Determination of Evapotranspiration and Crop Coefficients of Irrigated Legumes on Different Soil Types Using the FAO56 Approach

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Abstract

Climates and locations specific crop coefficients (CC) plays pivotal roles in effective water management and yield optimization. Research on crop coefficients for many staple crops remains limited in many regions across Africa. This study was designed to ascertain the crop coefficients of Sampea14 (V1), Sampea17 (V2), and TGX 1465-1D (V3) cultivated on sandy, sandy clay loam, and sandy loam soils, within Port Harcourt, Southern Nigeria. A 3x3 factorial experiment was designed in a Randomized Complete Block Design (RCBD), with three replicates. During the initial-growth stage, the average CC for V1, V2, and V3 were computed as 0.42, 0.54, and 0.24, respectively. At the mid-growth stage, these coefficients increased to 1.82, 2.04, and 2.59 and in the late season, the average CC were 0.89, 0.54, and 0.32, for the respective varieties. The outcomes of this study would enhance efficient water management practices and ultimately improve both crop and water productivity.

Keywords: Crop coefficients, Irrigation, Legumes, Soil types, Water consumption.

1.0 Introduction

Legumes, cost-effective nutrient sources and potential income generators for subsistent farmers lacking access to costly irrigation and fertilizers. Legumes serve as cover crops to mitigate soil erosion and demonstrate remarkable resilience to both water stress and waterlogging throughout their growth cycle (Ghosh et al., 2016). Furthermore, their symbiotic relationship with nitrogen-fixing Rhizopus in root nodules renders them valuable in crop rotation (Kalidass and Mahapatra, 2014).

Evapotranspiration is the total water loss from plants due to transpiration and soil surface evaporation, influenced by factors like temperature, humidity, sunlight, wind, and vegetation cover (Nouri et al., 2016). Water regularly evaporates from various surfaces, including lakes, rivers, pavements, soils, and wet vegetation (Dehghanisanij and Kosari, 2011). Different crops also have distinct water requirements or transpiration requirement at different growth stages, primarily determined by crop coefficients (K_c), which play a crucial role in estimating crop water needs (Rallo et al., 2021; Drechsler, 2022). Crop coefficients are inherent crop characteristics used to calculate crop evapotranspiration or water requirements (ET_c) (Chandra and Kumari, 2021). They compare the evapotranspiration of the specific crop to a well-calibrated reference crop under identical conditions. Crop Water Requirement (CWR) measures the evapotranspiration when soil water is adequate due to precipitation or irrigation,

https://doi.org/10.32388/7H4DG7

supporting unhindered plant growth and yield (Djaman et al., 2018). It also ensures water remains within the root system's absorption capacity (Silva et al., 2013). According to Sultana et al. (2022), CWR (mm) represents the water depth required to fulfil ET_c by a disease-free crop under unrestricted soil conditions, including water and fertility, to achieve maximum production potential in the given environment. Factors such as daily temperature, relative humidity, and wind velocity influence the CWR of crops (Khan et al., 2021; Sepaskhah and Razzaghi, 2022). Consequently, crops in hot, dry, windy, and sunny climates typically have the highest water requirements (Djaman et al., 2018).

The K_c is typically determined through empirical experimentation and encompasses the cumulative impact of multiple factors such as changes in leaf area, plant height, crop attributes, irrigation methods, developmental rate, planting date, canopy cover, canopy resistance, soil and climatic conditions, and agricultural management practices (Shenkut et al., 2013). Each crop is associated with a specific set of K_c values, which project varying water utilization across different crops during distinct growth stages (Pereira et al., 2021). The duration of these stages is contingent on local climate, latitude, elevation, planting date, crop type, and agricultural techniques. The most precise determination of a crop's growth stage, and subsequent adjustment of empirical K_c values, is achieved through on-site observations (Kenjabaev et al., 2020). According to Pereira et al. (2021), during the initial stages of crop germination and establishment, the majority of evapotranspiration (ET_c) primarily comprises soil surface evaporation, resulting in lower crop water use rates and smaller K_c values (referred to as the $K_{c\ \text{initial stage}}$). As the crop matures, with its canopy expanding to cover the soil surface, soil surface evaporation diminishes, and the transpiration component of ET rises. Agronomical plants reach their maximum ET_c rate when fully developed (referred to as the $K_{c\ \text{mid-season}}$), but as the season nears its end and the plant reaches physiological maturity, the ET rate decreases (referred to as the $K_{c\ \text{end season}}$) (Pereira et al., 2021).

In recent times, crop coefficients of various crops have been investigated using various methods. For instance, Hassan et al. (2022) utilized remote sensing and meteorological data to monitor plant phenology and estimate crop coefficients and evapotranspiration. They reported a strong coefficient of determination (0.98) between field crop coefficients derived from meteorological data and those predicted from an NDVI value of 0.147. In another study, Dingre et al. (2020) investigated the relationship between field water balance-derived crop coefficients and canopy reflectance-based NDVI for irrigated sugarcane. This relationship was described by a second-order polynomial regression equation. Similarly, Puig-Sirera et al. (2021) determined the transpiration and water use of a traditional olive grove under irrigation using the sap flow method and the FAO56 dual crop coefficient approach. Their findings indicated that the basal crop coefficient (K_{cb}) for the mid-season of the olive grove ranged from 0.40 to 0.45, while at the end of the season, K_{cb} ranged between 0.35 and 0.40.

In the context of Tangara da Serra, MT, Brazil, Bariviera et al. (2020) determined the dual crop coefficient for an early cycle soybean cultivar using a precise lysimeter. They reported K_{cb} and soil evaporation (K_e) values of 0.47, 1.15, 0.89, and 0.94, 0.14, 0.44 for the early, mid, and late growth stages, respectively. Additionally, Gong et al. (2020) conducted research on tomato cultivation in a solar greenhouse under both full and deficit irrigation conditions. They observed maximum crop evapotranspiration ranging from 0.15 to 1.88 mm/h under full irrigation and 0.15 to 0.89 mm/h under deficit irrigation. The average daily standard evapotranspiration was 5.11 mm/day, with a seasonal evapotranspiration of 1814 mm. The crop coefficients for citrus trees in the study of Jamshidi et al, 2020, ranged from 0.67 to 0.96. Lastly, in the semi-arid climate of the Senegal River Valley, average crop coefficient values of 1.01, 1.31, and 1.12 were reported for rice during the crop development, mid-season, and late-season growth stages (Djaman et al., 2020).

