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Soil Physical and Chemical Properties and Crop Water Requirement of Some Selected Vegetable Crops at Central Experimental Field of Urban Food Plus Project in Sanarigu District, Tamale, Ghana

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ABSTRACT

This study was carried out to determine the crop water requirement of some selected vegetable crops cultivated at the Central Experimental Site for Urban Food Plus Project. These crops include `Ayoyo` (Corchorus spp), Lettuce (Lactuca sativa), Cabbage (Brassica oleracea), Amaranthus (Amaranthus candatus) and Carrot (Daucus carota). Crop water requirement for each of the crops was determined by using 30-year climatic data from the Tamale Synoptic station as and input in CROPWAT programme, FAO, version 8, 2014. Using CROPWAT, Reference Evapotranspiration (ETo) was determined using the FAO Penman Monteith method. For all the crops, daily, decadal and seasonal crop and net irrigation requirements were computed for the various growth stages: initial, development, mid-season and late season. The soil infiltration test was conducted in situ while composite soil samples were also collected for laboratory analysis of some soil physico-chemical properties of the experimental site. The study shows that the soil was low in organic matter content, slightly acidic, but not saline and also has low water holding capacity due to its low amount of clay content. The site however, is well drained and is therefore suitable for cultivation of vegetables and upland arable crops. Climate conditions, however demand considerable amount of irrigation to supplement rainfall in the period mid- November to March, when the experiment was taking place. Reference Evapotranspiration (ETo) varied from 3.9 mm / d in August to 8.9 mm / d in February. Crop evapotranspiration (ETc) for `ayoyo` varied from 4.03 to 8.81 mm / d, for cabbage from 4.03 to 9.43 mm / d, for lettuce from 4.03 to 9.19 mm / d, for carrot, 4.03 to 10.53 mm / d, for amaranthus from 4.03 to 9.75 mm / d. Thus, with the calculation of crop water requirement and net irrigation demand for each of the crops cultivated, an appropriate water planning and management can be scheduled to ensure that adequate soil water is maintained by rainfall and/or irrigation, so that it does not limit plant growth and crop yield.

Keywords: *Crop, Irrigation, Soil, Water requirements, Vegetables*

INTRODUCTION

Water is important for plant growth and food production. The total amount of available water is crucial for the economy, health and welfare of a very large part of the developing world. There is competition between municipal, industry and agricultural users for the finite amount of available water. Thus, estimating irrigation water requirements accurately is important for water planning and management (Michael, 1999). The primary objective of irrigation is to apply water to maintain crop evapotranspiration (ETc) when precipitation is insufficient. Hess (2005) defined crop water requirements as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and / or irrigation, so that it does not limit plant growth and crop yield.

FAO (2005) defined crop water requirement (CWR) for a given crop as:

$$CWR_i = \sum_{t=0}^{T} \left(kc_{i_t} \cdot ET_{o_t} - P_{eff_t} \right)$$

(1) Unit: mm

Where, kc_i is the crop coefficient of the given crop i during the growth stage t and where T is the final growth stage. Each crop has its own water requirements.

Net irrigation water requirements (NIWR) in a specific scheme for a given year is the sum of individual crop water requirements (CWRi) calculated for each irrigated crop, i. Multiple cropping (several cropping periods per year) is automatically taken into account by separately computing crop water requirements for each cropping period. By dividing by the area of the scheme (S; in ha), a value for net irrigation water requirements is obtained and can be expressed in mm or in m^3 / ha (1 mm x 10, 000 m^2 = 10 m^3 / ha).

Crops will transpire water at the maximum rate when the soil water is at field capacity. Broner (2003) reported that knowing seasonal crop water requirements is crucial for planning crop pattern and intensity, especially during drought years. Scheduling irrigation according to crop water needs minimises the chances of under or over watering. Consequently, there is less crop failure and leaching of fertilizers beyond the root-zone, and more profit for growers. Adequate data on irrigation water requirements is not available in most irrigation schemes in developing nations. The objective of this research was to determine crop and irrigation water requirements of 'Ayoyo' (*Corchorus spp*), Lettuce (*Lactuca sativa*), Cabbage (*Brassica oleracea*), Amaranthus (*Amaranthus candatus*) and Carrot (*Daucus carota*) for the Zagyuri Central Experimental Site for Urban Food Plus Project.

