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Influence of Irrigation Levels and Mulching Types on Growth and Yield of Bean in Drought Prone Area of Bugesera, Eastern Rwanda

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Abstract

Purpose: Water saving practices are crucial for crop production in drought prone areas. This study was conducted in Bugesera District, in the Eastern Province of Rwanda. The objective was to determine the effect of irrigation levels and mulching types on growth and yields of beans.

Methodology: A split plot experiment consisting of three irrigation levels as main plots and three mulching types (no mulch, grass mulch and plastic mulch) as subplots, in a Randomized Complete Block Design (RCBD), with three replications was conducted. Climbing bean, Mac 44 variety, was planted at 50 cm × 20 cm spacing. Different levels of irrigation and mulching were applied from 3 weeks after crop emergence. Irrigation water was applied using a manual watering can.

Findings: Bean height and grain yield varied significantly due to the combined effects of irrigation × mulching. Highest value of plant height, 100 grain weight and yield value were obtained under the combination of 50% irrigation level with grass mulch. Compared to the control, yield improvement of 83%, 100 grains weight improvement of 39% and plant height increase of 20 % were observed under I_1M_1. Significant and positive correlations were observed between yield, plant height and yield parameters. The observed interdependence of yield parameters is illustrated by the positive and significant correlation between these parameters. Combining irrigation and mulching would improve climbing production while saving irrigation water up to 50%.

Recommendation: Both plastic and grass mulch gave similar results, however grass mulch is recommended for climbing bean production in the study area due to its additional advantages over the plastic mulch.

Keyword: *Climbing beans, yield, growth, irrigation, mulching.*

1.0 INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is one of Africa's most essential pulses and the most important legume for smallholder farmers in Eastern and Southern Africa (Darkwa et al., 2016; Raatz et al., 2019). In Rwanda, bean is a major subsistence crop grown by about 86 % of farmers (Larochelle et al., 2015), mainly in small scale farms under rain-fed conditions that are increasingly subjected to unreliable weather conditions (Ntukamazina et al., 2017). According to Katungi et al. (2019), approximately 50 percent of bean growers in Rwanda cultivate climbing bean varieties which suggest the popularity of the crop among the farmers. The North and Western regions of Rwanda show much higher contributions to the national volumes of production compared to the Eastern and Southern region. Despite the importance of common bean in food security and nutrition, biotic and abiotic stresses limit its production (Dagnew et al., 2014). Bean sensitivity to drought stress has been confirmed in many studies (Asfaw & Blair, 2014; Kazai et al., 2019; Sánchez-Reinoso et al., 2020).

Drought and uneven rainfall are linked to climate change and have negative impacts on growth of many field crops (Kazai et al., 2019). Rwanda is vulnerable to climate change as it strongly relies on rainfed agriculture (Bizimana & Sönmez, 2015; Haggag et al., 2016). Reports show noticeable impacts of climate change in Rwanda (Safari, 2012; Ngarukiyimana et al., 2021). They include unusual irregularities in climate patterns including extreme temperatures, variability in rainfall frequencies and intensity observed over the last 30 years (Munyeshyaka, 2016). Floods and landslides that occurred in 2006, 2010 and 2011, in Southern and North-Western parts of the country, caused losses of human life, destroyed houses and forced thousands of people to leave their homes (Bizimana & Sönmez, 2015). In the Eastern part of Rwanda, frequent droughts lead to significant reduction in crop yields while delayed onset of rains affect the timing of farm operations and shortens the growing season of crops resulting in poor crop yields (Kotir, 2011; Ayabagabo, 2018).

The Bugesera region located in Eastern province of Rwanda is characterized by erratic rainfall which affects crop growth and yields. In order to become more resilient to climate variability irrigation is recommended in such areas that face water shortage (Darkwa et al., 2016). Additionally, mulching helps to improve crop growth as well as yield while optimizing water use (Yu et al., 2018). Mulching improves soil moisture, regulates soil temperature and reduces evaporation (Teame et al., 2017; Al-Zboon et al., 2019). Improved water use through mulching can help reduce the irrigation frequency. According to Iqbal et al. (2020), combining mulch and irrigation results in higher and uniform soil moisture. Mulching and deficit irrigation have been studied in many studies respectively, however, no studies available in Rwanda on the combination of deficit irrigation and mulching. This study was conducted in Bugesera District, a drought prone area located in Eastern Province of Rwanda. The objective was to determine the effect of irrigation levels and mulching types on growth and yield of beans**.**

2.0 METHODOLOGY

2.1 Site Location and Climate

The study was conducted in Rwanda, Bugesera District, located at 30 º 30'–30 º 25' east and 2 º 05'– 2 º 30' south and at an altitude of 1,400 m above mean sea level. Bugesera (02° 17′ S; 30° 16′ E). The region covers a total area of 1,303 km^2 (Cush et al., 2014). The district is composed of 15 sectors. In the present study, two sites were selected. The first site was the Gashora sites located at 2° 20’45’’S and 30° 24’ 22’’E at 1384 m above mean sea level. The second site was the Rweru site located at 2° 18’ 45’’S and 30° 15’ 57’’ E at 1346 m above mean sea level.

Regarded as a drought prone area, Bugesera district is one of the drier parts of Rwanda which receives little rainfall (Benimana et al., 2015). Annual rainfall ranges from 850-1000mm, characterized by a bimodal pattern with peaks in April and November. Average temperature is around 21°C (Verdoodt & Ranst, 2003). During the study period, monthly rainfall ranged from 106 mm in March to 22.5 mm in June during the first season (March to June, 2019). During the second season experiment, monthly rainfall ranged from 165.8 mm in October to 46.3 mm in December as shown in Figure 1.

Soils in the Bugesera area region are generally fairly deep, well drained, clayey, sandy clay or sandy silt. Sand-clay soils are found at the edge of lakes, swamps and marshes. Majority of soils in Bugesera are classified under Oxisols and Ultisols according to USDA classification.

2.2 Study Area Soil Characterization

Disturbed soil samples were collected from 0-30 cm depth in the experimental field using a soil auger in a random zig zag manner for the initial physical and chemical properties analysis. The samples were composited, air-dried for a week, ground and sieved through a 2 mm wire mesh before analysis. Soil pH was determined potentiometrically in a 1:2.5 soil: water solution (Okalebo, 2002). Total nitrogen was determined using Kjeldhal digestion-distillation method (Okalebo, 2002). Soil organic carbon (OC) was determined by the modified Walkley and Black method according to Nelson and Sommers (1996). Soil OC was converted to soil organic matter by multiplying soil OC (%) by a factor of 1.724. Available P was extracted using Bray 1 solution and determined by spectroscopy at 882 nm flowing color development by the molybdenum blue method (Okalebo, 2002). Soil texture was determined by the Bouyoucos hydrometer method. Bulk density was determined by the core method (Blake & Hartge, 1986). Undisturbed soil samples were collected by inserting metal core rings with a known volume in soil at 0-30 cm depth, and thereafter determining weight of soil after oven drying. The soil infiltration capacity was determined by the double ring infiltrometer method according to Standard Test Method for Infiltration Rate of Soils in Field, D3385 – 03 (ASTM, 2003). The initial chemical and physical characteristics of the experimental soils are presented in table 1.

Table 1: Initial chemical and physical characteristics of the experimental soils

Soil parameters	Gashora site	Rweru site
Soil pH	5.32	5.50
Total nitrogen (%)	0.28	0.16
Available phosphorus (ppm)	9.1	7.7
OM (%)	6.87	4.40
Soil texture	Sandy loamy	Clay
Infiltration rate (mm hr^{-1})	10.2	5.8
Soil bulk density (g cm^{-3})	1.20	1.31

2.3 Experimental design and treatments

A split plot in a Randomized Complete Block Design (RCBD) was used, with three irrigation levels (I_0, I_1, I_2) as main plots and three mulching types [control (no mulch), organic mulch, plastic mulch] as subplots, replicated three times. The treatment combinations were; I_0M_0 = rain-fed+ no mulch, I_0M_1 = rain-fed + grass mulch; I_0M_2 = rain-fed + plastic mulch, I_1M_0 = 50% irrigation + no mulch, I_1M_1 = 50% irrigation + grass mulch, I_1M_2= 50% irrigation + plastic mulch, I_2M0=, I_2M_0=100% irrigation + no mulch, I_2M_1= 100% irrigation + grass mulch, I_2M_2= 100% irrigation + plastic mulch. Sub plots were separated by 0.5 m distance whereas main plots were separated by 1 m. Each plot measured 2 m × 2.4 m. In mulched plots, grass mulch (10 cm thick) and plastic (black) mulch were used. MAC 44 was the test variety of climbing bean in the experiment. The variety is adapted to low and medium altitudes, with a growing season of 87 days and has a potential yield of 3.5 t ha^{-1} (Katungi et al., 2019).

