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Original Research Article

Soil moisture levels affect growth, flower production and yield of cucumber

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Abstract

Field trial to determine the optimum soil moisture level for enhanced performance of cucumber was conducted in polyethylene covered rain shelter for two seasons in 2017 and repeated in 2018. The research was conducted at Rongo University Research and Teaching field. Three seeds of cucumber 'Ashley' were sown directly in 3.5 litre plastic pots containing 8 kg of sterilised air-dried growth medium made up of sand and top soil in the ratio of 1:2. The treatments were four levels of water applied at 100% (control), 80%, 60% and 40% pot capacity. The experimental design was completely randomised block design replicated three times. Data on the plant growth, flower production and yield were subjected to Analysis of Variance (ANOVA) and mean separation tests at $p \leq 0.05$ level of significance. There were significant differences on the vine growth, internodes length and diameter as a result of Water Stress (WS) levels. The treatments also significantly affected the Relative Leaf Water Content (RLWC) and Relative Leaf Expansion Rate (RLER) but did not affect the number of leaves per vine. Fruit firmness was also affected by water stress. To optimise the productivity of cucumber, the soil moisture level should be maintained to at least 80% of the field capacity throughout its productive phase.

Keywords: cucumber; pot capacity; relative leaf expansion rate; relative leaf water content; total soluble solids; water stress

INTRODUCTION

Cucumber is one of the ten most important vegetable crops grown in the world. Cucumber is highly nutritious with carbohydrates 3.63 g, fats 0.11 g, proteins 0.65 g, sugars 1.67, diet fibre 0.5 g, vitamin C 2.8 mg 5%, calcium 16 mg 2%, iron 0.28 mg 2% (USDA, 2004). Cucumber (*Cucumis sativus* L.) is a plant sensitive to water stress. The ideal conditions for cucumber growth include high and nearly constant soil matric potential, high soil oxygen diffusion rate, adequate incoming radiation, and optimal soil nutrients (Eliades, 1988). Irrigation experiments have shown that cucumber is sensitive to moisture stress because it has a sparse root system. Approximately 85% of the root length is concentrated in the upper 0.3 m soil layer (Randall and Locascio, 1988).

Cucumber production is affected by a number of factors including water. The onset of stress may initially cause a loss of cell turgor which in turn reduces gas exchange and leaf elongation since all are turgor-dependent processes. Kirnak et al. (2001) observed a reduced dry matter and chlorophyll content in eggplants under high water stress. These results are in agreement with the findings of Chartzoulakis et al. (1993). Kirnak et al. (2001) also observed reduced fruit yields of eggplants in water stressed plants. A number of other works have reported fruit yield reductions for a range of horticultural crops such as tomato (Rudich et al., 1977; Tan, 1988), peach (Tan and Buttery, 1982) and strawberry (Kirnak et al., 2001). Yesim and Yuksel (2003), found consistently increased watermelon fruit yield with the increase in water application for the total growing season. The highest watermelon yields were obtained when the irrigations were daily (Erdem et al., 2001). The results showed that the majority of the yield decreases occurred when the plants were subjected to deficit irrigation up to flowering period. However, fruit yields of plants subjected to water stress during the early and late vegetative period were not affected. On the other hand, the total sugar content was considerably decreased when water deficit was applied only up to the flowering period (Yesim and Yuksel, 2003).

Water stress often results in reduced vegetative and reproductive growth, photosynthesis, transpiration, ion uptake and translocation by the plant. Drought stress before anthesis may delay flowering, reduce plant stature, and change sex expression (from female to male). Water stress at the fruit enlargement stage can reduce both yield and quality at harvest (Thomas and Staub, 1992). Under flooding conditions, plant roots receive decreasing amounts of oxygen, depending on the amount and severity of the stress episode. Thus, cucurbits held for extended periods near 100% of soil water saturation can become yellow, and stunted. Cucumbers produce aerial roots at the base of the plant or just above the water line when exposed to flooding conditions (Thomas and Staub, 1992).

In most plants drought causes reductions of leaf area, dry matter production, decline in plant water status and transpiration. In one study on tomato, water stress resulted in significant decreases in chlorophyll content, leaf relative water content (LRWC) and vegetative growth (Sibomana et al., 2013). The authors attributed the observed decrease in the plant growth and yield to the effects of water on the physiology of the crop such as the stomata aperture regulations. Soil water deficits have also been associated with reductions in lateral branching, leaf production, shoot height and rates of leaf and shoot expansion in both herbaceous and woody plants (Osorio et al., 1998; Ngugi et al., 2003; Luvaha et al., 2008). Generally, plants show increased root:shoot ratio under water deficit conditions. This is thought to be an adaptation for survival in drought areas since increased root surface area allows more water to be absorbed from the soil (Luvaha et al., 2008).

Effects of water deficit on plant growth and metabolism have been extensively reviewed. At the whole plant level, limited soil water supply may have a strong effect on development, activity and duration of various sources and sink organs (Osorio et al., 1998). Under more prolonged water deficit, dehydration of plant tissue can result in an increase in oxidative stress which causes deterioration in chloroplast structure and an associated loss of chlorophyll. This leads to a decrease in the photosynthetic activity (Jafar et al., 2004) and reduction in total chlorophyll content compared to well-watered plants (Kirnak et al., 2001; Cengiz et al., 2006, Sibomana, et al., 2013). This research therefore aims at testing whether soil moisture levels have any significant effect on the growth and yield of the crop.

