalez-Dugo *et al*., 2014) and sap flow (Hechmi *et al*., 2014; Zuniga and Poblete-echeverría, 2014) can measure the water status of the plant (Fernández, 2014). It has been shown that stem water potential, leaf water potential, and sap flow could be used to determine the amount of water applied through irrigation to a plant. This, therefore, implies that a methodology which measures water content of both stems and leaves (shoot water content) could be more precise than either through destructive sampling of the shoot in the determination of the water requirement of the plant is involved. From the crop evapotranspiration (ET_C) calculation (Pereira *et al*., 2015), the only difference in amount of irrigation water applied to species grown in the same agro-ecological zone, influenced by similar atmospheric conditions and soils is crop coefficient. Considering this, reference evapotranspiration is calculated using Penmann-Monteith equation and finally calculation of crop evapotranspiration. The objective of this study was to establish crop coefficients and evapotranspiration of different soybean varieties using shoot water content and reference evapotranspiration (ET_0).

MATERIALS AND METHODS

Reference evapotranspiration. Reference evapotranspiration was calculated using the Penmann-Moteith Equation (Allen *et al*., 1998):

$$ET_0 = \frac{0.408\Delta(R_n-G)+900/(T+273)\gamma U_2(e_s-e_a)}{\Delta+\gamma(1+0.34U_2)}$$

.... Equation 1

Where:

ET_o = reference evapotranspiration [mm day^{-1}], Rn = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature at 2 m height [°C], U_2= wind speed at 2 m height [ms^{-1}], e_s= saturation vapour pressure [kPa], $e_{a=}$ actual vapour pressure [kPa], e_s-e_a= saturation vapour pressure deficit [kPa], " = slope vapour pressure curve [kPa °C^{-1}], and ã = psychrometric constant [kPa °C^{-1}] usually about 0.067 kPa°C^{-1}.

Rn and G were calculated using Shuttleworth, (1992) equations; whileeffective depth of the roots for all the varieties was assumed as 1m.

$$G = C_S d_S \frac{T_2 + T_1}{\Delta t}$$ .... Equation 2

Where:

G is soil heat flux (MJm^{-2} day^{-1}), C_S is soil heat capacity (MJm^{-3}°C^{-1}), d_s = effective soil depth (m), T_2 is air temperature at the end of the period considered (°C), $T_1$is air temperature at the beginning of the period considered (°C), and "t is length of time interval (days).

$$R_n = (1 - \alpha)\left(0.25 + 0.5\frac{n}{N}\right)S_0 - \left(0.9\frac{n}{N} + 0.1\right)(0.34 - 0.14\sqrt{Ed})\sigma T^4$$

.... Equation 3

Where:

n is the bright sunshine hours per day (h), N = the total day length (h), S_0= the extra-terrestrial radiation (MJm^{-2}day^{-1}), Ed = the vapor pressure (kPa), σ = the Stefan-Boltzmann constant (4.903 × 10^{-9} MJm^{-2}K^{-4} day^{-1}), T= the air temperature (K), and α = the reflection coefficient.

$$e_s = 0.6108 exp\left[\frac{17.27T}{T + 237.3}\right]$$ ..... Equation 4

Where:

e_s saturation vapour pressure [kPa], and T the air temperature (°C).

$$e_a = e_s \frac{RH}{100}$$ ....Equation 5

Where:

e_a is the actual vapour pressure (kPa), e_s is the saturation vapour pressure (kPa), RH is relative humidity (%).

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

.... Equation 6

Where:

Δ is the slope of saturation vapour pressure curve at air temperature T (kPa °C^{-1}), T is air temperature (°C).

Crop coefficient. Shoot water content was assumed to be crop coefficient, as crop evapotranspiration is always determined under unlimited water supply (Pereira *et al.*, 2015), and hence the shoot water content reflects the soil water content and the ability of absorption by a variety. Additionally, crop evapotranspiration is important in irrigation scheduling and so is the shoot water content (Fernández, 2014). The shoot water content was measured five times during the crop growth period. According to FAO Penman-Monteith (Allen *et al.*, 1998), K_C is:

$$K_C = \frac{ET_C}{ET_0}$$ .... Equation 7

$$ET_C = K_C \times ET_0$$ .... Equation 8

Assuming K_C to be equivalent to shoot water content over a given period, then:

$ET_C = shoot\ water\ content\ X\ ET_0$ ....

.... Equation 9

Model validation using Crop Production function. Jensen (1968), reported a crop production function of:

$$WUE = \frac{Y}{ET}$$ .... Equation 10

From this function, Y is yield and ET is actual evapotranspiration/crop evapotranspiration.

$$WUE = \frac{Y}{shoot\ biomass}$$ .... Equation 11

Using Equation 11, predicted yield was calculated. To evaluate the model proposed for calculation of ETc from dry shoot biomass, the observed and predicted yield were analysed for best fit using the normalised root mean square error (NRMSE) and index of agreement (d) where NRMSE closer to 0 and d near 1 signify best fit (Shabani *et al.*, 2015). After proving that, ETc was calculated using dry shoot biomass, Kc is calculated usingEquation 8knowing that ET_0 is calculated from Equation 1 using the weather data.

Site description and experimental procedure. The experiment was conducted in Rarieda district, Siaya County (0Ú 08´ N, 34Ú 23´ E). This area lies in Agro-ecological Zone LM 4 (Lower midland cotton zone), receiving a mean annual rainfall of 1000 mm and mean temperature of 22 ^{O}C. The soils are well drained, very deep and dark red (classified as Orthicferalisols) (Jaetzold*et al.*, 2005).

