INFLUENCE OF WATER REGIMES ON GROWTH; YIELD AND NUTRIENT UPTAKE OF SORGHUM

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Abstract

Water is one of yield limiting factor in most crop production. Although sorghum is known to be drought tolerant, the tolerance limit has been reported to vary depending on variety and whether the crop is meant for grain, fodder or bioethanol. Therefore, the current study examined the effects of three water regimes on growth and yields of two sorghum varieties (Seredo and Machakos local red) in the field for two cycles. The treatments were laid out in Randomized Complete Block Design in factorial arrangement and replicated three times. Growth parameters such as plant height and shoot biomass were measured. Also, the study determined yield and nutrient uptake. The results revealed that low soil water content significantly affected the growth of the two varieties of Sorghum. Machakos local red was the tallest (210.9 cm), while the Seredo variety had the greatest shoot biomass (133.0 g). Besides, the highest growth of the two sorghum varieties was achieved at 60% water regime. Seredo variety under 40% water regime recorded the maximum grain yield (3.23 tha^{-1}), Phosphorus (60.3 kg P ha^{-1}), and Nitrogen (25.2 kg Nha^{-1}). Furthermore, Seredo variety recorded the highest harvest index (0.43). The study revealed that low soil moisture content significantly declined sorghum plant growth, yield and yield components, phosphorus, and nitrogen concentration uptake of the two varieties. Plant growth was the highest underwater 60 % water regime, with Machakos local red variety having higher plant height, while Seredo was superior in shoot biomass. Seredo accumulated the highest yield, and also had the highest P and N uptake under 40% watering regime. The results showed that optimal watering regime does not significantly reduce sorghum growth, yields and nutrient uptake yet save on water. Therefore, the study recommends farmers growing sorghum in marginal areas to adopt to optimal watering regime.

Keywords: *Sorghum, water regimes, drought, growth, yield*

INTRODUCTION

Drought, a natural threat, is the leading cause of disturbing production by harshly affecting farming and increasing at any crop development stage (Ivits *et al*., 2014; Woldesemayat and Ntwasa, 2018). This phenomenon arises when rainfall amount is below the required levels by the crops. The situation is exacerbated by high temperatures that cause hydrological imbalances affecting farming production systems (Ibrahim and Ramadan, 2013; Ibrahim *et al*., 2018; Wijewardana *et al.,* 2019). Insufficient water in the soil is elicited when rainfall is not regularly distributed, coupled with fewer volumes of rain, high drought intensity, and prolonged, extensive periods (Kolenc *et al*., 2016; Wu and Zou, 2017).

One-third of the soils globally are exposed and affected by water stress, therefore, being not able to support normal crop growth (Calvo-Polanco *et al*., 2016**;** Kolenc *et al*. 2016;Wu and Zou, 2017; Asrar *et al*., 2012; Abdel-Salam *et al*., 2018). Additionally, water scarcity during plant development is detrimental in that it can intensely inhibit crop growth and production (Wu and Zou, 2017).

Its effects lower water potential in the soils leading to drying of the plant cells, inhibition of cell division and enlargement, reduction in nutrients uptake, the spread of the roots, low water use efficiency, and reduced leaf and stem by the plants (Kaushal and Wani, 2016; Wu and Zou, 2017). Besides, it also affects physiological, morphological, and metabolic roles in plants (Ibrahim *et al.,* 2018)**.** Subsequently, reduced leaf area lowers photosynthesis rate, undesirably affecting roots biomass, above-ground biomass, and yield of the crops (Jaleel *et al.* 2009; Kaushal and Wani, 2016; Craufurd and Peacock, 1993; Reddy, 2019) studies on Sorghum indicated that drought causes yield reduction. Severe drought conditions can cause leaf senescence and death of the plants (Kaushal and Wani, 2016; Carlson *et al*., 2020).

Plants have developed different mechanisms to help cope with the alarming drought stress physiologically, biochemically, and morphologically through tolerance, avoidance, and escape (Khoyerdi *et al.,* 2016; Wu and Zou, 2017; Carlson *et al*., 2020). The mechanism responses involve the production of signaling hormones such as salycilic acid, jasmonic, and ethylene and signaling network that involves intermediates reactive oxygen, cytosolic and hydrogen ions that activates physiological reactions such as reduction in leaf area, the closing of stomata, and reduction of cell turgor pressure as well as production of secondary metabolites (Carlson *et al*., 2020: Okello *et al*., 2017). Moreover, plants can produce phytochemicals such as glycine betaine, choline, and proline to cope with cell desiccation damage when drought arises (Kheiry *et al*., 2017). However, with the raising concerns on climate change negative effects of drought on the production of crops is bigger and is expected to be intensified in future (Trenberth *et al*., 2014; Ye *et al*., 2012; Heffernan, 2013). In the forthcoming years, climate change is anticipated to cause further adverse and recurring drought leading to food insecurity worldwide (Ye *et al*. 2012; Heffernan 2013; Ngugi *et al*., 2015). Therefore, there is a need to consider adopting crops such as Sorghum which are drought tolerant and can lower risks of production (Bell *et al*., 2020).