Experimental fields were hand tilled using hoes and the seedbed was prepared using rakes before sowing. Prior to planting the soil was wetted to field capacity. Between-row spacing was 50 cm, and the distance between each plant within the row was 20 cm. Two seeds were sown per hole and thinned to one seedling 3 weeks after emergence, to give a plant population of 100, 000 per hectare. All the plots were fertilized evenly at planting with the same amounts of diammonium phosphate fertilizer (50 kg ha^{-1}) and organic manure (5 tons ha^{-1}). In the first season, climbing beans were planted in March 2019 and harvested in July 2019, whereas in the second season, planting was done in October 2020 and harvesting in January 2021.

Different levels of irrigation and mulching were applied, according to treatments, from 3 weeks after emergence. Regular plant maintenance practices such as weeding and hoeing were done when necessary. Irrigation water was applied manually using a watering can. Irrigation water was applied once every 3 days at Rweru and once every two days at Gashora. The difference in irrigation frequencies was based on soil texture and infiltration rate of the two sites. Irrigation water application was stopped after yellowing of 50 % plant leaves. The amount of water applied was calculated using the recommendation rates proposed by Beebe et al. (2013) as presented in Table 2.

Table 2: Irrigation water rate at various growth rates (adapted from Beebe et al., 2013).

Growth stage	Recommended rate mm day^{-1}	Actual amount of applied water	
		I1	I2
Emergence	2	1	2
Vegetative	3	1.5	3
Flowering	6	3	6
Pod development	7	3.5	7
Seed filling	7	3.5	7
Physiological maturity	3	-	--
Leave yellowing	1	-	

I_1: 50% water requirement and I_2 (100%water requirement

2.4. Growth and Yield Data Collection

Growth and yield data collected include plant height, days to maturity, pod plant^{-1}, grains pod^{-1}, weight of 100 grains and grain yield plot^{-1}. Four plants from inner rows in each plot were identified for the measurements. Plant height was measured using a tape meter. Measurement started 3 weeks after emergence. Days to maturity was calculated as the number of days from seeding to 50% pod harvest maturity (fleshy pods with small green immature seeds). At harvest, quantitative data on yield parameters was collected; number of pod plant^{-1}, grains pod^{-1}, total grain yield and weight of 100 grains. For grain yield determination, the entire plot was harvested and weighed. Grain yield was determined by weighing bean grains dried up to 10% moisture content. A total of 100 bean grains were also counted and weighed.

2.5. Statistical Analysis

Microsoft Excel program was used to create different graphs presented in this work. GLM Procedures were performed using Statistical Analysis Software package (SAS) for each season, followed by Fisher's least significant difference (LSD, $p = 0.05$) procedure for treatment means comparison. Mixed LSD was calculated (hand computation) for comparison of subplot means across different main plot levels. Finally, the correlation analyses were performed using Minitab 17 software.

3.0 RESULTS

3.1 Effect of Irrigation Levels and Mulching Types on Plant Height

Mean height of climbing beans in the study area at the end of vegetative growth are shown in Table 3 whereas periodical plant heights are presented in Figures 2,3,4,and 5.

Table 3: Mean plant height in the study area (Mean ±SE)

Treatment combinations	**Plant height (cm)**			
	Rweru- S1	**Rweru** –S2	**Gashora-S1**	Gashora- S2
I_0M_0	147.4 ± 0.5 d	146.2 ± 19.2 c	153.5 ± 3.9 c	152.6 ± 0.4 e
I_0M_1	152.3 ± 6.8 d	151.0 ± 7.0 c	158.4 ± 0.5 bc	156.1 ± 0.8 d
I_0M_2	149.2 ± 1.0 d	148.0 ± 1.8 c	163.2 ± 1.9 b	161.3 ± 0.8 c
I_1M_0	154.1 ± 1.1 cd	157.8 ± 1.3 bc	162.4 ± 3.6 b	160.1 ± 1.4 c
I_1M_1	185.1 ± 3.5 a	181.8 ± 2.0 a	182.7 ± 1.1 a	182.6 ± 0.8 a
I_1M_2	167.2 ± 4.4 b	166.7± 1.3 b	179.9 ± 1.2 a	178.9 ± 0.9 b
I_2M_0	168.1 ± 2.4 b	167.2 ± 1.6 b	178.6 ± 1.6a	178.4 ± 0.8 b
I_2M_1	171.5 ± 3.9 b	172.9 ± 1.5 ab	181.9 ± 1.2 a	181.9 ± 0.7 a
I_2M_2	175.9 ± 6.3 ab	178.9 ± 2.7 ab	181.2 ± 1.5 a	182.9 ± 0.2 a
Mean	163.41	163.37	171.31	170.54
n	3	3	3	3
CV	4.21	3.10	1.82	0.85

Key: *Different letters in the same column indicate significantly different values at $P < 0.05$. I_0= No irrigation, I_1= 50%irrigation level; I_2 = 100% irrigation level; M_0= No mulch; M_1= grass mulch M_2= plastic mulch. CV- Coefficient of variation; ± values after the means represent the mean standard error; n- Number of observations/treatments. S1-Season 1; S2-Season.*

Analysis of Variance revealed significant ($P<0.05$) irrigation × mulching interaction effects both at Rweru and Gashora at the end of season 1 ($P= 0.0227, 0.0021$) and 2 ($P=0.0132, < 0.0001$). Generally, bean plants were slightly shorter at Rweru as compared to Gashora site. At Rweru during the first season, highest plant height was observed under I_1M_1 and I_2M_2 treatment combinations. In the second season, significantly taller plants were observed under I_1M_1, I_2M_1 and I_2M_2 treatments. Lowest values were recorded under I_0M_0, I_0M_1, I_0M_2 and I_1M_0 in both seasons at Rweru. At Gashora, in the first season taller plants were observed under I_1M_1, I_1M_2, I_2M_0, I_2M_1 and I_2M_2 treatments. In the second season taller plants were found in I_1M_1, I_2M_1 and I_2M_2 treatments combinations. The lowest bean heights in Rweru; 147.4 cm, 152.3cm and 149.2 in season 1 and 146.2cm, 151.0 cm and 148.0 cm in season 2 were observed in I_0M_0 and I_0M_1 and I_0M_2 treatments, respectively. Similarly, the lowest bean heights of 153.5 cm and 158.4cm were observed in season 1 in I_0M_0 and I_0M_1 treatments, respectively, and 152.6 cm in in I_0M_0 treatment in season 2, at Gashora.

