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WATER SAVING AND WATER PRODUCTIVITY UNDER BURIED CLAY POT AND DRIP IRRIGATION SYSTEMS FOR CABBAGE IN RWANDA

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ABSTRACT

This research evaluated the effects of Clay Pot Irrigation System (CPIS) on water saving and water productivity compared with Drip Irrigation System (DIS) as micro-irrigation systems in cabbage production in Rwanda. This research was conducted at the Rwanda Polytechnic/Integrated Polytechnic Regional College Huye (RP/IPRC Huye) farm (2°35'48" S and 29°44'21" E, Elevation of 1769 m above sea level), in Huye district of Rwanda. The experimental designed was a Randomized Complete Block Design (RCBD) with three treatments and three replications. The experimental treatments were Clay pot irrigation system, Drip irrigation system, and the control treatment (No irrigation). The soil type was a sand clay loam. The clay pots used were manufactured by mixing clay and sand at the ratio of 4:1 and dried with burning dry grass. Pots were buried under the soil up to their necks, with about 2 cm of their top above the surface of the surrounding. The crop variety used for the study was Zawadi F1 of cabbage produced by the East African Co. Seed, which is adaptable under the agroclimatic conditions of the Huye district of Rwanda. Crop water requirement and irrigation scheduling were estimated by using CROPWAT 8.0 software. Organic manure (20 tons ha^{-1}) was applied for whole trial during tillage, Nitrogen-Phosphorous-Potassium/ NPK 17-17-17 (300 kg ha^{-1}) was uniformly applied around the seedling (ring application) and Urea (300 kg ha^{-1}) was split applied, first after three weeks of transplanting, and the second application was five weeks after transplanting. The water productivity of CPIS was 36.17 kg m^{-3} for DIS was 25.4 kg m^{-3}, while the control was 31.1 kg m^{-3}. The results of this research show that CPIS increases water productivity and water saving. Water saved is 40.23% when CPIS is compared with DIS. Clay pot irrigation system can be a viable option for water scarce areas, particularly for small-scale farmers looking to improve their productivity with their small holdings of land in sandy and drier environments.

Key words: CPIS, DIS, Water saving, Water productivity, Clay pots, CROPWAT, Rwanda

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INTRODUCTION

Agriculture irrigation accounts for 70 – 80% of water use worldwide [1, 2]. Water is becoming a scarce economic resource in many areas of the world, especially in arid and semi-arid regions [3]. Scheduling water application is very critical, as excessive irrigations reduce yield, while inadequate irrigation also causes water stress [4]. It is necessary for vegetable growers to know how much water to apply to their crops, and when to apply it to a particular crop to enhance productivity with good yields and increased marketability [5]. The incidence of drought, rapid population growth, leading to food insecurity, and mismanagement of natural resources such as rainfall, have been identified as the most frequently observed problems in Africa, which affect water allocation systems, and water resources management plans to satisfy the basic water needs for both human and nature [6]. Scheduling irrigation according to crop water needs minimizes the chances of under or over watering, reduces crop failure and leaching of fertilizers beyond the root-zone, and increases profit for growers under well-established crop water requirement. Irrigation consists of the application of the right quantity of water at the right time to the soil for plant growth. It is sometimes supplemental to natural rainfall in areas where the amount of rainfall is limited and erratic, and thus, referred to as supplemental irrigation [7].

In Rwanda, irrigation started during the colonial era in 1945 as the result of the Ruzagayura famine. It has begun with a water channel of 11 km from Ntaruka to Rubengera in the Karongi district, mainly in the dry regions of Rwanda, where water was pumped to the surrounding hillside, and in 2006, the area irrigated with pumped water was 162 ha [8], and in 2012 the area irrigated had increased to 2,302 ha. Currently, the total area equipped with irrigation systems in Rwanda is estimated at 11,467 ha [9]. Earlier studies show that High-technology irrigation systems have been applied increasingly in recent years to improve water-use efficiency and saves up to about half the amount of the water currently used for irrigation. However, some technical, economic and sociocultural factors have hindered the adoption of those technologies because they are expensive [10]. Farmers, and landscapers have adopted micro-irrigation systems to suit their needs for precision water application. Micro-irrigation systems are immensely popular not only in arid regions and urban settings, but also in sub-humid and humid zones, where water supplies are limited, or water is expensive. Micro-irrigation is used extensively for row crops, mulched crops, orchards, gardens, greenhouses and nurseries [11], and are also important because they provide irrigation water directly into soil at the root zone of plants and thus, minimizes conventional losses of water such as deep percolation, runoff and soil erosion.