The treatments were two tillage methods (conventional tillage and no tillage) tested with three soybean varieties (Nyala, SB19, and SB20). The conventional farmer tillage method was the control treatment compared with no tillage, which is a component of conservation cultivation that has minimum soil disturbance and conserves soil moisture (Franchini *et al.*, 2012). During the long rains of March to August, 2011 (LR2011) and short rains season of September to December, 2011 (SR2011), the treatments were randomised in a split-plot arrangement and replicated thrice. Randomised complete block design was used. No tillage and conventional tillage methods were the main plots; while soybean varieties were sub-plots. Conventional tillage mimicked farmer's practice of hand-hoe tilling at 20 cm depth, before the onset of rains; and no tillage was done using non-selective herbicide. The herbicide sprayed at 1.5 litres in 100 litres of water contained glyphosate as active ingredient.

The three soybean varieties were: Nyala, a local early maturing variety which nodulates with specific rhizobia and is susceptible to soybean rust. This variety was suitable for the study as it was popular among farmers in Western Kenya. The rest were two International Institute for Tropical Agriculture (IITA) bred varieties called, TGx1740-2F and TGx1448-2E, but locally known in Kenya as SB19 and SB20, respectively. These two varieties are promiscuous, and SB19 is medium maturing; while SB20 is late maturing (Tefera, 2011). The two varieties were new introductions in Western Kenya, and hence testing their performance against a local variety was prudent to encourage adoption.

Phosphorus was blanketly applied at 30 kg P ha^{-1} as Triple Super Phosphate (TSP); and potassium at 30 kg K ha^{-1} as Muriate of Potash (MOP) in furrows of 5 cm depth by 5 cm away from planting rows before planting. Seeds were treated with BIOFIX inoculants containing rhizobium strain USDA 110, using the slurry method of Somasegaran and Hoben (1994) at 10 g of BIOFIX for every 1 kg of seeds. The inoculated seeds were sown immediately after inoculation to ensure maximum survival of introduced rhizobial cells. No tillage plots were weeded by hand pulling of weeds; whereas hoes were used in conventional tillage plots at interval of two weeks.

Data collection and analysis. Standard cores (diameter of 5cm and height of 5 cm) were used to collect soil samples at depths of 10, 20 and 30 cm,for soil water content measurement at 50% full bloom (R2), pod filling (R3) and seed filling (R5). These are the important stages of soybean growth in soil moisture studies (Doss *et al.*, 1974). The samples consisted of soils taken from three positions randomly selected within a plot.Their fresh and dry weights were measured. Weights were measured after drying the samples in oven at 105 ºC for 48 hours. Soil moisture content was calculated using a gravimetric method (Hillel, 1980).

Biomass samples were collected at 21, 36, 51, 66, and 81 (Nyala), 102 (SB19), 118 (SB20) days after planting (DAP). Plants were sampled randomly in an area of 0.1 m^2 within the net plot. Roots were separated from shoots at the first node from the ground, using a kitchen knife. Fresh weights were measured and dry weights determined after oven drying at 65 ºC in constant weight for 48 hours.

At physiological maturity, plants within a net plot of 7.8 m^2 were harvested. Fresh weight of pods sub-sampled was taken, before being threshed. Fresh weights of the seeds and husks were also recorded. The seeds were oven-dried at 65 ºC (model – Memmert UNB 500) for 72 hours and their dry weights taken.

Moisture content after drying was 12.5±0.5%.The total dry yield was calculated by multiplying dry weights of sub-samples by total fresh weight then diving the result by fresh weight of sub-samples.

Climatic data obtained from meteorological station were used in computation of ET_0. The climatic data were: radiation, daily maximum and minimum temperature, wind speed and direction, relative humidity, pan evaporation and rainfall amounts. Shoot biomass, shoot water content and yield data were analysed for ANOVA in SAS software version 9.2 (SAS, 2002). They were used to calculate water use efficiency (WUE). Soil moisture content data were also analysed in SAS and means separated using least significant difference (LSD).

RESULTS

Soil moisture content. Soil moisture content was not significantly different for tillage method and soybean variety interaction, neither was it significant for the interaction between tillage and soil depth. However, soil moisture content under interaction of soybean variety and soil depth was significant. Soil moisture content increased with depth under all varieties except for SB19 at full bloom (Table 1). At pod filling, soil moisture content under all the three varieties was not significant. At seed filling, there was significant difference between

10 cm depth and 20-30 cm depth. Soil moisture content at 10 cm depth was lowest under all varieties and increased with depth (Table 1). Soil moisture content under the varieties was significant except at pod filling stage. At full bloom, soil moisture content under SB19 was the highest followed by SB20, while at seed filling soil moisture was highest under Nyala (Table 2).

Crop evapotranspiration (ET_C). Regression of ET_0 against ETc indicated the coefficient of determination (R^2) was better with growing days except for SB20 (Figs. 1-3). At 81 days after planting Nyala, the ET_0 agreed with ETc (Fig. 1); while 98.45% ET_0 could predict ETc at 102 days (Fig. 2). As for SB20, only 19.2% of ET_0 could not predict ETc at 66 DAP (Fig. 3). Cropevapotranspiration (ET_C) of all varieties increasedrapidly with growing time, plateaued towards physiological maturity and slightly declined (Fig. 4). The third order polynomial fitted all the three varieties,ETcof Nyala was the lowest and of SB20 was the highest (Fig. 4). Further, calculated crop coefficient strongly correlated with observed shoot water content of Nyala (r = 0.9998), SB19 (r = 0.9997), and SB20 (r = 0.9998) (Fig. 9).