MATERIALS AND METHODS

The study area

The site is located in the northern part of Sagnarigu District in Tamale Metropolitan Area (TAMA). The distance from Tamale centre to the experimental site (Zagyuri) is about 8 km. The source of water used for irrigation is untreated domestic sewage effluent from the Kamina Military Barracks located upstream of the project site. The treatment plant at the site, which is no longer in use, is the trickling filter type. At present, the sewage from the sedimentation tank bypasses the trickling filter and the existing treatment facilities and flows into a nearby drain. The site is very large, covering more than 20 hectares and belongs to the Kamina Military Barracks. The farmers cultivate as much land as they can manage, under an arrangement with military. Many of the farmers are retired soldiers and farm at the site with their family members.

Soil Properties of the Central Experimental Field of Urban Food Plus Project in Tamale

The composite soil sample was analysed for physico-chemical properties, using standard procedures. Soil samples were collected from eight different locations at the depth of 0-30 cm in zig-zag pattern across the required areas. A composite sample was then first sieved by gyrator sieve shaker with approximately 2 mm spacing, to remove the coarser particles and then allowed to dry in air for 1 hour. The nutrient concentrations and physical parameters of the composite soil sample collected at 0-30 cm depth are represented in Table 1**.**

The samples were analysed for texture, moisture content, organic carbon, hydraulic conductivity and dry bulk density at the laboratory in Savannah Agricultural Research Institute (SARI) at Nyankpala, Tamale. However, soil infiltration rate was also conducted *in situ* at both the upstream and downstream locations of the site using double ring infiltrometer. The results of the soil physical properties are presented in Table 1. Plates 1 and 2 depict the results of the infiltration tests.

Plate 1: Infiltration test -upstream
(Source: field studies, 2016)

Plate 2: Infiltration test –downstream

Crop Water Requirement Calculation using CROPWAT 8.0 Model

FAO (1992) and Smith *et al.* (1991) reported that CROPWAT is meant as a practical tool to help agro-meteorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more specifically, the design and management of irrigation schemes.

It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation. Broner and Schneekloth (2003) reported that water requirements of crops depend mainly on environmental conditions. Plants use water for cooling purposes and the driving force of this process is prevailing weather conditions.

Different crops have different water use requirements, under the same weather conditions.

Input Requirement of CROPWAT

Calculations of the crop water requirement and irrigation needs were carried out with inputs of climatic, crop and soil data. For the estimation crop water requirements (CWR) the model required:
a) Reference Crop Evapotranspiration (ETo) values, measured or calculated using the FAO Penman-Montieth equation based on decade / monthly climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and wind speed;
b) Rainfall data (daily/decade/monthly data); monthly rainfall is divided into a number of rain storm each month;
c) A Cropping Pattern, consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100 % of the total area); a set of typical crop coefficient data files are provided in the program.
In addition, for Irrigation Scheduling the model requires information on:
d) Soil type: total available soil moisture, maximum rooting depth, initial soil moisture depletion (% of total available moisture); soil infiltration rate
e) Scheduling Criteria – several options can be selected regarding the calculation of application timing and application depth (e.g. 80 mm every 14 days (d), or irrigate to return the soil back to field capacity when all the easily available moisture has been used).

Output of CROPWAT

Once all the data is entered, CROPWAT Windows automatically calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly. The output parameters for each crop in the cropping pattern are:

-Reference crop evapotranspiration – Eto (mm/period);

-Crop Kc - average values of crop coefficient for each time step;

-Effective rain (mm / period) - the amount of water that enters the soil;

-Crop water requirements – CWR or Etm (mm/period);

-Irrigation requirements – IWR (mm/period);

The crop and irrigation water requirements were determined from the inter-relationships of the ET, soil type, bulk density of the soil, field capacity and permanent wilting point of the soil. The crop ET (ET_C) was estimated by FAO Penman-Monteith equation (Allen *et al*., 1998).