In many regions across Africa, comprehensive research on crop coefficients for key staple crops remains limited due to the diverse climatic variations (Ghosh et al., 2016). The primary objective of this study is to precisely determine the crop coefficients of three distinct legumes crop species—Sampea 14 (V1), Sampea 17 (V2) of cowpea, and TGX 1465-1D (V3) of soybean. This research is conducted across various soil types, including sandy, sandy clay loam, and sandy loam soils. The investigation spans multiple growth stages, encompassing emergence (initial), flowering (development), pod-setting (mid), and maturity (late), all within the prevailing climatic conditions of Port Harcourt, located in southern Nigeria. Results from this study would enable irrigation planning and water management in the cultivation of different varieties of soybean and cowpea on different soil types.

2.0 Materials and Methods

2.1 Study Area

This study was conducted at the agricultural research facility within the Department of Crop and Soil Science, situated in the Faculty of Agriculture at the University of Port Harcourt. This facility is located at coordinates 4.847°N latitude and 6.975°E longitude, as illustrated in Figure 1. It is positioned in the Obio/Akpor Local Government Area of Rivers State, Nigeria, at an elevation of approximately 15.85 meters above mean sea level. The climate in Port Harcourt is predominantly humid, characterized by an average annual precipitation of 2,293 mm, and the mean annual temperature and relative humidity levels are approximately 28°C and 75%, respectively.

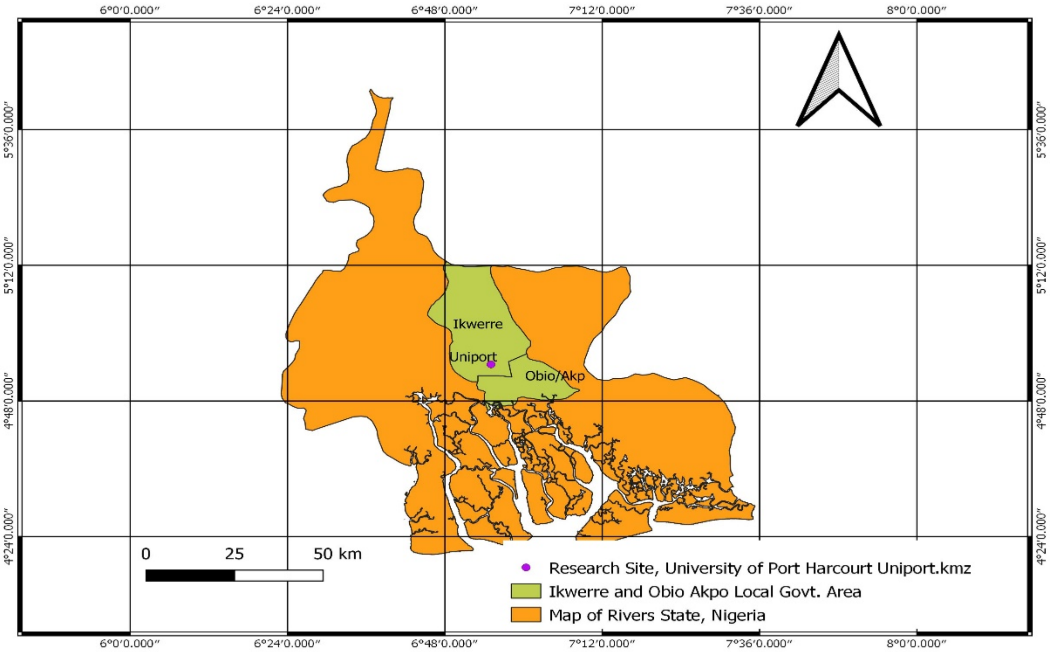

Figure 1: Map of Rivers State, Delineating Obio-Akpor Local Government, Nigeria

2.2 Experimental Design

The study was structured as a 3 x 3 factorial experiment, and it was organized using a Randomized Complete Block Design (RCBD) with three replications within a controlled environment. Twenty-seven experimental plots (each with 4 m^2 size) were used for the experiment while considering an effective root zone depth of 0.5 m. The experimental treatments consisted of three different varieties of leguminous crops, namely two types of cowpeas (Sampea 14 and Sampea 17) and one type of soybean (TGX 1465-1D). The blocks in the experiment were represented by three distinct soil types, specifically sandy, sandy clay loam and sandy loam soils. Some soil movements from other sites were done to ensure planting beds were made from the soil types.

2.3 Physicochemical Properties of Collected Samples

The soils physiochemical properties and structural characteristics of soil have great influence on the soil moisture content management. Saturated hydraulic conductivity is one of the most important soil properties and essentially required for irrigation design, drainage and waste water systems, and modelling infiltration, runoff. However, the accuracy of saturated hydraulic conductivity is highly dependent on soil and surface characteristics (Islam et al., 2017). The soil infiltration rate is also an important physical property measured as the speed at which water infiltrates through the soil surface and percolates through the soil (Farooqi et al., 2020). Soils' bulk densities often depend on the soil texture, organic matter content, root penetration, and soil structure. Soil bulk density is used to evaluate hydraulic properties of the soil (Jabro et al., 2020). The bulk densities of the sand, sandy clay and sandy clay loam soils also indicated the level of compaction which influences the soil water holding capacity, water movement, plant water availability and crop rooting depth (Jabro et al., 2020). Investigation on bulk densities, hydraulic conductivities, particle size analysis and moisture content were carried out on collected soil samples. The saturated hydraulic conductivity was carried out using the method specified by Reynolds et al., (2002). Soils' bulk densities were determined according to Blake and Hartage method (1986). Soil's particle sizes were analysed determine the relative proportion of sand, silt, and clay in the soils and the soil texture and characteristics using the hydrometer method as described by Gavlack et al. (2005).