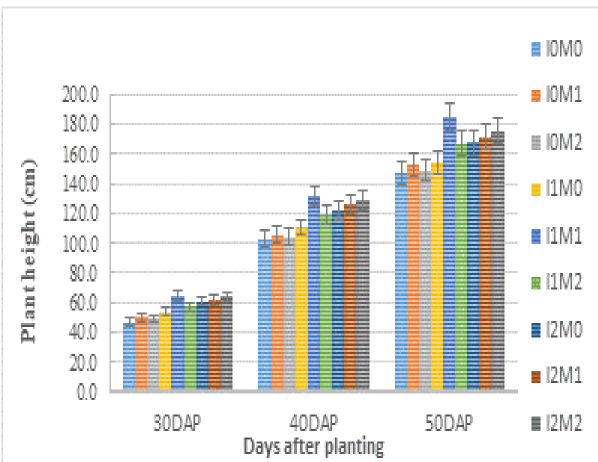

Figure 2: Periodical plant height at Rweru season 1

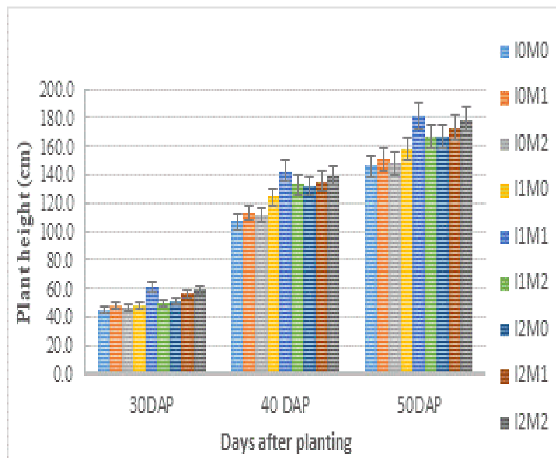

Figure 3: Periodical plant height at Rweru season 2

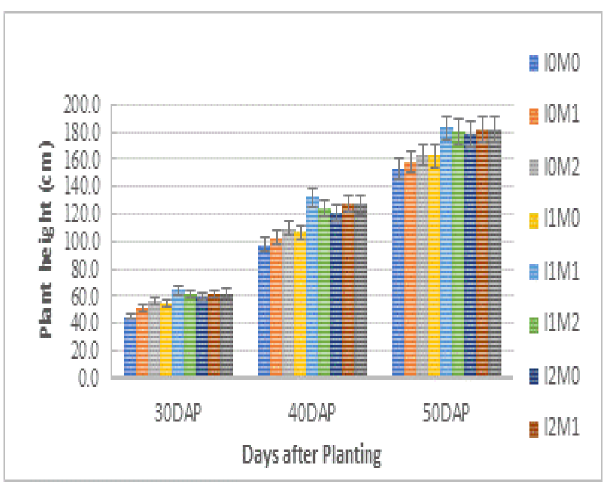

Figure 4: Periodical plant height data at Gashora in season 1

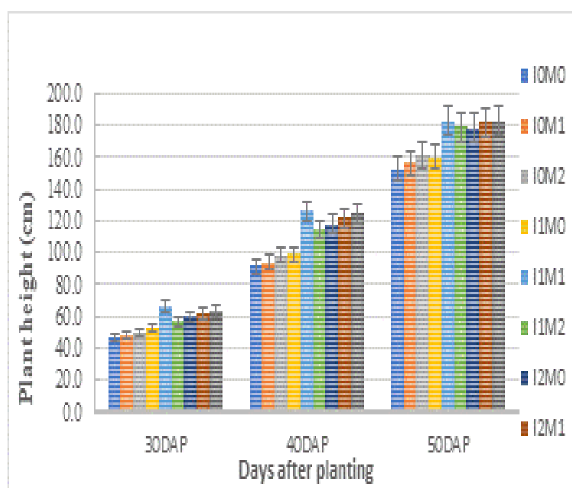

Figure 5: Periodical plant height data at Gashora in season 2

Mostly, plant height increased with progression of time, according to the periodical record of plant height (figures 2, 3, 4 and 5). Maximum plant height at different periods were recorded under treatment I_1M_1, I_2M_2, I_2M_1, I_1M_2 and I_2M_0. In contrast the shortest plants were recorded under I_0M_0, I_0M_1, I_0M_2 and I_1M_0 at both sites at different recording periods. This trend was similar at both sites through different recording periods as shown in the figures 2, 3, 4 and 5.

3.2 Effect of Irrigation Levels and Mulching Types on Days to Maturity

The days to bean maturity varied from 72 to 85 days and from 75 to 84 days in seasons 1 and 2, respectively at the Rweru site. For the Gashora site the range was between 71 to 83 days and 72 to 83 days, for seasons 1 and 2, respectively (Table 4).

Table 4: Days to maturity of climbing bean during the study (mean ±SE)

Treatment combinations	Days to Maturity			
	Rweru S1	**Rweru S2**	**Gashora S1**	**Gashora S2**
I_0M_0	72.3 ± 1.2	75.7 ± 0.9	71.3± 0.9 b	72.3 ± 0.67
I_0M_1	80.3 ± 0.9	81.0 ± 1.2	78.0± 0.6 b	77.0 ± 1.15
I_0M_2	73.0 ± 1.0	74.7 ± 0.9	72.7± 0.3 b	74.3 ± 0.88
I_1M_0	81.3 ± 1.5	80.3 ± 0.9	80.7± 1.2 a	76.7 ± 0.88
I_1M_1	85.0 ± 0.6	84.3 ± 0.3	82.7± 0.3 a	83.0 ± 0.58
I_1M_2	81.7 ± 0.9	81.0 ± 0.6	79.7± 0.9 a	79.7 ± 0.33
I_2M_0	80.7 ± 1.2	79.3 ± 0.9	79.7± 0.7 a	81.3 ± 0.88
I_2M_1	84.3 ± 0.9	85.0 ± 0.6	82.7± 0.7 a	81.3 ± 0.88
I_2M_2	83.7 ± 0.7	82.3 ± 1.2	82.0± 0.6 a	80.7 ± 0.67
Mean	80.26	80.41	78.81	78.70
n	27	27	27	27
CV	2.30	1.94	1.52	1.77

Key: *Different letters in the same column indicate significantly different values at P< 0.05.* I_0*= No irrigation,* I_1*= 50%irrigation level* I_2 *= 100% irrigation level;* M_0*= No mulch;* M_1*= grass mulch* M_2*= plastic mulch. CV= Coefficient of variation; ± values after the means represent the mean standard error; N = Number of observations/treatments S1= Season 1; S2= Season 2*

Anova results for days to maturity revealed significant (P < 0.05) interaction effects (irrigation × mulching) during the 1st season (P= 0.0127) at Gashora site (Table 4) while during the second season significant differences in days to maturity were due to main effects of mulching and irrigation. In contrast at Rweru, significant differences in days to maturity during the season 1 and season 2 were due to main effects of irrigation *(*P= 0.0002 and 0.0016), and mulching (P= 0.0002 in the season 1 and P < 0.0001 in the season 2). The main effects of irrigation and mulching at Gashora are given in Figure 6, whereas the main effects for Rweru are shown in Figures 7 and 8.

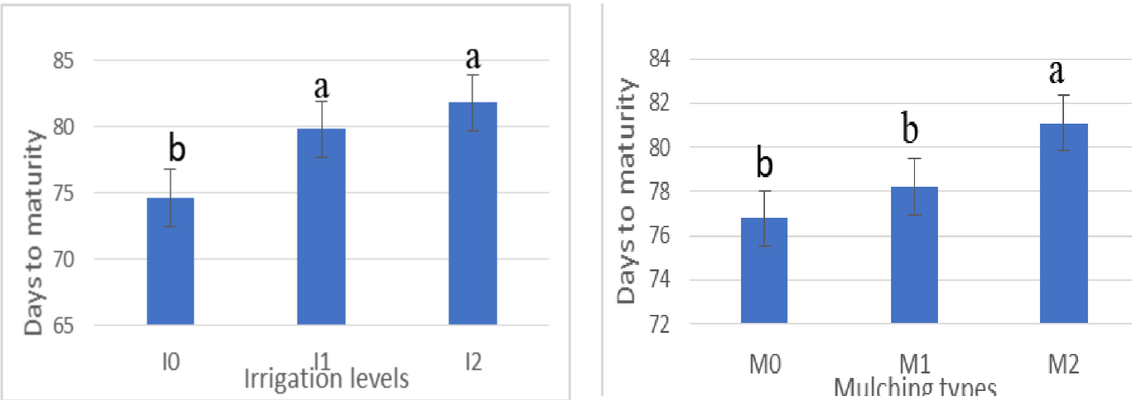

Figure 6: Effect of irrigation levels (left) and mulching types (right) on days to maturity at Gashora in season 2

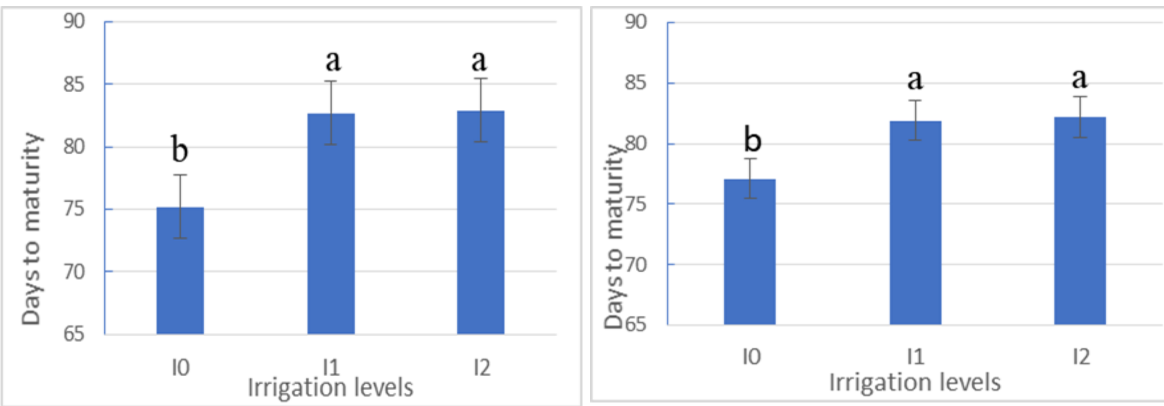

Figure 7: Effect of irrigation levels on days to maturity at Rweru in season 1 (left) and 2 (right)