Sorghum (*Sorghum bicolor* L. Moench) is known as an important source of food that sustains livelihoods in rising countries and thus substantial in food security (Rooney *et al*., 2007; Carlson *et al*., 2020; Duodu *et al*., 2003). It's a C4 grass ranked 5thcereal crop after rice, wheat, barley, and maize globally (FAOSTAT, 2015). The harvest has been cultivated long ago in marginal areas as a staple food for millions of people. It is a very genetically significant key grain crop, more and more affected by water deficiency (Woldesemayat and Ntwasa, 2018). Its wide adaptations make it able to grow in areas with hostile ecological conditions such as high temperatures, drought and saline stress, insufficient and unreliable rainfall, low soil fertility, and poor soil structure (Dicko *et al*., 2006).This is due to its ability to regulate stomatal opening and closing, adjustment of root structure, osmotic adjustment, and maintenance of photosynthesis even at low water levels (Tari et al., 2013; Carlson *et al*., 2020).Its deep roots can draw water from large soil depths, thus more tolerant to drought stress than other cereal crops (Singh and Singh, 1995; Farré and Faci, 2006). Studies by Singh *et al*. (2010) on Sorghum and maize in terms of root system demonstrated how sorghum roots were more efficient in water uptake than maize roots (Hasan *et al*., 2017).

Cereal grains in developing countries, including Kenya, are the most common foods used since they have been the main sources of human diets (Taylor *et al*., 2012; White and Broadley, 2009; Burke et al., 2013). Sorghum cereal is used as food in sub-Saharan Africa and Asia due to its essential nutrients such as proteins, carbohydrates, vitamins, minerals, antioxidants, cholesterol-lowering wax, and phenolic waxes (Taylor *et al*., 2006; Perazzo *et al*., 2017). Besides, the cereals are known to be gluten-free and have other health benefits such as anti-inflammatory, inhibition of colon cancer cell growth, cholesterol-lowering, and slow digestibility (Pontieri *et al*., 2013;Awika *et al*., 2009;Carr *et al*., 2005; Moraiset *al*., 2017; Paiva *et al*., 2017). The abundance of minerals such as potassium, phosphorus, magnesium, zinc, and iron in Sorghum has increased interest in using it for human consumption (Afify *et al*., 2012; Pontieri *et al*., 2014; Muui *et al.,* 2013). It is also used in industries to produce alcohol, make local bread, and cooked as boiled or roasted grains (Mar *et al.,*2019). Further, Sorghum is used as forage for feeding animals, and the stalks are used as building materials (Muui *et al*., 2013). However, drought being the major constraint in sorghum production has reduced its quality and yield worldwide (Sabadin *et al*., 2012; Besufekad and Bantte, 2013). The study, therefore, evaluated the effects of three water levels on the growth, yield, and nutrient uptake of two sorghum varieties.

MATERIALS AND METHODS

Description of the Study Area

The research was carried out in Machakos County at Yatta NYS field station, Kenya, for two cycles (December 2019 to April 2020) and (April 2020 to July 2020). The Yatta NYS field is positioned at the latitude of -1.088439 South and longitude of 37.476116 east. The region receives an average rainfall of about 450-800mm per year, bimodal with two rainy seasons (March and May), long rains, and (October and December) short rains. The area receives an average temperature ranging between 29^{0}C and 36^{0}C. Soil samples were collected at a depth of 0-20cm to determine initial physical and chemical parameters. The analysis was done using procedures by Okalebo *et al.* (2002), as presented in table 1.

Table 1: Selected physical and chemical characteristics of the experimental soil

Parameter	Value
pH (1:2.5, soil: water)	6.33
Total organic carbon (%)	0.18
Soil organic matter (%)	0.31
Total Nitrogen (%)	0.06
Available phosphorus (%)	0.01
Exchangeable potassium (%)	0.07
Exchangeable magnesium (%)	0.44
Exchangeable calcium (%)	1.26
EC (mhos/cm)	0.023
Bulky density (g/cm^3)	1.56
Field water capacity (%)	22.7
Sand (%)	76
Silt (%)	14
Clay (%)	10
Soil textural class	Loamy sand

Experimental design, Crop Establishment and Management

The study was performed as a factorial trial based on Randomized Complete Block Design (RCBD) replicated three times. There were two factors, including two sorghum varieties (Machakos local red and Seredo) in main plots and water regimes (60% FC, 40% FC, and 20% FC) subplots, giving a total of 6 treatments. Experimental plots measured 3m by 3m where healthy sorghum seeds were planted at a recommended spacing of 75cm between the rows and 25cm within the rows. Watering regimes were introduced at floral initiation, which is the last stage of the vegetative phase. A moisture meter was used to measure field water capacity every day to check on reducing the stored water in the soil. Whenever soil water content was below the required water levels (60% FC, 40% FC, and 20% FC), irrigation to the three water regimes was done. The irrigation of the required water regimes was done throughout the trial period. The crop was exposed to the normal day and night weather conditions that were held constant. Fertilization was done with P being added at 45kgha^{-1}P (3.44 g P per plant) as basal, whereas N at 180kgha^{-1}N (5.87g N per plant) as a top dressing (Galal, 2016). All agronomic practices were maintained throughout the experimental period.