The investigation on total nitrogen, total phosphorus, cation exchange capacity, calcium, magnesium, and potassium content were carried out on collected soil samples to determine the soil nutrient level and to inform the need for fertilizer application to planted crops. The total nitrogen was determined according to the O'Dell (1993) method. The total phosphorous was determined using the colorimetric, ascorbic acid, two reagents (1978) method was used. The Cation Exchange Capacity (CEC) is a measure of the number of ions that can be adsorbed in an exchangeable fashion, on the negative charge sites of the soil (Bache, 1976). The Cation Exchange Capacity was determined according to (Bache, 1976) method which is known as the ammonium acetate extraction Method. Calcium, magnesium and potassium were determined using the calcium chloride extraction method described by Houba et al. (2000).

2.4 Planting and Crop Management

Three different varieties of leguminous crops were planted on March 15, 2022. These varieties included Sampea 14 (V1), and Sampea 17 (V2), TGX 1465-1D (V3). The planting depth was 2cm below the soil surface. Each legume variety was planted on three distinct soil types in three replicates, resulting in a total of 27 experimental plots with nine plots per replicate. The experiment lasted for 15 weeks and concluded on July 18, 2022. The experiment's duration was divided into specific growth stages as defined by Allen et al. (1998), which included emergence, flowering, pod setting, and maturity stages for both soybeans and cowpeas. During the experiment, water use and crop coefficients were estimated at three stages: the initial (15 days for soybeans and 20 days for cowpea varieties), mid-season (55 days for soybeans and 60 days for cowpea varieties), and late stages (15 days for soybeans and 20 days for cowpea varieties).

To enhance the nutrient content of the collected soil samples, granular water-soluble fertilizers with a ratio of N: P: K at 6: 25: 5 were applied to the soil surface before planting, following the recommended agronomic rate of 50kg/ha. Fertilizer application was repeated 21 days after planting to promote the healthy development of the plants. Weed control measures were implemented to maintain disease-free plants and prevent competition with the main crops for nutrients and water. Throughout the growth period of the crops, efforts were made to prevent water stress, and irrigation was consistently applied whenever the soil water content reduced to 40% of the soil's field capacity, at an average rate of 593Mm^3/ha.

2.5 Agrometeorological Data Collection

Daily remotely sensed agrometeorological data for the experimental location (4.847 °N, 6.975 °E) were obtained from the National Aeronautics and Space Administration's (NASA) website. Data collected include daily minimum and maximum temperature, daily maximum and minimum relative humidity, and daily average wind velocity and mean hours of daily sunlight. Collected data spanned from the 1st of March 1981 to 31st July 2022. Averages of these data were employed for the estimation of potential evapotranspiration throughout the growth period of planted crops.

2.6 Estimation of Potential Evapotranspiration (PET)

Among all methods, the Penman-Monteith equation has been recommended by the Food and Agriculture Organisation (FAO) as the standard method for the computation of ET_o, especially under arid conditions (Allen et al., 1998). Adesogan and Sasanya (2023) also recommended the method, since the PET values obtained from it closely related with measured PET values from class A pan

The Potential or reference evapotranspiration (ET_o) at the growth stages of the crops was thus computed for the growing period by the Penman-Monteith Method. The FAO-56 recommended method is chosen as the standard for its accuracy in the estimation of Potential evapotranspiration from climatological data (Adesogan and Sasanya, 2023). Daily ET_o was estimated from Equations 1 through 11.

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

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \qquad (2)$$

$$R_{so} = (0.75 + 2\,z * 10^{-5})R_a \quad (3)$$

$$R_{ns} = (1-\alpha)R_s \quad (4)$$

$$R_{nl} = \sigma\left[\frac{(T_{maxk})^4+(T_{mink})^4}{2}\right]\left(0.34-0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}}-0.35\right) \quad (5)$$

$$G = 0.14(T_{MONTH\,i} - T_{MONTH\,I-1}) \quad (6)$$

R_n = Average net radiation at the crop surface ($MJ/m^2/day$), G is soil flux density ($MJ/m^2/day$), ɣ = Psychometric constant (kPa/ ^{0}C) = 0.067, U_2 = Wind velocity at 2m height (m/s), e_s = Saturation vapor pressure (kPa), e_a = Actual vapor pressure (kPa), $e_s - e_a$ = Saturation vapor pressure deficit (kPa), T = air temperature at 2m height (^{0}C), Δ = Slope vapor pressure curve (kPa/ ^{0}C).

R_s is the incoming solar radiation; obtained from the relationship between angstrom values a_s = 0.25, b_s = 0.5 and R_a. (equation 1b). R_{so} is the clear sky solar radiation obtained from elevation (z m) and R_a (equation 1c). R_{ns} is the shortwave radiation; calculated from albedo (α) and R_s (equation 1e). R_{nl} was estimated from equation (1e). σ is Stefan Boltzmann constant = 4.903 x 10^{-9} MJ/ K^4/m^2/day, T_{maxk} and T_{mink} are absolute values of monthly minimum and maximum temperatures. R_n was calculated as the difference between the net long wave radiation (R_{nl}) and net shortwave radiation (R_{ns}) measured in $MJ/m^2/day$. The soil flux G from obtained from equation 1f. $T_{MONTH\,i}$ is the mean temperature of the present month and $T_{MONTH\,i-1}$ is the mean temperature of the previous month in ^{0}C. 0.408 is a constant which converts the unit $MJ/m^2/day$ to mm/day.

$$e_s = e^o(T_{mean}) = 0.611\exp\left(\frac{17.27T_{mean}}{T_{mean}+237.3}\right) \quad (7)$$

$$\Delta = \frac{4098e_s}{(T+237.3)^2} \quad (8)$$

$$e_{a_1} = \frac{e^o(T_{min})\,x\,RH_{max}}{100} \quad (9)$$

$$e_{a_2} = \frac{e^o(T_{max})\,x\,RH_{min}}{100} \quad (10)$$

$$e_a = \frac{e_{a_1}+e_{a_2}}{2} \quad (11)$$

RH_{max} = Maximum relative humidity (%), RH_{min} = Minimum relative humidity (%). T_{min},T_{max} and T_{mean} are the monthly minimum, maximum and mean temperature in ^{0}C.