TABLE 1. Soil moisture content under soybean varieties at full bloom, pod filling and seed filling at three soil depths

Variety	Depth (cm)	Soil moisture (mm mm^{-1})		
		Full bloom (R2)	Pod filling (R3)	Seed filling (R5)
Nyala	10	0.0855±0.0042a	0.1803±0.0118a	0.0724±0.0064b
	20	0.0969±0.0040a	0.1529±0.0091a	0.0906±0.0058a
	30	0.1053±0.0046a	0.1542±0.0097a	0.1016±0.0055a
SB19	10	0.2434±0.0031a	0.1559±0.0133a	0.0418±0.0036b
	20	0.2161±0.0033b	0.1551±0.0125a	0.0724±0.0047a
	30	0.2436±0.0044a	0.1696±0.0147a	0.0740±0.0065a
SB20	10	0.2220±0.0065a	0.1707±0.0152a	0.0481±0.0044b
	20	0.2119±0.0052a	0.1604±0.0098a	0.0726±0.0032a
	30	0.2122±0.0041a	0.1384±0.0111a	0.0808±0.0071a

Means with different letters are significantly different at P<0.05 within a variety for mean separation, ±SE (standard error)

TABLE 2. Effect of soybean variety on soil moisture content at different stages of growth

Variety	Soil moisture (mm mm^{-1})		
	Full bloom (R2)	Pod filling (R3)	Seed filling (R5)
Nyala	0.0959±0.0083c	0.1625±0.0147a	0.0881±0.0079a
SB19	0.2344±0.0091a	0.1602±0.0154a	0.0627±0.0058b
SB20	0.2154±0.0096b	0.1565±0.0144a	0.0672±0.0060b

Means with different letters are significantly different at P<0.05 within a columnfor mean separation, ±SE (standard error)

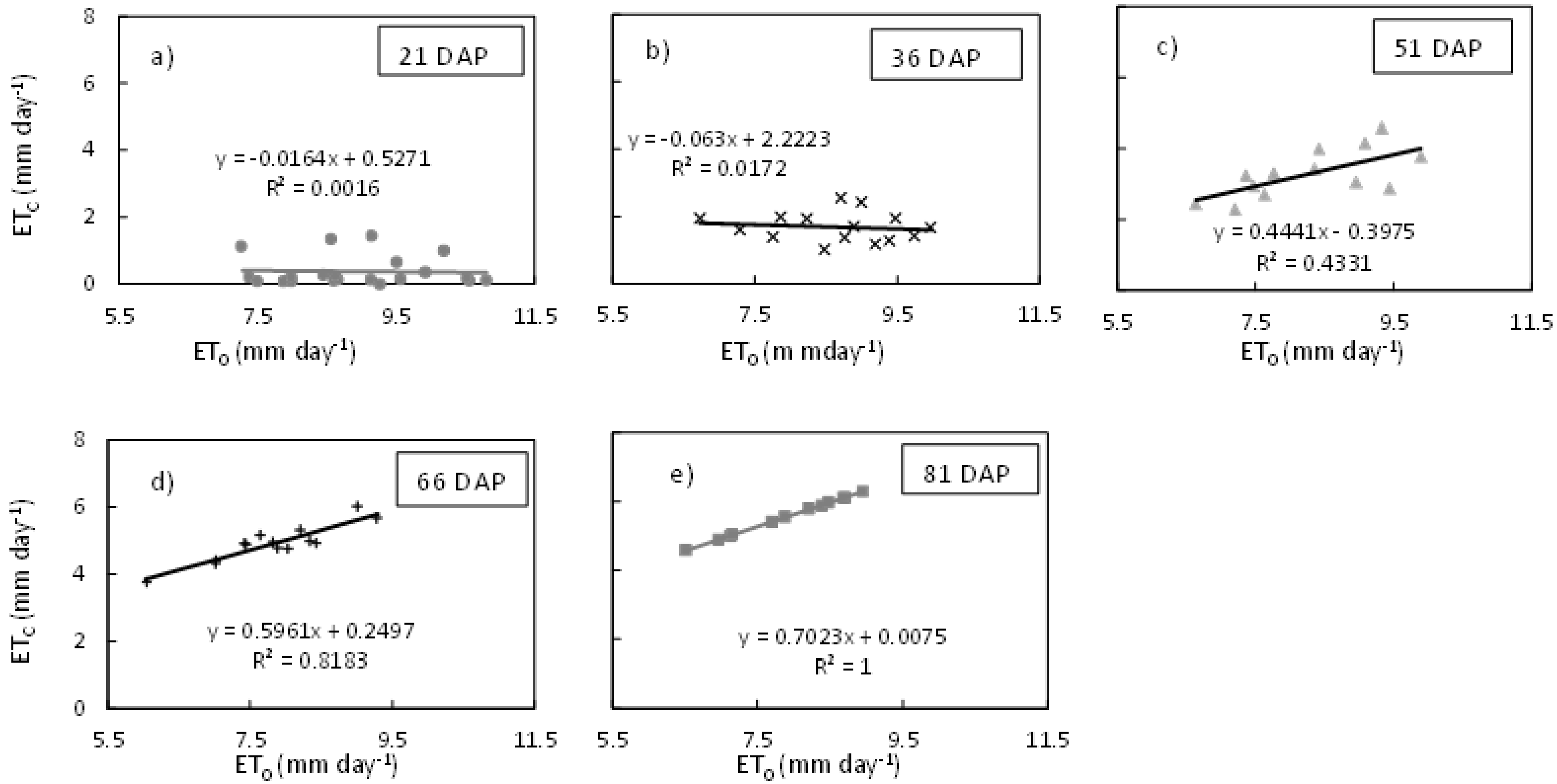

Figure 1. ET_C of Nyala soybean variety against ET_0 at different growth periods: a) 21, b) 36, c) 51, d) 66, and e) 81 DAP. DAP is days after planting at Rarieda District in Kenya.