Data Collection

Determination of Plant Growth Parameters

Growth parameters such as plant height and shoot biomass were evaluated. Three plants were tagged from each trial plot; the size was measured from the tip of the youngest leaf to the top of the soil (base of the plant) in centimeters using a meter rule. This was done from the sixth week after planting up to the grain filling stage biweekly. For the shoot biomass, destructive sampling was done on the two outer rows where three plants were uprooted dried in the oven at 60˚C for 72 hours till they reached a constant weight. Electronic weighing balance was used to measure the dry weight of the plants, and the average weight was recorded. This activity was done biweekly from the sixth week after planting up to grain filling.

Yield and Yield Component

The above-ground biomass for each trial net plot was determined after harvesting. Samples were dried in an oven at 60˚C for 72 hours till they reached a constant weight and weight recorded. For the yield determination, threshed grains from the trial net plot were dried in an oven at 60˚C for 72 hours until the moisture content was at 12^{0}C and weight measured. Kilogram weight was transformed into kg ha^{-1}. The harvest index of each trial unit net plot was determined by dividing grain weight by the total of the above-ground biomass multiplied by 100 according to Leport *et al.* (2006) protocol.

Nutrient Analysis and Uptake in Plant Tissues

Samples for nutrient analysis were collected during harvesting from plant tissue and grains. Plant stover and grains samples were prepared by washing and rinsing with deionized water and dried at 70^{0}C for 48 hours. Dried plant stover and grains samples were grounded using a blender to fine powder ready for the analysis process. Acid digestion was used to extract nutrients following Okalebo *et al.* (2002) spectrometry analysis. Phosphorus in plant tissues and grains was determined using the colorimetric method according to Okalebo *et al.* (2002) procedures. Standards and sample absorbance were measured using u/v spectrophotometer at the wavelength of 880nm. The calibration curve of the standards series, concentration against the absorbance was plotted. The slope was to calculate P concentration as shown in equation 1. Phosphorus uptake was calculated using equation 2.

$$\%\ \mathrm{P} = \frac{(a-b)\times V\times f\times 100}{1000\times W\times 1000} \qquad (1)$$

$$\text{P uptake (kg ha}^{-1}) = \frac{\%P\times drymatter\ \ (kg\ ha^{-1})}{100} \qquad (2)$$

Kjeldahl distillation method following procedures described by Okalebo *et al.* (2002) was used to determine total Nitrogen in the digestate. Percentage N in the plant tissue and N uptake in grain samples were calculated using equations 3 and 4, respectively.

$$\%\mathrm{N} = \frac{(a-b)\times V\times 100}{1000\times W\times al\times 100} \qquad (3)$$

$$\text{N uptake (kg ha}^{-1}) = \frac{\%N\times drymatter\ \ (kg\ ha^{-1})}{100} \qquad (4)$$

Data Analysis

Data on growth parameters, yield, and nutrient uptake were subjected to a one-way analysis of variance (ANOVA) test. Using R software, version 4.0.2 for windows significant difference was evaluated between the treatments. Tukey's test was used to separate significant means at 5% significance level.

RESULTS

Plant Growth Parameters

The results from the study exposed that there was a significant ($p < 0.001$) difference between the sorghum varieties in terms of plant height throughout the growth period in the two cycles (Table 2). Machakos local red was superior in plant height, recording 210.9cm and 190.8cm week 15 in both cycles correspondingly. Seredo variety recorded the least plant height, 24.4cm, and 19.3cm in cycle one and two week six, respectively. Plant height of drought-stressed sorghum varieties was significantly ($p < 0.001$) inferior (Table 2). However, the declines in plant height due to low soil moisture were more evident in the present study results. Sixty percent water regime was greater in plant height in both cycles recording 193.7cm, 173.5cm in week 15 in the two cycles respectively while, 20% water regime recorded the minimum 174.9cm, 154.6cm plant height.

Table 2: Plant height as affected by sorghum varieties and water regimes cycle one and two

Plant height (cm)								
Weeks	Week 6		Week 9		Week 12		Week 15	
Cycles	C1	C2	C1	C2	C1	C2	C1	C2
Variety								
Srd	24.4^{b}	19.3^{b}	72.9^{b}	57.9^{b}	119.6^{b}	106.4^{b}	159.4^{b}	139.2^{b}
Mlr	30.6^{a}	20.4^{a}	91.1^{a}	76.1^{a}	163.3^{a}	150.1^{a}	210.9^{a}	190.8^{a}
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Water regimes (%)								
20wr	22.5^{c}	14.9^{c}	71.0^{c}	56.0^{c}	130.6^{c}	117.8^{c}	174.9^{c}	154.6^{c}
40wr	28.1^{b}	20.9^{b}	81.9^{b}	66.8^{b}	141.8^{b}	128.5^{b}	187.29^{b}	167.29^{b}
60wr (control)	31.9^{a}	24.5^{a}	93.2^{a}	78.1^{a}	152.1^{a}	139.8^{a}	193.7^{a}	173.5^{a}
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Within the column means followed by different letters are significantly different at alpha=0.05. $p < 0.001$, Wr=Water regime (20%, 40% and 60% field capacity); Srd= Seredo sorhugm variety; Mlr= Machakos local red sorghum variety; C= Experiment cycle.