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This allows the utilization of fertilizers, pesticides, and other water-soluble chemicals along with irrigation water, resulting in higher crop yield and better-quality produce.

The widespread adoption of drip irrigation technology in recent years began in the late 1960s to early 1970s for its advantages of less water loss, reduction in weed growth, less labor requirements, minimal evaporation compared to surface irrigation methods, less usage of fertilizer, reduced soil erosion, equitable water distribution and higher crop production [12]. In drip irrigation, water is applied to each plant separately in small, frequent and precise quantities through emitters. It is the most advanced irrigation method with the highest application efficiency, with the water delivered continuously in drops at the same point, moves into the soil, and wets the root zone vertically by gravity and laterally by capillary action, with the planted area only partially wetted [13]. Water is applied either on the surface, next to the plant, or subsurface, near the root zone. In dry areas, fewer weed seeds germinate between rows because there is less water available beyond the plant root zone [14].

The clay pot irrigation technology is a conservation irrigation system, which saves between 50 and 70 % of water compared with the conventional watering can irrigation system [15]. The application of pitchers (clay pot system) in irrigation is gaining substantial attention in arid and semi-arid lands due to its simplicity and auto-regulative capabilities [10]. It was possible to use 68.7% - 69.9% water by using clay pot than furrow irrigation system [16]. Tripathi *et al.* [17] indicated that clay pot irrigation could have self-regulative capability in conditions where seepage is controlled by the soil water pressure head, which is, in turn, a function of the soil water content around the clay pot. The clay mineral type is a more important factor in accumulation and sequestration of Stabilization of soil organic Carbon [18]. Adding clay to non-wetting sands also increases potential to store soil organic carbon. The positive effects of claying last for many years [19]. It is understandable that the soil Carbon sink has significant impact on sequestering CO_2 [20]. Addition of clay to soils lead to increased Organic Carbon. Therefore, addition of clay to soil may enhance net sequestration of Carbon [21]. However, despite its potential advantages, clay pot irrigation is not yet known in Rwanda. The objectives of this research were to evaluate the effects of buried clay pot on water saving and water productivity compared with drip irrigation systems as micro-irrigation systems for cabbage production in Rwanda.

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MATERIALS AND METHODS

Site description

This research was carried out on a farm at the Rwanda Polytechnic/ Integrated Polytechnic Regional College Huye Campus (RP/IPRC Huye) located in Huye district, Rwanda, which is 2°35'48" S and 29°44'21" E, at an elevation of 1769 m above mean sea level.

The experimental design was a Randomized Complete Block Design (RCBD) with three treatments and three replications. The crop variety used for the study was Zawadi F1 of cabbage produced by the East African Co. Seed (https://easeed.com), which is adaptable under the agroclimatic conditions of the Huye district of Rwanda. The individual plot sizes measured 7.5 m long and 3.6 m wide with an area of 27 m^2. The size of the experimental area was 243 m^2. The total plant population was 1350 plants, with a plant population density of 5.6 plants m^{-2} (150 plants per plot). Data on growth parameters were recorded from a sample of 20 plants, randomly selected from each plot. Data on growth parameters were recorded three and eight weeks after transplanting. Irrigation data was recorded after crop establishment until crop maturity for harvest. The three treatments applied in the study were clay pot irrigation system (hereinafter referred as “CPIS”), drip irrigation system (hereinafter referred as “DIS”) and the control treatment (with no irrigation system). Parameters evaluated during this research were soil texture, plant height, number of leaves per plant, leaf width, leaf length, crop yield (ton ha^{-1}), water saving (%), and water productivity (kg m^{-3}).

Land preparation

The first tillage, which was done on 11th February 2021 to create favorable conditions for plant growth removed plant residues, broke down, and loosened. The second tillage to further breakdown soil clods, smoothen, and level the surface seed bed in the plots was done on 25th February 2021. Cabbage seedlings were transplanted in the plots on 5th March 2021.

