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Effect of Plant Population on Yield of Selected Maize (*Zea mays L.*) Varieties in Mwea and Bura in Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Authors JMK, GNC and DDA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JMK and DDA managed the analyses of the study. Authors JMK and DDA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The objective of the study was to determine the effect of plant population on the growth and yield of maize. The study was conducted during the short rainy season of December 2018 and April 2019 in Mwea, Kirinyaga County and Bura, Tana River County, in Kenya. An experiment was set in a split-split plot design with three replications. Five selected maize (*Zea mays*) varieties commonly grown in these areas namely: *Pioneer, DH04, Sungura*, *SC Duma* and *DH02* were grown under three plant population densities namely: 53,333, 66,666 and 88,888 plants ha^{-1} under irrigated conditions. Cob length, ear height, plant height, above ground biomass and grain yield data was collected. Plant population had significant effects on the grain yield and yield components of the selected maize varieties. The plant population of 53,333 plants ha^{-1} gave significantly higher above ground biomass in Mwea than population of 88,888 plants ha^{-1}, though not significantly different from population of 66,666 plants ha^{-1}. In Bura, the plant population of 88,888 plants ha^{-1} gave significantly higher above ground biomass than that of 66,666 and 53,333 plants ha^{-1} respectively. An increase in plant population reduced the grain yield of the selected maize varieties but increased the above ground biomass of the varieties.

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1. INTRODUCTION

Maize (*Zea mays*) is the principle staple food crop in most countries in Eastern and Southern Africa; hence its availability and affordability have been central to food security in the region. Maize is the most popular and palatable feed for all kinds of livestock and poultry birds all over the world [1]. Production of the main food security crops – maize, wheat and rice has generally been below Kenya's consumption requirements [2]. The country's productivity in 2009 stood at 1.3 Mg ha^{-1}, compared to South Africa at 5 tons per hectare, Malawi at 2 tons per hectare, Zambia at 2 tons per hectare, Uganda at 1.4 tons per hectare, and Tanzania at 1.1 tons per hectare [3]. Kenya's maize national productivity in 2013 was 1.6 tons per hectare as compared to South Africa at 6 tons per hectare, Egypt at 9 tons per hectare and USA at 12 tons per hectare [3]. Whereas there's projection of enormous increases in human and livestock populations in the decades to come, coupled with massive increases in levels of urbanization [4,5], there is clear indication that productivity of maize in Kenya is not increasing proportionately to its demand.

Within the last decade, Africa has witnessed a four-to-five-fold increase in the number of seed companies marketing various types of improved maize seed [6]. The correct choice of maize cultivar and plant spacing is important to maximize on maize productivity, and this may vary with climatic conditions. The recommended plant population in maize will depend on the local climatic and soil conditions, and the maize cultivar grown. With modern hybrids, the spacing is about 75 cm to 100cm between rows, and 15 cm to 25cm between plants, so as to achieve a plant population of about 53,333 to 88,888 plants per hectare.

Maize yield estimated from Food and Agriculture Organization of the United Nations Statistics for Kenya, Ethiopia, Uganda, Rwanda, Malawi and Tanzania indicate that maize yields on average have increased between 1993 and 2013 but remained fairly steady at around 1,500 kg ha^{-1} with slight annual fluctuations.

Kenya has a deficit of about 400,000 to 700,000 metric tons of maize which is imported [7]. Maize prices in the country are prohibitive to consumers and poor households spend about 30% of their income on maize crop [8].

1.1 Effect of Plant population on the Cob length, Ear height, plant height, above ground biomass, and grain yield of maize (*Zea mays* L.)