The trial results revealed that sorghum varieties were considerably ($p < 0.001$) diverse from each other in terms of shoot biomass across the weeks in the two cycles (Table 3). Seredo variety recorded greater shoot biomass 133.0g, 113.1g week 15 in the two cycles, respectively. In contrast, the lowest shoot biomass, 15.6g, 14.3g, was recorded in Machakos local red in week six cycle one and two. There was a significant decrease ($p < 0.001$) in growth in terms of shoot biomass in the two cycles due to drought stress (Table 3).Water regime 60% accumulated greater shoot biomass 123.6g and 103.1g in week 15 in both cycles, respectively. An increase in the amount of water applied led to higher shoot biomass so that the water regime 60% gave the maximum shoot biomass all over the growth period in the two cycles. However, minimum shoot biomass 113.7g and93.8g in week 15 was recorded underwater regime 20% in the two cycles correspondingly as shown in (Table 3).

Table 3: plant shoot biomass as affected by sorghum varieties and water regimes cycle one and two

	Shoot dry weight (g)							
Weeks	Week 6		Week 9		Week 12		Week 15	
Cycles	C1	C2	C1	C2	C1	C2	C1	C2
				Variety				
Mlr	15.6^{b}	14.3^{b}	19.4^{b}	17.3^{b}	63.1^{b}	48.2^{b}	107.2^{b}	87.9^{b}
Srd	17.4^{a}	15.7^{a}	27.3^{a}	22.8^{a}	78.7^{a}	63.1^{a}	133.0^{a}	113.1^{a}
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
				Water regimes (%)				
20wr	15.1^{c}	13.6^{c}	22.3^{c}	18.5^{c}	67.2^{c}	52.1^{c}	113.7^{c}	93.8^{c}
40wr	16.3^{b}	14.8^{b}	22.4^{b}	19.3^{b}	71.4^{b}	56.6^{b}	123.1^{b}	103.2^{b}
60wr (control)	18.0^{a}	16.5^{a}	25.2^{a}	21.8^{a}	73.7^{a}	58.1^{a}	123.6^{a}	103.1^{a}
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Within the column means followed by different letters are significantly different at alpha=0.05. p <0.001, Wr=Water regime (20%, 40% and 60% field capacity); Srd= Seredo sorhugm variety; Mlr= Machakos local red sorghum variety; C= Experiment cycle.

Yield and Yield Component

Sorghum varieties considerably ($p < 0.001$) affected grain yield, stover yield, and harvest index in the two cycles (Table 4). The highest stover and grain yield and harvest index 5.17 tha^{-1},3.63 tha^{-1} and 2.72 tha^{-1}, 2.18 tha^{-1} and 0.38, 0.36 was recorded in Seredo variety in both cycles, respectively. Water regime significantly ($p <0.001$) affected grain and stover yield and harvest index (Table 4). Water regime 40% accumulated the highest stover and grain yields and harvest index of 6.47 tha$^{-1,}$ 4.02 tha^{-1} and 2.68 tha^{-1}, 1.94tha^{-1} and 0.38, 0.39 in both cycles respectively. Sorghum varieties and water regimes had interactive effects that significantly ($p < 0.001$) affected yields and harvest index. Seredo variety under 40% water regime occasioned greatest stover yield 6.80 tha^{-1},4.30 tha^{-1},grain yield 3.23 tha^{-1}, and 2.42 tha^{-1} harvest yield in the two cycles, respectively (Table 5). Seredo variety under 40% water regime occasioned greatest stover yield 6.80 tha^{-1}, 4.30 tha^{-1}, grain yield 3.23 tha-1, 2.42tha^{-1} and harvest index 0.43, 0.42 in the two cycles respectively (Table 5).

Phosphorus and Nitrogen Concentration and Uptake in Sorghum Plant Tissues

The amount of P accumulated by sorghum plants demonstrated significant deviations ($p < 0.001$) owing to the varieties and water regimes (Table 6). Seredo variety earned the greatest P uptake 48.6 kgha^{-1}and 40.5 kgha^{-1}, equated to Machakos local red 44.7 kgha^{-1}and 33.7 kgha^{-1}in cycle one and two, respectively. Superior P uptake 57.2 kgha^{-1}and 47.9 kgha^{-1}was noted in 40% water level in cycle one and two, respectively (Table 6). However, the 20% water regime accumulated the minimum total above ground P 36.0 kgha^{-1} and 28.1 kgha^{-1}in both cycles, respectively. Water regimes and Sorghum varieties significantly ($p <0.001$) interacted in the uptake of P by Sorghum (Figure 1). Seredo variety gathered the highest P 60.3 kgha^{-1} and 50.0 kgha^{-1} in above-ground biomass in both cycles, respectively, when interacting with 40% water regime.