Installation of clay pot irrigation system

The clay pot used in this experiment was manufactured by mixing the clay and sand at ratio of 4:1 and burnt using dry grasses. For pot installation, a clay pot with a capacity of 3 liters was placed between two plants spaced at 60 cm. Each pot installation hole was three times wider in diameter compared with the clay pot, and its depth twice deeper than clay pot for easy placement. Clay pots were buried in the soil up to their necks, with about 2 cm of the pot above the soil surface to allow its lid to cover the pot.

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Installation of drip irrigation system

An overhead tank was used as a pressurized water source for the drip irrigation system elevated at 2 m above the ground. A High-density polyethylene (HDPE) mainline of 32 mm attached with valve and water meter was installed to convey water from the water tank to the plots. Three HDPE manifolds (25mm internal diameter) were connected to main line to distribute water into laterals in each plot. There were six laterals of 16 mm internal diameter together with their drippers. The spacing between emitters was 30 cm and spacing between drip lines was 60 cm with 25 emitters per lateral to irrigate 25 plants.

Estimation of Crop Water Requirement for cabbage using CROPWAT software

The CROPWAT 8.0 software was used to estimate crop water requirement and irrigation scheduling. Estimation of crop water requirement and irrigation scheduling for cabbage in the experimental plot was done by feeding different input data pertaining to location details, weather, soil, rainfall, and crop. The weather data from 1984 to 2020 were provided by Meteo Rwanda. Mean monthly data were estimated from daily data collected over 36 years, including the monthly averages of minimum and maximum temperature, rainfall, relative humidity, wind velocity, and sunshine hours. Besides weather data, other data input on crop, soil, and characteristics of the meteorological station (including name, latitude, and longitude of station) were used as input data for the CROPWAT 8.0 software [22].

Fertilizer application and mulching

Organic manure (20 t ha^{-1}) was applied for whole trial during second tillage, NPK 17-17-17 (300 kg ha^{-1}) was uniformly ring-applied around the seedling on 11th March 2021, and Urea (300 kg ha^{-1}) applied in two splits, 3 weeks, and 5 weeks after transplanting, respectively. Mulching was done after plants were established one week after transplanting with dry grass applied at 5 cm thickness to control soil surface evaporation to retain soil moisture, suppress and control weed growth, and to keep cabbage crops clean from soil particles during irrigation.

Amount of water in DIS and CPIS

In measuring the quantity of water used by drip irrigation, amount of water was recorded in m^3 from water meter installed on the irrigation system. The starting point of the water meter was 0.0 m^3 and for the CPIS, all the amount of water filled and refilled in the clay pot were recorded, summed up, and the water remaining in the clay pot before harvest was subtracted from the total to determine the amount of water used by the crop before harvesting.

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The formula below was utilized:
Amount of water used through clay pot irrigation system is equal to:

$$\Sigma w_{CPIS} = (\Sigma w_{f0} + \Sigma w_{rf}) - \Sigma w_r$$

Where:
Σw_{CPIS}: Amount of water used by clay pot irrigation system
Σw_{f0}: Sum of water filled at first time
Σw_{rf}: Sum of water refilled during cropping season
Σw_r: Amount of water remained in the pot at the harvesting time

Water saving
The amount of water saved between CPIS and DIS methods was determined by using relation of Tagar *et al.* [23]:

$$\text{WS (\%)} = \frac{\text{WDIS} - \text{WCPIS}}{\text{WDIS}} \text{ X } 100$$

Where:
WS = Water saving in (%).
WCPIS =Total water used for growing cabbage under Clay pot irrigation system.
WDIS = Total water used for growing cabbage under drip irrigation system.

Water productivity per each treatment
Water productivity was computed using the following equation [5]

$$\text{WP} = \text{Y/W (irrigation + effective rainfall)}$$

where:
WP = Water productivity (kg/ m^3),
Y = Crop yield (kg/ ha)
W = (irrigation + effective rainfall)

Statistical analysis
Data collected during the experiment were analyzed using the analysis of variance (ANOVA) generated by Genstat Data Analysis Software developed by VSN International (2 Amberside House, Wood Lane, Hemel Hempstead HP2 4TP, England UK, https://vsni.co.uk). Differences among treatment means were separated using the least significant difference (LSD) at 5%.

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RESULTS AND DISCUSSION

Soil characteristics

The soil texture of the experimental site was a sandy clay loam 68.625 % (sand), 23.5% (clay), and 7.875% (silt) according to the USDA texture triangle [20], (Table 1). According to the FAO, the soil of the experimental area can hold moisture because of clay content but can also quickly drain excess water because its sand content [24]. Crops grown in a sandy clay loam soil will require more frequent watering and fertilization because of its higher sand content.

