ISSN 2349-7823

International Journal of Recent Research in Life Sciences (IJRRLS)
Vol. 4, Issue 3, pp: (27-33), Month: July - September 2017, Available at: www.paperpublications.org

Effect of Regulated Deficit Irrigation and Ridging on the Performance of Maize (*Zea mays* L.) in Kenya

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Abstract: **Growing crops in an arid area or in a dry year should not automatically lead to absence of harvest because agriculture has many options for the mitigation of rainfall inadequacy, irrigation being one of such options. However, irrigation requires some adjustments when water is limited. This study investigated the performance of maize in dry areas under regulated deficit irrigation (RDI) in combination with soil water conservation measures. The study was carried out at Marimanti in Tharaka Nithi county and Isiolo in Isiolo county. Deficit irrigation except during the exponential growth stage (DIE) and deficit irrigation except during the reproductive (DIR) stage were compared to full irrigation (FI) and deficit irrigation throughout (DI). Ridging was compared to flatbed. The experimental design was RCBD replicated three times. Growth parameters used were plant height to flag leaf and plant diameter while yield indicators were stand count, productive plants per plot, ear size, above ground biomass, grain yield, and harvest index. The data was summarized in MS ACCESS and SPSS version 24 was used for F-test at 5% level of significance and for post-hoc tests where necessary. FI gave the highest diameter (2.206 cm) and plant height (148.02 cm to the flag leaf) and the highest grain yields (3019 kg/ha) but DIR gave the highest harvest index (0.4665) while DIE had the highest water productivity (0.5082kg/m^3). Ridging and its interaction with regulated deficit irrigation had a significant effect on various yield indicators and on water productivity. The study concluded that regulated deficit irrigation increases water productivity when combined with ridging and DIE was recommended as a viable practice when water for irrigation is limited.**

Keywords: **Kenya, limited water for irrigation, maize, regulated deficit irrigation, ridging.**

1. INTRODUCTION

Due to a growing demand for agricultural products used as food for humanity, feeds for domestic animals and raw material for industries, agriculture is under constant pressure to increase the total world production (Acquaah, 2007). Over the years, the demand for agricultural products has been met by increasing land under production and by improving the productivity of the available arable land by use of improved technologies that allowed humanity to be less dependent on the clemency of nature (Rengel, 2013). As the world population increases, population pressure results in a decrease in arable land forcing crop production to be directed towards dry areas where water is a limited commodity and yet irrigation is inevitable (Ahmad, Khan and Naeem, 2014). In Kenya, Liniger (1988, cited in Gicheru, Gachene, & Mbuvi, 2005) argues that whereas most of the soils in marginal rainfall areas have high potential for agriculture, low soil water constitutes a major limiting factor for crop production. Unfortunately, little research has been done locally to understand how deficit irrigation can be used as a strategy for water conservation in the semi – arid areas of Kenya.

Existing technologies for areas expected to receive inadequate rains include forcing rain water to infiltrate in the soil profile by use of terracing, contouring, tied ridges, and strip cultivation. Such water stored in the soil can lead to increased soil – water storage and reduced runoff (Kahlon & Lal, 2011). Furthermore, when rainfalls cannot sustain crop production, irrigation is used to meet crop water demand with satisfactory results.

However, irrigation in view of meeting the full water requirements becomes a challenge when water is in limited supply. That is why deficit irrigation which aims at increasing productivity per unit of water adopts technologies that do not target full evaporative requirements. Unlu, Kanber, Koc, Tekin, & Kapur (2011) recommended 50% deficit irrigation as giving significantly higher water use efficiency (WUE) and harvest index (HI) compared to treatments where 100% of the water required was applied to reach field capacity. On the other hand, regulated deficit irrigation (RDI) improves water use efficiency of crops by producing almost the same yields with less water (Du, Kang, Sun, Zhang, & Zhang, 2010). Moreover, RDI may also offer additional advantages such as: (i) reduction of the number of irrigations if the irrigation frequency is reduced; (ii) reduction in energy to lift water if pumping is involved; and (iii) reduction of the total cost of production if water used on the field is paid for (Igbadun, 2012). Klocke, Currie, Tomsicek, & Koehn (2011) and Ayana (2011) found RDI to improve crop water productivity in maize. Regulated deficit irrigation was recommended by Cosgrove and Rijsberman (2000) to supplement rainfall in order to increase the productivity of water when a limited supply is made available to crops at critical periods. Though Kipkorir, Raesa, and Massaweb (2002) recommended the use of deficit irrigation for maize production in the Kenyan drylands under rain–fed conditions with irrigation as a supplementary input, information remains scanty. Furthermore, as Du et al. (2010) caution, the timing of RDI and the degree of soil water deficit in different climates, varieties and planting conditions need to be investigated before it can be concluded whether it is practical in those specific conditions.