RESULTS AND DISCUSSION

The pH (5.76) values indicated that the soil sample was acidic. The values of electrical conductivity (4.75 µS / cm) showed that composite soil sample was non saline in nature.
From the Table 1, it could be realised that the soil has very low organic carbon (0.51 %) and organic matter (0.87 %), resulting in low water holding capacity. This is further emphasized by Field Capacity, FC and Permanent Wilting Point, PWP values of 13.9 % and 3.2 %, respectively, as seen in Table 1. The soil also had very low clay content (3.9 %), supporting the findings by Senayah *et al.* (2009) that, within the drier Savannah agro-ecological zones, soils are relatively poor in clay content. The soil, however, showed appreciable levels of silt

(36.3 %) and is mostly silty loam in texture, with isolated areas of sandy loam . The water retention capacity was low, due to low clay and organic matter content as seen in Table 1.

The high dry bulk density (1.56 g / cm^3) value could be attributed to low organic matter and clay content in the soil, as well as little compaction, due to continuous cropping.

However the bulk density of the soil was within the range for agricultural soils, as indicated by Hillel (1982), who stated that the dry bulk density of most soils varies within the range of 1.1-1.6 g / cm^3. Due to the coarse textured nature of the soil (sandy loam) it is well drained with saturated hydraulic conductivity of 49.68 mm / h.

Table 1: Soil physical and chemical properties at the project site

pH (1:2.5)	EC (µS/cm)	OC (%)	N (%)	FC (%)	PWP (%)	Sat. (%)	Soil Texture (Sandy loam)			Sat. HC (mm/h)	Bulk Density (g/cm^3)
							% Sand	% Clay	% Silt		
5.76	4.75	0.51	0.05	13.9	3.2	41.3	59.8	3.9	36.3	49.68	1.56

(Source: field studies, 2016)

Soil Infiltration Rates

Infiltration is the downward movement of water from the land surface into the soil profile. Infiltration can occur naturally following precipitation, or can be induced artificially through structural modifications in the ground surface such as application of organic manure and tilling of the soils. The capacity can be expressed as a depth of water that can be infiltrated per unit time (usually in mm / h). The water infiltration rate of the soils at the experimental site varies between 5.3 mm / h for the downstream and 10.7 mm / h for the upstream, with the average water infiltration rate of 8 mm / h.

The soils of the experimental site can be categorized into hydrologic soils group A (8-12 mm / h) in terms of the infiltration rates of the soils (Rao and Karanth, 1988). The hydrologic soil group refers to the soil characteristics. Group A soils are sand, loamy sand, or sandy loam soil types; with low runoff potential and high infiltration rates, even when thoroughly wet. They are suitable for vegetables and upland arable crops, such as maize, cowpea, sorghum, groundnuts, yam and millet.

Tamale Climatic Water Balance

Mean annual rainfall for Tamale Metropolis is 1082.9 mm (Table 2), with almost all of the precipitation falling during the wet season (April- October), amounting to 1021.8 mm. According to the Ghana Meteorological Service, the mean dry season rainfall (November – March) is 61.1 mm. Mean annual moisture deficit is between 500 mm and 600 mm (Figure 3). As shown in Figure 3, there are periods within the year when there is the need for supplementary or full irrigation to ensure effective crop production. This period of water deficit is from Mid-October to Mid-June, during which period the monthly reference evapotranspiration exceeds the monthly rainfall amounts. However, effective wet season starts from Mid-June and lasts to Mid-October. In this period there is adequate moisture to support rain-fed crop production. Temperature in Tamale ranges between 21°C- 36 °C.