Maize is a plant with individual productivity [9]. Therefore, plant density determines yield significantly. Different hybrids endure production using higher plant densities in different extent [10]. Plant density is a production factor that affects yield to the greatest extent. There is a close relationship between maize yield and plant density [11]. There are significant differences between the yields of different plant population which increase with the increase in plant density [4]. Mohseni et al., 2013 confirmed that the increase of plant density from 66,666 plants ha^{-1} (9.09 tons ha^{-1}) to 88,888 plants ha^{-1} (11.14 tons ha^{-1}) resulted in a yield increment as well. The population and distribution of plants have a profound effect on grain yield. Wade et al., 1988 observed that the population of plants per square meter (density) and arrangement of individual plants within a square meter determine nutrient use and grain yield of maize. Narrowing plant spacing can allow plants to take spatial advantage and increase resource capture and utilization [12]. Grain yield increases with increasing plant density and then comes to a plateau at some point above which increasing plant population is not economical. This is because above the plant population that gives the maximum grain yield, the reduction in grain yield due to crowding stress cannot be compensated by increasing plant stands (Duncan et al., 1984). The extent to which plant density affects grain yield depends on the hybrid and other environmental conditions (Wade et al., 1990; Duncan 1984; Fukai et al., 1988). Plant population and row width determine light interception and consequently photosynthesis and yield (Stewart et al., 2003). [13] Observed that within the normal range of crop population, increase in crop yield from increasing plant population is related to the increase in light interception. He further noted that maximizing light interception during grain production is a paramount importance of optimum grain yield.

The objective of the study was to determine the effect of plant population on the growth and yield of maize.

2. MATERIALS AND METHODS

2.1 Study Sites

The study was conducted in Mwea and Bura Irrigation Schemes in Kenya, in December 2018. Five (5) selected maize varieties, namely *Pioneer*, *DH04*, *SC Duma*, *Sungura* and *DH02* were planted in a total of ninety (90) experimental plots per site, with 3 replications in 5m by 4m plots in Mwea and Bura Irrigation Schemes under irrigated conditions.

Mwea Irrigation Scheme is located in Kirinyaga County at an altitude of 1,159 meters above sea level, 0º37'S and 37º27'E. The climate is tropical with equatorial and medium high-altitude characteristics within agro-ecological zones LM3 and LM4. Rainfall pattern is bimodal; the long rainy season is from March to May and short rains from October to November. Annual mean rainfall is about 930 mm, out of which 510 mm is during the long rainy season. The mean temperature is 22ºC with a wide range between minimum of 17ºC and maximum of 28 ^{0}C. The relative humidity varies from 54.7 % to 87.2 %. During the months of August to September and January to February, the area is generally dry. The soils are predominantly Vertisols (LB 8) imperfectly drained, dark grey to black, cracking with calcareous deep sub soil. Soil nutrient content indicates nitrogen levels of 0.149 % and Phosphorous levels of 20 ppm (equivalent to 44 kg P_2O_5 ha^{-1}) and potassium level of 0.1485 mg/l. The pH level is 6.6, near to neutral and hence suitable for adequate availability of phosphorous to most crops.

Bura Irrigation Scheme is situated on Latitude 1^0 9' S and Longitude 39º52' E. Bura falls in the arid and semi-arid region of Kenya characterise by hot and warm climate. The temperature range is between 20°C and 30°C (Ministry of Lands, Agriculture, Livestock and Fisheries, Tana River County 2016).Tana River County lies within four Agro-ecological zones namely: Coastal Land 3, Coconut-Cassava zone; Coastal Land 4, Cashew nuts-Cassava zone where the main economic activity is subsistence mixed farming; Coastal land 5, Lowland Livestock zone; and Coastal land 6 Lowland ranching zones where the locals are involved in pastoral activities (Ministry of Lands, Agriculture, Livestock and Fisheries, Tana River County 2016). As in many parts of the Country, the region receives a bimodal rainfall season; namely March-May and October-December with the peak rainfall periods received in April (100th day) and November (325th day) respectively. The annual rainfall in Bura averages 400 mm [14]. The soils in Bura are well drained, moderately dark red to yellowish red sandy clay loam soils.

2.2 Experimental Design and Treatments

The experiment was laid out in a split-split plot design with three replications, with plot sizes of 5m by 4m. Drought stress was the main plot while varieties and plant population were the sub-plots and sub-sub plots respectively. Treatments consisted of five maize varieties; *Pioneer, DH04, Sungura*, *SC Duma* and *DH02*, three plant densities of 53,333 plants ha^{-1}, 66,666 plants ha^{-1}, 88,888 plants ha^{-1} under drought stress and non-stress water conditions, on yield and yield components of maize. Drought stress treatments received 0.5 m^3 of water at eight-day intervals while no-drought stress treatments had 0.5 m^3 of water at four-day intervals. Drought stress treatments were implemented 55 days after emergence of the maize plants until maturity, prior to which all the maize plants received 0.5m^3 of water per plot at an interval of 4 days. A mean of 17.8% soil moisture content was achieved for the drought stress treatment in Mwea whereas a mean of 19.3% soil moisture content was achieved for the no-drought stress treatment in this site. In Bura site, a mean of 6.9% soil moisture content was achieved for the drought stress treatment whereas a mean of 12.8% soil moisture content was achieved for the no-drought stress treatment in this study site. Soil moisture content was determined using gravimetric method.