This study generated information on the performance of regulated deficit irrigation under local dryland conditions and it is our hope that its findings will be useful to those in charge of guiding farmers on how to practice crop production with limited water supply.

2. MATERIALS AND METHODS

2.1 Site Description:

2.1.1 Location:

Two field experiments were conducted at Marimanti Rural Training Center located on a latitude of 0°9′ S, a longitude of 37°54′ E and an altitude of about 845 m above sea level (absl), and at Isiolo Maili Saba on a farm located on a latitude of 0°16′ N, a longitude of 37°33′ E, and an altitude of about 1120 m absl.

2.1.2 Climatology:

Both Marimanti and Isiolo receives an average annual rainfall of about 850 mm, which is bimodal in distribution, average temperature of 16 to 35°C. The experiments at Isiolo and Marimanti were carried out under rain – fed conditions with irrigation as a supplemental measure during the short rainy season of October, 2016 to February, 2017. The total amounts of rainfall recorded at Marimanti and Isiolo during the experiment were 212.7 and 209.4 mm, respectively.

2.1.3 Soils:

The soil type of the Marimanti site was sandy loam, while the Isiolo site had clay loam type of soil. Soil analysis for both sites was done and the suggested corrective measures were used to determine the inorganic fertilizers to use as basal fertilizer applied at planting and as top-dressing fertilizer applied in two splits at 21 and at 45 days after sowing (DAS).

2.2 Treatments and Treatment Combination:

Four regulated deficit irrigation treatments were used: (i) full irrigation during the first 30 days after sowing followed by deficit irrigation throughout the season with only 50% of the required amount (DI); (ii) full irrigation until after the end of the exponential growth stage and then 50% deficit irrigation (DIE); (iii) full irrigation during the first 30 days after sowing followed by 50% deficit irrigation during growth stage and full irrigation from tasseling to grain filling (DIR); and (iv) Full Irrigation throughout the season (FI). Ridging (R) was compared to a control with flatbed (F).

2.3 Experimental Procedure:

Each experimental site consisted of three blocks divided into eight plots each, while the plots were sub-divided into four sub-plots each. Primary and secondary cultivation were done manually and different treatments were assigned to the split plots. Two seeds were planted per hill, and thinning was later done leaving one plant per hill to obtain a uniform plant population. Penman-Monteith method was used for the calculation of the reference evapo-transpiration from long term averages of climatic data from CLIMWAT. Fertilization and weed control were done as per agronomic requirements.

2.4 Data Analysis:

The data collected were summarized in MS ACCESS then analyzed using SPSS (version 24). Analysis of Variance (ANOVA) was conducted to determine if there were significant differences between the treatment means at $\alpha=0.05$ followed by post hoc tests where necessary.

3. RESULTS AND DISCUSSION

3.1 Effect of Regulated Deficit Irrigation:

3.1.1. Effect of regulated deficit irrigation on growth:

Plant diameter and plant height were measured from the 30 days after sowing and the data obtained is summarized in Figure 1.

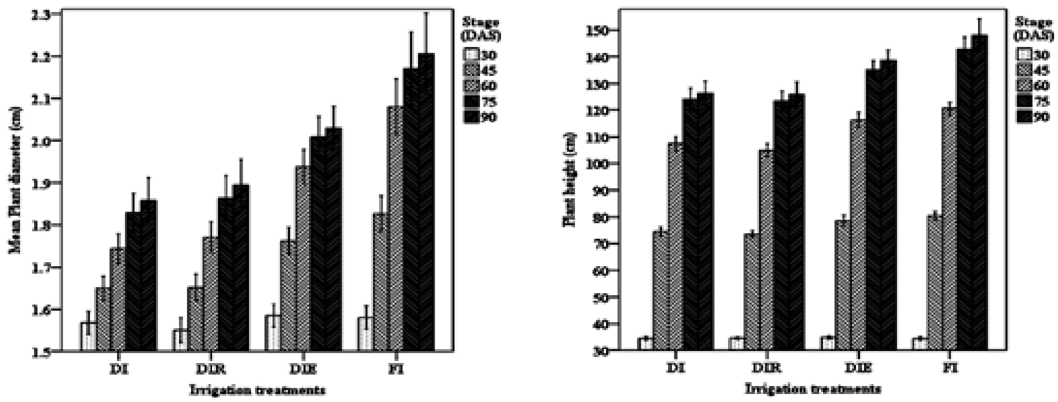

Figure 1: Effect of regulated deficit irrigation on plant diameter and plant height