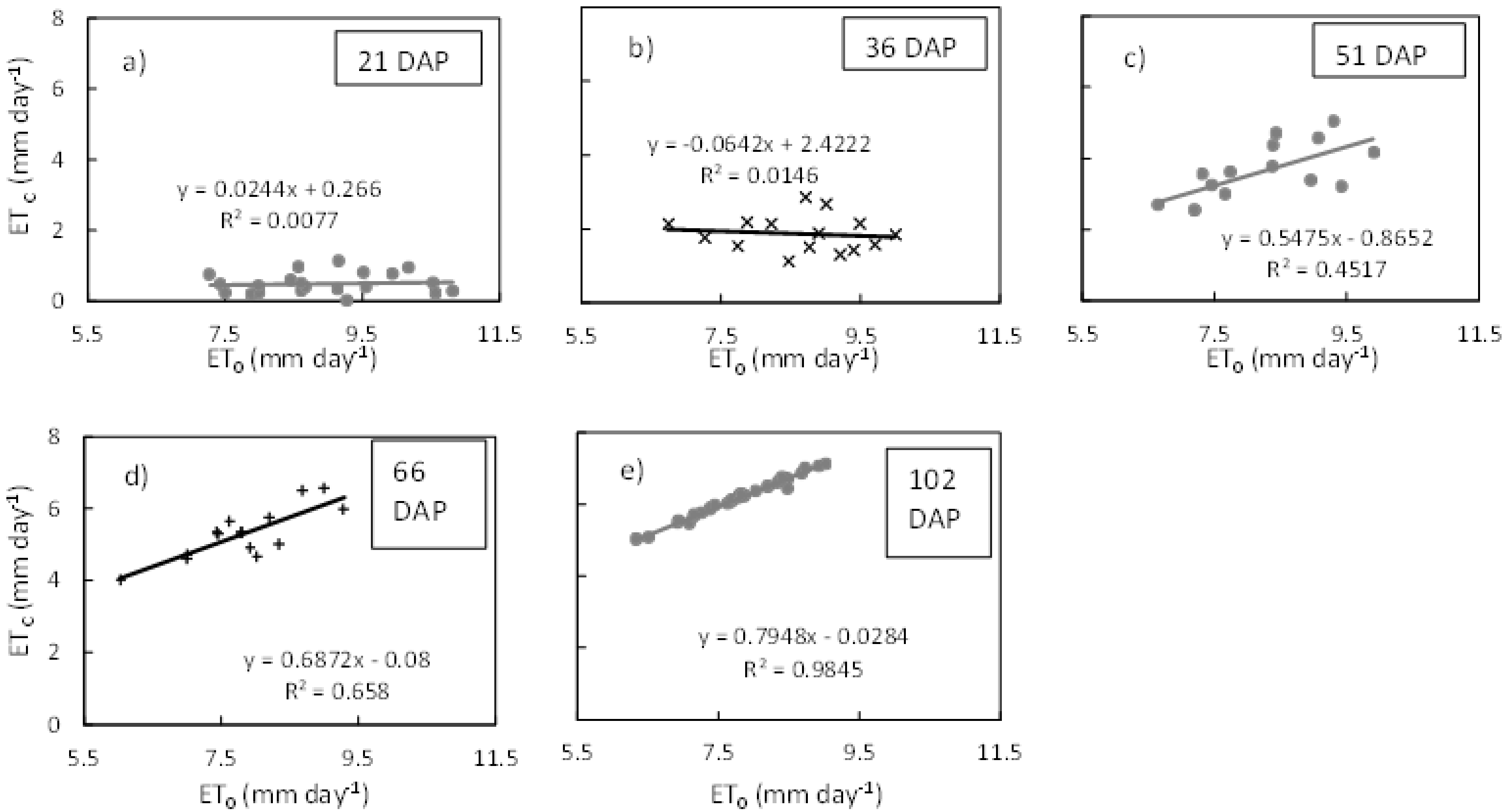

Figure 2. ET_C of SB19 soybean variety against ET_0 at different growth periods: a) 21, b) 36, c) 51, d) 66, and e) 102 DAP. DAP is days after planting at Rarieda District in Kenya.

