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Performance Evaluation Of Drip Irrigation System Under Onion Crop In Semi-Arid Region Of Eastern Rwanda

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Abstract – Efficient irrigation systems are needed not only to reduce environmental hazard but also to promote sustainable utilization of water resources. Drip irrigation is common irrigation systems that can save water and increase crop production by transferring small amounts of water frequently to the periphery of the roots of plants. So far, to establish a better irrigation system, it is necessary to improve onion growth, and yield. The present study was carried out to evaluate drip irrigation in 8 hectares for growing different crop particular onion vegetableat The Fresh Gate East Africa farm located in Rwamagana district, of Eastern province of Rwanda. A research study was conducted from January to May, 2020. The meteorological data were collected and analysed. Soil physical properties like soil texture, bulk density and infiltration rate were determined. The observations on water application through drippers and performance indicators were assessed. The results revealed that the rainfall in the study area is not sufficient in all decades of the months taken for crop period so irrigation is inevitable. The soil of the area is sandy loam and suitable for crop production. The performanceindicators like Distribution efficiency (Ed), application efficiency (Ea), field emission uniformity (EUf), Absolute emission uniformity (EUa) and design emission uniformity (EUd) with the corresponding values of 91.66, 88.23%, 91.20%, 89.25% and 78.60% respectively were fitting in the standards of good to excellent performance. The value of coefficient of variance (Cv) with 0.085 falls in the category of marginal While statistical uniformity coefficient (SUC) with 91.5% presents good to perfect drip system.

We conclude that drip irrigation has increased more 100% of onion production with the harvest of 12 Tons/Ha at FGEA Farm. It is therefore recommended that drip system is highly efficient irrigation system for Rwandan conditions and can easily be promoted through farmer's sensitization and government support.

Keywords – Drip irrigation, Emitter, Efficiency, Onion.

I.INTRODUCTION

Water use efficiency has a significant role in addressing the challenges faced by the agricultural water use (Robert and John, 2008). While irrigation can increase yields of most crops by 100 to 400 percent, water resources remain limited. Enhancing water use efficiency requires actions at all levels, from agricultural practitioners to scheme managers, and up tothe policy-makers.

Water scarcity is becoming more frequent and durable, and should, thus, be addressed by better irrigation practices. In light of the exacerbating water scarcity, the efficiency of irrigation water should be increased as possible and supply should carefully match crop water requirement (Maher et al., 2019). Currently, this water balance approach is missing and farmers are in lack of monitoring tools. In areas where irrigation is needed, efficient technologies such as drip irrigation can reduce water consumption by 30 to 70 percent and improve yields by 30 to 200 per cent for various crops like onion, beans, maize and wheat (Maher et al., 2019).

Drip irrigation has shaped the economies of many semiarid and arid areas, permanently coloring the social fabric of numerous regions around the world. It has stabilized rural communities, increasing income and providing many new opportunities for economic advancement (Robert and John, 2008).

Soil monitoring and irrigation scheduling are also helpful techniques in this area. In addition, more efficient water management in agriculture, including improved watershed management, can considerably reduce soil degradation by minimizing runoff that washes out nutrients (Maher et al., 2019).

Economic growth in Rwanda relies critically on agricultural growth, yet Rwanda's agricultural sector faces critical constraints such as fragmentation, dependence on erratic rainfall, and challenging geography. As the country's agriculture is mostly rain-fed, production is exposed to climatic variation and unreliable rainfall.

Rwanda initiated the development of a strategy to fight poverty focused on improved crop production through irrigation. Rwanda is adopting strategies to intensify both food and cash crop production and to increase investment in support infrastructure. Importantly, irrigation has been identified as a key strategic activity (RIMP, 2010).

Although Rwanda possesses considerable water resources, they are not evenly distributed. For example, while water is abundant in the marshlands, facilities for storing it elsewhere are lacking. This explains why farming during dry seasons is limited.

In order to enhance land and water productivity, Government of Rwanda is promoting drip irrigation systems amongst the farmers. The system is highly efficient and has potential to increase crop yield up to 3 times of rain fed crop yields, it contribute to food security and reduce public expenditure on food purchased abroad in case of prolonged droughts. The advantage is that it can operate with little water pressure in the hillside. Hillsides locations with water sources (lake, river, stream etc) or water harvesting potential can easily be exploited for using drip irrigation system on onion production. In Rwanda, drip irrigation investments have enormous potential to improve the lives of smallholder farmers who otherwise depend on rain-fed agriculture, through improving onion yields, increasing cultivation in the dry season, and reducing risk. Also, water conservation can lead to decreased energy use and associated air pollution associated with pumping and treating less irrigation water (Florence and Maria, 2018).

The Fresh Gate East Africa farm is located in Rwamagana district of Eastern province and using drip irrigation in 8 hectares for growing banana, maize and vegetables (onion, tomato, cabbage and pepper). In order to assess the performance evaluation of drip irrigation on oniona research study was undertaken during January to May, 2020.

II.Materials And Methods

Site description

The study was carried out in Fresh Gate East Africa Farm located in Munyiginya Sector of Rwamagana district, Rwanda. The farm is located at 30°21'59'' E longitude 1°52'47''S latitude and 1535 m elevation above mean sea level near Lake Muhazi which is the source irrigation water. The study area represents tropical savanna wet climate with an average annual rainfall of 855mm. The total coverage area of the irrigation scheme 20ha with irrigated area of 8ha. The type of irrigation system is drip system.

Climate

The climate is a moderate tropical climate with four seasons (two dry and two wet seasons), with a tendency to aridity. The rainfall increases during the months of April-May and October-December of every year. The District has very fertile soils (Rwamagana DDPdocument, 2013).

Average annual precipitation based on 30 years (1988 – 2017) data is 1059mm while the average temperature ranges between 19^o C and 30^o C with the minimum of 13^{o}C andmaximum of 30^{o}C sometimes exceeding, and less variability throughout the year.

Hydrology

The hydrographic network of the District of Rwamagana belongs to the river Akagera basin, the main tributary of Lake Victoria. The District has Lake Mugesera in the South and Lake Muhazi in the North, two rivers Sumo and Nyabarongo and accounts for some marshes gorged with water namely: Cyaruhogo, Bigezi, Kavura, Rwarugaju, Nyabarongo, Mutukura, Ruhita, Cyimpima, Rwandenzi, Sumo which constitute a significant potential for rice growing and horticultural production (Rwamagana DDP document, 2013).

Computer Software

The computer software used was CROPWAT Version 8.0. (FAO, 1992) The CROPWAT version 8 was originally developed by the FAO to determine crops water requirements and irrigation scheduling.

Data Sources and Data Processing

Meteorological data of Gishari station of Rwamagana district were obtained from the Rwanda Meteorological Agency. Monthly rainfall data of 30 years (1988-2017) while 5 years data of minimum and maximum temperature, sun shine hours, wind velocity and relative humidity from 2013-2017 were used. The average monthly data of such climatic components were used as an input data for CROPWAT 8 software.