2.3 Data Collection

Data was collected on plant height and above ground biomass at physiological maturity, cob length, ear height, grain yield at 13.5% moisture content. Soil moisture content data prior to every scheduled irrigation water treatment was also determined using the gravimetric method. Plant height, cob length, ear height, above ground biomass, and grain yield measurements were collected from 10 maize plants per experimental plot, plants which were tagged during their 10-leaf stage of growth.

2.3.1 Determination of plant height and ear height at physiological maturity

Plant height and ear height was measured using a measuring tape. Measurements were obtained from the soil surface to the tip of the tassel of the maize plants, at maturity [15].

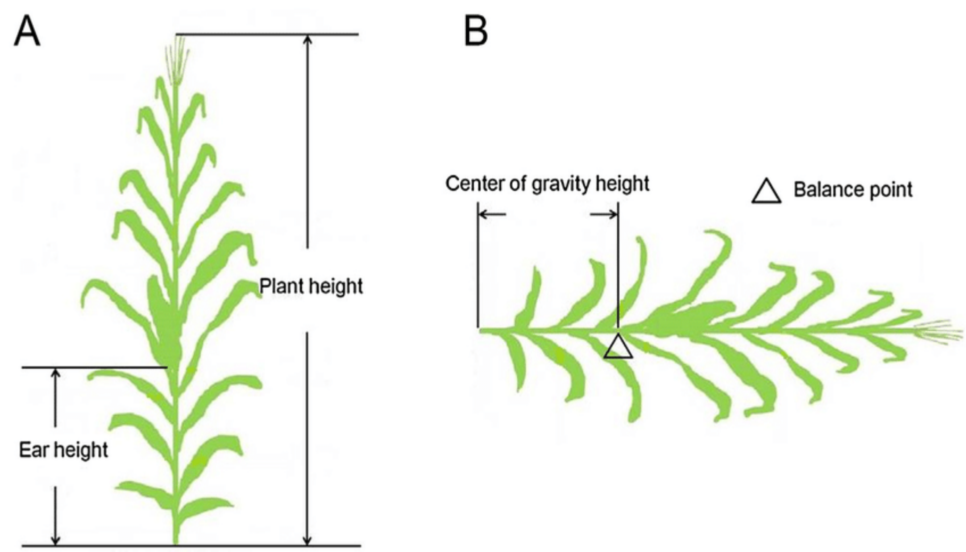

Fig. 1. Rahman, Md. (2017). Re: What is right method of plant height measurement of maize or corn?

2.3.2 Determination of above ground biomass at physiological maturity

The above ground biomass was obtained by measuring the weight of the 10-tagged plants using a digital weighing scale, plants which were oven dried in the lab at 80^0C for 24 hours prior to the weighing. The average weight per plant was determined in units $Kgha^{-1}$. The above-ground biomass was determined at the harvest stage of the crops by cutting the tagged maize plants at the point of attachment to the soil/ground using a sharp machete, and placed in polypropylene bags for oven drying at the lab.

2.3.3 Determination of cob length

Cob length was measured using a measuring tape; measurements were done after kernels had been extracted from the cob and the average cob length recorded in units' centimeters.

2.3.4 Determination of grain yield at 13.5% moisture content

Grain weight was determined from the 10-tagged plants after separation of the grains from the maize cobs obtained from these plants. The weight of grains from each plant was measured using a weighing scale. Moisture content of the grains was also measured using a moisture meter. The grain weight recordings obtained from the 10-tagged plants were converted to grain yield per hectare at 13.5% moisture content using a formula.

2.3.5 Determination of soil moisture content using gravimetric method

The gravimetric method involves collecting a soil sample using a soil auger, weighing the sample before and after drying it and calculating its original soil moisture content. Rusell et. al., 1950 reporting on work completed in 1843 and Whitney et al., 1894 describe some of the first scientific investigations of soil moisture using gravimetric methods.