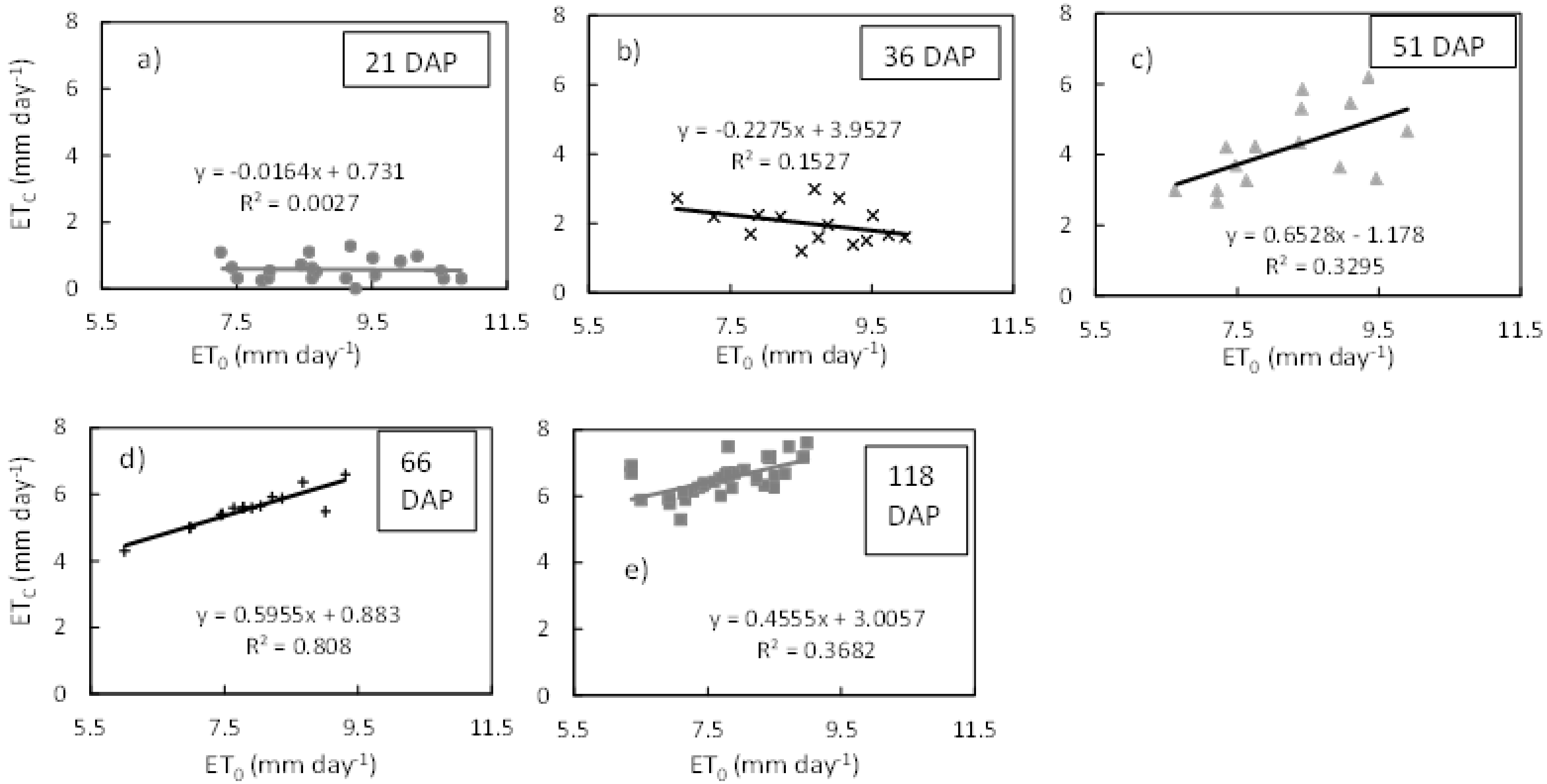

Figure 3. ET_C of SB20 soybean variety compared to ET_0 in the growing period: a) 21, b) 36, c) 51, d) 66, and e) 118 DAP. DAP is days after planting at Rarieda District in Kenya.

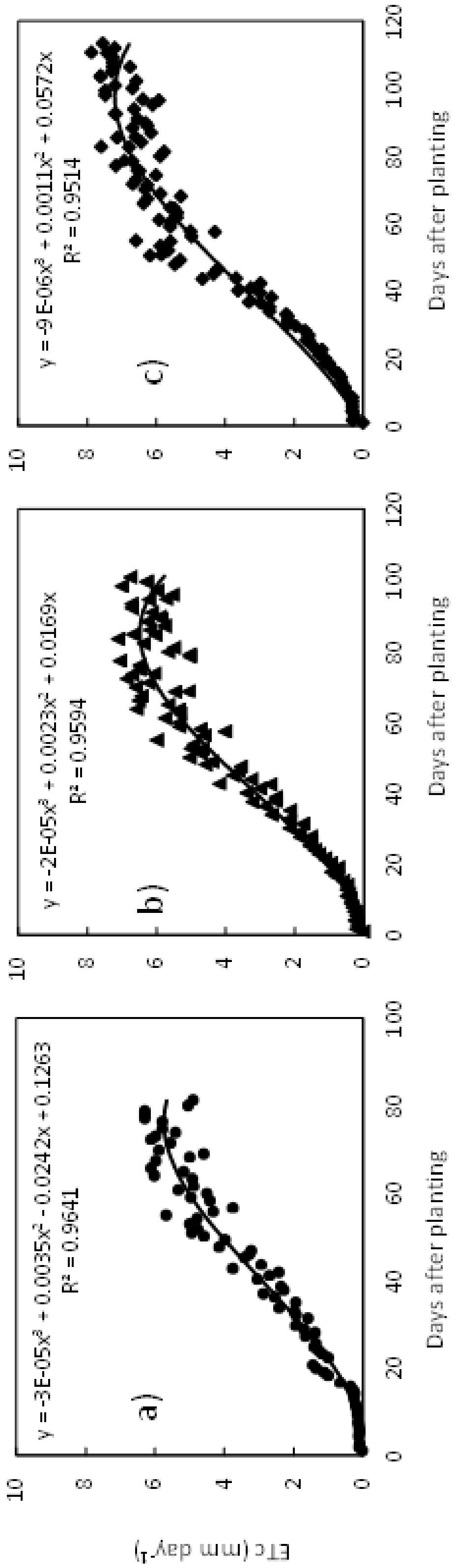

Figure 4. Distribution of ET_C of: (a) Nyala, (b) SB19, and (c) SB20 soybean varieties in the growing period at Rarieda District in Kenya.