Design and soil sampling

Drip irrigation with specifications at FGEA farm

This section comprises of the water source, pumping systems, main pipes, sub-main, lateral pipe, spacing between plant to plant (20cm) and row to row (30cm). The water source was Muhazi lake from where water is pumped to a reservoir of 4000 cum. Capacity. The water is brought to field by gravity through main, sub-main and laterals and apply to plants by emitters fitted on laterals. The size of main pipe, sub-main and lateral are of the size of 75mm, 32mm and 16mm respectively. The inline drippers spaced at 20cm are used on 50m long lateral to emit water at a rate of 2.2 l/h.

Modeling of crop water requirement and drip irrigation scheduling of onion

Using CROPWAT 8.0, the determination of ETo and ETc along with decade wise irrigation requirement was done.

Performance testing of drip irrigation system

Performance evaluation of drip irrigation system installed at Fresh Gate East Africa Farm at Rwamagana. It was made to work efficiently. Four laterals were selected from inlet end,1/3rd down, 2/3rd down and far end on the sub-main.

Similarly, the discharge of emitters was measured using catch can for 3 minutes from the emitters at the inlet end, 1/3rd distance, 2/3rd distance and far end on each selected lateral. The constant operating pressure of 0.5 kg/cm^2 was maintained throughout the period of application. Evaluation of the system was done by the equations as suggested by different scientists.

Performance testing of drip irrigation system was done through computations of a) Distribution Efficiency, b) Field emission uniformity c) Design emission uniformity d) Coefficient of variation and e) Statistical Uniformity Coefficient of the drip irrigation system.

a) Distribution Efficiency of drip system (Ed)

The distribution efficiency determines how uniformly irrigation water can be distributed through a drip irrigation system in to the field. Wu and Gitlin (1973) used the statistical approach for obtaining irrigation uniformity as suggested by Christiansen. They gave the following relationship:

$$Ed = \left(1 - \frac{\Delta qa}{qm}\right) \text{ ------------- eq.(5)}$$

Where,

Ed=distribution efficiency (%) or uniformity coefficient,qm = mean emitter flow rate (l/h)

Δqa = average absolute deviation of each emitter flow from the mean emitter flow

b) Application Efficiency of drip system (Ea)

The application efficiency is defined as the ratio of water required in the root zone to the totalamount of water applied (Arya et. Al., 2017) and can be expressed as,

$$Ea = \left(\frac{Qmin}{Qavg}\right) \times 100 \text{ ----------------eq.(6)}$$

Where:

Ea=application efficiency, %,

Qmin= minimum emitter flow rate (l/h) and

Qavg= average emitter flow rate (l/h)

c) Field emission uniformity of drip system (EUf)

To define the uniformity of water application by drip irrigation method, Keller and Karmeli (1974) suggested two parameters, namely field emission uniformity (EU_f) and absolute emission uniformity (EU_a). The relations are given as under:

$$EUf = \left(\frac{qn}{qa}\right) \times 100 \text{ --------------eq.(7)}$$

Where:

EUf = Field emission uniformity,

qn= The average of lowest 1/4th of the emitter flow rate (l/h),

qa = The average of all emitters flow rate (l/h)

d) Absolute emission uniformity (EUa)

The absolute emission uniformity, Eua, gives a concept of the overall uniformity of an operating drip irrigation system. It is a function of the minimum, mean and maximum emitterdischarges. It is defined by the equation

$$EUa = \left[\frac{Qmin}{Qavg} + \frac{Qavg}{Qx}\right] \times \frac{1}{2} \times 100 \text{-eq.(8)}$$

Where:

EUa = Absolute emission uniformity,

Qmin= minimum flow rate through emitter, l/h

Qavg =average flow rate through emitter (l/h),

Qx = average of the highest 1/8th of the emitters flow rate (l/h).

e) Design emission uniformity (EUd)

Keller and Karmeli (1974) suggested design emission uniformity by the following equation:

$$EUd = 100 \times \left[1 - 1.27 \frac{V_m}{N_e^{0.5}}\right] \times \frac{q_{min}}{q_{avg}} \text{ -eq.(9)}$$

Where:

EUd=design emission uniformity, (%),

Vm= manufacturing coefficient of variation

Ne=number of emitters per plant,

q_{min}=minimum flow rate through emitter, l/h

q_{avg}= average flow rate through emitter, l/h

f) Coefficient of variation (Cv)

The coefficient of variation (CV) is a statistical measure of the dispersion of data points in adata series around the mean. The coefficient of variation represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation fromone data series to another, even if the means are drastically different from one another.

$$Cv = \frac{S}{qm} \text{-----------------------------eq.(10)}$$

Where,

Cv= Coefficient of variation of emitter flow,

S = Standard deviation of the emitter flow

q_m= average flow rate through emitter (l/h)

g) Statistical Uniformity Coefficient of the drip irrigation system (SUC).

The statistical uniformity coefficient describes the uniformity of drip water distributionassuming a normal distribution of flow rates from the emitters.

Statistical Uniformity Coefficient (SUC) = 1 - C_v ---eq.(11)

Where,

SUC =Statistical Uniformity CoefficientC_v= Coefficient of variation

h) Comparison of yield of onion under drip and conventional production

The yield obtained from onion crop under drip irrigation system and adjacent farms using and conventional irrigation was compared.

Statistical analysis

The findings of drip irrigation performance were classified in good, moderate, excellent ortypical, marginal and acceptable depending on their values.

III.RESULTS AND DISCUSSION

Rain fall and Effective rainfall

The historical rainfall data of 37 years (1981-2017) was gathered from website of Rwanda Meteorological Agency (www.maproom.meteorwanda.gov.rw). The rainfall data was used asan input data for CROPWAT 8. The following **Figure 1** illustrates the monthly average rainfall and effective rainfall.

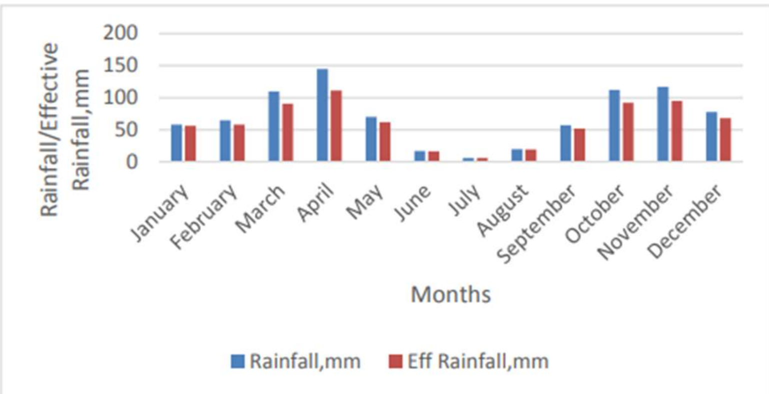


Figure 1: Rainfall and Effective rainfall of study area

It is evident from **Figure 1** that the highest rainfall of 145mm is received during April. The other months where rainfall of more than 100mm is received are November, October and March with 117mm, 112mm and 110mm respectively. These all months fall in the rainy seasons. The driest month of study area is July with 6mm rainfall followed by June (17mm) and August (20mm). Remaining months receive above 50mm of rainfall. It is also evident that effective rainfall is proportionally dependent on rainfall and its amount increases or decreases according to variation of rainfall.