Effect of CPIS on water used during crop growing stages

The amount of water used by buried clay pot irrigation system at each growing stage of cabbage crop is in Table 2. The growing season of cabbage was divided into four growing stages: Initial stage (IS) of 10 days (one decade), Development stage (DS) of 20 days (2 decades), Midi season (MS) of 40 days (4 decades), and late season (LS) of 30 days (3 decades). These results are presented in Table 2. The highest amount of water was used at the initial stage of crop growth as the cabbage seedlings require more water to grow at that stage, and the soil was dry for lack of rainfall. The second stage of high water-use by the cabbage crop was in the mid-season, where the cabbage crop required more water to form head. This water saving of clay pot was agreed. The study by Tripathi *et al.* [17] confirmed the importance of the CPIS in water conservation, as the water seeps out of the buried clay pot from a pressure head gradient across the wall of the clay pot directly into the root zone of the irrigated crop. The CPIS has proved useful for land restoration in very arid environments. The CPIS is better suited for cabbage production for its higher irrigation efficiency, better fertilizer use efficiency, and maintenance of favorable soil water around the root zone of the crop [25].

Effect of DIS on water used during crop growing stages

Table 2 shows how cabbage water requirements were determined by using the software Crop Wat 8.0 and DIS during the months of March and April due to insufficient rainfall during that period. Water was applied at 3 days interval to compensate for the water lost per day through crop evapotranspiration (Etc) to allow crop to grow without water stress. Treatment 3 received only water from rainfall and did not receive any irrigation treatment. According to the type of the soil (sandy clay loam soil) and based on Beshir [7], irrigation frequency of cabbage varies between 3 and 12 days depending on climate, crop development and soil type. However, irrigation frequencies between 3 to 7 days interval are common, and the researchers decided to use 3 days of irrigation interval because on a

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sandy soil, the frequent application of water is highly productive due to high water infiltration compared with clay soil [26].

Comparison of water used, and water saved between CPIS and DIS

According to the data presented in Table 3, CPIS used less water compared to DIS and there was little difference because in the second stage of crop development, there was rainfall and irrigation was not required. The results of this study showed 40.23% of water conserved with CPIS compared with DIS. These results are consistent with the findings of Daka [25], who also reported a greater amount of water conservation by CPIS compared with DIS, which was attributable to the supply of water below the soil surface directly to the root zone, which reduces soil water loss by evaporation and deep percolation. Daka [22] also reported that using clay pots can save up to 70% of water compared to watering with buckets and sprinkler irrigation. The clay pot irrigation system is claimed to be a self-regulative system with very high water conservation potential with the ability to irrigate various types of crops [27, 28]. The results of this study are also consistent with the results of Ansari *et al.* [29], who reported that the application of CPIS can conserve approximately 3-60% of water compared with the DIS.

Number of plant leaves

On the last day of data collection at eight weeks after transplanting, the results of the number of leaves per cabbage head in treatments 1, 2 and 3 were 29.08 cm, 19.7 cm and 18.04 cm, respectively (Table 4). The number of leaves per the CPIS was 32.3% when compared with DIS and 38.0% when compared with the control. The percentage difference between DIS and the control of was 8.4%, which demonstrates very little to no difference between the DIS and control. The increase in the number of leaves in the CPIS, showed that irrigation impacted the growth and vigor of the vegetative parts of cabbage compared with the other irrigation systems used in this study. Data presented in Table 4 shows that the effect of irrigation system on cabbage production is significant high at $P<0.05$. Similar results were obtained by Ansari *et al.* [29] who found that CPIS can provide the best condition for leaf growth, and further observed the incredible performance of CPIS on crop growth with more leaves and taller plants.

Plant height

On the last day of data collection at eight weeks after transplanting, the results of plant height for treatments 1, 2 and 3, were 15.63 cm, 13.1 cm and 10.43 cm, respectively (Table 4). The difference in plant height between treatments 1 and 2 was significant at $P<0.05$, and 33.3% increase in plant height with treatment 1 compared with treatment 3. Treatment 1 was self-automated (regulated), which

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facilitated water seepage from the clay pot while in treatment 2 the water was estimated based on climatic data and crop growth stages, and treatment 3 was the control treatment without irrigation. Therefore, the results in Table 4 show a significant effect (P<0.05) of irrigation on plant height. The increase in plant height of cabbage under CPIS is consistent with previous reports by Daka [25] and Bainbridge [30], who reported faster growth and establishment of plants under CPIS than surface irrigation methods.