2.3.5.1 Apparatus used

1. A thermostatically controlled oven capable of maintaining a temperature between 105^0C and 110^0C.
2. A weighing scale balance that can measure up to an accuracy of 0.01 grams
3. Numbered aluminum weighing tins with close fitting lids

2.3.5.2 Soil sample collection

Soil samples were collected at the experiment sites using a hand-soil auger, to a depth of 20cm below the ground, and transferred to aluminum tins with air tight lids. The sampling schedule that was implemented is highlighted in Tables 2 and 3.

2.4 Data Analysis

The data was collected and Analysis of Variance done using SAS version 9.1, and where there were differences in means, the significance was determined using the Least Significance Difference (LSD) method at *P= .05*

3. RESULTS

3.1 Soil Moisture Content

In Mwea site, the soil moisture content mean was 17.8% for the drought Stress treatment against 19.3% soil moisture content for the No-drought Stress treatment. For Bura, the soil moisture content was 6.9% for the drought stress treatment against a mean of 12.8% for the No-drought Stress treatment (Appendix 1). In this experiment, the determination of soil moisture content prior to each and every irrigation water application was done so as to confirm that drought stress was achieved.

3.2 Effect of Plant Population on Growth, Yield and Yield Components of Selected Maize Varieties

Plant population had significant effect on growth, yield and yield components of selected maize varieties in both Mwea and Bura experimental sites (Table 1). In Mwea, plant population of 53,333 plants ha^{-1} gave significantly higher above ground biomass of 1,300 $Kgha^{-1}$, though not significantly different from the above ground biomass produced by plants at a population of 66,666 plants ha^{-1}, while the least was from 88,888 plants ha^{-1} at 978 $Kgha^{-1}$. Cob length for plants grown under plant population treatments of 53,333 plants ha^{-1} and 66,666 plants ha^{-1} at 18.3cm and 18.0 cm respectively were not significantly different though these two had significantly different cob length from that of 88,888 plants ha^{-1} with cob length of 17.4cm, under the experiment's conditions in Mwea. In Bura, plant population of 88,888 plants ha^{-1} gave significantly higher above ground biomass of 686 $kgha^{-1}$ than plant population of 53,333 plants ha^{-1} and 66,666 plants ha^{-1} at

Table 1. Soil sampling and irrigation dates for Mwea site

Irrigation frequency 55 days after sowing	Experiment plots with No-water stress treatment		Experiment plots with water-stress treatment	
	Soil Sampling date	Irrigation date	Soil Sampling date	Irrigation date
1st	15th February 2019	16th February 2019	24th February 2019	24th February 2019
2nd	19th February 2019	20th February 2019	4th March 2019	5th March 2019
3rd	24th February 2019	25th February 2019	12th March 2019	13th March 2019
4th	4th March 2019	5th March 2019	20th March 2019	21st March 2019
5th	8th March 2019	9th March 2019	Nil	Nil
6th	12th March 2019	13th March 2019	Nil	Nil

Table 2. Soil sampling and irrigation dates for Bura site

Irrigation frequency 55 days after sowing	Experiment plots with No-water stress treatment		Experiment plots with water-stress treatment	
	Soil Sampling date	Irrigation date	Soil Sampling date	Irrigation date
1st	6th February 2019	7th February 2019	10th February 2019	11th February 2019
2nd	11th February 2019	12th February 2019	21st February 2019	22nd February 2019
3rd	16th February 2019	17th February 2019	3rd March 2019	4th March 2019
4th	21st February 2019	22nd February 2019	11th March 2019	12th March 2019
5th	26th February 2019	27th February 2019	Nil	Nil
6th	3rd March 2019	4th March 2019	Nil	Nil

612 Kgha^{-1} and 566 Kg ha^{-1} respectively, which also had significantly different above ground biomass. Plant population of 53,333 plants ha^{-1} had significantly higher grain yield of 2,151 Kgha^{-1} than plant population of 66,666 plants ha^{-1} and 88,888 plants ha^{-1} at 1,950 Kg ha^{-1} and 1,923 Kg ha^{-1} respectively. Grain yield produced by plant population of 66,666 plants ha^{-1} was not significantly different from that of plant population of 88,888 plants ha^{-1} in the experiment's condition in Bura.