Table 4: yield and yield components as influenced by sorghum varieties and water regimes in the two cycles

	Stover yield(tha^{-1})		Grain yield(tha^{-1})		Harvest index	
Cycles	C1	C2	C1	C2	C1	C2
			Variety			
Mlr	4.42^{b}	3.01^{b}	1.73^{b}	1.30^{b}	0.29^{b}	0.31^{b}
Srd	5.17^{a}	3.63^{a}	2.72^{a}	2.18^{a}	0.36^{a}	0.38^{a}
P-value	<.001	<.001	<.001	<.001	<.001	<.001
			Water regimes (%)			
20Wr	2.50^{c}	2.34^{c}	1.63^{c}	1.50^{c}	0.19^{c}	0.25^{c}
40Wr	6.47^{a}	4.02^{a}	2.68^{a}	1.94^{a}	0.38^{a}	0.39^{a}
60Wr (control)	5.42^{b}	3.61^{b}	2.06^{b}	1.78^{b}	0.30^{b}	0.33^{b}
P-value	<.001	<.001	<.001	<.001	<.001	<.001

Within the column means followed by different letters are significantly different at alpha=0.05. p <0.001, Wr=Water regime (20%, 40% and 60% field capacity); Srd= Seredo sorhugm variety; Mlr= Machakos local red sorghum variety; C= Experiment cycle

Table 5: interactive effects between sorghum varieties and water regimes on plant stover yield (tha^{-1}), Grain yield (tha^{-1}), and Harvest index cycle one and two.

		Stover yield (tha^{-1})		Grain yield (tha^{-1})		Harvest index	
Variety	Water regimes (%)	C1	C2	C1	C2	C1	C2
Srd	60	5.88^{c}	3.99^{b}	2.85^{b}	2.12^{b}	0.33^{c}	0.36^{b}
	40	6.80^{a}	4.30^{a}	3.23^{a}	2.42^{a}	0.43^{a}	0.42^{a}
	20	2.80^{d}	2.62^{e}	2.07^{d}	1.00^{e}	0.30^{b}	0.30^{c}
Mlr	60	4.96^{d}	3.23^{d}	1.89^{e}	1.25^{d}	0.27^{bc}	0.23^{e}
	40	6.07^{b}	3.73^{c}	2.13^{c}	1.69^{c}	0.35^{b}	0.29^{d}
	20	2.20e	2.06^{f}	1.19^{f}	0.89^{f}	0.24^{c}	0.17^{f}
P-value	V*Wr	<.001	<.001	<.001	<.001	<.001	<.001

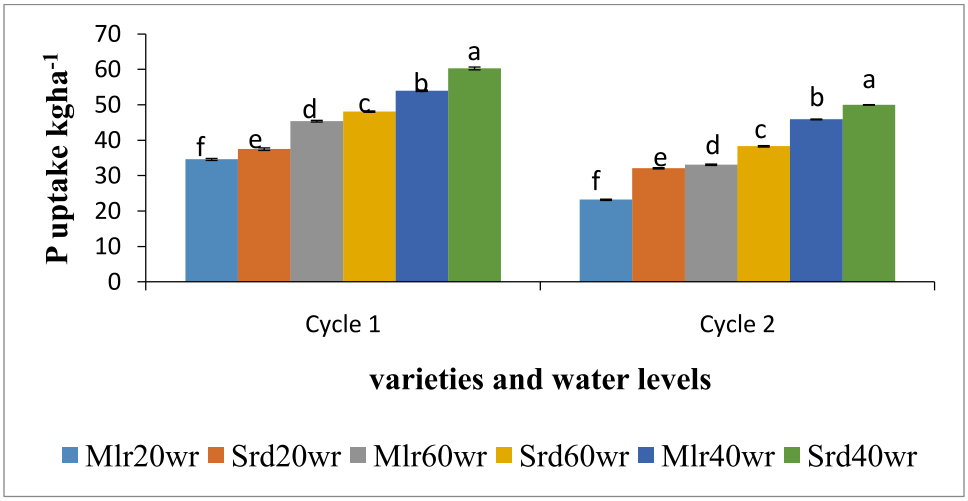
Within the column means followed by different letters are significantly different at alpha=0.05. p <0.001, Wr=Water regime (20%, 40% and 60% field capacity); Srd= Seredo sorhugm variety; Mlr= Machakos local red sorghum variety; C= Experiment cycle.

The study findings revealed variability in sorghum N uptake in line with water regimes and varieties. There were substantial differences (p <0.001) in the above-ground N buildup of the plant due to varieties, as shown in Table 6. The Greatest N uptake, 22.5 kgha^{-1} and 12.0 kgha^{-1}, were recorded in Seredo variety compared to Machakos local red 15.3 kgha^{-1}and 7.6 kgha^{-1} cycle one and two, respectively (Table 6). Water levels significantly (p <0.001) affected the above-ground N uptake (Table 6). The highest N accumulation was observed under 40% water level that recorded 21.6 kgh^{-1} and 12.0 kgha^{-1} in both cycles, respectively. Nonetheless, the lowest N uptake, 16.0 kgha^{-1}, and7.5 kgha^{-1}, was revealed under 20% in cycle two and one. There were interactive effects between the water regimes and the sorghum varieties in N uptake that was significant (p <0.001) in the two cycles (Figure 2). The 40% water regime application increased N's uptake by the sorghum plant in cycle one and two. A high response on uptake of N 25.2 kgha^{-1} and 14.1 kgha^{-1} was observed on Seredo variety under 40% water regime in both cycles.