2.7 Collection of Water Use and Agronomic Data

Depletion in the soil water content and changes in the agronomic properties of the planted crops were monitored and measured on a weekly basis. These enabled the monitoring of evapotranspiration rate and changes in the plant development.

2.7.1 Monitoring Soil Moisture Depletion

The soil moisture was monitored from the water balance Equation 12. Depletion of soil moistures were monitored using the gravimetric method as employed by Alla Jabow et al. (2015) and Djaman et al. (2019).

$$ET_c = I + R_a + G - R - D \mp \Delta S \qquad (12)$$

I is Irrigation, R_a is the rainfall, G is capillary water, R is runoff, D is deep drainage, ΔS is the change in soil moisture. I was considered to be equal to zero before and after irrigation as at when needed, P is zero during the cultivation period, the groundwater table in the study area is not close to the soil surface, therefore capillary rise from groundwater G was zero. Runoff and deep drainage were zero, since the right amount of irrigation water without permitting excesses.

The change in soil moisture (ΔS) were estimated by collecting soil samples from the effective root zone, weekly from each experimental plots in replicates, by means of the soil cores samplers. Soil samples in soil core samplers were oven dried for 24 hours at 105°C and the dry weight were determined afterwards. These were done before and after water application. Weekly depletion of soils was determined from Equation 13.

$$\Delta S = \frac{SWC1 - SWC2}{\Delta t} \qquad (13)$$

Where ΔS = Gravimetric Weekly Water Depletion (g/g), SWC= Soil Water Content at week 1 (g/g), SWC= Soil Water Content at week 2 (g/g), Δt is the change in time.

The gravimetric water content was converted to volumetric water content using Equation 14. The volumetric water depletion is equivalent to the actual evapotranspiration (ET_c) of water used by the crops. The seasonal ET_c was estimated from the total ET_c over the cultivation period from planting to harvesting.

$$\Delta\theta = \frac{\rho \times \Delta S}{A} \qquad (14)$$

$\Delta\theta$= Volumetric change in water (mm/mm), ρ = Dry bulk density (g/mm^3), ΔS= Change in gravimetric moisture content, A= Cross Sectional Area (mm^2).

2.7.2 Crop Data Collection

Agronomic data including plant height, leaf length, leaf width, number of leaves and leaf area index were measured weekly starting from the 7th day after planting. The leaf area index (LAI) is the green leaf area of plants per unit area. The plant height (cm), leaf length (cm) and leaf width (cm) were measured weekly using a meter rule. The LAI was estimated from Equation 15.

$$LAI = \frac{LA}{CA} \quad (15)$$

Where LA= Leaf Area, LL= Leaf Length, LW= Leaf Width and CA= Cultivated Area

2.8 Crop Coefficients

The crop coefficients (K_c) values represent the integrated effects of changes in leaf area, plant height, crop characteristics, irrigation method, rate of crop development, crop planting date, degree of canopy cover, canopy resistance, soil and climate conditions, and management practices (Allen et al., 1998). Each crop will have a set of specific crop coefficient and will predict different water use for different crops for different growth stages (Irkman, 2008). The crop coefficient was estimated for each growth stage from Equation 16.

$$\mathrm{Kc} = \frac{\mathrm{ET_a}}{\mathrm{ET_p}} \quad (16)$$

Where K_c= Crop Coefficient, ET_a= Actual Evapotranspiration (mm/week) ET_p= Potential Evapotranspiration (mm/week)

2.9 Data analysis

Analysis of variance (ANOVA) was used to statistically determine the differences in measured means and variances of all data using R Studio, 7th edition. Least significant difference (LSD) was used to separate all means at the 95% level of confidence.

3.0 Results and Discussions

3.1 Soil Physical Properties

Table 1 presents the mean values and standard deviations for soil bulk densities and hydraulic conductivities. The bulk densities of the soil samples exhibited a range from 1.40 g/cm^3 to 1.55 g/cm^3. Notably, sandy soil displayed the highest bulk density, whereas loam and clay soils exhibited similar bulk density values. In terms of saturated hydraulic conductivities, there were no significant variations observed among the three soil types, with values ranging from a maximum of 0.11 cm/sec to a minimum of 0.09 cm/sec, as detailed in Table 1. The results pertaining to saturated hydraulic conductivity indicated a close proximity between the values for sandy clay loam and sandy loam soils, particularly. Specifically, the mean bulk density of sand was found to be 1.55 g/cm^3, which was significantly higher when compared to the values obtained for both sandy clay loam (1.40 g/cm^3) and sandy loam (1.45 g/cm^3) at a significance level of $p \leq 0.05$.

Table 1: Mean and Standard Deviation of Soil Physical Properties

Physical Parameters	Sandy	Sandy Clay Loam	Sandy Loam	LSD
Density (g/cm^3)	1.55±0.11^{a}	1.40±0.12^{b}	1.45±/0.09^{b}	0.12
Hydraulic Conductivity (cm/sec)	0.11±0.02^{a}	0.09±0.03^{a}	0.10±0.03^{a}	0.02
Sand (%)	91.11±3.56^{a}	74.72±2.99^{c}	75.83±3.12^{b}	2.08E-14
Clay (%)	7.22±2.99^{c}	23.33±3.12^{a}	18.06±3.07^{b}	3.55E-14
Silt (%)	1.67±2.87^{c}	1.95±1.94^{b}	6.11±1.71^{a}	6.74E-14

*Values with the same superscripts are not significantly different

3.2 Agronomic Growth Parameters

3.2.1 Plant Height

Table 2 provides an overview of the mean plant heights and their standard deviations recorded throughout the growth stages of three different legume varieties. During the emergence stage following planting, the plant heights ranged from 18.83 cm to 36.17 cm across the various legume varieties grown in the three soil types. When flowering occurred, plant heights ranged from 31.43 cm (V3 on sandy soil) to 59.40 cm (V2 on sandy soil). Notably, V2's height differed significantly from Variety 3's height on sandy soil during this stage.