Maximum and Minimum Temperatures

The data of average maximum and minimum temperature were gathered for 56 years (1961- 2016). The Figure 2 presents the month wise average maximum and minimum temperatures.

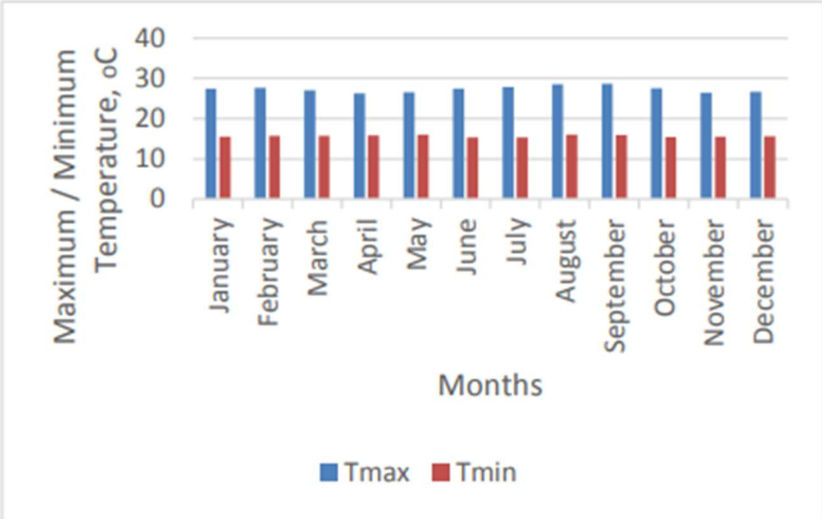


Figure 2: Maximum and Minimum Temperatures

It is clear from the **Figure 2** that the average maximum monthly temperature ranges from 26.3°C to 28.6°C andthe minimum temperature ranges from 15.3°C to 16.05°C. The month of September was the hottest with 28.6°C while the month of April was coldest with 26.3°C of maximum temperature. The average minimum temperature recorded was lowest in the month of July (15.3°C) while highest minimum temperature was recorded during August (16.05°C).

a) Relative Humidity and Rainfall

The mean monthly relative humidity percentage and the monthly rainfall in mm are presented in Figure 3.

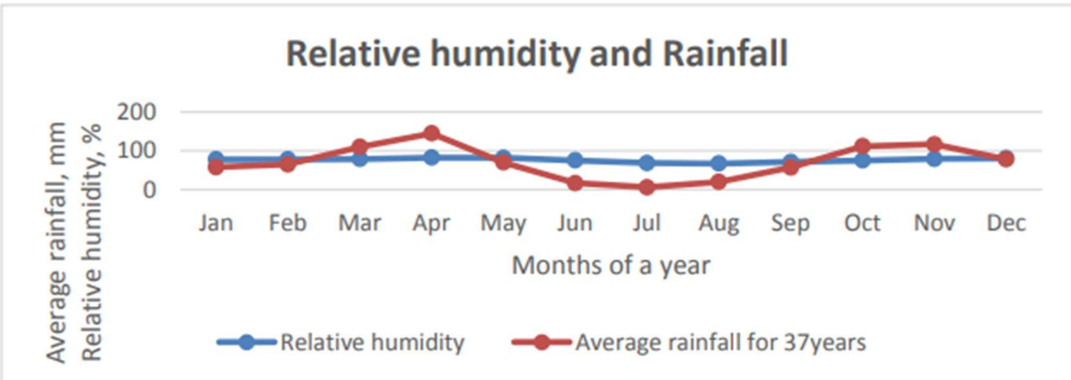


Figure 3: Relative Humidity and Rainfall

As shown in the **Figure 3** it is clear that during rainy season, the percentage of relative humidity is more as compared to dry season. The month of long rainy season viz March (110mm), April (145mm)and May (70mm) present 78.9%, 82.3% and 82% relative humidity. The same thing is evident in the months of short rainy season having months of September (57mm), October

(112mm), November (117mm) and December (78mm) with relative humidity of 71.3%, 75.1%, 79.1% and 80.6% respectively. The lowest relative humidity was found in the month of August (20mm) with 67.3% followed by July (6mm) with relative humidity of 68.7%. Though July is the driest month, it presents second lowest relative humidity. The reason of August having lowest RH is due to its driest preceding month.

b) Wind speed and sunshine hours

The **Figure 4** generated by CROPWAT 8 presents the monthly average sun shine hours and wind speed in km/day. From the figure, it is evident that highest sun shine hours are observedduring July with 8.0 hours followed by June, August and September with 7.0, 7.0 and 7.0 hours respectively. The lowest sun shine hours are observed during December with 4.0 hours.The **Figure 4** also presents the average monthly wind speed. It ranges from 6.4 km/day to 8.5km/day. The highest wind speed found was 8.5 km/day during June, July and August followed by 7.9km/day during September. Most of these months are in dry season.

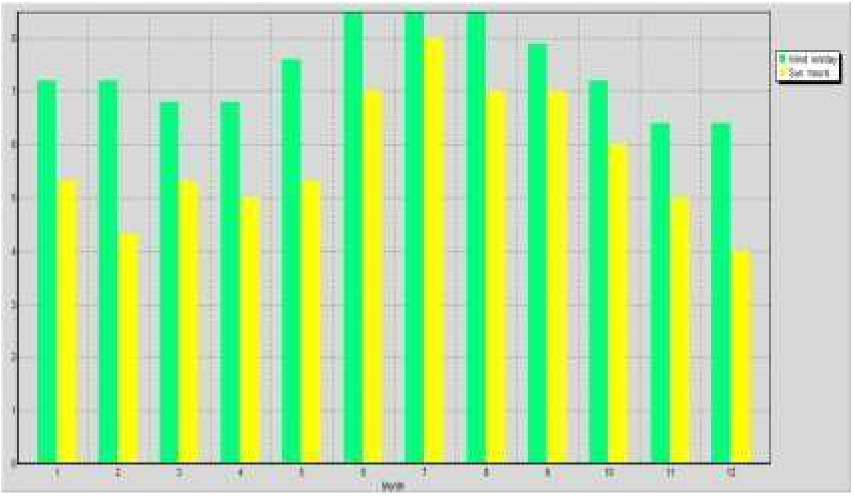


Figure 4: Wind speed and sunshine hours

Irrigation water requirement and irrigation schedule for onion

As evident from **Figure 5**, the highest irrigation requirement is during 3rd decade of January with 12.5mm followed by 2nd decade of same month and 1st decade of February with 11.1 and8.7mm respectively. It is because during these month and decades ETc was 30.1mm, 27.7mmand 26.7mm respectively.