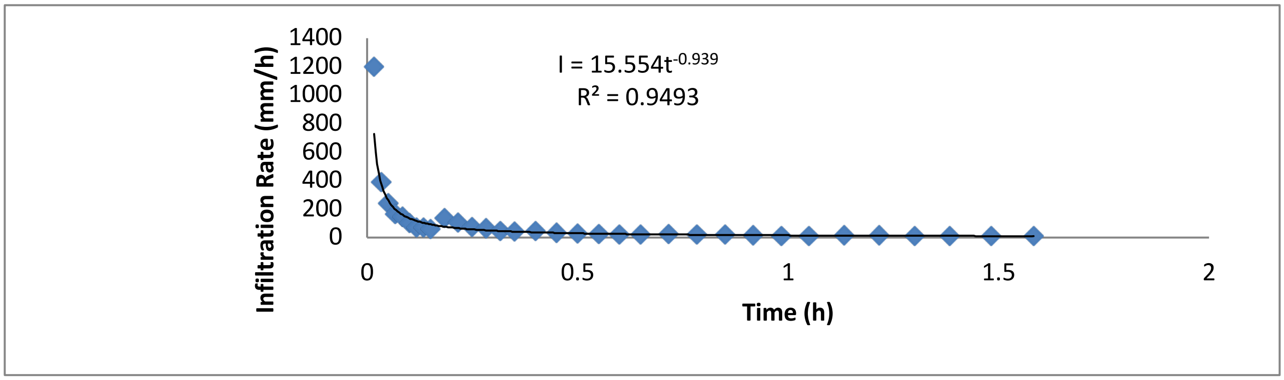

Figure 1: Soil infiltration rate for upstream location
(Source: field studies, 2016)

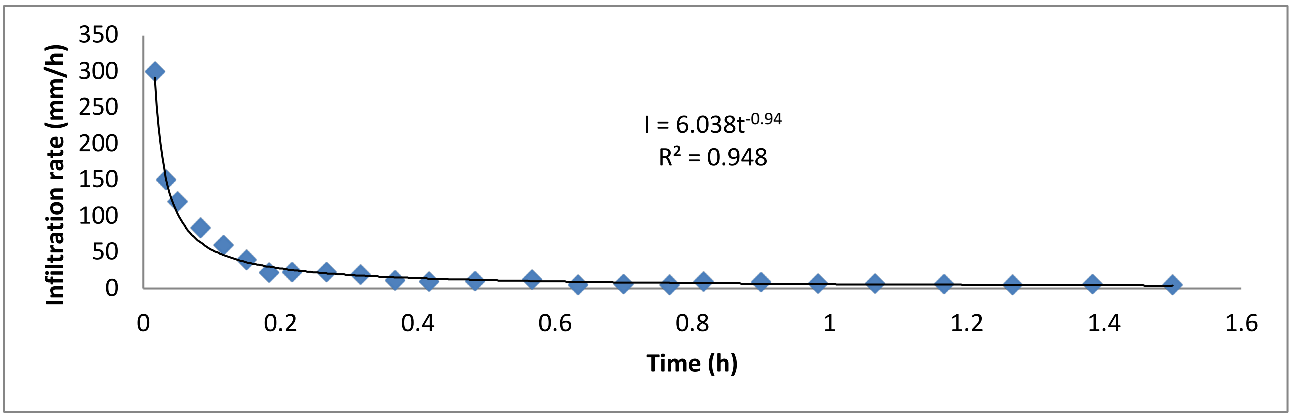

Figure 2: Soil infiltration rate for downstream
(Source: field studies, 2016)

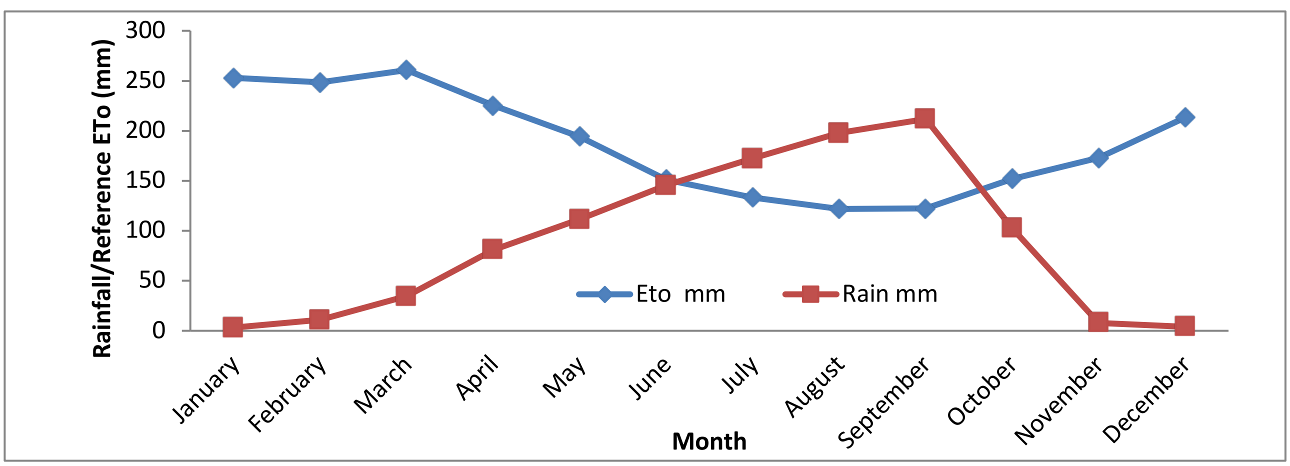

Figure 3: Climatic water balance for Tamale
(Source: field studies, 2016)