Moving to the pod setting growth stage, a significant difference was observed between V1 on sandy soil and V2 on sandy clay loam. This trend persisted into the maturity stage. Interestingly, the performance of V2 on sandy clay loam soil exhibited the lowest plant height. The maximum plant height recorded at maturity was 115.50 cm, observed in V1 on sandy soils. Between the flowering and emergence stages, plant heights for Varieties 1, 2, and 3 increased by average percentages of 40.29%, 31.24%, and 31.74%, respectively. However, between the pod setting and maturity stages, the growth rate slowed down, resulting in average increases of 17.73 cm, 16.26 cm, and 0.60 cm for Varieties 1, 2, and 3, respectively.

Notably, legume varieties planted in sandy soil exhibited the highest plant heights, whereas those planted in sandy clay loam showed the lowest plant heights. This discrepancy may be attributed to root restriction due to the compacted nature of clay soil, which hinders the plants' ability to adequately absorb water from the soil (Eldeiry, 2005).

Table 2: Mean and Standard Deviation of Plant Height of Legume Varieties at Different Growth Stages (cm)

Growth Stages	Variety/Treatment	Sandy	Sandy Clay Loam	Sandy Loam
Emergence	V1	27.50± 1.22^{abc}	30.00±3.77^{ab}	26.17±5.10^{bc}
	V2	36.17±4.13^{a}	30.83±1.65^{ab}	33.17±4.90^{ab}
	V3	26.50±1.63^{bc}	32.67±8.99^{ab}	18.83±4.50^{c}
	LSD	9.44		
Flowering	V1	56.50± 9.39^{a}	42.00±5.72^{ab}	44.33±6.51^{ab}
	V2	59.40±22.34^{a}	42.93±2.67^{ab}	45.10±5.78^{ab}

	V3	31.43±14.70^{b}	44.17±11.26^{ab}	40.50±11.50^{ab}
	LSD	24.49		
Pod setting	V1	97.00±2.45^{a}	73.33±15.56^{ab}	72.17±9.72^{ab}
	V2	90.83±43.41^{ab}	55.17±8.37^{b}	56.33±5.24^{ab}
	V3	75.83±24.87^{ab}	92.00±15.58^{ab}	95.50±14.84^{ab}
	LSD	40.68		
Maturity	V1	115.50±1.22^{a}	100.50±3.27^{ab}	80.33±13.68^{ab}
	V2	99.00±42.43^{ab}	55.67±8.18^{b}	93.33±45.73^{ab}
	V3	75.90±11.64^{ab}	92.00±11.66^{ab}	97.17±15.97^{ab}
	LSD	46.74		

*Values with the same superscripts are not significantly different. V1 is variety 1 of cowpea (sampea 14), V2 is variety 2 of cowpea (sampea 17) and V3 is a variety of soybean (TGX 1465-1D), LSD is Least Significant Difference

3.2.2 Number of Leaves

The number of leaves generated by the various legume varieties at specific growth stages is a crucial parameter for assessing crop transpiration and water usage. The resulting leaf counts for the planted legume varieties are presented in Table 3. During the emergence stage, the number of leaves observed across the three soil types ranged from 4 to 9. Notably, V1 cultivated in sandy soil exhibited the highest leaf count (9), while the same variety in sandy clay loam soil had the lowest leaf count (4). Among the legume varieties, V2 produced the greatest number of leaves across all three soil types.

As the flowering stage approached, V1 on sandy loam soil displayed the highest leaf count (16), whereas V1 on sandy clay loam had the lowest leaf count (6). When the legumes entered the pod-setting stage, V3 on sandy loam soil bore the highest number of true leaves (30), whereas V1 and V2 on sandy clay loam exhibited the lowest leaf counts (10). However, at maturity, V1 on sandy soil had the highest number of true leaves (34), while V2 on sandy clay loam had the lowest leaf count (14).

Between the flowering and emergence stages, there was a substantial increase in the number of leaves for each variety, with V1, V2, and V3 showing average percentage increases of 47.36%, 40.76%, and 33.33%, respectively. However, between the pod-setting and maturity stages, the rate of increase in leaf numbers slowed down to 27.68%, 25.00%, and 8.39%, respectively. This phenomenon can be attributed to physiological leaf deterioration, aging, and leaf shedding (Nuwamanya, et al., 2019).

From a statistical perspective, significant differences were observed at emergence in the number of leaves produced by V1 on sandy soil and V1 and V3 on sandy clay loam, as well as among the three varieties on sandy loam soils (Table 3). At the flowering stage, the leaf counts of V1 on sandy soil differed significantly from those of V3 on sandy soil, V1 and V2 on sandy clay loam, and V3 on sandy loam. During the pod-setting stage, significant differences were noted in the leaf counts produced by V3 on sandy loam soil compared to the counts for V2 on sandy loam and Varieties 1 and 2 on sandy clay loam. Additionally, at maturity, significant differences in leaf counts were observed between legume Variety 2 on sandy clay loam and Varieties 1 and 3 on sandy soil, as well as Variety 3 on sandy clay loam.