Length and width of leaves

Table 4 shows results of leaf length on the last day of data collection, eight weeks after transplanting. Leaf length for treatments 1, 2 and 3 were 30.9 cm, 24.33 cm and 21.01 cm, respectively. The differences in leaf sizes between the control treatment and DIS was not significant, but the differences in the leaf sizes of treatments 3 and 2 compared with treatment 1 was significant (P<0.05). The CPIS had 32% bigger leaves than the control and 21.3% more than the DIS.

Table 4 shows data for leaf width on the last day of data collection, eight weeks after transplanting. The results of leaf width for treatments 1, 2 and 3 were 29.08 cm, 19.71 cm and 18.26 cm, respectively. The differences were 32.0% for CPIS vs DIS and 37.2% vs the control, and 7.4% for the DIS and the control. There difference between the DIS vs control was significant (P<0.05). Although the difference in the control and the DIS was significant, the control treatment was competitive because it was a wet season and both crops received rain. These results are consistent with the findings of Saha *et al.* [31] who recorded significantly higher values for all stages of plant growth of pumpkin with the CPIS method.

Total crop yield (T per Ha)

The data in Table 4 show the mean of yield of cabbage per hectare of land. The yield of cabbage under clay pot irrigation was 60.5 ton and 47.9 ton under the drip irrigation system, and 38.2 ton in treatment 3 (control).

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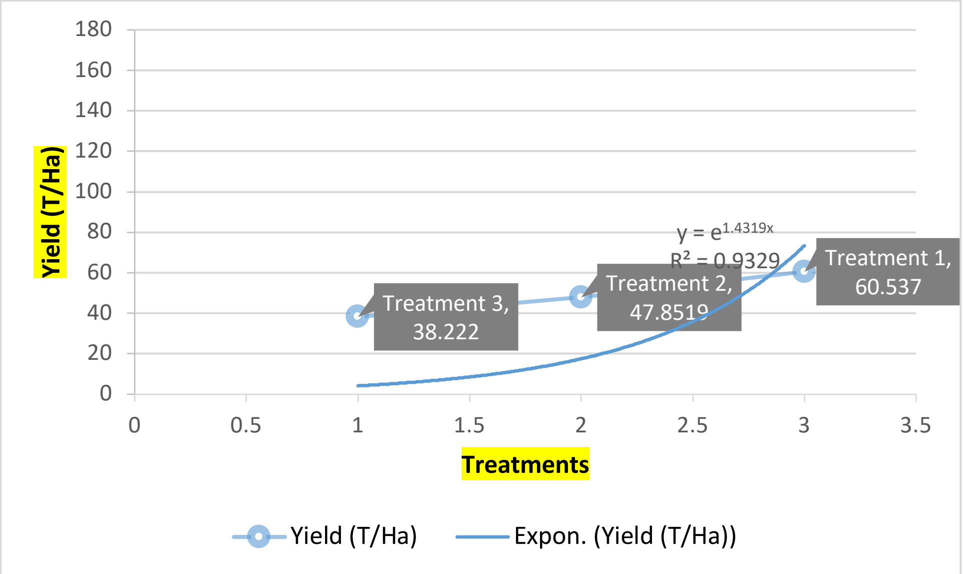

Figure 1: Mean yields of cabbage per treatment during the growing season

The differences in yield among treatments were significant ($P<0.05$). The correlation regression of yield among treatments (Fig. 1) was positive (R^2 = 0.9128), and the exponential equation of the yield was also positive, which verifies the impact of the irrigation among treatments. The results showed there was 20.9% and 36.9% increment in crop performance when treatment 3 was compared with treatment 2, and 1, respectively. The difference between treatments 2 and 1 was 20.1%. The efficient use of irrigation water resulted in the high yield for CPIS compared with the other irrigation systems. These findings are supported by the finding of Gebru [6], who found a significantly higher fruit weight and yield per plot under CIPS, and Pachpute [32], who also concluded that the increase in total yield was due to water management practices including CPIS. In an experiment by Batchelor *et al.* [33] in south-east Zimbabwe and northern Sri Lanka between 1985 and 1995, the conclusion was that subsurface irrigation using clay pipes was particularly simple and easy to use, effective in improving crop yields, crop quality, and water-use efficiency.