Effective Rainfall (ERF)

Effective rainfall is the amount of water available for crop growth from rainfall except surface runoff loss. Effective rainfall during irrigation seasons depends on rainfall amount, rainfall intensity, topography, soil infiltration rate, soil moisture, water management practices and so on. (Yoo *et al.,* 2008) The effective rainfall was calculated using the USDA S.C. Method in CROPWAT software. The average monthly rainfall data for 1986-2015, thirty (30) years from the Tamale Synoptic station was inputted into the software for the computation of both monthly and decadal effective (ERF) rainfall by the software. Table 2 presents the monthly ERF for the Tamale Synoptic station.

Table 2: Monthly climatic parameters for Tamale (1986-2015)

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day	Rain mm	Eff rain mm
January	19.0	35.9	25	320	7.7	18.8	8.16	3.2	3.2
February	22.8	38.0	31	346	7.9	20.3	8.87	11.0	10.8
March	25.8	38.6	45	354	7.2	20.3	8.41	34.5	32.6
April	26.0	36.9	60	389	7.6	21.2	7.51	81.0	70.5
May	24.9	34.6	69	354	7.8	21.1	6.27	111.3	91.5
June	23.5	32.0	77	320	7.3	19.9	5.05	145.2	111.5
July	23.0	30.5	81	302	5.9	18.0	4.30	172.1	124.7
August	22.8	30.2	83	259	5.0	17.0	3.93	197.7	135.2
September	22.6	31.1	82	190	5.8	18.2	4.07	211.8	140.0
October	22.9	33.5	76	190	8.2	21.0	4.90	102.7	85.8
November	21.9	36.1	60	207	9.0	20.9	5.76	8.1	8.0
December	19.5	36.2	40	268	8.3	19.2	6.89	4.3	4.3
Average/ Total	22.9	34.5	61	292	7.3	19.7	6.18	1082.9	818

(Source: field studies, 2016)

Water Requirement at Different Growth stage of 'Ayoyo', Cabbage, Carrot, Amaranthus and Lettuce

Crops and Irrigation Requirements for 'Ayoyo' (*Corchorus spp*)

'Ayoyo' (*Corchorus spp*) is a crop that matures in 70 - 100 d with 20 d initial period, 25 d for crop development, 30 d for mid-season and 25 d for late season. Due to repeated harvesting it is cultivated from the mid-November, at the beginning of the dry season to January. The crop water requirement during this period varied from 4.03 mm / d to 8.81 mm / d (Table 3), with total seasonal crop water requirement of 701.2 mm. However, the net irrigation water requirement in mm / d for `*Ayoyo*` is from 4.03 mm / d to 9.53 mm / d with total seasonal net water requirement of 688 mm, when effective rainfall is considered (Table 3).

Table 3: Crop water requirement for 'Ayoyo' (*Corchorus spp*)

Month	Decade	Stage	Kc coeff	ETc mm/d	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/d	Irr. Req. mm/dec
Nov	2	Init	0.70	4.03	24.2	0.0	4.03	24.2
Nov	3	Init	0.70	4.30	43.0	0.4	4.26	42.6
Dec	1	Deve	0.73	4.75	47.5	1.8	4.58	45.8
Dec	2	Deve	0.86	5.94	59.4	1.3	5.81	58.1
Dec	3	Mid	1.01	7.37	81.0	1.2	7.98	79.8
Jan	1	Mid	1.05	8.15	81.5	0.9	8.06	80.6
Jan	2	Mid	1.05	8.60	86.0	0.7	8.53	85.3
Jan	3	Late	1.05	8.81	96.9	1.6	9.53	95.3
Feb	1	Late	0.98	8.56	85.6	2.3	8.33	83.3
Feb	2	Late	0.90	8.10	81.0	3.0	7.81	78.1
Feb	3	Late	0.86	7.51	15.0	1.4	1.50	15.0
Total					701.2	14.6		688