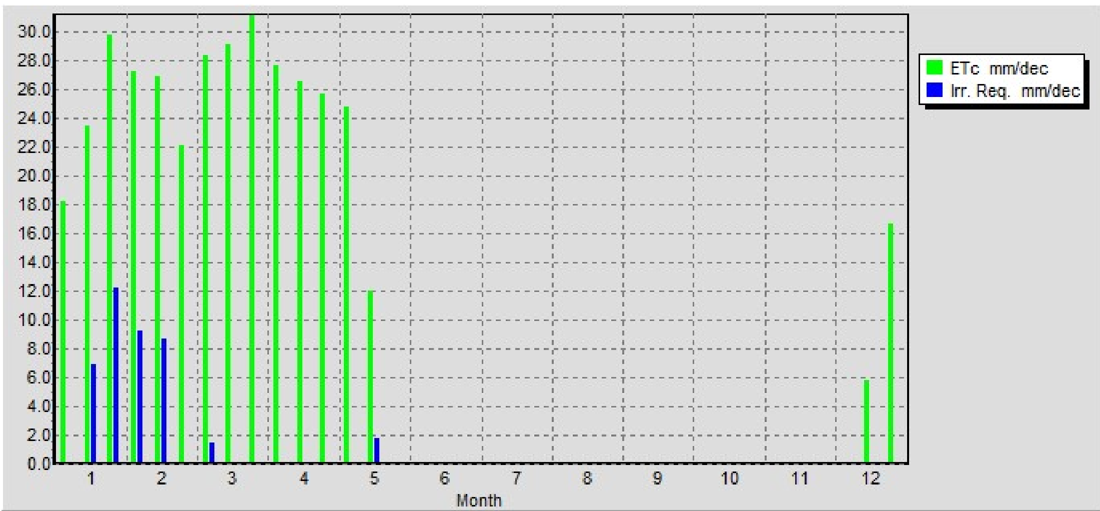


Figure 5: Effective rainfall and ETc

During this period the effective rainfall was 17.5mm, 16.6 and 18mm. To compensate the deficit moisture irrigation was needed.

It is also the case for other decades where irrigation was needed.

Analysis of soil characteristics of the FGEA farm

The soil characteristics studied are 1) soil texture 2) bulk density of soil and 3) Infiltration rate of soil. These soil characteristics play an important role in soil water plant relationship**.**

Soil texture

Soil texture is one of the important characteristics of soil. It describes the proportion of sand, silt and clay particles. The soil samples were analyzed using hydrometer method in the laboratory at University of Rwanda-CAVM, Busogo campus.

Soil texture at 0 to 90 cm

The results of soil textural analysis of soil samples taken from three onion plots at the soil depth of 0 to 30 cm, 30 to 60 cm and 60 to 90 cm are presented in **Table 1** and show the average clay average percentage ranging from 19.86% to 19.89%. The silt percentages withinall the plots was found as range of 0.05% to 0.06% whereas sand was dominating soil particle ranging from 80.05% to 80.10%.

Table 1: Soil texture of the experimental field at the depth of 0 to 30 cm

Crop	Plots	Soil depth, cm	Average Clay %	Average Silt %	Average %	Soil texture based on Textural Triangle
Onion	3Plots	0-30	19.89	0.06	80.05	Sandy loam
Onion	3Plots	30-60	19.88	0.05	80.05	Sandy loam
Onion	3Plots	60-90	19.86	0.06	80.10	Sandy loam

The classification of soil from all the plots at 0 to 90 cm was found as sandy loam soil.

Bulk density of soil at 0 to 90 cm depth

The results of soil bulk density analysis of soil samples taken from three onion plots at the soil depth of 0 to 30 cm are presented in **Table** and show the bulk density ranging from 1.10 gm/cm^3 to 1.12 gm/cm^3 which is ideal for plant growth.

Table 2: Bulk density of soil samples taken at 0 to 90 cm depth

S.No	Plots	Average Depth (cm)	Average Oven dry weight, gm	Average Volume, cm^3	Average BD, gm/cm^3
1	Plot 1,2,3	0-30 cm	125.30	113.47	1.10
2	Plot 1,2,3	30-60 cm	114.73	102.05	1.12
3	Plot 1,2,3	60-90 cm	101	90.77	1.11

Suitability of soil texture and soil bulk density for crop root growth

The Soil Quality Kit guidelines given by the USDA, Natural Resources Conservation Services was used to compare the soil texture of the experimental plots and the soil bulk densities computed for different depth of soils of the experimental plots. As presented in **Table** , all three samples from plots 1, 2 and 3 from 0 to 90 cm depth are ideal for plant growth as their bulk densities are always lesser compared to the prescribed bulk densities for ideal plant growth and the soil texture is sandy loam.

Table 3: Suitability of soil texture and soil bulk density for crop root growth

Soil Depth Cm	Soil texture	Average Bulk Density (BD) of experimental plots, gm/cm^3.	USDA-NRCS guidelines Bulk Density (BD) in gm/cm^3 and soil texture			Remarks
			Ideal BD forplant growth	BD that affect root growth	BD that restrict root growth	
0–30	Sandy loam	1.10	< 1.40	< 1.63	>1.80	Bulk density of 1.10 gm/cm^3 is ideal for plant growth
30-60	Sandy loam	1.12	< 1.40	< 1.60	>1.75	Bulk density of 1.12 gm/cm^3 is ideal for plant growth
60-90	Sandy loam	1.11	< 1.40	< 1.60	>1.75	Bulk density of 1.11 gm/cm^3 is ideal for plant growth

As evident from the results found for soil texture, the sandy loam soil is good for root development; however, its water holding capacity is comparatively low and any crop grown on such soils need frequent irrigation during dry periods.

Infiltration rate of soil at FGEA farm

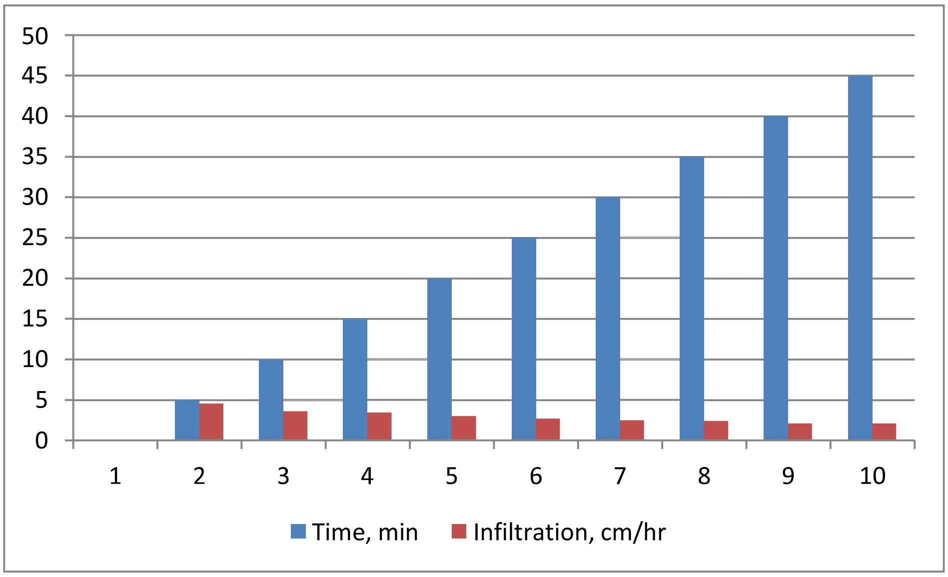
The infiltration rate is the speed at which water enters into the soil. It is usually measured by the depth in mm or cm of the water layer that can enter the soil in one hour. The **Table 2** shows the results obtained during the experiment.