Table 3: Mean and Standard Deviation of Number of Leaves of Legume Varieties at Different Growth Stages

Growth Stages	Variety/Treatment	Sandy	Sandy Clay Loam	Sandy Loam
Emergence	V1	9.00±1.00^{a}	4.00±2.00^{c}	5.00±2.00^{bc}
	V2	8.00±0.00^{ab}	7.00±1.00^{abc}	6.00±1.00^{bc}
	V3	7.00±0.00^{abc}	6.00±1.00^{bc}	5.00±2.00^{bc}
	LSD	3.04		
Flowering	V1	15.00±3.00^{a}	6.00±0.00^{c}	16.00±5.00^{a}
	V2	13.00±3.00^{ab}	10.00±2.00^{bc}	13.00±1.00^{ab}
	V3	7.00±2.00^{c}	12.00±1.00^{ab}	10.00±2.00^{bc}
	LSD	4.57		
Pod setting	V1	26.00±4.00^{ab}	10.00±6.00^{c}	19.00±9.00^{abc}
	V2	22.00±12.00^{abc}	10.00±2.00^{c}	15.00±5.00^{bc}
	V3	26.00±7.00^{ab}	28.00±9.00^{ab}	30.00±1.00^{a}
	LSD	14.98		
Maturity	V1	34.00±5.00^{a}	20.00±4.00^{ab}	21.00±7.00^{ab}
	V2	22.00±8.00^{ab}	14.00±6.00^{b}	28.00±1.00^{ab}
	V3	31.00±4.00^{a}	32.00±13.00^{a}	29.00±11.00^{ab}
	LSD	28.17		

*Values with the same superscripts are not significantly different. V1 is variety 1 of cowpea (sampea 14), V2 is variety 2 of cowpea (sampea 17) and V3 is a variety of soybean (TGX 1465-1D), LSD is Least Significant Difference

3.2.3 Leaf Area Index

Leaf area is a critical growth parameter that serves as an indicator of both leaf canopies and the extent of soil coverage by leaves. It plays a significant role in influencing water evaporation from the soil surface and transpiration from leaf surfaces. Table 4 presents the estimated mean values of the leaf area index (LAI) for the various legume varieties grown in three distinct soil types.

During the emergence stage, the LAI of the legume varieties ranged from 0.015 to 0.021, and these ranges did not exhibit statistically significant differences. Notably, V1 cultivated in sandy clay loam soil displayed the highest LAI (0.021), while the same V1 planted in sandy clay loam had the lowest LAI. As the flowering stage approached, the LAI range expanded from 0.015 (V3 on sandy clay loam) to 0.027 (V1 on sandy soil), with these two values being significantly different. This suggests that, despite having a high number of leaves at this growth stage, these leaves had relatively smaller surface areas, resulting in smaller canopies and LAI. During the pod-setting phase, V 1 planted on sandy soil exhibited the highest LAI (0.108), while V1 planted on sandy clay loam had the lowest LAI (0.027). This significant difference in LAI was observed between V1 on sandy soil and V3 on sandy soil, as well as between V1 and V3 on sandy clay loam and V 3 on sandy loam soil.

At maturity, the highest LAI was recorded for V1 planted on sandy soil, whereas V3 planted on sandy clay loam and sandy loam exhibited the lowest LAI values (Table 4). Consequently, the LAI of V1 on sandy soil differed significantly from that of all other legume varieties on different soil types, except for V2 on sandy soil and sandy loam soil. In summary, it appears that legume varieties V1 and V2 had better LAI on sandy soil compared to the other soil types.

Table 4: Mean and Standard Deviation of Leaf area index of Legume Varieties at Different Growth Stages

Growth stages	Variety/Treatment	Sandy	Sandy Clay Loam	Sandy Loam
Emergence	V1	0.021±0.01^{a}	0.015±0.005^{a}	0.018±0.01^{a}
	V2	0.025±0.01^{a}	0.017±0.002^{a}	0.016±0.004^{a}
	V3	0.023±0.01^{a}	0.018±0.004^{a}	0.018±0.001^{a}
	LSD	0.012		
Flowering	V1	0.027±0.002^{a}	0.017±0.000^{ab}	0.017±0.00^{ab}
	V2	0.015±0.010^{b}	0.021±0.004^{ab}	0.021±0.003^{ab}
	V3	0.018±0.010^{ab}	0.015±0.002^{b}	0.019±0.003^{ab}
	LSD	0.010		
Pod setting	V1	0.108±0.007^{a}	0.027±0.009^{c}	0.063±0.026^{abc}
	V2	0.096±0.085^{ab}	0.045±0.011^{abc}	0.063±0.036^{abc}
	V3	0.036±0.008^{bc}	0.031±0.0160^{c}	0.041±0.002^{bc}
	LSD	0.064		
Maturity	V1	0.131±0.016^{a}	0.040±0.002^{cd}	0.063±0.022^{bcd}
	V2	0.101±0.082^{ab}	0.042±0.020^{bcd}	0.100±0.005^{abc}
	V3	0.040±0.010^{bcd}	0.031±0.016^{d}	0.032±0.007^{d}
	LSD	0.061		

*Values with the same superscripts are not significantly different. V1 is variety 1 of cowpea (sampea 14), V2 is variety 2 of cowpea (sampea 17) and V3 is a variety of soybean (TGX 1465-1D), LSD is Least Significant Difference

3.3 Crop Water Use and Crop Coefficients

Crop water consumption is a crucial factor in assessing the viability of crop cultivation in any given region, as highlighted by Wang et al. (2018) and Fan et al. (2021). Tables 5 and Figure 2 present data on the water consumption and resulting crop coefficients for each legume variety, respectively

During the initial growth stage, it was observed that legume V2 planted on sandy soil had the highest water consumption, followed by V1 on sandy soil. In contrast, V3 planted on all soil types exhibited lower water consumption compared to the other two varieties. The water consumption for soybean (V3) ranged from 12.6 mm to 16 mm across the three soil types. On average, legumes grown in sandy soil consumed more water than those in sandy clay loam and sandy loam soils. This outcome can be expected because during the initial stage, when the soil is uncovered, the larger pore spaces in sandy soils allow for increased water release to the atmosphere through evapotranspiration. Consequently, more water is required to fulfil the crop's water requirements during this stage (Vallejos, 2018; Somers et al., 2010). Additionally, at the initial stage, when leaf area is limited, evapotranspiration primarily occurs through soil evaporation (Myneni et al., 2002; Dong et al., 2019). Statistically, significant differences were observed in the water consumption at the initial stages, particularly between V2 on sandy soil and V1 on sandy loam soil, as well as between V2 on sandy clay soil and V3 on all soil types, at a significance level of 0.05.