From Equation 9:

$$Y = WUE \times ET \quad \text{................ Equation 12}$$

The results in Figures 5 and 6 show that:

$$Y = mx \quad \text{................................ Equation 13}$$

Where:

Y is yield; m is slope, x is dry shoot mass (Fig. 5) or ET_C (Fig. 6), there is an indication that ET_C and dry shoot mass are related. Considering Fig. 5b and Fig. 6b of SB19:

$$Y = 0.5767x \quad \text{...................... Equation 14}$$

for Figure 5b, where x = dry shoot mass (kg ha^{-1})

$$Y = 57.667x \quad \text{..................... Equation 15}$$

for Figure 6b, where x = ET_C (mm day^{-1})

Both calculations show the same yield, it therefore means that:

$$0.5767 \text{ dry shoot mass} = 57.667\ ET_C \quad \text{.. Equation 16}$$

$$\frac{\text{dry shoot mass}}{100} = ET_C \quad \text{............. Equation 17}$$

Thus

$$\%ET_C = \text{dry shoot mass} \quad \text{........... Equation 18}$$

Dry shoot mass and yield. The grain yields of each variety were accurately predicted by their dry shoot masses. A total of 52.3% of Nyala'sdry shoot mass produced grain yield, as 57.7% of SB19 dry shoot mass did the same; and 47% of SB20 dry shoot mass produced grain yield (Fig. 5). Similar results were obtained on correlating ET_C with yield (Fig. 6). Validation of the measured yield of

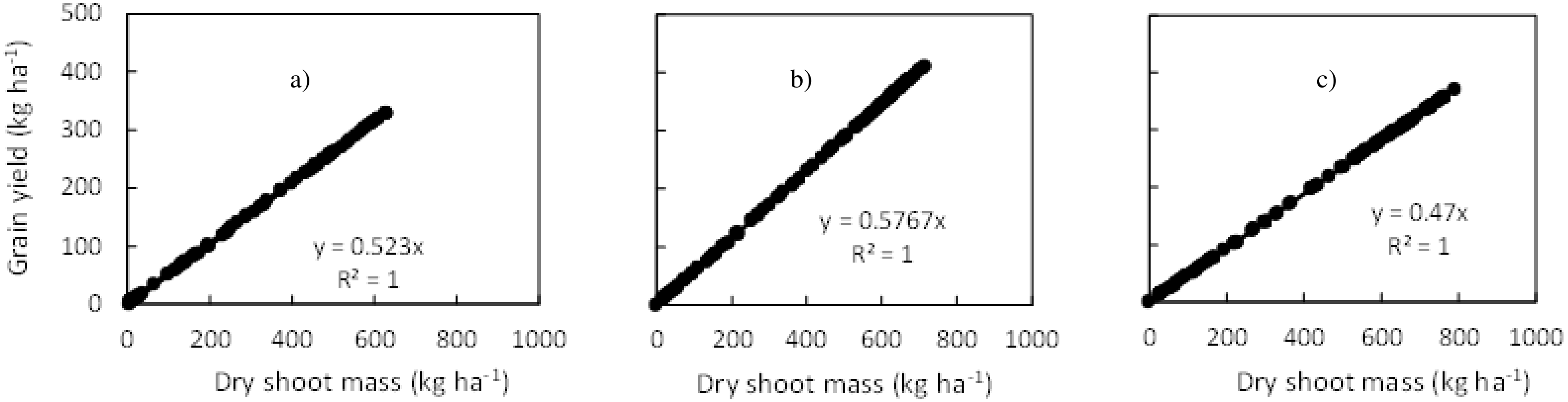

Figure 5. Relationship between grain yield and dry shoot mass of: a) Nyala, b) SB19, and c) SB20 soybean varieties at Rarieda District in Kenya.

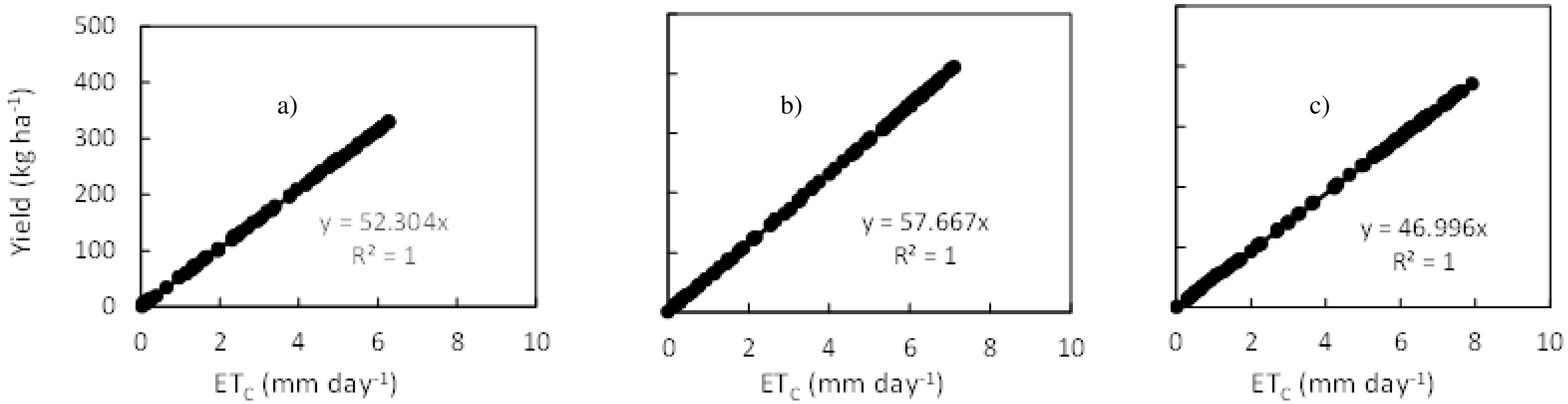

Figure 6. Relationship between grain yield and ET_C of: (a) Nyala, (b) SB19, and (c) SB20 at Rarieda District in Kenya.