Table 2: Infiltration rate of soil in experimental plots

Time, min	Before filling	After filling	Infiltration, mm	Infiltration, mm/hr	Infiltration, cm/hr
0		155			
5	151.2	155	3.8	45.6	4.56
10	149	155	6	36.0	3.6
15	146.4	155	8.6	34.4	3.44
20	145	155	10	30.0	3.00
25	143.8	155	11.2	26.88	2.69
30	142.6	155	12.4	24.8	2.48
35	141	155	14	24.0	2.40
40	140.7	155	14.3	21.44	2.14
45	138.92	155	16.08	21.44	2.14
Average				29.4	2.94

Table 2 shows the infiltration rate of the soil in the onion field. It is evident that in the beginning when soil moisture in selected site is low, the infiltration rate is high. As time elapses, the infiltration rates get reduced. Finally, it becomes constant, which is also called basic infiltration rate. The average infiltration rate of the experimental field at FGEA site found to be 2.9 cm/hour or 29.3 mm/hour. The basic infiltration rate found was 21.44mm/hr.

The range of infiltration rate of the experimental plot was found from ***Annexure 3*** (FAO, 2002) also verify that the soil falls under the category of sandy loam. As per Majumdar (2000) classification of infiltration rate of the soil from ***Annexure 2***, the experimental plot at FGEA farm was found to be moderate infiltration rate.



The figure above shows the infiltration rate in cm/hr and time taken to infiltrate in minutes ony axis and number of observations on x axis. The infiltration was so speedy after the first 5min and relaxed as the time goes on.

Performance evaluation of drip irrigation system

Performance evaluation of drip irrigation system was done through computations of Distribution Efficiency, b) Application Efficiency c) Field emission uniformity d) Design emission uniformity e) Coefficient of variation and f) Statistical Uniformity Coefficient of thedrip irrigation system.

a) Distribution Efficiency of drip system (Ed)

The distribution efficiency (Ed) determines how uniformly irrigation water can be distributed through a drip irrigation system in to the field

$$Ed = \left(1 - \frac{\Delta qa}{qm}\right)$$

Ed=distribution efficiency (%) or uniformity coefficient,

qm = mean emitter flow rate (l/h)

Δqa = average absolute deviation of each emitter flow from the mean emitter flow

$$Ed = \left(1 - \frac{0.085}{1.02}\right) X\ 100 = 91.66\%$$

Ed or uniformity coefficient of drip irrigation system was 91.66%

According to Al-Ghobari (2012), the distribution efficiency or uniformity coefficient 91.66%is above the acceptable uniformity level 80%.

b) Application Efficiency of drip system (Ea)

The application efficiency is defined as the ratio of water required in the root zone to the totalamount of water applied. It can also be expressed by the following relationship.

$$Ea = \left(\frac{Qmin}{Qavg}\right) \times 100$$

Where,

Ea=application efficiency, %,

Qmin= minimum emitter flow rate (l/h) and

Qavg= average emitter flow rate (l/h)

$$Ea = \left(\frac{0.90}{1.02}\right) \times 100 = 88.23\%$$

According to Raghuwanshi (2013), the application efficiency 88.23% falls in the range of 70

-95% which is typical value for line source emitter in drip irrigation.

c) Field emission uniformity of drip system (EUf)

To define the uniformity of water application by drip irrigation method, Keller and Karmeli (1974) suggested two parameters, namely field emission uniformity (EU_f) and absolute emission uniformity (EU_a). The relations are given as under:

$$EUf = \left(\frac{qn}{qa}\right) \times 100$$

Where,

EUf = Field emission uniformity,

qn= The average of lowest 1/4th of the emitter flow rate (l/h),

qa = The average of all emitters flow rate (l/h)

$$EUf = \left(\frac{0.93}{1.02}\right) \times 100 = 91.2\%$$

According to Sharu and Razak (2020), the performance indicator from the

Annexure 10 shows that the field emission uniformity 91.2% is above 90% and it is found to be excellent.

d) Absolute emission uniformity (EUa)

The absolute emission uniformity, EUa, gives a concept of the overall uniformity of an operating drip irrigation system. It is a function of the minimum, mean and maximum emitterdischarges.

$$EUa = \left[\frac{Qmin}{Qavg} + \frac{Qavg}{Qx}\right] \times \frac{1}{2} \times 100$$

Where,

EUa = Absolute emission uniformity,

Qmin= minimum flow rate through emitter, l/h

Qavg =average flow rate through emitter (l/h),

Qx = average of the highest 1/8th of the emitters flow rate (l/h).

$$EUa = \left[\frac{0.90}{1.02} + \frac{1.02}{1.13}\right] \times \frac{1}{2} \times 100 = 89.25\%$$

Referring to Kumari, Bhagat and Neeraj (2018), the general rating for uniformity is 90% or greater, 80% to90%, 70 to 80% and less than 70%; Excellent, good, fair and poor respectively. The absolute emission uniformity was found 89.25% in the drip irrigationsystem. Therefore, the drip irrigation system in water distribution uniformity is good.

e) Design emission uniformity (EUd)

Keller and Karmeli (1974) suggested design emission uniformity by the following equation:

$$EUd = 100 \times \left[1 - 1.27 \frac{V_m}{N_e^{0.5}}\right] \times \frac{q_{min}}{q_{avg}}$$

Where,

EUd=design emission uniformity, (%),

Vm= manufacturing coefficient of variation or Std Variation/ Qavg

Ne=number of emitters per plant,

q_{min}=minimum flow rate through emitter, l/h

q_{avg}= average flow rate through emitter, l/h

$$EUd = 100 \times \left[1 - 1.27 \frac{0.086}{1^{0.5}}\right] \times \frac{0.9}{1.02} = 78.6\%$$

As per recommended range of classified design emission uniformity presented in ***Annexure 12***, it falls in between good and acceptable.

f) Coefficient of variation (Cv)

The coefficient of variation (CV) is a statistical measure of the dispersion of data points in a data series around the mean. The coefficient of variation represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from one another.

$$Cv = \frac{S}{qm}$$

Where,

Cv= Coefficient of variation of emitter flow,

S = Standard deviation of the emitter flow

q_m= average flow rate through emitter (l/h)

$$Cv = \frac{0.087}{1.02} = 0.085$$

According the performance indicator from the

Annexure 10, the coefficient of variation 0.085 is ranging between 0.07 and 0.11, and isfound to be marginal.

g) Statistical Uniformity Coefficient of the drip irrigation system (SUC).