(Source: field studies, 2016)

Crops and Irrigation Requirements for Cabbage (*Brassica oleracea var capitata*)

Cabbage crop matures in 90-120 d, with 20 / 30 d initial period including nursing, 30 / 40 d for crop development, 25 / 35 d for mid-season and 15 d for late season. It is cultivated from the mid-November at the beginning of the dry season to March, with the crop water requirement varied from 4.03 mm / d to 9.43 mm / d (Table 4) and with total seasonal crop water requirement of 851.2 mm. The net irrigation water requirement (mm / d) for Cabbage is 4.03 mm / d to 9.53 mm / d with total seasonal net water requirement of 819.4 mm.

Table 4: Crop water requirement for Cabbage (*Brassica oleracea var capitata*)

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/d	Irr. Req. mm/dec
Nov	2	Init	0.70	4.03	24.2	0.0	4.03	24.2
Nov	3	Init	0.70	4.30	43.0	0.4	4.26	42.6
Dec	1	Init	0.70	4.56	45.6	1.8	4.38	43.8
Dec	2	Deve	0.72	4.95	49.5	1.3	4.82	48.2
Dec	3	Deve	0.81	5.89	64.8	1.2	6.36	63.6
Jan	1	Deve	0.90	6.95	69.5	0.9	6.86	68.6
Jan	2	Deve	0.99	8.05	80.5	0.7	7.98	79.8
Jan	3	Mid	1.05	8.81	96.9	1.6	9.53	95.3
Feb	1	Mid	1.05	9.15	91.5	2.3	8.91	89.1
Feb	2	Mid	1.05	9.43	94.3	3.0	9.13	91.3
Feb	3	Late	1.05	9.22	73.8	5.6	6.82	68.2
Mar	1	Late	1.00	8.58	85.8	7.9	7.79	77.9
Mar	2	Late	0.95	7.99	31.9	4.0	2.69	26.9
Total					851.2	30.8		819.4

(Source: field studies, 2016)

Crops and Irrigation Requirements for Lettuce (*Lactuca sativa*)

Lettuce matures in 75-100 d with 20 / 25 d initial period, 30 / 35 d for crop development, 15 / 30 d for mid-season and 10 d for late season. It is cultivated from the mid-November at the beginning of the dry season to February. The crop water requirement varied from 4.03 to 9.19 mm / d (Table 5). Total seasonal crop water requirement was 695.5 mm. However, the net irrigation water requirement (mm / d) for lettuce varied from 4.03 mm / d to 8.96 mm / d. Total seasonal water requirement was 682.2 mm when irrigation was considered with effective rainfall (Table 5).

Table 5: Crop water requirement for lettuce (*Lactuca sativa*)

Month	Decade	Stage	Kc coeff	ETc mm/d	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/d	Irr. Req. mm/dec
Nov	2	Init	0.70	4.03	24.2	0.0	4.03	24.2
Nov	3	Init	0.70	4.30	43.0	0.4	4.26	42.6
Dec	1	Deve	0.70	4.57	45.7	1.8	4.39	43.9
Dec	2	Deve	0.77	5.28	52.8	1.3	5.15	51.5
Dec	3	Deve	0.87	6.39	70.2	1.2	6.90	69.0
Jan	1	Deve	0.98	7.59	75.9	0.9	7.49	74.9
Jan	2	Mid	1.05	8.60	86.0	0.7	8.53	85.3
Jan	3	Mid	1.06	8.87	97.6	1.6	9.60	96.0
Feb	1	Mid	1.06	9.19	91.9	2.3	8.96	89.6
Feb	2	Late	1.02	9.14	91.4	3.0	8.85	88.5
Feb	3	Late	0.96	8.42	16.8	1.4	1.68	16.8
Total					695.5	14.6		682.2

(Source: field studies, 2016)

Crops and Irrigation Requirements for Carrot (*Daucus carota*)

Carrot matures in 100-120 d, with 20 d initial period including nursing, 30 d for crop development, 30 / 50 d for mid-season and 20 d for late season. It is to be cultivated from the mid-November to March, with the crop water requirement from 4.03 to 10.37 mm / d (Table 6) and total seasonal crop water requirement of 953.1 mm. The net irrigation water requirement (mm / d) for Carrot varied from 4.03 mm / d to 10.52 mm / d. The total seasonal water requirement is 921.3 mm when irrigation is considered with effective rainfall (Table 6).