During the mid-season, there was a noticeable increase in water consumption for all three legume varieties compared to the initial and developmental stages. Among them, soybean (V3) planted on sandy loam exhibited the highest water consumption (874.2 mm), while the lowest water consumption was recorded for V1 on sandy loam (389.30 mm). At this growth stage, there were significant differences in water consumption, particularly for V3 on sandy soil compared to V2 on sandy clay loam, V1 and V2 on sandy soil, as well as V1 on sandy loam, at a significance level of 5%.

As the late season approached, characterized by pods nearing harvest, water consumption rates for all three varieties decreased compared to the mid and developmental growth stages. During this late season, the crops experienced reduced transpiration, resulting in significantly lower water usage when compared to the mid-season. This decrease in transpiration rates was attributed to physiological leaf deterioration, aging, and leaf shedding, in line with the findings of Nuwamanya et al. (2019). Notably, the water consumption of legume V3 was lower than that of V1 and V2 across all soil types. V1, on the other hand, consistently exhibited higher water consumption than the other two varieties.

At maturity, the water use of V1 on sandy soil differed significantly from the water consumption of V2 and V3 on all soil types, thus, highlighting variations in water usage patterns among these legume varieties. The FAO-56 crop coefficient approach, which is commonly used for estimating crop water requirements under well-watered conditions, is the standard method widely adopted for irrigation management, especially for scheduling irrigation (Allen et al., 1998). According to this approach, crop coefficients (K_c values) tend to increase as the crop develops, with the maximum values reached when the plants are fully mature (Abedinpour, 2016; López-Urrea et al., 2021). In our study, we observed a gradual increase in K_c values from the initial growth stage to the developmental and mid-season stages, followed by a decrease in the late season. This pattern of increasing crop coefficients reflects the impact of crop growth, development, and physiological processes on water consumption and evapotranspiration (Shenkut et al., 2013).

Table 5: Mean and Standard Deviation of Actual Evapotranspiration by Legume Varieties at Different Growth Stages (mm)

Growth stages	Variety/Treatment	Sandy	Sandy Clay Loam	Sandy Loam
Initial Season	V1	48.7 ± 14.6^{ab}	51.2 ± 9.0^{ab}	38.6 ± 14.0^{b}
	V2	99.8 ± 69.0^{a}	39.9 ± 35.9^{b}	42.8 ± 7.3^{ab}
	V3	16.0 ± 1.3^{b}	12.6 ± 2.8^{b}	26.3 ± 8.6^{b}
	LSD	59.3		
Mid-Season	V1	509.3 ± 108.7^{bcd}	678.6 ± 124.3^{abc}	389.3 ± 55.1^{d}
	V2	470.4 ± 17.8^{cd}	546.2 ± 54.2^{bcd}	754.9 ± 207.2^{ab}
	V3	653.4 ± 30.4^{abc}	662.5 ± 140.9^{abc}	874.2 ± 164.2^{a}
	LSD	252.2		
Late Season	V1	123.3 ± 24.7^{a}	75.1 ± 4.4^{bc}	87.2 ± 39.4^{ab}
	V2	56.1 ± 13.1^{bcd}	43.9 ± 12.9^{cde}	74.7 ± 15.4^{bc}
	V3	23.7 ± 5.3^{de}	19.5 ± 8.0^{de}	11.6 ± 3.36^{e}
	LSD	38.55		

*Values with the same superscripts are not significantly different. V1 is variety 1 of cowpea (sampea 14), V2 is variety 2 of cowpea (sampea 17) and V3 is a variety of soybean (TGX 1465-1D), LSD is Least Significant Difference

According to Allen et al. (1998), crop coefficients of 0.4, 1.15, and 0.55 were determined for legumes during the initial, mid-season, and late-season growth stages, respectively. However, in our study, we calculated average crop coefficients of 0.4, 2.15, and 0.58 for legumes planted in the order of growth stages on all soil types. Specifically, for legumes grown on sandy soil, we obtained average crop coefficients of 0.52, 1.90, and 0.67 for the initial, mid-season, and late-season stages, respectively. On sandy clay loam soil, the average crop coefficients were 0.33, 2.20, and 0.46 for the corresponding growth stages. On sandy loam soil, the averages were 0.36, 2.35, and 0.56, following the same sequence of growth stages (Figure 2). The differences in crop coefficients observed can be attributed to variations in climate and soil characteristics, as noted by Kullberg et al. (2017) and Jamshidi et al. (2020).

It's worth noting that the crop coefficients obtained for legume varieties during the initial and late stages closely resemble those estimated by Alla Jabow et al. (2015) for faba bean, chickpea, and common bean in a semi-desert climatic region with very hot conditions in Ed-Damer, Sudan. However, there are slight differences in the coefficients obtained during the mid-season. Specifically, Alla Jabow et al. (2015) estimated values of 0.33, 0.26, and 0.52 for faba beans, chickpea, and common bean, respectively, during the initial stages. During the mid-season, crop coefficients of 1.08, 1.22, and 1.07 were determined for faba beans, chickpea, and common beans, respectively. These coefficients increased when compared to the values obtained during the initial stage. However, during the late season, the crop coefficients decreased to 0.60, 0.52, and 0.52 for faba beans, chickpea, and common beans, respectively.

In a similar study conducted by El-Noemani et al. (2015) on irrigated *Phaseolus vulgaris L.* (common beans) varieties in Nile Delta clay loam old alluvial soil, crop coefficients were reported. During the initial growth stage of the Bronco variety, crop coefficients ranged from 0.63 to 0.64. For the Bronco variety, coefficients ranged from 0.82 to 0.87, 0.99 to 1.09, and 0.80 to 0.95 during the developmental, mid-season, and late-season stages, respectively, at varying levels of water application (40%, 60%, and 80%). For the Contender variety, the corresponding coefficients were in the ranges of 0.59-0.61, 0.78-0.98, 1.07-1.19, and 0.73-0.88 for the respective growth stages and water application levels.