The results presented in Figure 1 show that plant growth was affected by deficit irrigation treatments with FI giving the tallest and the biggest plants while DI gave the thinnest and shortest plants. The two regulated deficit irrigation treatments also had different effects on plant growth with DIE producing the second tallest and biggest plants while DIR was almost comparable to DI. When ANOVA was used to check for significant differences and thereafter a post-hoc analysis was done to compare the treatments means, the summary in Table 1 was obtained.

Table 1: Comparison of the effect of deficit irrigation treatments on growth components

Irr.	Plant diameter (cm)					Plant height (cm)				
Treat.	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
DI	1.568a	1.650a	1.744a	1.829a	1.859a	34.50a	74.54a	107.44a	124.04a	126.20a
DIR	1.551a	1.652a	1.771a	1.863a	1.883a	34.60a	73.49a	104.94a	123.40a	125.86a
DIE	1.585a	1.762b	1.938b	2.009b	2.027b	34.88a	78.58b	116.24b	135.15b	138.53b
FI	1.581a	1.827c	2.080c	2.170c	2.206c	34.47a	80.45b	120.55c	142.80c	148.02c

Means in the same column with the same letter are not significantly different ($p > 0.05$)

It can be found from the results in Table 1 that irrigation treatments had a significant effect with plots under FI producing significantly bigger and taller plants while plants in plots under DI and those under DIR produced the thinnest and the shortest plants. On the other hand, plants under DIE did not show any significant difference from the ones under full irrigation at until 60 days after sowing. However, plants under DIE were significantly smaller and shorted than the ones under full irrigation at 90 days after sowing though significantly bigger and taller than plants under DI and DIR.

3.1.2 Effect of regulated deficit irrigation on yields:

The effect of deficit irrigation treatments on yields was analyzed using yield indicators which were observed at harvest and a summary of the results after ANOVA and Post-hoc analysis is given in Table 2.

Table 2: Post-hoc analysis results for the effect of RDI on yield indicators

Irrig. Treat.	Stand count	Number of Productive plants	Ear diameter (cm)	Ear height (cm)	Above ground biomass (g)	Grain yield per plant (g)	Total grain yield (kg/ha)	Harvest index
DI	35.67a	33.44a	4.112a	13.03a	131.71a	39.69a	1323.7a	0.3111a
DIE	35.29a	33.90ab	4.021 a	14.44b	154.02b	66.94b	2278.6b	0.4415 bc
DIR	35.21a	33.96ab	4.003 a	14.88 b	151.18b	69.93b	2372.3b	0.4665c
FI	35.25a	34.54b	3.923 a	17.14 c	202.95c	87.29c	3019.5c	0.4342b

Means in the same column with the same letter are not significantly different ($p > 0.05$).

The results in Table 2 show that FI recorded significantly higher values for ear height, above ground biomass, grain yield per plant and total grain yield. For the number of productive plants and weight of 100 grains the regulated deficit irrigation treatments (DIE and DIR) had the same means as full irrigation. Similarly, DIR and DIE had a harvest index significantly higher than that of full irrigation. This result corroborates the findings of Pandey et al. (2000, as cited in Djaman, Irmak, Rathje, Martin, & Eisenhauer, 2013) who reported that when limited irrigation was imposed during the vegetative period, maize grain yield was reduced by 7% to 11% relative to the fully irrigated treatment, and when water deficit occurred during both the vegetative stage and early reproductive stage, significant yield reductions of 23% to 26% were observed. These results are consistent with recommendations made by Kamana, Kirdab, and Sesverenc (2010) who recommended deficit irrigation practices to prevent drastic crop-yield reductions in regions of high recurrent water scarcity.

3.1.3 Effect of regulated deficit irrigation on water productivity:

The effect of regulated deficit irrigation on water productivity was evaluated in the two open field experiments. The results obtained are represented in Table 3.

Table 3: Effect of irrigation treatments on water productivity

Irrigation treatments	Irrigation water productivity
DI	0.3693a
FI	0.4828b
DIR	0.4987b
DIE	0.5082b

Means in the same column with the same letter are not significantly different ($p > 0.05$).