Table 6: Crop water requirement for carrot (*Daucus carota*)

Month	Decade	Stage	Kc coeff	ETc mm/d	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/d	Irr. Req. mm/dec
Nov	2	Init	0.70	4.03	24.2	0.0	4.03	24.2
Nov	3	Init	0.70	4.30	43.0	0.4	4.26	42.6
Dec	1	Deve	0.73	4.77	47.7	1.8	4.59	45.9
Dec	2	Deve	0.87	6.03	60.3	1.3	5.89	58.9
Dec	3	Deve	1.03	7.57	83.2	1.2	8.20	82.0
Jan	1	Mid	1.15	8.91	89.1	0.9	8.82	88.2
Jan	2	Mid	1.16	9.44	94.4	0.7	9.37	93.7
Jan	3	Mid	1.16	9.71	106.8	1.6	10.52	105.2
Feb	1	Mid	1.16	10.06	100.6	2.3	9.83	98.3
Feb	2	Mid	1.16	10.37	103.7	3.0	10.07	100.7
Feb	3	Late	1.13	9.91	79.3	5.6	7.37	73.7
Mar	1	Late	1.03	8.86	88.6	7.9	8.06	80.6
Mar	2	Late	0.96	8.08	32.3	4.0	2.72	27.2
Total					**953.1**	**30.8**		**921.3**

(Source: field studies, 2016)

Irrigation Requirement for Amaranthus (*Amaranthus candatus*)

Amaranthus (*Amaranthus candatus*) matures in 75-100 d with several harvests, taking at least two and half to three months, 20 d initial period including nursing, 25 / 30 d for crop development, 20 / 30 d for mid-season and 10 / 20 d for late season. It is to be cultivated from the mid-November at the beginning of the dry season to January, the crop water requirement varied from 4.03 to 9.75 mm / d (Table 7), given total seasonal crop water requirement of 755.1 mm. However, the net irrigation water requirement (mm / d) for amaranthus varied from 4.03 mm / d to 10.53 mm / d given total seasonal water requirement of 741.8 mm when irrigation is to be considered with effective rainfall (Table 7).

Table 7: Crop water requirement for amaranthus (*Amaranthus candatus*)

Month	Decade	Stage	Kc coeff	ETc mm/d	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/d	Irr. Req. mm/dec
Nov	2	Init	0.70	4.03	24.2	0.0	4.03	24.2
Nov	3	Init	0.70	4.3	43.0	0.4	4.26	42.6
Dec	1	Deve	0.73	4.77	47.7	1.8	4.59	45.9
Dec	2	Deve	0.88	6.03	60.3	1.3	5.90	59.0
Dec	3	Deve	1.04	7.57	83.3	1.2	8.21	82.1
Jan	1	Mid	1.15	8.92	89.2	0.9	8.83	88.3
Jan	2	Mid	1.16	9.45	94.5	0.7	9.39	93.9
Jan	3	Mid	1.16	9.72	107.0	1.6	10.53	105.3
Feb	1	Late	1.12	9.75	97.5	2.3	9.52	95.2
Feb	2	Late	1.02	9.15	91.5	3.0	8.85	88.5
Feb	3	Late	0.96	8.42	16.8	1.4	1.68	16.8
Total					755.1	14.6		741.8

(Source: field studies, 2016)

CONCLUSION

The soil of the experimental site was low in organic matter content, slightly acidic but not saline and also has low water holding capacity due to its limited amount of clay content. The site however, is well drained and is therefore, suitable for cultivation of vegetables and upland arable crops, such as maize, cowpea, sorghum, groundnuts, yam and millet, considering its soil properties. Climate conditions, however demand considerable irrigation to supply rainfall in the period mid- November to March.

The crop water requirement and net irrigation demand have been calculated for each of the crops selected for cultivation in order to develop an appropriate cropping schedule and estimate the need for irrigation water for the season.

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