3.3 Performance of Selected Maize Varieties on Growth, Yield and Yield Components of Maize in Mwea and Bura Schemes in Kenya

The maize variety treatments significantly affected cob length, ear height, plant height, above ground biomass and grain yield in both Mwea and Bura experimental sites (Table 3). In Mwea, Maize Variety DH02 had significantly shorter plants of 200.5cm, significantly shorter cob length of 16.0cm, and significantly shorter ear height of 113.2cm and produced significantly least above ground biomass of 618.1 Kgha^{-1}. Maize Variety Pioneer had significantly longest cob length at 19.1cm though not significantly different from that of variety Sungura at 18.4cm, significantly longest ear height of 154.0cm, significantly tallest plants of 228.2cm though not significantly taller than plants of DH04 at 224.3cm, Sungura at 227.9cm and SC Duma at 224.8cm. Variety DH04 had significantly highest above ground biomass of 1,655 Kgha^{-1}, variety Pioneer had the second highest at 1,418 Kgha^{-1} whereas variety SC duma had the third highest above ground biomass of 1,071 Kgha^{-1}, though not significantly different from Variety Sungura at 973 Kgha^{-1}. Variety Sungura had significantly highest grain yield at 4,076 Kgha^{-1}, though not significantly different from that of DH02 and DH04 which had the 2nd and 3rd highest at 3,836 Kgha^{-1} and 3,591 Kgha^{-1} respectively, whereas Pioneer variety produced significantly least grain yield of 2,885 Kgha^{-1}. There was no significant difference in the ear height, Plant height, and grain yield of the three plant population treatments. There was also no significant effect of interaction amongst variety, irrigation regime and plant population.

In Bura, Maize Variety DH02 had significantly shorter plants of 263.3cm, shorter cob length of 15.9cm, and produced least above ground biomass of 462 Kgha^{-1}. Pioneer maize variety had significantly tallest plants of 293.6cm, significantly longest cob length of 17.7cm, and significantly highest grain yield of 2,256 kgha^{-1} though not significantly different grain yield from that of variety Sungura at 2,182 Kgha^{-1}.Maize variety DH04 had significantly highest above ground biomass of 767 kgha^{-1}, whereas variety Pioneer at 672 Kgha^{-1} and variety SC Duma at 639 Kgha^{-1} were not significantly different. Maize variety Pioneer had significantly highest grain yield of 2,256 Kgha^{-1} though not significantly different from that of variety Sungura at 2,182 Kgha^{-1} whereas maize variety DH02 at 1,810 Kgha^{-1} was third, and DH04 at 1,754 Kgha^{-1} had significantly lowest grain yield, though grain yield of variety DH04 and DH02 were not significantly different. The effect of interaction between varieties and water regimes was not significant on Cob length and ear height.

4. DISCUSSION

Plant population density had significant effect on the above ground biomass and grain yield of maize. Plant population of 53,333 plants ha^{-1} had the highest significant grain yield, followed by 66,666 plants ha^{-1}, and the least was 88,888 plans ha^{-1} across all the varieties in the experiment. The plant population of 88,888 plants ha^{-1} also had the highest significant above ground biomass. This is because high plant density decreases the availability of resources per plant in the period surrounding silking and generates a marked fall in yield per plant that is not offset by the increase in the number of plants [16]. Maize yield is low with low plant population density because of little plasticity in leaf area per plant. Additionally, maize plants have small capacity to develop new productive structures in response to an increase in available resources per plant. In dense populations, many kernels may not develop. This occurs in some hybrids due to poor pollination resulting from delayed silking period compared with tassel emergence and/or due to a limitation in assimilate supply that caused kernel and ear abortion. In dense populations, many kernels may not develop. These findings are consistent with previous studies [16,17]. Therefore, optimizing harvestable maize yield requires matching the best maize hybrids with optimal plant populations. The finding is consistent with previous studies [12].