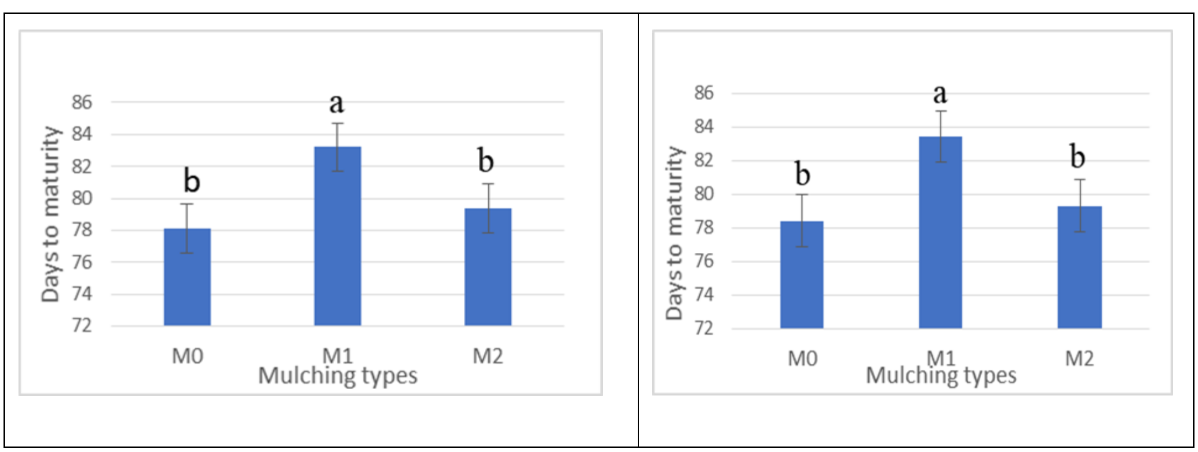

Figure 8: Effect of mulching types on days to maturity at Rweru in season 1(left) and 2(right)

3.3 Effect of Irrigation Levels and Mulching Types on Yield Parameters

In this study, three yield parameters namely pods plant^{-1}, grains pod^{-1} and 100 grains weight, were considered. Mean values of these yield parameters and grain yield are given in Table 5.

Table 5. Effect of irrigation and mulching on yield parameters (mean ±SE)

Treatment combinations	Pods plant^{-1} Rweru	Gashora	Grains pod^{-1} Rweru	Gashora	100 grains weight(g) Rweru	Gashora
Season 1						
I_0M_0	11.0 ± 0.68 d	10.0 ± 0.6	3.0 ± 0.0	3.5 ± 0.3 c	46.0 ± 1.0	46.7 ± 1.8 b
I_0M_1	12.3 ± 0.3 d	11.7 ± 1.5	3.3 ± 0.3	3.3 ± 0.3 c	54.3 ± 0.9	56.0 ± 1.2 ab
I_0M_2	11.3 ± 0.9 d	13.3 ± 0.3	3.3 ± 0.3	4.0 ± 0.0 bc	52.0 ± 0.6	57.7 ± 1.5 a
I_1M_0	14.3 ± 0.9 cd	15.0 ± 1.0	4.3 ± 0.7	4.0 ± 0.6 bc	58.3 ± 0.9	60.3 ± 1.5 a
I_1M_1	22.3 ± 1.2 a	23.5 ± 3.5	6.0 ± 0.6	6.0 ± 0.0 a	61.0 ± 1.5	64.7 ± 3.8 a
I_1M_2	18.3 ± 1.2 b	16.7 ± 3.8	5.3 ± 0.3	4.6 ± 0.3 b	64.0 ± 1.0	62.0 ± 2.4 a
I_2M_0	17.0 ± 0.6 b	16.0 ± 1.7	5.3 ± 0.7	5.0 ± 0.0 ab	58.3 ± 0.9	60.0 ± 5.0 a
I_2M_1	21.0 ± 1.2 ab	20.0 ± 1.2	5.7 ± 0.3	5.7 ± 0.3 a	61.0 ± 1.5	62.0 ± 6.1 a
I_2M_2	20.3 ± 0.9 ab	19.0 ± 1.2	6.3 ± 0.3	5.3 ± 0.3 ab	64.0 ± 1.0	62.0 ± 4.2 a
Mean	16.44	16.13	4.74	4.6	57.7	59.0
n	27	27	27	27	27	27
CV	9.96	25.63	17.93	9.33	3.75	4.42
Season 2						
I_0M_0	10.0 ± 0.67 b	10.3 ± 0.9	3.0 ± 0.0	2.7 ± 0.3 c	47.0 ± 0.6	45.6 ± 1.2 c
I_0M_1	11.0 ± 1.0 b	12.0 ± 0.6	3.3 ± 0.3	3.0 ± 0.6 c	55.0 ± 1.2	54.3 ± 1.3 b
I_0M_2	11.3 ± 0.3 b	14.0 ± 1.2	3.0 ± 0.0	3.0 ± 0.6 c	52.7± 0.7	57.3 ± 0.9 b
I_1M_0	14.7 ± 1.2 b	16.7 ± 1.9	4.3 ± 0.7	3.0 ± 0.0 c	59.3 ± 1.9	58.0 ± 0.6 b
I_1M_1	21.7 ± 1.2 a	21.3 ± 1.5	6.3 ± 0.3	5.7 ± 0.3 ab	62.3 ± 1.5	63.7 ± 0.7 a
I_1M_2	17.0 ± 1.2 ab	16.0 ± 1.5	5.3 ± 0.3	4.0 ± 0.0 bc	65.3 ± 0.3	61.0 ± 3.5 ab
I_2M_0	17.7 ± 0.9 ab	15.7 ± 1.5	5.3 ± 0.7	3.3 ± 0.3 c	61.0 ± 1.5	60.0 ± 2.5 ab
I_2M_1	19.0 ± 0.6 ab	19.3 ± 0.3	5.7 ± 0.3	6.0 ± 0.0 a	64.0 ± 1.0	60.0 ± 1.2 ab
I_2M_2	21.0 ± 1.5 ab	17.3 ± 0.9	6.0 ± 0.6	4.7 ± 0.3 b	62.0 ± 1.0	58.0 ± 1.2 b
Mean	15.93	15.85	4.7	3.9	58.7	57.6
n	27	27	27	27	27	27
CV	10.36	12.73	14.75	13.87	3.27	5.62

Key: Different letters in the same column indicate significantly different values at P< 0.05. I_0= No irrigation, I_1= 50%irrigation level; I_2 = 100% irrigation level; M_0= No mulch; M_1= grass mulch M_2= plastic mulch. CV- Coefficient of variation; ± values after the means represent the mean standard error; n- Number of observations/treatments

3.3.1 Pods plant^{-1}

Results showed that mean pods plant^{-1} varied from 11 to 22.3 in season 1 and from 10 to 22 in season 2 for the Rweru site. At Gashora, pod plant^{-1} ranged from 10 to 24 and 10 to 21.7 in the first and second seasons, respectively (Table 5).

Significant ($P < 0.05$) interactions effects (irrigation × mulching) were observed during both first ($P = 0.0432$) and second seasons ($P = 0.0191$) at Rweru site. The highest number of pods were observed under I_1M_1, I_2M_1 and I_2M_2, in season 1 and I_1M_1, I_2M_0, I_2M_1 and I_2M_2 in season 2. In contrast, at Gashora significant ($P < 0.05$) differences in pods plant^{-1} were due to main effects (irrigation) in both the first ($P = 0.0018$) and second seasons ($P = 0.0115$). The main effects of irrigation on pods plant^{-1} at Gashora is shown in Figure 9.

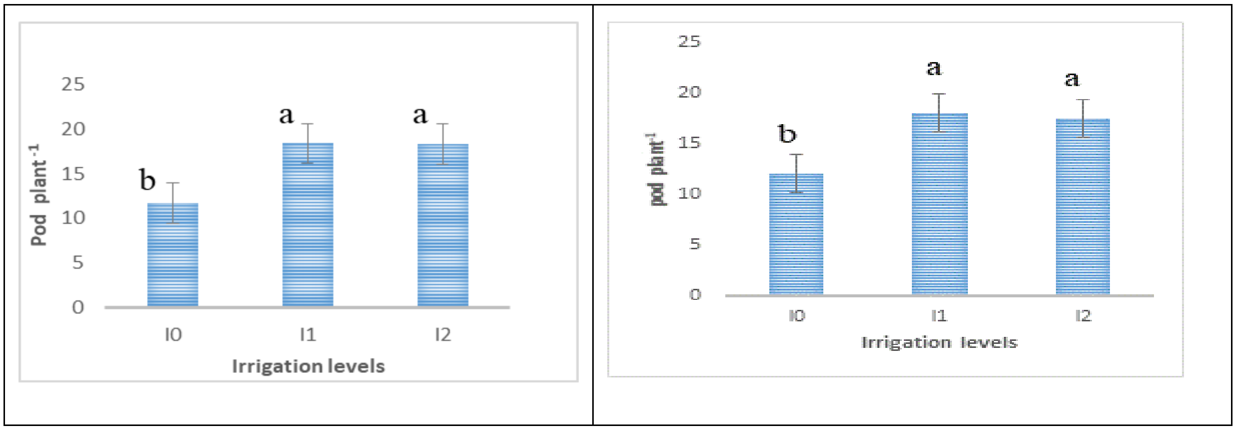

Figure 9: Effect of irrigation levels on pods plant^{-1} at Gashora in season 1 (left) and 2 (right)

3.3.2. Grains pod^{-1}

Mean grains pod^{-1} varied from 3 to 6.3 at Rweru in both seasons. For Gashora the mean grains pod^{-1} ranged from 3.3 to 6 and 2.7 to 6 in the first and second seasons, respectively (Table 5). Anova results of grains pod^{-1} for Gashora showed significant irrigation × mulching interactions effects for both season 1 (P=0.0069) and 2 (P = 0.0151). Significantly (P < 0.05) higher number of grains pod^{-1} were observed in I_1M_1, I_2M_0, I_2M_1 and I_2M_2 treatments in season 1, and I_1M_1 and I_2M_1 in season 2. In contrast, results of grains pod^{-1} for Rweru, showed significant differences due to main effects of irrigation (P ≤ 0.0001) during the two seasons. The main effects of irrigation on grains pod^{-1} are presented in Figure 10.