Table 6: mean phosphorus and nitrogen uptake by plant as affected by sorghum varieties and water regimes trial cycle one and two

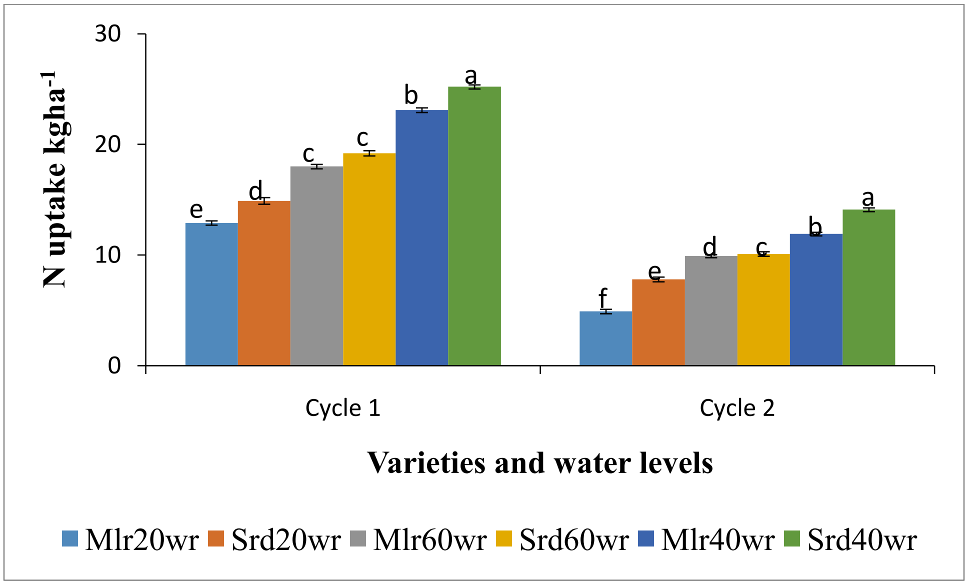
	Nutrient Uptake Kgha^{-1}			
	P uptake kgha^{-1}		N uptake kgha^{-1}	
Cycles	C1	C2	C1	C2
	Variety			
Mlr	44.7^{b}	33.7^{b}	15.3^{b}	7.6^{b}
Srd	48.6^{a}	40.5^{a}	22.5^{a}	12.0^{a}
P-value	<.001	<.001	<.001	<.001
	Water regimes (%)			
20Wr	36.0^{c}	28.1^{c}	16.0^{c}	7.5^{c}
40Wr	57.2^{a}	47.9^{a}	21.6^{a}	12.0^{a}
60Wr (control)	46.7^{b}	35.2^{b}	18.9^{b}	9.7^{b}
P-value	<.001	<.001	<.001	<.001

Within the column means followed by different letters are significantly different at alpha=0.05. p <0.001, Wr=Water regime (20%, 40% and 60% field capacity); Srd= Seredo sorhugm variety; Mlr= Machakos local red sorghum variety; C= Experiment cycle.



Srd= Seredo variety; Mlr= Machakos local red variety Wr= Water regime (20%, 40% and 60% field capacity).

Figure 1: Interactive effects between varieties and water regimes on sorghum phosphorus uptake cycle 1and 2.



Srd= Seredo variety; Mlr= Machakos local red variety Wr= Water regime (20%, 40% and 60% field capacity).

Figure 2: Interactive effects between varieties and water regimes on sorghum nitrogen uptake cycle 1and 2.

DISCUSSION

Plant Growth Parameters

Drought is a significant constraint to crop progression and plant production. In the existing research, decreased development of sorghum plants due to water deficit in the soil may be related to a reduced rate of transpiration and stomatal conductance to reduce water loss, therefore, interfering with the photosynthesis process (Heidari and Karami, 2014). Findings of the study indicated that Machako's local red variety had the tallest plants compared with the improved Seredo variety. This suggests that there was a genetic makeup difference with dissimilarity in the genetic factor action articulating phenotypes between varieties tested (Mwamahonje and Maseta, 2018). The study by Muhammad *et al.* (2020) on Sorghum exhibited that variety Quetta had the highest plant height than other varieties tested.

Water deficiency has become a global problem to crop production; it decreases plant growth, yield, and physiological processes of field crops and economic ornamental crops (Abdel-Salam *et al.*, 2018). In the present research, results displayed that reduction in soil moisture content decreased the height of the Sorghum. This could be due to water deficiency that undesirably affected crop nutrition and physiological growth of crops, thus reduced size, yield, biomass, and crop quality (Aladenola and Madramootoo, 2014; Rossini *et al.*, 2013; Syengo *et al.*, 2019). Significant reduction of the size of the plant by drought stress could also be attributed to low turgor pressure Shao *et al.* (2008) that led to suppression of cell enlargement, division, and development of the crop (Manivannan *et al.*, 2007). This is in agreement with Yaqoob *et al.* (2013) study that advocated that drought stress being damaging and detrimental in all growth stages of chickpea.