In this study, during the initial stage, the average coefficients for varieties V1, V2, and V3 were 0.42, 0.54, and 0.24, respectively. At the mid-growth stage, the coefficients for the same varieties were notably higher at 1.82, 2.04, and 2.59. In the late season, the average values were 0.89, 0.54, and 0.32, respectively (Figure 2). These coefficients depict variations in crop water requirements and transpiration rates at different growth stages and among the legume varieties studied.

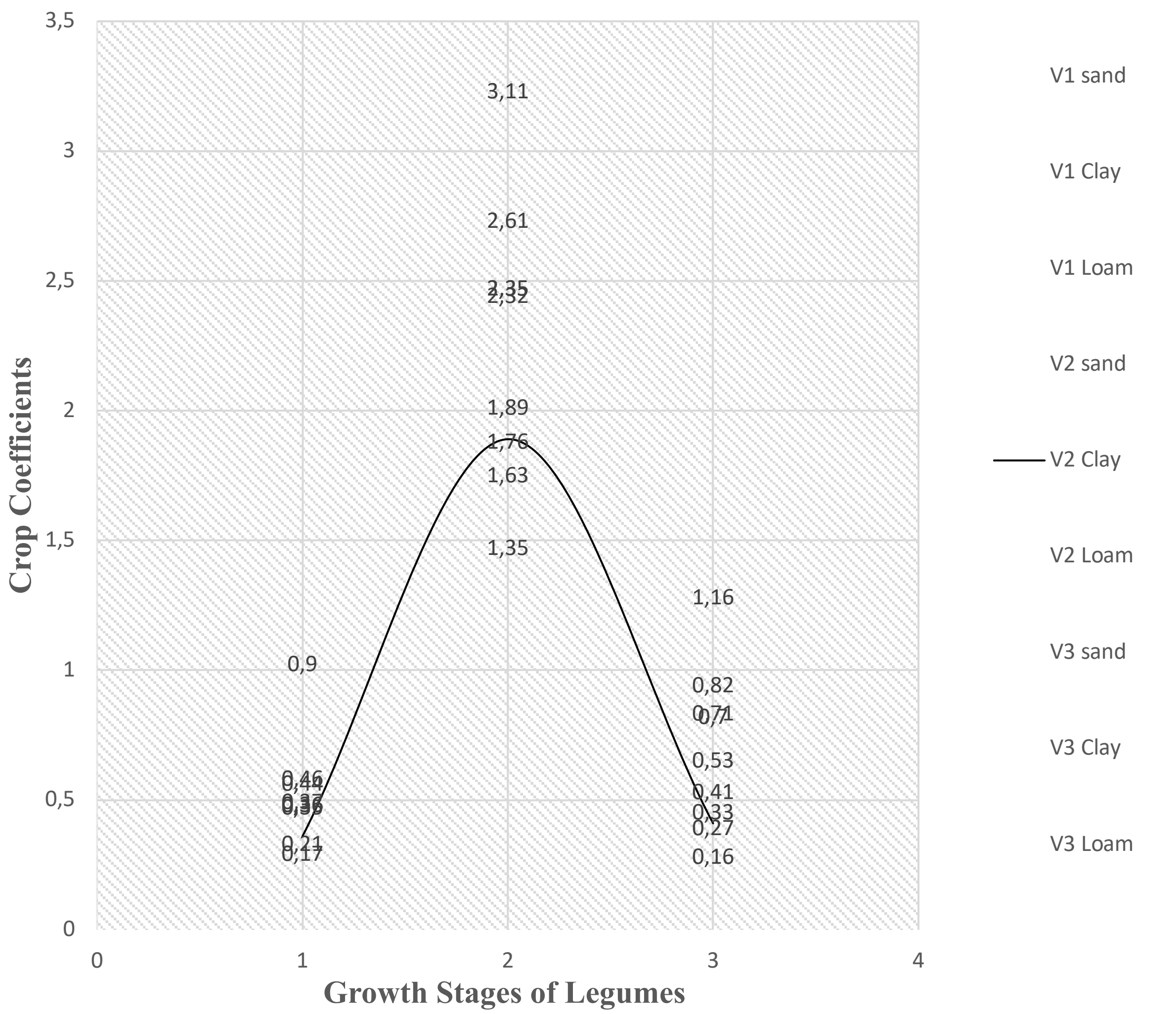

Figure 2: Crop Coefficient of Three Varieties of Legumes on Three Different Soil Types at Each Growth Stage

4.0 Conclusions

This study aimed to investigate water use and crop coefficients of legumes cultivated on three distinct soil types in southern Nigeria to improve crop and water management practices. The findings indicated that legume water consumption was highest during the mid and developmental growth stages and was influenced by various factors, including climatic conditions, months, and seasons of the year.

Legume varieties planted on sandy loam soils exhibited the highest average actual evapotranspiration, indicating greater water usage or soil water depletion on this soil type. Notably, crop coefficients estimated for legumes grown on sandy clay loam were generally higher than those recorded for sandy and sandy loamy soils, particularly during the mid-season

In terms of legume varieties, the soybean variety (TGX 1465 -1D) consistently displayed higher crop coefficients compared to the two cowpea varieties (Sampea 14 and Sampea 17) during the developmental and mid growth stages. However, during the initial and late seasons, the crop coefficients varied, with V2 consuming more water and having the highest crop coefficients at the initial season, while V1 consumed more water during the late season.

The implications of this study are significant, especially for irrigation engineers, agriculturists, soil scientists, and environmentalists. The findings can inform improved irrigation scheduling, water management practices, and enhance crop and water productivity in agriculture, particularly in regions with a climate similar to southern Nigeria.

DECLARATIONS

Conflict of Interests: The Author and Co-author declare no conflict of interest in this research article.

Data Availability: The raw data are available at reasonable request from the authors.

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