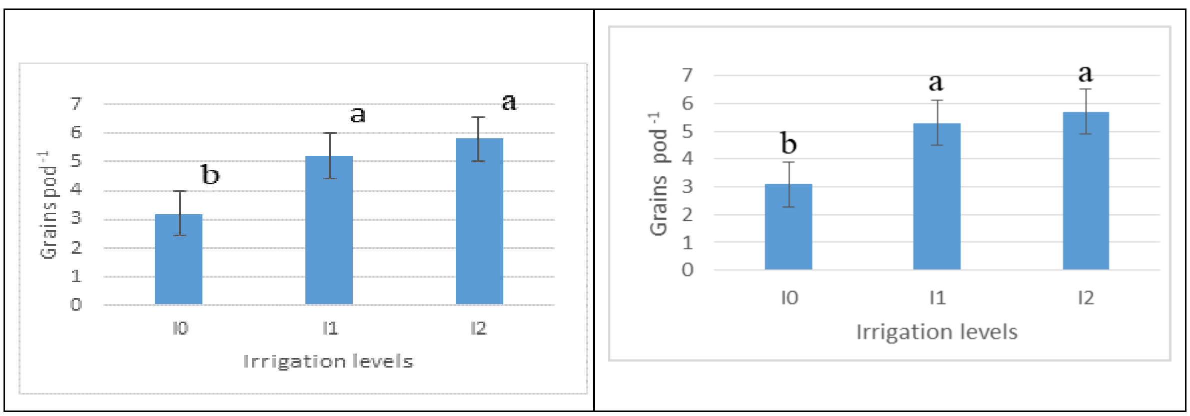

Figure 10: Effect of irrigation levels on grains pod^{-1} at Rweru in season 1(left) and 2(right)

According to Figure 10, mean grains pod^{-1} was significantly higher in 100% irrigation and 50% irrigation treatments, than the control.

3.3.3 Hundred grains weight

Results presented in Table 5 show the lowest mean of 100 grains weight of 46 g and 46.7g at Rweru in first and second season, respectively. The highest mean weights for 100 grains of 64 g and 65.3g were recorded in the first and second seasons, respectively. Results of 100 grains weight revealed significant (P<0.05) interaction effects (irrigation × mulching) for both season 1 (P = 0.0431) and 2 (P = 0.0356) at Gashora. Significantly higher means were observed under treatments; I_0M_2, I_1M_0, I_1M_1, I_1M_2, I_2M_0, I_2M_1 and I_2M_2 compared to the control (I_0M_0). In the second season treatment I_1M_1 had significantly higher 100 grains weight. In contrast at Rweru, significant differences were due to main effects of both irrigation and mulching in the first season ($P \leq 0.0001$, $P = 0.0001$) and the second ($P \leq 0.0001$, $P = 0.0004$) season. The effect of both irrigation levels and mulching types at Rweru are presented in Figures 11 and 12.

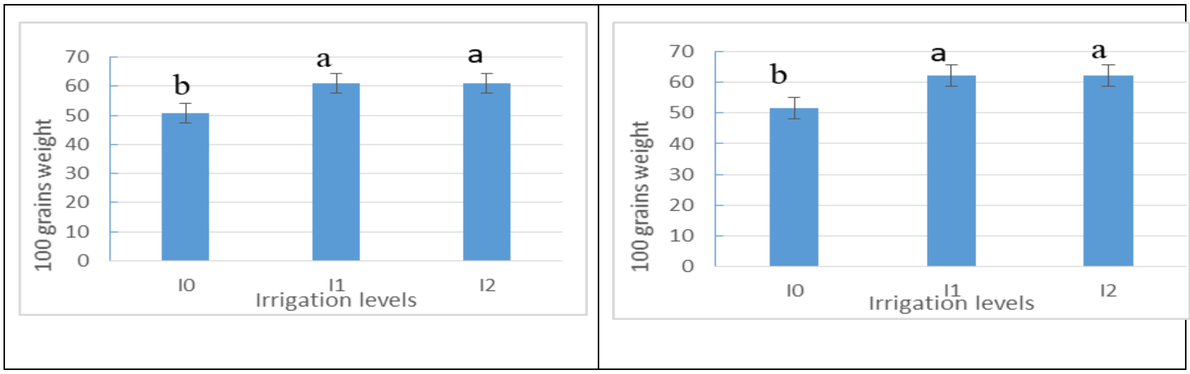

Figure 11: Effect of irrigation levels on 100 grains weight at Rweru in season 1(left) and 2(right)

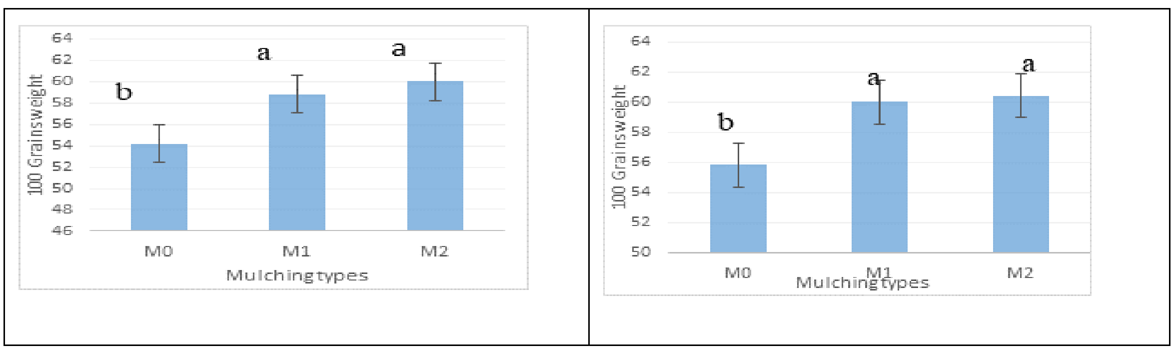

Figure 12: Effect of mulching types on 100 grains weight at Rweru both season 1(left) and 2 (right)

According to Figure 11, the lowest mean of 100 grains weight was recorded in the control. The highest mean were observed under both 100% irrigation level and 50% irrigation level treatments, in both seasons (1 and 2). From Figure 12, the lowest mean was found in treatment with no mulch in both season 1 and 2. The highest value was recorded under grass mulch and plastic mulch.

3.4 Effect of Irrigation Levels and Mulching Types on Yield

Results of grain yield (Rweru) are presented in Table 6. Significant ($P < 0.05$) interaction effects (irrigation × mulching) during both seasons 1 ($P = 0.0018$) and 2 ($P = 0.0125$) were observed. Similarly, results for Gashora show significant ($P < 0.05$) interactions effects for first ($P = 0.0031$) and second seasons ($P = 0.0036$).

Table 6: Grain yield (g plot-1) during the study (means ± SE)

Treatment combinations	Rweru	Gashora	Rweru	Gashora
	Season 1		Season 2	
I_0M_0	630.0 ± 10.7 d	695.3 ± 20.2 e	653.0 ± 4.4 d	683.7 ± 17.0 de
I_0M_1	711.0 ± 15.5 d	758.0 ±21.8 de	715.0 ± 11.3 d	742.3 ± 18.0 d
I_0M_2	679.3 ± 5.4 d	735.7 ± 18.3 e	696.7 ± 23.9 d	721.0 ± 10.4 d
I_1M_0	910.0 ± 9.0 c	895.3 ± 4.6 d	917.0 ± 4.5 c	881.3 ± 4.4 c
I_1M_1	1221.0 ± 27.1 a	1233.7 ± 43.2 a	1257.0 ± 23.3 a	1250.3 ± 29.3 a
I_1M_2	1019.7 ± 34.6 b	1035.3 ± 35.4 b	1058.3 ± 12.2 b	1084.0 ± 34.4 b
I_2M_0	951.0 ± 38.1 bc	992.3 ± 13.0 bc	972.0 ± 18.0 bc	995.7 ± 24.7 bc
I_2M_1	1117.3 ± 38.3 b	1113.3 ± 51.3 ab	1128.3 ± 48.5 b	1189.0 ± 57.5 ab
I_2M_2	1146.3 ± 38.3 ab	1146.3 ± 40.1 ab	1134.0 ± 59.9 b	1113.7 ± 55.5 b
Mean	931.74	947.93	956.15	962.33
n	27	27	27	27
CV	4.76	6.32	5.42	5.27

Key: Different letters in the same column indicate significantly different values at P≤ 0.05. I_0 = No irrigation, I_1 = 50%irrigation level, I_2 = 100% irrigation level, M_0= No mulch, M_1= grass mulch M_2= plastic mulch; CV-Coefficient of variation; ± values after the means represent the mean standard error; n- Number of observations/treatments

As shown in Table 6, in the first season treatments I_1M_1 and I_2M_2 at Rweru and I_1M_1, I_2M_1 and I_2M_2 at Gashora had the highest mean grain yield plot^{-1}, respectively. In season 2 at both Rweru, and Gashora, significantly higher yields were obtained in I_1M_1 treatment. The lowest mean in both seasons was recorded under no irrigation with or without mulching. At Rweru site, mean grain yield plot^{-1} ranged from 630.00g under I_0M_0 to 1221. 00g under I_1M_1 for season 1 and from 653.00g to 1257.00 g for season 2. Similarly, at Gashora grain yield plot^{-1} ranged from 695.3 g to 1233.7 g during the 1st season and from 683.67 to 1250.30 g in the second season.