The results in Table 3 show that DIE had the highest water productivity and it was followed by DIR. DI had the lowest water productivity. These results are in agreement with the findings of Li et al. (2007, as cited in Chai et al., 2016) who interpreted the beneficial effect of deficit irrigation treatments by the fact that nutrient use efficiency is increased through the promotion of nutrient recovery after a short period of water stress thus leading to better harvestable products. This result is also supported by Sani, Oluwasemire, & Mohammed (2008) who state that crops irrigated with full irrigation tend to use more water; and they tend to grow luxuriantly due to the abundance of soil moisture.

3.2 Effect of Ridging:

3.2.1 Effect of ridging on growth and yields:

From the data collected, it was that both plant diameter and plant height increased from planting to 90 DAS but with a slower rate of growth between 60 and 90 DAS as can be seen from the data in Table 4 which also gives a comparison of the treatment means.

Table 4: Effect of ridging on plant growth

	Plant diameter (cm)					Plant height (cm)				
	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Ridges	1.570a	1.730a	1.893a	1.978a	2.006a	34.46a	77.37 a	113.37a	133.02a	136.37a
Flatbed	1.572a	1.715a	1.873a	1.957a	1.982a	34.77a	76.16 a	111.22a	129.68a	132.94a
Sig.	0.869	0.433	0.499	0.553	0.548	0.289	0.192	0.173	0.145	0.216

Means in the same column with the same letter are not significantly different ($p > 0.05$)

The results in Table 4 show that ridging, though having encouraged more growth than in plots with flatbeds, did not have any significant effect at any of the stages ($p > 0.05$). Ridges were expected to serve as barriers to stop runoff water and force water to infiltrate in the soil among benefits thus affecting favorably plant growth as is suggested by Li, Gong, & Wei (2000, cited in Xiao-Long, Peng, Xiao-Lin, & Zhi-Kuan, 2016); Wang, Li, & Xie (2005); and Wang, Tian, & Li (2004). Similarly, a summary of the means of yield indicators under the two treatments is given in Table 5 which also shows the results of the t-test used for the comparison of the pairs.

Table 5: Comparison of the effect of ridging and flatbed on yield components

PWCP	Stand count	Productive plants per plot	Ear diameter (cm)	Ear height (cm)	Above ground biomass (g)	Grain yield per plant (g)	Total grain yield (kg ha^{-1})	Harvest index
Flatbeds	35.38a	33.82a	3.983a	14.837a	154.1a	61.098a	2077.4a	0.3983a
Rigdes	35.33a	34.09a	4.047a	14.909a	165.9b	70.828b	2419.6b	0.4283b
Sig.	0.833	0.452	0.398	0.870	0.038	0.001	0.001	0.002

The results in Table 5 show that ridging had a significant effect on above ground biomass; grain yield per plant; total grain yield and harvest index. This means that even tough ridging did not affect growth significantly, it created favorable conditions for higher yields both in terms of biomass and grains and this is in line with results reported by Ashidi & Eshavarzpour (2012). However, not all studies agree on this finding; for example Araya & Stroosnijder (2010, as cited by Grum et al., 2016) warned that "ridges alone or combined with mulching may cause excess water in the root zone thus resulting in aeration stress. Similarly, Belay, Gebrekidah and Uloro (1998) found that ridge treatments did not have any significant effect on grain yield when no crop residues were applied.

3.2.2 Effect of ridging on water productivity:

Water productivity was calculated for ridging compared to flatbed as the ratio of the grain yield to the amount of water used during the season for the same unit area. The means were compared using the t-test for independent groups and the results showed that with a mean water productivity of 0.5026 $kg/m^3$for ridges against 0.4269 kg/m^3 for flatbed, ridging had a significant effect.

3.5 Interaction Effects between Regulated Deficit Irrigation and Ridging:

To check for interaction effect between irrigation treatments and ridging, Duncan test was used after F-test had detected significant differences and the results summarized in Table 6.