Further, Shamsi *et al.* (2010) research on chickpea demonstrated that water stresses significantly reduced the number of branches and plant height. Similarly, Mustapha *et al.* (2014); Mekonnen, (2020) studies on soybean revealed the same results. In trials carried out by Cakir, 2004) on cotton plants determined that drought stress considerably reduced stem diameter, weight, number of nodes, and plant height of cotton. Moreover, Bhatt and Rao's (2005) study on Okra, showed the harmful effects caused by water stress. Also, the findings of Cheruth *et al.* (2009) investigation on soybean reported a reduction of stem length due to drought. Apparently, it is perceived that up to 25% height of citrus is adversely affected by water stress (Wu *et al.,* 2008; Jaleel *et al.,* 2009). As well, Jaleel *et al*. (2009) examination on potato tuber (*Solanum tuberosum*), Okra (*Abelmoschus esculentus),* soybean (*Glycine max*), parsley (*Petroselinum crispum*), and cowpeas (*Vigna unguiculata*) conveyed reduced stem length due to low soil moisture.

Analysis of variance results disclosed that there was significant variation in terms of shoot biomass accumulation due to differences between sorghum varieties. Seredo variety accumulated the highest shoot biomass equated to Machakos local red. This could be owing to genetic makeup differences and such that Seredo is an improved variety. This was in collaboration with the study by Randhawa *et al*. (2014) and Mekonnen (2020) on chickpea, who testified of genotypic variation on dry biomass accumulation. Water stress significantly decreased the shoot dry mass, as shown by the outcomes of this study. This specifies that nutrient uptake from the soil and photosynthesis process, which is the end product of dry matter amassing, was greatly affected by water stress in Sorghum (Hasan *et al*., 2017). Low water moisture in the soil may have reduced carbon dioxide buildup in the processes of photosynthesis, lowering the production of carbohydrates hence low dry mass accumulation (Dixon, 2009). Also, this could be attributed to a reduced rate of photosynthesis due to closed stomata and reduced leaf area in reaction to drought (Boldaji *et al*., 2012; He *et al*., 2017). Zuccarini and Savé's (2016) study on *spinacea oleracea* L.stated that inadequate water to a plant reduces photosynthesis, therefore, causing growth inhibition. The findings also agree with those of Siddique *et al*. (2000) and Farooq et al. (2018) who investigated chickpea and reported that exposure of plants to drought reduces the water content and leaf water potential significantly, subsequently affecting the development and enlargement of the crops. Studies by Pembleton *et al*. (2009) on alfalfa likewise confirmed that drought harmfully affects its growth, consequently lowering shoot biomass accumulation. Cakir (2004) correspondingly concurs with the present study results by informing that water stress affected the collection of shoot dry weight on corn.

Yield and Yield Components

The study results validated that Seredo (improved variety) performed better than Machakos local red (local variety) in terms of stover and grain yield and harvest index. This collaborates with the work of Mekonnen (2020) and Shaban *et al*. (2012), who informed of variations of performance between genotypes when tested on diverse moisture content levels in the soil. Likewise, the study by Mansur *et al*. (2010) and Mansourifar *et al.* (2011) in chickpea revealed that harvest index was affected by varieties. Drought considerably reduced the final grain harvest, above-ground biomass, and harvest index. The Sorghum yield under the 40% water regime was highest compared to those under the 20% water regime. This concurs with results from the study by Martínez *et al*. (2007) and Caser *et al*. (2017), who concluded that common plants under water-stressed conditions showed decline in leaf size and cell enlargement due to reduced turgor pressure. The present study agrees with Mekonnen, (2020) research on corn, where they revealed that low soil moisture caused about 50-80% grain loss when introduced during flowering and grain filling. Equally, Mansourifar *et al*. (2011) Mekonnen

(2020) study on chickpea stated that treatments that received optimal water during crop development had the maximum number of pods per plant water-stressed treatments that recorded a low number of pods.

The low yields could also be attributed to intense photosynthesis due to restricted carbon dioxide into the plant caused by plant stomata closure to reduce water loss through transpiration hence low yields (Moreira *et al.,* 2018). Moreover, water stress can cause degradation of chlorophyll that decreases its synthesis rate leading to low performance (Marenco and Lopes, 2005). Findings by Cakir (2004)on corn who concluded that water stress during plant growth phases reduces above-ground biomass, and final yield; these agree with the results from the current study. Moreover, water stress may have hindered the uptake of nutrients repressing the crop development, consequently lowering the yields (Shah *et al*., 2017). Comparably, Ferrara *etal*.'s (2011)study on pepper response was the same. Heidari and Karami (2014); Stone *et al*. (2001); Ashraf and Mehmood, 1990) conveyed that considerable crop yield losses can be triggered even by short-term water shortage in the soil.