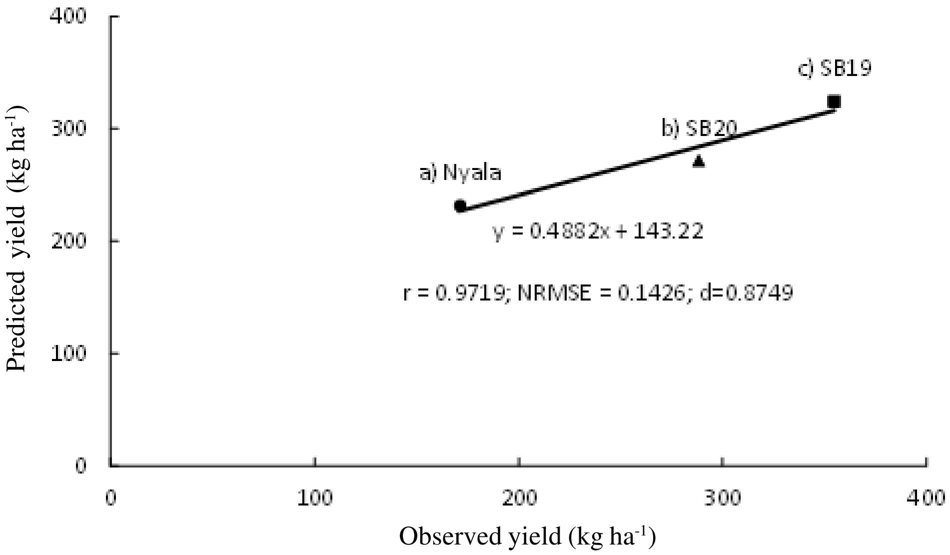

Figure 7. Comparison of the observed grain yield of: (a) Nyala, (b) SB20, and (c) SB19 soybean varieties with predicted.

Nyala, SB19, and SB20 against the calculated indicated a strong correlation of r = 0.9719. Furthermore, the normalised root mean square error (NRMSE) and the index of agreement (d) were 0.1426 and 0.8749, respectively; indicating the best fit (Fig. 7). After validation, crop coefficient (K_C) was calculated, and the results showed increase in K_C during the growth period(Fig. 8). However, the maximum K_C for each variety was recorded at different days – Nyala was at 65 days, SB19 at 70 days and SB20 at 82 days after planting.

DISCUSSION

Soil moisture content. Soil moisture is important for successful crop production. However, soil moisture is highly critical in soybean at flowering and seed filling (Foroud *et al.*, 1993; Karam *et al.*, 2005). The ET_C increase as soybean grew, followed by plateau at physiological maturity observed in the current experiment was due to increase in water requirement at the critical growth stages. Payero and Irmak (2013) also confirmed this trend. Further, a decline in soil moisture at seed filling of Nyala, SB19, and SB20 was indicative of increased water absorption at this stage. Withholding irrigation at flowering have been indicated to lead to 4% reduction in seed yield (Karam *et al.*, 2005), while soil moisture decline at seed filling leads to 25% (Foroud *et al.*, 1993) or 28% (Karam *et al.*, 2005) reduction.

Crop evapotranspiration. Crop evapotranspiration (ET_C) is central to irrigation. It was different among the tested soybean varieties. These differences in ETc among varieties (Fig. 4) was majorly due to crop factors such as shoot and root growth. Wang and Liu (2007) reported that leaf area index (LAI) influences evaporation, actually, SB20 variety as an example in the current experiment had high shoot and root biomasses (Omondi *et al.*, 2014) and hence high LAI which reduced evaporation. However, the gains in soil moisture content through canopy cover were negated by the absorption of more moisture to sustain this heavy vegetative growth and increased transpiration. This led to the overall decline in soil moisture under SB20 (Table 2).

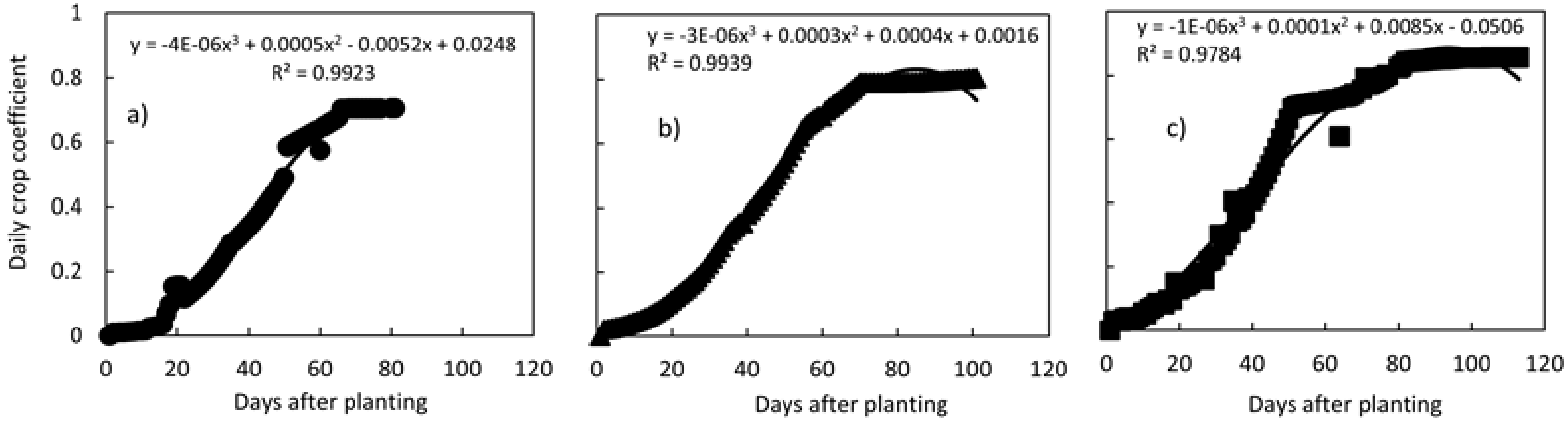

Figure 8. Distribution of crop coefficient of: (a) Nyala, (b) SB19, and (c) SB20 soybean varieties in the growing period.