International Journal of Recent Research in Life Sciences (IJRRLS)
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Table 6: Interaction between irrigation treatments and ridging on yield indicators

Treatment	Stand count	Product. plants	Ear diam. (cm)	Ear height (cm)	Biomass (g)	Yield (g/plant)	Yields (kg ha^{-1})	Harvest index
DI + Flatbed	35.71a	33.33a	4.099a	12.79a	126.5a	33.31a	1108.0a	0.2717a
DI + Ridging	35.63a	33.54a	4.126a	13.28ab	137.0ab	46.07b	1539.3b	0.3505b
DIE + Flatbed	35.38a	33.58a	4.028a	14.71bc	144.0bc	61.49c	2077.7c	0.4354cd
DIE + Ridging	35.21a	34.21a	4.014a	14.17ab	164.1d	72.39e	2479.5e	0.4476cd
DIR + Flatbed	35.21a	33.92a	3.965a	14.47bc	144.5bc	67.25d	2279.4d	0.4693d
DIR + Ridging	35.21a	34.00a	4.042a	15.28c	158.0cd	72.60e	2465.3e	0.4636d
FI + Flatbed	35.21a	34.46a	3.838a	17.38d	201.4e	82.34fg	2844.6f	0.4167c
FI + Ridging	35.29a	34.63a	4.008a	16.91d	204.5e	92.25h	3194.4g	0.4516cd

The parameters for which Table 5 shows a significant interaction effect between pairs of same irrigation treatments are above ground biomass, grain yield per plant, total grain yield, and harvest index. Figure 2 also shows interaction effects between irrigation treatments and physical water conservation on above ground biomass, total grain yield, and harvest index. It can be seen from Figure 2 that ridging had a positive effect on biomass with ridging and DIE and DIR producing higher increase in biomass compared to other irrigation treatments. On the other hand, though ridging produced the smallest increase in yield under DIR it produced the highest increase under DIE. This shows that under DIE, ridging allowed better biomass accumulation and better grain formation than both full irrigation and deficit irrigation throughout the season.

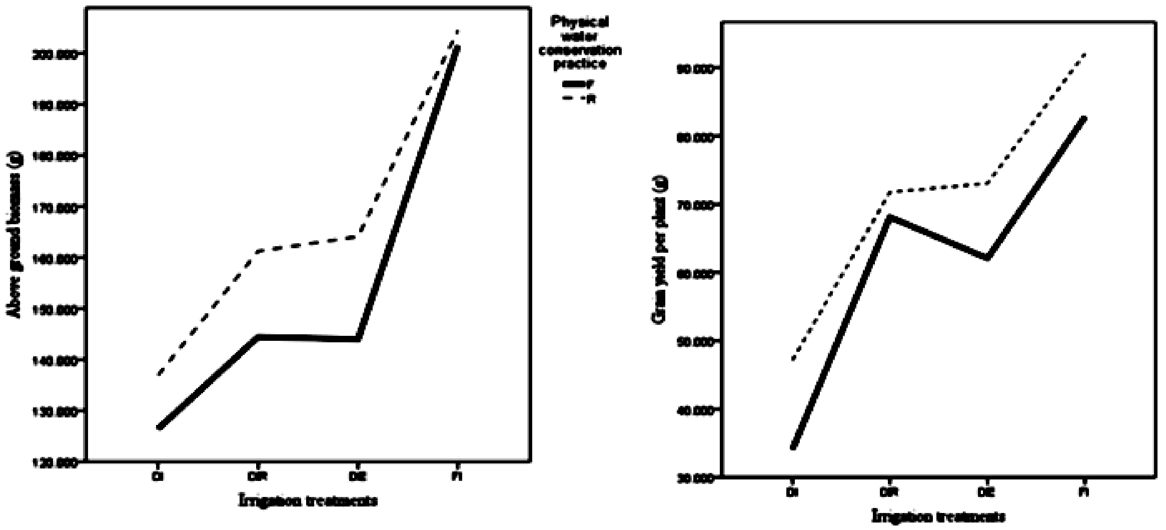

Figure 2: Interaction effects between irrigation treatments and ridging on above ground biomass and grain yield per plant

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions:

The study has proved that: (i) Regulated deficit irrigation treatments affected significantly maize growth, maize grain yields, and irrigation water productivity with full irrigation giving the highest results except water productivity which was higher under regulated deficit irrigation; (ii) ridging had a significant effect on maize grain yields, and irrigation water productivity; (iii) the interaction effect between RDI and ridging affected maize grain yields positively.

4.2 Recommendations:

Based on the findings of the study, the following recommendations were made: (i) Regulated deficit irrigation is a viable practice under limited water supply; (ii) it is beneficial to combine regulated deficit irrigation with ridging as it improves grain yields and water productivity; (iii) there is need for further research on the interaction effects between ridging and mulching under conservation tillage and regulated deficit irrigation; further research is also recommended on the response of high yield potential varieties to regulated deficit irrigation.

ISSN 2349-7823

International Journal of Recent Research in Life Sciences (IJRRLS)
Vol. 4, Issue 3, pp: (27-33), Month: July - September 2017, Available at: www.paperpublications.org

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