3.5 Correlation Results

Results of Pearson's correlation between grain yield and yield components under the study as well as plant height are given in Tables 7 and 8. At Rweru site a positive and very high significant correlation was found between grain yield and pods plant^{-1}, grain yield and grains pod^{-1}, and yield and plant height (P < 0.0001). The correlation between yield and 100 grain weight was also positive and significant for seasons 1 (P = 0.002) and 2 (P = 0.001).

Table 7: Correlation-Rweru

		Correlation	Plant height	Pods plant^{-1}	Grains pod^{-1}	100 Grains weight	Yield
Season 1	Pearson's coefficient	Plant height	1				
		Pods plant^{-1}	0.889	1			
		Grains pod^{-1}	0.933	0.959	1		
		100 grains weight	0.833	0.851	0.759	1	
		Yield	0.934	0.969	0.949	0.833	1
	P value	Plant height					
		Pods plant^{-1}	0.003				
		Grains pod^{-1}	0.001	0.000			
		100 grains weight	0.010	0.007	0.029		
		Yield	0.001	0.000	0.000	0.010	
Season 2	Pearson's coefficient	Plant height	1				
		Pods plant^{-1}	0.828	1			
		Grains pod^{-1}	0.828	0.864	1		
		100 grains weight	0.788	0.859	0.634*	1	
		Yield	0.946	0.919	0.907	0.785	1
	P value	Plant height					
		Pods plant^{-1}	0.006				
		Grains pod^{-1}	0.006	0.003			
		100 grains weight	0.012	0.003	0.067		
		Yield	0.000	0.000	0.01	0.012	

**Not significant*

Table 8: Correlation analysis -Gashora

		Correlation	Plant height	Pods plant^{-1}	Grain pod^{-1}	100 grains weight	Yield
Season 1	Pearson's coefficient	Plant height	1				
		Pods plant^{-1}	0.889	1			
		Grains pod^{-1}	0.933	0.959	1		
		100 grains weight	0.833	0.851	0.759	1	
		Yield	0.934	0.969	0.949	0.833	1
	P value	Plant height					
		Pods plant^{-1}	0.003				
		Grains pod^{-1}	0.001	0.000			
		100 grains weight	0.010	0.007	0.029		
		Yield	0.001	0.000	0.000	0.010	
Season 2	Pearson's coefficient	Plant height	1				
		Pods plant^{-1}	0.828	1			
		Grains pod^{-1}	0.828	0.864	1		
		100 grains weight	0.788	0.859	0.634*	1	
		Yield	0.946	0.919	0.907	0.785	1
	P value	Plant height					
		Pods plant^{-1}	0.006				
		Grains pod^{-1}	0.006	0.003			
		100 grains weight	0.012	0.003	0.067		
		Yield	0.000	0.000	0.01	0.012	

**Not significant*

Similarly, a positive and highly significant correlation was found between grains pod^{-1} and plant height (r = 0.949 and 0.998 for season 1 and 2), grains pod^{-1} and pods plant^{-1}(r = 0.966 and 0.990). The correlation between plant height and pod plant^{-1} was highly significant (r = 0.974 and 0.995). The correlation between 100 grain weight and other parameters were also significant and positive.

At Gashora in both seasons, the correlation analysis (Table 8) showed a positive and highly significant association between grain yield, yield parameters and plant height. The association was positive and significant between yield and grain.pod^{-1} (r = 0.949 and 0.907) yield and pod plant^{-1} in both season 1(r = 0.969) and season 2(r = 0.919). There is also a significant correlation between yield and plant height (r = 0.934 for season 1 and r = 0.946 for season 2) as well as yield and hundred grains weight (r = 0.833 in the season 1 and 0.785 in season 2), pods plant^{-1} was also highly associated with grains pod^{-1} (r = 0.959 in season 1 and r = 0.869 in season 2). Hundred grains weight and pod plant^{-1} (r = 0.851 and 0.859), the association between 100 grains weight and grain pod^{-1} was significant only for 1st season (r = 0.759) similarly, the correlation between plant height and pod plant^{-1} was also positive and significant in both season 1(r = 0.889 and season 2 (r= 0.828).

4.0 DISCUSSIONS

4.1 Plant Height

In the present study, significant differences in climbing bean height due to irrigation × mulching interaction effects were observed. These findings are consistent with Meena et al. (2019) and Iqbal et al. (2021). Tallest plant observed under irrigation combined with mulching treatments could have been resulted from conducive growth conditions such as optimum temperature, better availability of soil moisture and nutrients. This subsequently enhanced vegetative growth, through increased cell division and enlargement. In addition, processes such a photosynthesis and respiration vital for plant growth took place at optimum rate (Morales et al., 2020). In the present study, irrigation and water conservation by grass mulch availed moisture to plants. The mulch improved hydraulic properties of soil and reduced evaporation. The absence of weeds due to mulching might have also resulted in improved plant growth/height due to the absence of competition especially for water and nutrients (Nwosisi et al., 2019, Datta et al., 2017, Iqbal et al., 2020, Baker et al., 2021)

On the contrary, shortest beans observed under the combination of no irrigation with or without mulching might have been due to limited soil moisture and poor nutrient availability. Additionally, under limited moisture, processes such as cell division and enlargement, and photosynthesis are negatively affected and results in reduced plant height. Moisture stress also causes stomatal closure and reduced CO_2 and nutrient uptake by the plants, hence negatively affects plant growth. Similar effects of low moisture on plant height have previously been reported (Kapoor et al., 2020, Singh, et al., 2021). Plant height is a fundamental morphological phenotype. It directly indicates the plant growth and is one of indirect measures of plant health. Plants are susceptible to environmental stress mainly at an early stage. Soil moisture is an important factor in plant growth. Results from the present study are in agreement with the findings of Kwambe et al. (2015) and Ni et al. (2016). The relative means revealed maximum beans height improvement of 26% and 24% under I_1M_1 compared to the control (I_0M_0) at Rweru and 19 and 20% for Gashora in seasons 1 and 2, respectively).

4.2 Days to Maturity

Days to maturity results indicated significant differences in relation to irrigation × mulching interactions effects for the first season, at Gashora. In contrast, during the second season at Gashora during both seasons 1 and 2 at Rweru differences were due to main effects irrigation and mulching. Days to maturity varied from 72 and 76 days to 84 and 82 days at Rweru and from 71 and 71 days to 82 and 80 days at Gashora. Days to maturity increased with irrigation and mulching. Low moisture accelerated the physiological maturity by 12 and 6 days (season 1 and 2) on average at Rweru. Whereas at Gashora site, the physiological maturity was accelerated by 11 and 9 days on average. Lowest number of days to maturity were noted in I_1M_0 treatment as results of limited soil moisture. This is obvious, plants growing in moisture limited soil tend to mature faster to escape to moisture deficiency. Similarly, irrigation and mulching might have favoured vegetative growth through availability of soil moisture, improved soil properties and moderation of temperature which favored vegetative growth and delayed maturity. Similar findings have been previously reported (Ashraf et al., 2016; Ntukamazina et al., 2017; Teame et al. 2017). The extended growth duration may result in a prolonged grain filling period, hence increased grain yield.

Main effects of irrigation and mulching were significant at Gashora in season 2, and Rweru in both seasons 1 and 2 (Figures 6 and 7). Inadequate moisture could have resulted in the acceleration of bean maturity due to stress caused by limited soil and unfavorable temperature. The findings are in line with Qaseem, et al. (2019).