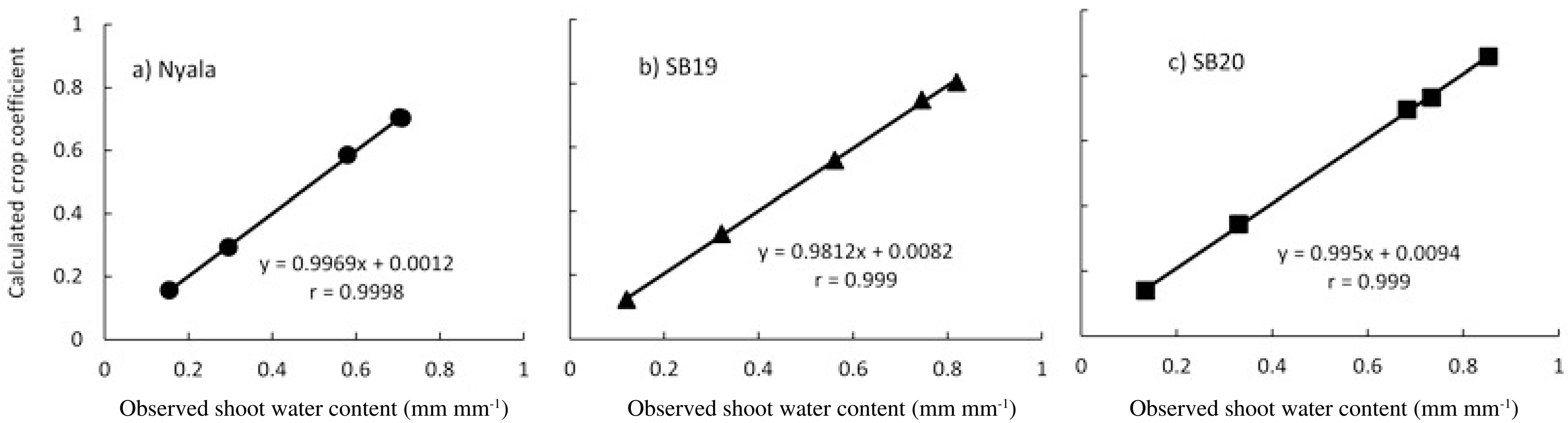

Figure 9. Correlation between shoot water content and calculated crop coefficient during growth of: (a) Nyala, (b) SB19, and (c) SB20 soybean varieties.

Arnold *et al.* (2015) and Yan *et al.* (2014) also reported the influence of minimum canopy as the cause for increased evaporation. Evaporation as a factor of ETc had minimum fluctuation as it is dependent on solar radiation (Wang and Liu, 2007).

The days when the slope of the relationship between ET_0 and ET_C were negative (Fig. 1a,b, Fig. 2b, Fig. 3a, b) was perhaps due to high evaporation compared to transpiration (Sepaskhah and Ilampour, 1995; Villegas *et al.*, 2015). Low transpiration was possible as the plants were young (21 and 36 days after planting) with less developed shoot biomass leading to low water requirement (Sepaskhah and Ilampour, 1995; Suku *et al.*, 2014). As the plants grew water requirement increased (Suku *et al.*, 2014) and transpiration and ET_C too (Zhu *et al.*, 2014; Villegas *et al.*, 2015).

Crop coefficient. The crop evapotranspiration calculated predicted yield of Nyala, SB19 and SB20 (Fig. 6). This eases calculation of Kc without conducting complex soil water balance experiments, as these experiments usually require sensitive and sophisticated equipment (Irmak *et al.*, 2013; Majidi *et al.*, 2015; Ruiz-Peñalver *et al.*, 2015) which are not readily available to resource-limited farmers. In the current experiment, calculated K_C increased with growth period and canopy expansion (Figs. 8 and 9). This increase in K_C as growth period and shoot biomass was also observed by Lopez-Urrea *et al.* (2013). As the shoot expands, transpiration is increased this influences crop evapotranspiration and K_C. The calculated maximum Kc was 0.70 for Nyala, 0.80 for SB19 and 0.86 for SB20, while the value previously reported was 0.81 at mature pods (Karam *et al.*, 2005). This proves that K_C of the varieties are different within the same species, thus the need to always calculate it. Moreover, it has been shown that crop factors such as crop type, variety and stage of development influence evapotranspiration (Allen *et al.*, 1998). Since the K_C is different among various varieties, the simple equation developed in the current study is convenient for irrigation water calculations in the areas experiencing midseason drought. The successful application of the %ETc = dry shoot mass equation in soybean could extend to other crops, once it is validated with field experiments. The calculation of the Kc through this equation, coupled with weather data to calculate ET_0 facilitates ETc calculation leading to precise irrigation. This optimises the production system, saving water, fertiliser if fertigation method is applied and reduces leaching leading to yield increase per drop of water.

CONCLUSION

Calculating K_C of varieties using biomass data enables its calculation in other agroecological zones where it is difficult to obtain K_C due to lack of sophisticated equipment required. Knowing K_C of each variety enhance precise irrigation and water management of crops.

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