Further, low soil moisture content reduced harvest index, as illustrated from the present study results. These results are in line with those of (Cakir 2004; NeSmith and Ritchie, 1992), who assessed reactions of the corns to water stress where a loss of 15-25% was designated as long-term. Wenzel and Van Rooyen, (2001) trial on Sorghum concluded that adverse water stress caused regular yield loss of about 44%, significantly affecting harvest index.

Nutrient concentration and uptake in plant tissues

Nutrient absorption by crops is associated with water availability to the soil and rate of diffusion of the nutrients from the soil solution to the root surfaces, which reduces with low water content in the ground (Doğan and Akinci, 2011) which could be caused by the disruption of several metabolic pathways can also cause a decrease of nutrients due to low soil water content affecting the regulation of stomatal osmotic and permeability of plasma membrane (Doğan and Akinci, 2011). Nitrogen and phosphorus absorptions in plants are influenced by environmental factors such as water availability in the soils that are reflected as key pointers to plant adaptations *(Guo et al*., 2014). Phosphorus is a vital nutrient to crops for the major roles its plays such as transport of carbohydrates, store and transfer energy, enzyme regulation, and photosynthesis (Heidari and Karami, 2014).

The superiority of Seredo variety in the uptake of P in the current study demonstrates that there was a varietal difference in the amassing of the P nutrient by sorghum plants. This agrees with Tadayyon *et al.* (2018) research on tomatoes that showed that nutrients accumulation varied with cultivars. Water availability in the soil plays an important role in the uptake of phosphorus by crop *(*Karimzadeh *et al*. (2021). McBeath *et al.* (2012) demonstrated a synergistic association between P nutrition for crops and moisture content in the soil. Commonly, P absorption by the plants is usually low in reduced moisture soil conditions; for instance, the transportation of P to the shoots of plants is strictly constrained even under moderately slight water stress (Heidari and Karami, 2014). Diminution of moisture in the soil restricts diffusion of P towards the roots surfaces, but then again, when the humidity in the ground rises, the absorption of P and other crucial elements increases, thus enhancing plant development and crop P content (McBeath *et al*., 2012; Celiktopuz *et al.*, 2020) informed that drought reduces P accumulation in plants, reduce soil pore diameter, consequently lowering the mobility of P. Likewise, the outcome of the research by (Hosseinzadeh and Ahmadpour, 2018) designated that farms with low soil moisture content mostly have reduced available nutrients (N, P, Ca and K). Besides, Gordon and Tindall (2006) disclosed that the adsorption and release of P on clay surface is determined by moisture content in the soil flowing through its pores. Conversely, Liebersbach *et al.*(2004); Heidari and Karami (2014) study described that if plants produce molecular exudates in large quantity in low moisture soils can offset the decreased P movement. Furthermore, augmentation of soil moisture content leads to greater solubility of nutrient P and roots expansion, therefore, increasing uptake of P by plants (Misra, 2003).

Nitrogen as a mineral component is required in great quantities by crops as it is a fundamental constituent of plant cells such as nucleic and amino acids (Heidari and Karami, 2014; Gweyi-Onyango, 2018). The current study findings specified that N's uptake was at variance amongst the varieties of the Sorghum planted. Similar results have previous been reported in rice by Ntinyari and Gweyi-Onyango (2018). The plants generally absorb Nitrogen through the mass flow method; therefore, water is required for the process to take place (Schlegel et al., 2017). As conveyed by the outcome of the current study drought conditions, significantly lowered the N accumulation in the above-ground biomass. This could be attributed to a reduced rate of transpiration to mobilize N from roots to the shoots and decreased soil N mineralization due to low moisture content in the soil hence lowering the availability of N to plants and the uptake (Heidari and Karami, 2014). The occurrence could also have been attributed to reduced N2 fixation activity and inhibition of Nitrogenase due to reduced soil moisture content (Ding et al., 2018). Similarly, inhibitory effects of N buildup in the above-ground biomass could be ascribed to the water stress of decreasing rate of photosynthesis N absorption in plants (Boldaji *et al.*, 2012;He *et al.*, 2017). The outcome of the research by Emam *et al.*(2014) on rice grain agrees with the results of this study, where it establishes that there is low protein content and N concentration in plants when exposed to water deficit in the soil. Moreover, Havlin *et al.* (2013) and Ibrahim *et al.* (2018) demonstrated that water stress reduced the ability of rice plants to absorb nutrients such as N, thus decreasing the concentration of nutrients in the rice straws. Celiktopuz *et al.* (2020) supported the findings of this experiment by directing that the incidences of short N are associated with low water content in the soil. Tadayyon *et al.* (2018) added that sufficient water in the soil increases the uptake of micronutrients by the plants due to N's availability in the ground.

Conclusions

Low soil moisture content significantly declined sorghum plants growth, yield, yield components as phosphorus and Nitrogen concentration, and the uptake of the two varieties. Plant growth was the highest under 60% water regime, while Machakos local red recorded the highest height and Seredo the greatest shoot biomass. Seredo accumulated the highest yield, P and N concentration, and uptake under 40% water regime.

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