4.3 Yield Parameters

In the present study the interaction effect (irrigation × mulching) on pod plant^{-1} was significant ($P < 0.05$) for Rweru site in both seasons. Similarly, a significant interaction effect on grain plant^{-1} was observed in Gashora during two seasons. Furthermore, interactions effect on 100 grains weights were significant at Gashora during the two seasons. Significant interactions observed on these yield parameters could be a result of improved soil moisture conservation near the field capacity under irrigation and mulching throughout the growing period of the crop, and its positive effects on different plant growth stages such as vegetative growth, fruits formation and grain filling. The present findings agreed with Abd El-Wahed et al. (2017), who noted a significant influence of irrigation and mulching on all yield parameters under their study.

Significant effects of irrigation on grain pod^{-1} at Gashora, pod plant^{-1} and 100 grains weight at Rweru, due to irrigation effects, might have resulted from optimum moisture in the root zone, improved nutrients absorption and consequently optimum metabolic mechanisms. Our results agree with Pushpavalli et al. (2014) and Nadeem et al. (2019). Mulching also significantly improved yield parameters (pods plant^{-1}, grains pod^{-1} as well as 100 grains weight). Better performance of yield parameters under mulching treatment might be due to higher water saving, optimum soil moisture availability and the subsequent effect on nutrient uptake and moderation of soil temperature and subsequent improved plant growth. The present results agree with Kwambe, et al. (2015); Abdelrahman et al. (2016); Gao et al. (2020) and Roosda, et al. (2021).

4.5 Grain Yield

Significant grain yield difference due to irrigation × mulching effects observed in the present study, might have resulted from better soil moisture conservation and subsequent nutrient availability, which favored plant growth, physiological process and metabolic processes. Our findings are in agreement with Adekaldu et al. (2021). Low moisture at a given crop growth and/or reproductive stage has negative effects on yield through the effect on different yield attributes. The effects of low soil moisture on yield have been previously reported (Pushpavalli et al., 2014 and Ntukamazina et al., 2017).

Compared to the control (M_0I_0), yield improvement of 94% and 92% respectively for the first and second season was observed at Rweru under I_1M_1. Whereas at Gashora the most improvement of 75% and 83% respectively for first and second season was noted under I_1M_1. Yield differences between irrigated plots and no irrigated plots might have resulted from improvement in nutrient availability, increased vegetative growth and optimum metabolic activity resulting from sufficient available soil moisture in the root zone.

As found in the Table 7 and 8 of Pearson correlation, there was a significant and positive correlation between yield and all yield parameters as also reported by Xu et al., (2020). From the correlation results, it is clear that maximum yield would result from more pods plant^{-1}, grains pod^{-1} as well as 100 grain weight. This suggests that the parameters/variables are very important in the yield obtained. The role played by the yield parameters presented above are well known. More pods plant^{-1} have a positive effect on yield. In addition, production of more grains pod $^{-1}$ would contribute to the increase in total grain, therefore increased grain yield.

Significant and positive correlations between pod plant^{-1} and grains pod^{-1}, pods plant^{-1} and 100 grains weight, grains pod^{-1} and 100 grain weight were observed. In the present study there was interdependence of different parameters. A positive and significant correlation between yield and bean height explains the indirect effect of plant height on grain yield. This translates to increase in grain yield with increase in plant height. The increase in plant height would favor more pod plant^{-1} and subsequently result in more grain yield. These results are obvious, as plant height is a fundamental trait that directly indicates the plant growth and is highly predictive of biomass and final grain yield.

5.0 CONCLUSION

This study investigated the effect of irrigation levels and mulching types on growth and yield of climbing beans. Interaction effects of irrigation and mulching significantly affected plant height and grain yield of climbing beans in both sites during both seasons 1 and 2. Main effect of irrigation and mulching significantly affected days to maturity and yield parameters. The control treatment showed the lowest mean for most parameters under the study. In this study, the best response of climbing beans in drought prone areas was obtained by applying 50% of water requirement together with grass mulch. Highest value of plant height, 100 grain weight and yield value were obtained under the combination of 50% irrigation level with grass mulch. Compared to the control, yield improvement of 83%, 100 grains weight improvement of 39% and plant height increase of 20 % were observed under I_1M_1. Significant and positive correlations were observed between yield, plant height and yield parameters under the present work. The interdependence of yield parameters under the present work was noted as shown by positive and significant correlation between these parameters. From the results, combining irrigation and mulching would improve climbing production while saving irrigation water up to 50%. Both plastic and grass mulch gave similar results, however grass mulch is recommended for climbing bean production in the study area due to its additional advantages over the plastic mulch.

REFERENCES

1. Abdelrahman, N. A., Abdalla, E. A., Ibrahim, E. A., & El Naim, A. M. (2016). The Effect of Plastic mulch on growth and yield of rain-fed Cowpea and watermelon in north Kordofan state of Sudan. *World*, *4*(5), 139-142.

2. Abd El-Wahed, M. H., Baker, G. A., Ali, M. M., & Abd El-Fattah, F. A. (2017). Effect of drip deficit irrigation and soil mulching on growth of common bean plant, water use efficiency and soil salinity. *Scientia Horticulturae*, *225*, 235-242. https://doi.org/10.1016/j.scienta.2017.07.007.

3. Adekaldu, E., Amponsah, W., Tuffour, H. O., Adu, M. O., & Agyare, W. A. (2021). Response of chilli pepper to different irrigation schedules and mulching technologies in semi-arid environments. *Journal of Agriculture and Food Research*, *6*, 100222. https://doi.org/10.1016/j.jafr.2021.100222.

4. Al-Zboon, K. K., Al-Tabbal, J. A., Al-Kharabsheh, N. M., & Al-Mefleh, N. K. (2019). Natural volcanic tuff as a soil mulching: effect on plant growth and soil chemistry under water stress. *Applied Water Science*, *9*(5), 1-10.

5. Asfaw, A., & Blair, M. W. (2014). Quantification of drought tolerance in Ethiopian common bean varieties. *Agricultural Sciences*,

6. Ashraf, U., Salim, M. N., Alam, S. H. E. R., Aqil, K. H. A. N., Shenggang, P. A. N., & Xiangru, T. A. N. G. (2016). Maize growth, yield formation and water-nitrogen usage in response to varied irrigation and nitrogen supply under semi-arid climate. *Turkish Journal of Field Crops*, *21*(1), 88-96.

7. ASTM. (2003). *D3385-03. Standard test method for infiltration rate of soils in field using double-ring infiltrometer. Annual Book of ASTM Standards 04.08.* Amer. Soc. Testing Materials, West Conshohocken, PA.

8. Ayabagabo, P. (2018). *Empirical Analysis Of Seasonal Rainfall Variability And Its Associated Effects On Major Food Crop Yields In Rwanda* (Doctoral dissertation, University of Nairobi).

9. Baker, C., Modi, A. T., & Nciizah, A. D. (2021). Weeding Frequency Effects on Growth and Yield of Dry Bean Intercropped with Sweet Sorghum and Cowpea under a Dryland Area. *Sustainability*, *13*(21), 12328.

10. Beebe, S. E., Rao, I. M., Blair, M. W., & Acosta-Gallegos, J. A. (2013). Phenotyping common beans for adaptation to drought. *Frontiers in physiology*, *4*, 35. https://doi.org/10.3389/fphys.2013.00035

11. Benimana, J. C., Wali, U. G., Nhapi, I., Anyemedu, F. O. K., & Gumindoga, W. (2015). Rainwater harvesting potential for crop production in the Bugesera District of Rwanda. *African Journal of Agricultural Research*, *10*(19), 2020-2031. https://doi.org/10.5897/AJAR12.820

12. Bizimana, H., & Sönmez, O. (2015). Landslide occurrences in the hilly areas of Rwanda, their causes and protection measures. *Disaster Science and Engineering*, *1*(1), 1-7.

13. Blake, G. R., & Hartge, K. H. (1996). Bulk density. *Methods of soil analysis: Part 1 Physical and mineralogical methods*, *5*, 363-375. https://doi.org/10.2136/sssabookser5.1.2ed.c13

14. Cush, N. L., Jean-fiston, N., Akombo, R. A., Mukashema, A., Nzeyimana, I., Ruhakana, A., ... & Mathenge, J. M. (2014). Overlaying Spatial Parameters to Determine the Most Suitable Irrigation Strategies in Bugesera Region, Eastern Rwanda.

15. Darkwa, K., Ambachew, D., Mohammed, H., Asfaw, A., & Blair, M. W. (2016). Evaluation of common bean (Phaseolus vulgaris L.) genotypes for drought stress adaptation in Ethiopia. *The crop journal*, *4*(5), 367-376.

16. Datta, D., Saxena, S. C., & Ghosh, S. (2017) Mulch and herbicide impact on weed management, nodulation and quality of soybean [Glycine max L. Merrill]. *Annals of Agricultural Research*, *38*(4).