The statistical uniformity coefficient describes the uniformity of drip water distributionassuming a normal distribution of flow rates from the emitters.

Statistical Uniformity Coefficient (SUC) = 1 - C_v

Where,

SUC =Statistical Uniformity Coefficient

C_v = Coefficient of variation

SUC = 1- 0.085 = 0.915 or 0.915x100 = 91.5%

As presented in ***Annexure 12*,** SUC falls under the category of excellent.

h) Summary of performance parameters found at FGEA farm

It is evident from the **Figure 6** that all the performance parameters of drip irrigation system atFGEA farm found was Distribution efficiency (Ed), application efficiency (Ea), field emission uniformity (EUf), Absolute emission uniformity (EUa) and design emission uniformity (EUd) with the corresponding values of 91.66, 88.23%, 91.20%, 89.25% and 78.60% respectively meeting the standards of good to excellent performance.

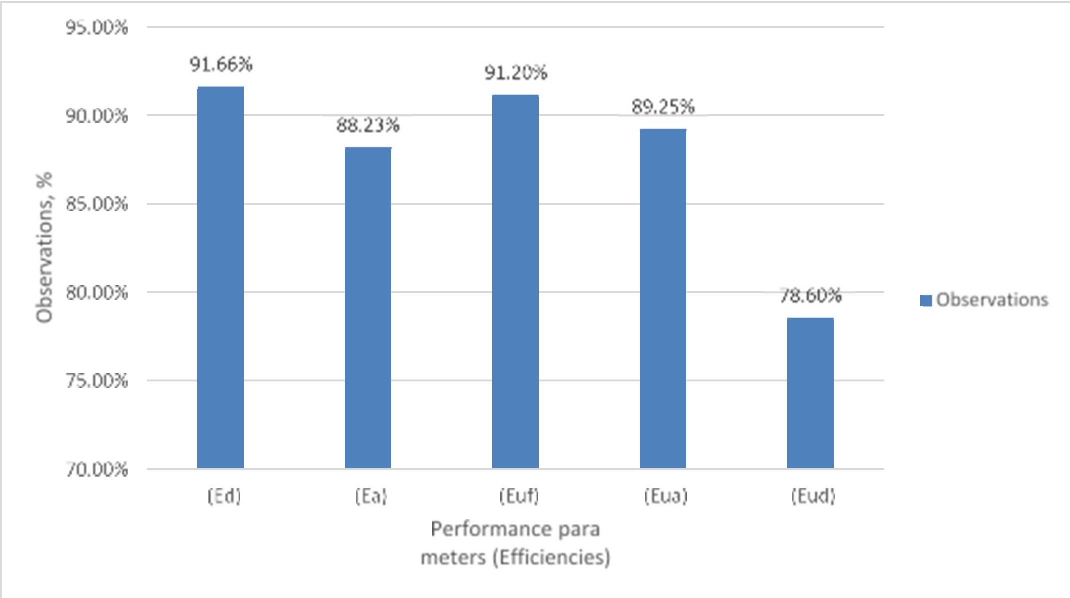


Figure 6: Performance parameters (efficiencies)

As presented in **Figure 6**, It is discovered from the ***Annexure 12*** that the field emission uniformity (EUf) is excellent. And the distribution efficiency is above the acceptable level as endorsed by Al-Ghobari (2012)

i) Coefficients of variance (Cv) and statistical uniformity coefficient (SUC)

As illustrated in Figure 7, the coefficient of variance (Cv) and statistical uniformity coefficient (SUC) of drip irrigation system in FGEA farm were found 0.085 and 0.915(91.5%) respectively. The value of Cv falls in the category of marginal

Annexure 10 and SUC falls in the range of good to perfect ***Annexure 11*.**

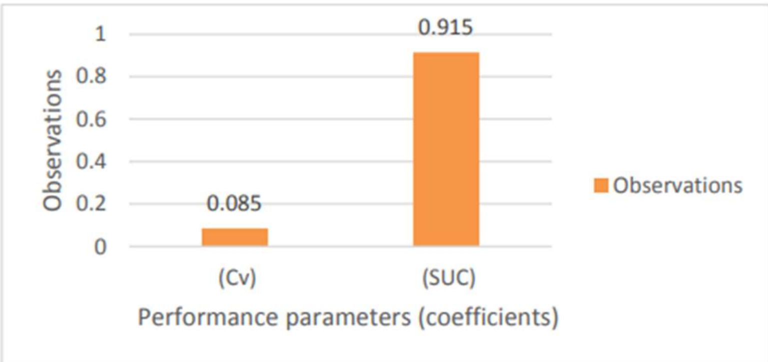


Figure 7: Performance parameters (coefficients)

As per the ***Annexure 10***, the coefficient of variance (Cv) is marginal, while the statistical uniformitycoefficient (SUC) is excellent as revealed from ***Annexure 12*.**

The yield of onion under drip irrigation system

From the data collected from FGEA farm, it was found that about 3 tons of onions wereharvested from 0.25 ha plot under drip irrigation system. This yield is equivalent to 12tons/ha which can not be obtained without irrigation scheduling and the input management.

IV.CONCLUSION

Based on the methodology and results found, the conclusions which can be drawn from theresearch are presented in following paragraphs.

The rainfall in the study area is not sufficient in all decades of the months taken for crop period, Therefore irrigation is needed in 2nd and 3rd decades of January, 1st and 2nd decades of February, 1st decade of March, and 2nd decade of May with 6.9 and 12.2 and 8.7, 1.4, and 1.8 mm/decade respectively.

In the April and October, the average monthly rainfall is higher than the crop water needs, hence no irrigation is required. The maximum and minimum temperatures were found to be higher in August and September with 28.5, 16.1°C and 28.6, 15.9 °C respectively. The soil type was sand loamy soil with an average bulk density of 1.11gm/cm^3. The bulk density ofthe soil of study area is ideal for onion roots growth. The basic infiltration rate found was 21.44mm/hr.

The performance indicators like Distribution efficiency (Ed), application efficiency (Ea), field emission uniformity (EUf), Absolute emission uniformity (EUa) and design emission uniformity (EUd) with the corresponding values of 91.66, 88.23%, 91.20%, 89.25% and 78.60% respectively were found meeting the standards of good to excellent performance.