Water productivity per each treatment

Water productivity of CPIS was 36.17 kg m^{-3} and for DIS was 25.4 kg m^{-3} for DIS, and 31.1 kg m^{-3}, for the control (Table 4). These results are consistent with the results of the study by Gebru [6] who reported increase in a higher water productivity for crops under CPIS for Swiss chard, tomato, and pepper. And also, the results are supported by Ferrarezi and Testezlaf [34] who observed that wick irrigation system obtained higher crop water productivity resulting in high quality plants.

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CONCLUSION

The literature shows that CPIS was mainly tested in arid soils and the results showed its importance and usefulness in agriculture. This study tested the CPIS and DIS irrigation systems in cabbage under a sand clay loam soil and concluded that the CPIS conserves water and increases water productivity compared with the DIS. Clay pot irrigation system can be a viable option for water scarce areas, particularly for farmers looking to improve their productivity with small holdings of land in sandy and drier environments. The CPIS is particularly useful under conditions of limited water supply to increase crop performance.

Conflicts of interest

The authors have no competing financial and/or research interests in relation to this research.

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Table 1: Soil texture of the research

Number of samples	Soil depth (cm)	Sand %	Clay %	Silt %
1	0 – 20	65.5	24.5	10
1	21 – 40	69	23	8
Average for 2 samples	0 – 40	68.625	23.5	7.875

Table 2: Crop water requirements at each growth stage of cabbage and water used

Month	Decade	Stage	Kc (Coeff)	Etc (mm/day)	Etc (mm/dec)	Eff rain(mm/dec)	Irr. Req(mm/dec)	Gross Irrigation (liters)	Irrigation water in (m3/Ha)	Water used (m3/Ha)
Mar	1	IS	0.45	1.69	11.8	27.6	0	955.8	118	321.09
Mar	1	DV	0.46	1.69	16.9	43	0	1368.9	169	199.64
Mar	2	DV	0.67	2.38	26.2	44.5	0	2122.2	262	
Apr	1	MS	0.95	3.2	32	47.4	0	2592	320	234.5
Apr	2	MS	1.01	3.24	32.4	50	0	2624.4	324	
Apr	3	MS	1.01	3.19	31.9	44.4	0	0	0	
May	4	MS	1.01	3.15	31.5	39	0	0	0	
May	1	LS	1	3.09	30.9	34.9	0	0	0	31.38
May	2	LS	0.95	3.12	34.3	25.2	9.1	737.1	91	
Jun	3	LS	0.91	3.18	3.2	1.3	1.9	259.2	32	
Total	**10**				**251.2**	**357.3**	**11**	**10,659.60**	**1316**	**786.61**

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Table 3: Comparison of water used and water saving

Growth stage	DIS Gross irrigation (m3/ha)	CPIS Water used (m3/Ha)	Drip/Clay ratio	Water saved (%)	Rainfall (m3/ha)	DIS+Rainfall	CPIS+ Rainfall	Control
Initial stage (IS)	118	321.09	0.37	-172.11				
Development stage (DV)	431	199.64	2.16	53.68				
Midi season (MS)	644	234.5	2.75	63.59				
Late season (LS)	123	31.38	3.92	74.49				
Total	**1316**	**786.61**	**1.67**	**40.23**	**5137.097**	**6453.097**	**5923.707**	**5137.097**

Table 4: Results found on different vegetative parts of the plant

Treatments	Number of leaves	Plant height	Length of leaves	Width of leaves	Water productivity (Kg/m3)	Yield per Ha (Tons)
Treatment 3	18.04[a]±0.89	10.43[a]±1.32	21.01[a]±0.50	18.26[a]±0.38	7.44 ±0.92	38.2 ±0.12
Treatment 2	19.7[a]±1.04	13.1[b]±1.49	24.33[a]±3.19	19.71[a]±2.66	7.42±0.94	47.9±0.39
Treatment 1	29.08[b]±0.76	15.63[c]±0.71	30.9[b]±1.97	29.08[b]±1.65	10.21±1.86	60.5 ±0.13
F prob.	**0.004**	**0.002**	**0.009**	**0.004**		
LSD	**4.426**	**1.605**	**4.452**	**4.426**		

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