17. Gao, Y., Li, Y., Wang, Y., Wu, B., Ke, J., Niu, J., & Guo, L. (2020). Effect of different film color mulching on dry matter and grain yield of oil flax in dry-land. *Oil Crop Science*, *5*(2), 17-22.

18. Haggag, M., Kalisa, J. C., & Abdeldayem, A. W. (2016). Projections of precipitation, air temperature and potential evapotranspiration in Rwanda under changing climate conditions. *African Journal of Environmental Science and Technology*, *10*(1), 18-33.

19. Iqbal, R., Habib-ur-Rahman, M., Raza, M. A. S., Waqas, M., Ikram, R. M., Ahmed, M. Z., ... & Haider, I. (2021). Assessing the potential of partial root zone drying and mulching for improving the productivity of cotton under arid climate. *Environmental Science and Pollution Research*, 1-19.

20. Iqbal, R., Raza, M. A. S., Valipour, M., Saleem, M. F., Zaheer, M. S., Ahmad, S., ... & Nazar, M. A. (2020). Potential agricultural and environmental benefits of mulches—a review. *Bulletin of the National Research Centre*, *44*, 1-16. https://doi.org/10.1186/s42269-020-00290-3

21. Kapoor, D., Bhardwaj, S., Landi, M., Sharma, A., Ramakrishna, M., & Sharma, A. (2020). The impact of drought in plant metabolism: how to exploit tolerance mechanisms to increase crop production. *Applied Sciences*, *10*(16), 5692. https://doi.org/10.3390/app10165692

22. Katungi, E., Larochelle,. C, Mugabo J., & Buruchara R. (2019). Climbing bean as a solution to increase productivity in land-constrained environments: Evidence from Rwanda. *Outlook on Agriculture*, *48*(1), 28-36. doi:10.1177/0030727018813698

23. Kazai, P., Noulas, C., Khah, E., & Vlachostergios, D. (2019). Yield and seed quality parameters of common bean cultivars grown under water and heat stress field conditions. *AIMS Agriculture and Food*, *4*(2), 285-302. DOI: 10.3934/agrfood.2019.2.285

24. Kotir, J. H. (2011). Climate change and variability in Sub-Saharan Africa: a review of current and future trends and impacts on agriculture and food security. *Environment, Development and Sustainability*, *13*(3), 587-605. https://doi.org/10.1007/s10668-010-9278-0

25. Kwambe, X. M., Masarirambi, M. T., Wahome, P. K., & Oseni, T. O. (2015). The effects of organic and inorganic mulches on growth and yield of green bean (Phaseolus vulgaris L.) in a semi-arid environment. *Agriculture and Biology Journal of North America*, *6*(3), 81-89. doi:10.5251/abjna.2015.6.3.81.89

26. Larochelle, C., Alwang, J., Norton, G. W., Katungi, E., & Labarta, R. A. (2015). Impacts of improved bean varieties on poverty and food security in Uganda and Rwanda. In *Crop improvement, adoption, and impact of improved varieties in food crops in sub-Saharan Africa* (pp. 314-337). Wallingford UK: CABI.

27. Meena, S. K., Yadav, P. K., Bhunia, S. R., Das, K. K., & Bunker, R. R. (2019). Effect of irrigation levels and mulch on growth and soil moisture content of cabbage (Brassica oleracea var. capitata L.) under drip irrigation. *IJCS*, *7*(5), 474-476.

28. Morales, F., Ancín, M., Fakhet, D., González-Torralba, J., Gámez, A. L., Seminario, A., ... & Aranjuelo, I. (2020). Photosynthetic metabolism under stressful growth conditions as a bases for crop breeding and yield improvement. *Plants*, *9*(1), 88.

29. Munyeshyaka, J. (2016). *Assessing the Socio-economic Vulnerability of Smallholder Farmers to Climate Variability in Rwanda: Case Study of Rice Farmers in Bugesera District Jean* (Doctoral dissertation, University of Rwanda).

30. Nadeem, M., Li, J., Yahya, M., Sher, A., Ma, C., Wang, X., & Qiu, L. (2019). Research progress and perspective on drought stress in legumes: a review. *International journal of molecular sciences*, *20*(10), 2541.

31. Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. *Methods of soil analysis: Part 3 Chemical methods*, *5*, 961-1010.

32. Ngarukiyimana, J. P., Fu, Y., Sindikubwabo, C., Nkurunziza, I. F., Ogou, F. K., Vuguziga, F., ... & Yang, Y. (2021). Climate Change in Rwanda: The Observed Changes in Daily Maximum and Minimum Surface Air Temperatures during 1961–2014. *Frontiers in Earth Science*, *9*, 106. https://doi.org/10.3389/feart.2021.619512

33. Ni, X., Song, W., Zhang, H., Yang, X., & Wang, L. (2016). Effects of mulching on soil properties and growth of tea olive (Osmanthus fragrans). *Plos one*, *11*(8), e0158228. https://doi.org/10.1371/journal.pone.0158228

34. Ntukamazina, N., Onwonga, R. N., Sommer, R., Mukankusi, C. M., Mburu, J., & Rubyogo, J. C. (2017). Effect of excessive and minimal soil moisture stress on agronomic performance of bush and climbing bean (Phaseolus vulgaris L.). *Cogent Food & Agriculture*, *3*(1), 1373414. https://doi.org/10.1080/23311932.2017.1373414

35. Nwosisi, S., Nandwani, D., & Hui, D. (2019). Mulch treatment effect on weed biomass and yields of organic sweetpotato cultivars. *Agronomy*, *9*(4), 190. https://doi.org/10.3390/agronomy9040190

36. Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). Laboratory methods of soil and plant analysis: a working manual second edition. pp. 128. *Sacred Africa, Nairobi*, *21*.

37. Pushpavalli, R., Zaman-Allah, M., Turner, N. C., Baddam, R., Rao, M. V., & Vadez, V. (2014). Higher flower and seed number leads to higher yield under water stress conditions imposed during reproduction in chickpea. *Functional Plant Biology*, *42*(2), 162-174. https://doi.org/10.1071/FP14135

38. Qaseem, M. F., Qureshi, R., & Shaheen, H. (2019). Effects of pre-anthesis drought, heat and their combination on the growth, yield and physiology of diverse wheat (Triticum aestivum L.) genotypes varying in sensitivity to heat and drought stress. *Scientific reports*, *9*(1), 1-12. https://doi.org/10.1038/s41598-019-43477-z

39. Raatz, B., Mukankusi, C., Lobaton, J. D., Male, A., Chisale, V., Amsalu, B., & He, C. (2019). Analyses of African common bean (Phaseolus vulgaris L.) germplasm using a SNP fingerprinting platform: diversity, quality control and molecular breeding. *Genetic resources and crop evolution*, *66*(3), 707-722. https://doi.org/10.1007/s10722-019-00746-0

40. Roosda, A. A., Ramdhani, T., & Birnadi, S. (2021). Liquid organic fertilizer and types of organic mulch toward photosynthesis translocation of green beans (Phaseolus vulgaris L.). In *IOP Conference Series: Materials Science and Engineering* (Vol. 1098, No. 5, p. 052004). IOP Publishing. DOI 10.1088/1757-899X/1098/5/052004

41. Safari, B. (2012). Trend analysis of the mean annual temperature in Rwanda during the last fifty two years. *Jep* 03 (6), 538–551. doi:10.4236/jep.2012.36065

42. Singh, S. K., Reddy, V. R., Devi, M. J., & Timlin, D. J. (2021). Impact of water stress under ambient and elevated carbon dioxide across three temperature regimes on soybean canopy gas exchange and productivity. *Scientific Reports*, *11*(1), 1-13. https://doi.org/10.1038/s41598-021-96037-9

43. Teame, G., Tsegay, A., & Abrha, B. (2017). Effect of organic mulching on soil moisture, yield, and yield contributing components of sesame (Sesamum indicum L.). *International journal of agronomy*, 2017:1–6. https://doi.org/10.1155/2017/4767509

44. Verdoodt, A., & Van Ranst, E. (2003). *Land evaluation for agricultural production in the tropics. A large-scale land suitability classification for Rwanda*. Ghent University. Laboratory of Soil Science.

45. Yang, J. C., Zhang, J. H., Wang, Z. Q., Xu, G. W., and Zhu, Q. S. (2004). Activities of key enzymes in sucrose-to-starch conversion in wheat grains subjected to water deficit during grain filling. *Plant Physiol.* 135(3), 1621–1629. https://doi.org/10.1104/pp.104.041038

46. Yu, Y. Y., Turner, N. C., Gong, Y. H., Li, F. M., Fang, C., Ge, L. J., & Ye, J. S. (2018). Benefits and limitations to straw-and plastic-film mulch on maize yield and water use efficiency: A meta-analysis across hydrothermal gradients. *European journal of agronomy*, *99*, 138-147. https://doi.org/10.1016/j.eja.2018.07.005