The coefficient of variance (Cv) and statistical uniformity coefficient (SUC) of drip irrigationsystem in FGEA farm were found 0.085 and 0.915 (91.5%) respectively. The value of Cv falls in the category of marginal (

***Annexure 10*)** and SUC falls under good to perfect. The FGEA farm harvested 12 tons/ha,while the nearby farmers did not ever reach such onion production.

V.ANNEXURES/APPENDICES

Annexure 1: General relationship of soil bulk density to root growth based on soil texture.(USDA NRCS guidelines)

Soil texture	USDA-NRCS guidelines Bulk Density (BD) in, gm/cm^3 and soil texture		
	Ideal BD for plant growth	BD that affect root growth.	BD that restrict root growth
Sands, loamy sands	<1.60	<1.69	>1.80
Sandy loams, loams	<1.40	<1.63	>18.0
Sandy clay loams, clay loams	<1.40	<1.60	>1.75
Silts, silt loams	<1.30	<1.60	>1.75
Silt loams, silty clay loams	<4.40	<1.55	>1.65
Sandy clays, silty clays, some clay loams (35 -45% Clay)	<1.10	<1.49	>1.58
Clays (> 45% clay)	<1.10	<1.39	>1.47

Annexure 2: Classification of infiltration rates

Class	**Rate (cm/hr)**
Very rapid	> 25.4
Rapid	12.7 – 25.4
Moderately rapid	6.3 – 12.7
Moderate	2.0 – 6.3
Moderately slow	0.5 – 2.0
Slow	0.1- 0.5
Very slow	< 0.1

Source: Majumdar, 2000

Annexure 3: Typical infiltration rates for different soils

Soil type	Infiltration rate mm/hr
Sand	>30
Sandy loam	30-20
Silt loam	20-10
Clay loam	10-5
Clay	<5

Source: FAO, 2002.

Annexure 4: Infiltration rate test

Time, min	Before filling	After filling	Infiltration, mm	Infiltration, mm/hr	Infiltration, cm/hr
0		155			
5	151.2	155	3.8	45.6	4.56
10	149	155	6	36.0	3.6
15	146.4	155	8.6	34.4	3.44
20	145	155	10	30.0	3.00
25	143.8	155	11.2	26.88	2.69
30	142.6	155	12.4	24.8	2.48
35	141	155	14	24.0	2.40
40	140.7	155	14.3	21.44	2.14
45	138.92	155	16.08	21.44	2.14
Average				29.4	2.94

Annexure 5: CROPWAT - Climate / ETo

Country: Rwanda | Station: Gishari
Altitude: 1438 m. | Latitude: 1.22 °S | Longitude: 30.30 °E

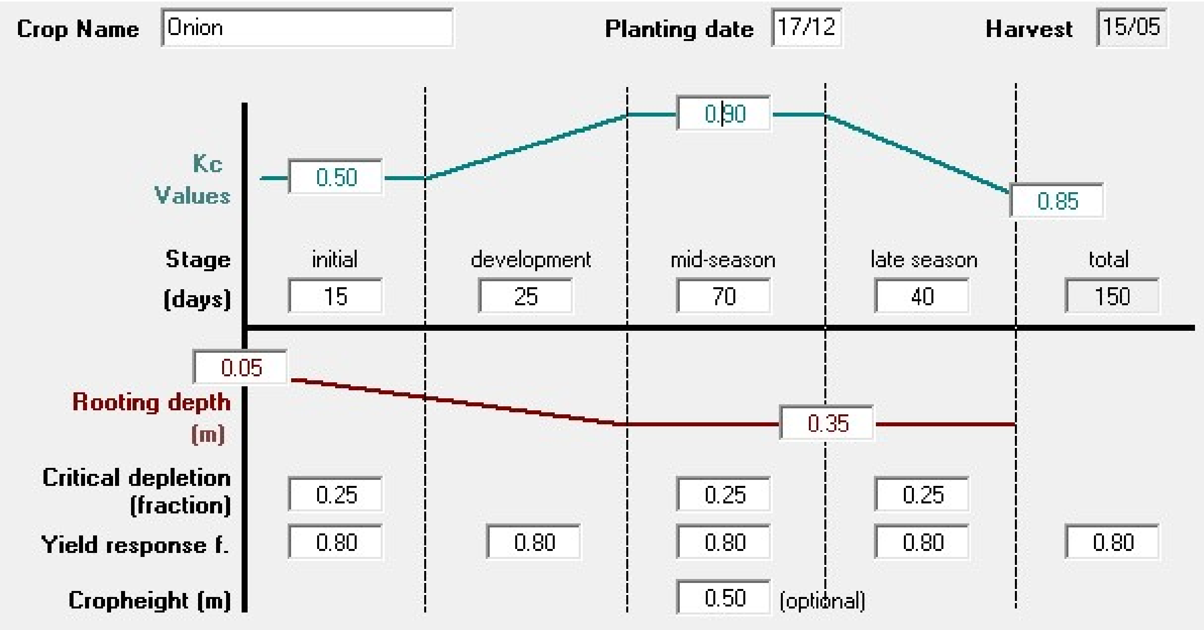
Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	15.5	27.4	78	7	5.3	17.2	3.28
February	15.8	27.7	78	7	4.3	16.1	3.18
March	15.7	27.1	78	7	5.3	17.8	3.44
April	15.8	26.3	82	7	5.0	16.7	3.20
May	16.0	26.6	82	8	5.3	16.2	3.05
June	15.4	27.5	75	9	7.0	17.9	3.24
July	15.3	27.8	68	9	8.0	19.6	3.45
August	16.1	28.5	67	9	7.0	19.2	3.54
September	15.9	28.6	71	8	7.0	20.1	3.81
October	15.4	27.6	75	7	6.0	18.7	3.58
November	15.6	26.5	79	6	5.0	16.8	3.21
December	15.6	26.7	80	6	4.0	15.0	2.91
Average	**15.7**	**27.4**	**76**	**7**	**5.8**	**17.6**	**3.32**

Annexure 6: CROPWAT – Rainfall

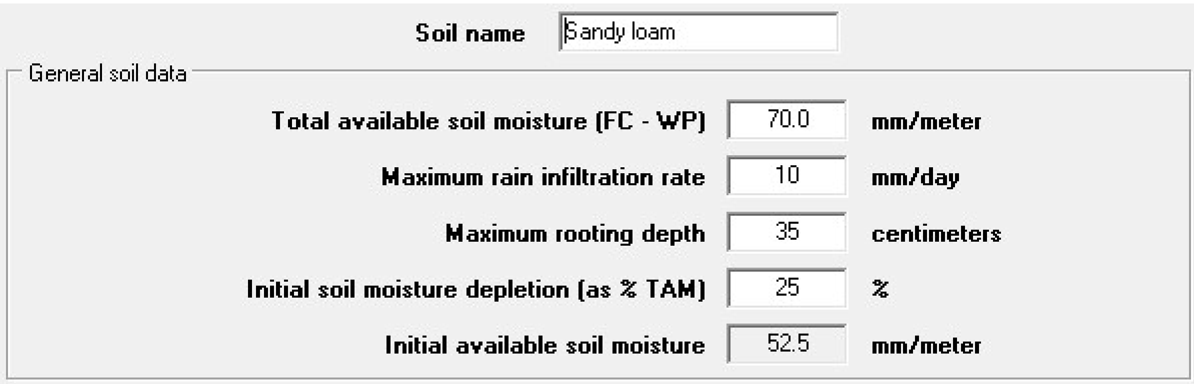
Station: Gishari | Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	58.0	52.6
February	65.0	58.2
March	110.0	90.6
April	145.0	111.4
May	70.0	62.2
June	17.0	16.5
July	6.0	5.9
August	20.0	19.4
September	57.0	51.8
October	112.0	91.9
November	117.0	95.1
December	78.0	68.3
Total	**855.0**	**724.0**