Table 3. Effects of Plant population and Maize Variety on the yield and yield components of maize in Mwea and Bura in 2018/2019

Mwea site					
Treatment	**Cob length (cm)**	**Ear height (cm)**	**Plant height (cm)**	**Above ground biomass (Kg/ha)**	**Grain yield (Kg/ha)**
Pioneer	19.1	154.0	228.2	1,418	2,885
DH04	17.6	132.5	224.3	1,655	3,591
Sungura	18.4	121.7	227.9	1973	4,076
SC Duma	18.2	129.9	224.8	1,071	3,476
DH02	16.0	113.2	200.5	618	3,836
Means	17.9	130.3	221.1	1,146.9	3,572.4
P-value	<0.0001	<0.0001	0.0034	<0.0001	0.0002
LSD	0.706	8.8	15.7	183.4	493.9
CV (%)	5.9	10.1	10.6	24.0	20.7
88,888 plants ha^{-1}	17.4	131.7	224.3	978	3,579
66,666 plants ha^{-1}	18.0	128.7	217.1	1,163	3,468
53,333 plants ha^{-1}	18.3	130.4	222.0	1,300	3,671
Means	17.9	130.3	221.1	1,146.9	3,572.4
P-value	0.0086	0.6893	0.4750	0.0001	0.5706
LSD	0.5469	NS	NS	142.1	NS
CV (%)	5.9	10.1	10.6	24.0	20.7
Bura site					
Treatment	**Cob length (cm)**	**Ear height (cm)**	**Plant height (cm)**	**Above ground biomass (Kg/ha)**	**Grain yield (Kg/ha)**
Pioneer	17.7	147.0	293.6	672	2,256
DH04	16.1	125.4	269.1	767	1,754
Sungura	16.4	108.5	274.0	566	2,182
SC Duma	16.4	122.8	287.2	639	2,037
DH02	15.9	112.9	263.3	462	1,810
Means	16.5	123.3	277.4	621.1	2,007.8
P-value	0.01	<0.0001	<0.0001	<0.0001	<0.0001
LSD	1.02	7.34	8.6	51.3	87.0
CV (%)	9.3	8.9	4.6	12.4	6.5
88,888 plants ha^{-1}	16.3	123.1	275.7	686	1,923
66,666 plants ha^{-1}	16.6	123.2	279.2	566	1,950
53,333 plants ha^{-1}	16.7	123.7	277.4	612	2,151
Means	16.5	123.3	277.4	621.1	2,007.8
P-value	0.59	0.98	0.57	<0.0001	<0.0001
LSD(0.05)	NS	NS	NS	39.7	67.4
CV (%)	9.3	8.9	4.6	12.4	6.5

5. CONCLUSION

Maize varieties Sungura and Pioneer produced the highest significant grain yields in Mwea and Bura respectively while DH04 produces the highest above ground biomass in both Bura and Mwea. The plant population of 53,333 plants ha^{-1} produced the highest grain yield. This plant population of 53,333 plants ha^{-1} was achieved by planting at a spacing of 0.25m between plants by 0.75m between rows. Variety Pioneer grown in plant population of 88,888 plants ha^{-1} produces the highest grain yield in Bura compared to that of the other sampled maize varieties grown under plant population of 53,333 plants ha^{-1} and 66,666 plant ha^{-1}.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Soil moisture content prior to water stress treatment, 55 days after sowing

Mwea site			
No.	**Water treatment**	**Irrigation frequency 55 days after sowing**	**Average moisture content prior to irrigation water application (%)**
1	Water stress	1st	15.1
2	No water stress	1st	18.6
3	Water stress	2nd	17.6
4	No water stress	2nd	19.0
5	Water stress	3rd	13.1
6	No water stress	3rd	16.2
7	Water stress	4th	19.4
8	No water stress	4th	20.9
9	Water stress	5th	17.9
10	No water stress	5th	22.1
11	Water stress	6th	23.6
12	No water stress	6th	19.1
13.	Mean m.c. For waters stress treatment (%)	17.8	
14	Mean m.c. For no-waters stress treatment (%)	19.3	

Bura site			
No.	**Water treatment**	**Irrigation frequency 55 days after sowing**	**Average moisture content prior to irrigation water application (%)**
1	No water stress	1st	7.6
2	Water stress	1st	4.8
3	No water stress	2nd	8.8
4	Water stress	2nd	3.7
5	No water stress	3rd	15.0
6	Water stress	3rd	8.0
7	No water stress	4th	13.9
8	Water stress	4th	7.4
9	No water stress	5th	18.8
10	Water stress	5th	10.0
11	No water stress	6th	14.0
12	Water stress	6th	5.9
13	No water stress	7th	11.6
14	Water stress	7th	7.3
15	No water stress	8th	13.0
16	Water stress	8th	8.2
17	Mean m.c. For waters stress treatment (%)	6.9	
	Mean m.c. For no-waters stress treatment (%)	12.8	

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