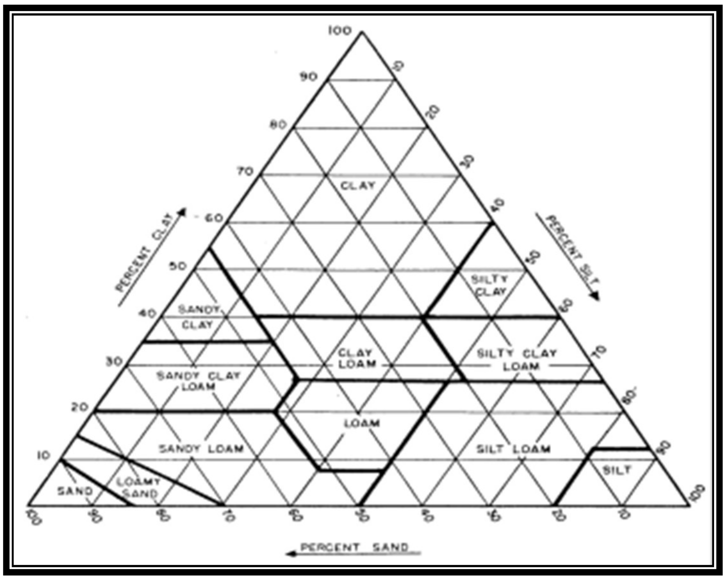
Annexure 7: CROPWAT – Onion crop



Annexure 8: CROPWAT – Soil at Fresh Gate East Africa farm



Annexure 9: Soil texture triangle



Source: USDA, 2018

Annexure 10: Table for Emission Uniformity (Eu) and Coefficient of Variation (Cv).

Emission Uniformity (Eu)		Coefficient of variation (Cv)	
≥ 90 %	Excellent	< 0.05	Excellent
80 - 90%	Good	0.05 - 0.07	Average
70 - 80 %	Fair	0.07 - 0.11	Marginal
≤ 70 %	Poor	0.11 - 0.15	Poor
		> 0.15	Unacceptable

Source: Sharu and Razak, 2020.

Annexure 11: Criteria for Statistical Uniformity of emitters

Us Range (%)	Classification
95 to 100	Perfect
85 to 90	Good
75 to 80	Tolerable
65 to 70	Very bad
Below 60	Unacceptable

Source: ASABE, 2003.

Annexure 12: Table for Statistical Uniformity Coefficient and Design Emission Uniformity

Classification	Us (%)	EU (%)
Excellent	95-100	94-100
Good	85-90	81-87
Acceptable	75-80	68-75
Poor	65-70	56-62
Unacceptable	<60	<50

Source: IJAERD, 2017, Zamaniyan, Fatahi, and Boroomand, 2014

Annexure 13: Typical values of application efficiency for different irrigation systems

System Type	Application Efficiency Range* (%)
Surface Irrigation	
Basin	60 - 95
Border	60 - 90
Furrow	50 - 90
Surge	60 - 90
Sprinkler Irrigation	
Handmove	65 - 80
Traveling Gun	60 - 70
Center Pivot & Linear	70 - 95
Solid Set	70 - 85
Microirrigation	
Point source emitters	75 - 95
Line source emitter	70 - 95

Source: Raghuwanshi, 2013

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REFERENCES

[1]. Rwanda Irrigation Master Plan, 2010. World Agroforestry Centre (ICRAF), United Nations Avenue, Gigiri. P. O. Box 30677– 00100. Nairobi, Kenya. 2010. World Agroforestry Centre (ICRAF) Water Management Unit, Ebony Enterprises Ltd (Israel), Ministry of Agriculture and Animal Resources (MINAGRI), Rwanda

[2]. National Institute of Statistics of Rwanda (NISR), Seasonal Agricultural Survey 2019 annual report, December 2019

[3]. Rwanda Agriculture & Animal Resources Development Board, 2018. Improving and Updating Rwanda IMP: Irrigation Potential Considerations Report

[4]. Rwanda Development Board, 2020. https://rdb.rw/investment-opportunities/agriculture/

[5]. Rwanda Meteorological Agency (www.maproom.meteorwanda.gov.rw).

[6]. Arya C.K; Purohit, R.C; Dashora, L.K; Singh, P.K; Mahesh Kothari. 2017. Performance Evaluation of Drip Irrigation Systems, publsihed in International Journal of Current Microbiology and Applied Sciences, ISSN: 2319-7706 Volume 6 Number 4 (2017) pp. 2287-2292.

[7]. RDB, 2020. Retrieved from https://rdb.rw/investment-opportunities/agriculture/ on18th August, 2020

[8]. FAO, 2002. Irrigation Manual Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation. Pp-4

[9]. Sharu E.H, and Razak M.M.Ab, 2020. Hydraulic Performance and Modelling of Pressurized Drip Irrigation System, Pp.5.

[10]. Kumari C.P, Bhagat E. and Neeraj K. (2018). Emission uniformity evaluation of installed drip irrigation system. International Journal of Chemical Studies 2018; 6(3): 1651-1654

[11]. Al-Ghobari H.M, (2012). Sustainable Irrigation and Drainage IV: A comparison of water application uniformity for drip irrigation system above and below soil surface at various soil depths and scheduling techniques in arid region. WIT Transactions on Ecology and The Environment,Vol 168.

[12]. Raghuwanshi, N.S. (2013). On-farm water management class notes, IIT Kharagpur.

[13]. Rwamagana district development strategy (DDS) 2018-2024. https://www.rwamagana.gov.rw/fileadmin/user_upload/RWAMAGANA_DISTRICT

[14]. _DEVELOPMENT_STRATEGY 2018-2024_.docx

[15]. Robert G.E, John S.E, (2008) Methods and technologies to improve efficiency of water use

[16]. Maher Salman, M., Pek, E. and Lamaddalena, N. (2019). Field guide to improve water use efficiency in small-scale agriculture: The case of Burkina Faso, Morocco and Uganda. Rome, FAO.

[17]. Florence K., Maria R. et al. (2018) Impacts and sustainability of irrigation in Rwanda: Policy brief. *International growth center*