MATERIALS AND METHODS

Study site and the treatments

Research on the growth, yield and quality of cucumber under different water levels was carried out at Rongo University, Research and Teaching field from July to October 2017 and repeated from October 2017 to January 2018. Three seeds of cucumber 'Ashley' were directly sown in 3.5 litre plastic pots containing 8 kg autoclaved sterile air-dried growth medium composted from sand and top soil in the ratio of 1:2, respectively. The growth medium was autoclaved at 128 °C for two hours and allowed to cool for 14 days in gunny bags to allow it regain its regeneration characteristics. All treatments were replicated three times under completely randomised block design. Plants were thinned two weeks after planting to one plant per pot and grown to maturity. Six pots with one plant each were used per treatment giving a total of 24 plants equally spaced at 1.8 m × 0.3 m (equivalent to a total of 18,529 plants/ha). The pots were covered with black plastic mulch to exclude light and prevent water evaporation.

Known amounts of water were poured into a pot and the drain collected at the bottom. The differences in the water volume were the water retained in the pot at field capacity (the pot capacity). The water applied at stress levels were calculated based on the pot capacity. Therefore, each pot received four levels, 100% pot capacity, 80% of pot capacity, 60% of pot capacity and 40% of pot capacity. Control plants were irrigated to pot capacity which was equivalent to field capacity (100% PC). Soil water potentials were monitored using a tensiometer at 15 cm depth of the pot. Pots were watered as soon as water potential reached −10 kPa to field capacity. Before initiation of the treatment, all plants were irrigated to pot capacity for one week in order to improve root development.

Data collection and analysis

Growth parameters

Plant vine length was measured on weekly basis starting from the third week after seedling emergence to the final harvest. In order to determine the influence of water deficit on the leaf growth, two plants per treatment were randomly selected. The area of each leaf was measured with a portable leaf area meter on weekly basis up to the start of harvesting. The resulting total leaf area was used to calculate LAI using the formula: LAI = Total leaf area (cm^2)/ground area (cm^2) (Beedle, 1987).

The relative leaf expansion rate (RLER) was then computed using the formula:

$$RLER = LA_2 - LA_1/LA_2/T_2 - T_1$$

where:
LA_1, LA_2... the initial and final leaf areas
T_1, T_2 .... the time of the two measurements

Data on the number of days to flowering and days to fruit maturity were also collected. The number of leaves on the main vine, stem diameter, number of nodes and internodes length on each vine was measured at the start of harvesting.

Transpiration was obtained by use of a porometer on a weekly basis starting from the fourth week up to the start of harvesting. Evaporation from the pots was negligible since they were covered with polyethylene.

Leaf relative water content: The method of measuring Leaf Relative Water Content (LRWC) was adopted from Yamasaki and Dillenburg (1999) and the results computed using the formula:

$$LRWC\% = \left[\frac{(FM - DM)}{(TM - DM)}\right] * 100$$

where:
FM ... the fresh mass of the leaves obtained at harvest,
TM... the turgid mass obtained by floating the leaves in distilled water inside a closed Petri dish.
DM .. the dry mass of the leaves obtained by placing leaf samples in a pre-heated oven at 65 °C for 48 h.

Yield parameters: Fruits were harvested from the three plants per replicate per week and their number and weight recorded. Fruit diameter and fruit length were also measured from five randomly selected fruits from each treatment.

Data analysis: All data collected were subjected to analysis of variance using SAS 2002 and significant means were then separated by Duncan's multiple range tests at $p \leq 0.05$.

RESULTS

Effects of water stress on selected growth parameters of cucumber

Vine length and internodes growth

Because there were no discernable differences in vine length between the two trials, the data were pooled as presented in Table 1. At 77 d after planting the vine length of cucumber plants subjected to the highest water stress (40% PC) were reduced by 20% compared to the control (Table 1). Water stress also resulted in thinner vines with longer internode lengths. For

Table 1. Effects of water stress levels on cucumber vine length (cm)

Water stress %(pot capacity)	Days after planting					
	21	28	35	42	49	77
40	10.1	15.9b*	22.8c	36.8d	54.0d	126.2d
60	10.2	17.6ab	27.4b	45.1c	64.2c	137.0c
80	10.0	19.3a	34.5a	55.9b	77.4b	148.1b
100	11.3	19.7a	35.1a	62.9a	86.3a	157.6a

*Means followed by same letter or no letter, within columns are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.005$

Table 2. Effects of water stress levels on selected parameters of cucumber vine

Water stress (% Pot Capacity)	No. internodes per vine	Internode length (cm)	Internode diameter (cm)
40	37.6a*	5.2b	0.6c
60	37.4ab	5.4b	0.76b
80	37.0ab	5.9a	0.78ab
100	36.5b	6.1a	0.80a

*Means followed by same letter or no letter, within columns are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.005$

Table 3. Effect of water stress on cucumber leaf growth

Water stress (% Pot capacity)	No. leaves per vine	Leaf area (cm)	Leaf area index	RLWC	RLER
40	36.5b*	368.6b	6.6c	58.7b	0.028c
60	37.0ab	373.9b	6.7c	60.2b	0.028c
80	37.4ab	423.2a	7.4a	66.9a	0.032b
100	37.7a	429.9a	7.5a	68.5a	0.037a

*Means followed by same letter or no letter, within columns are not significantly different according to Duncan's Multiple Range Test at p ≤ 0.005

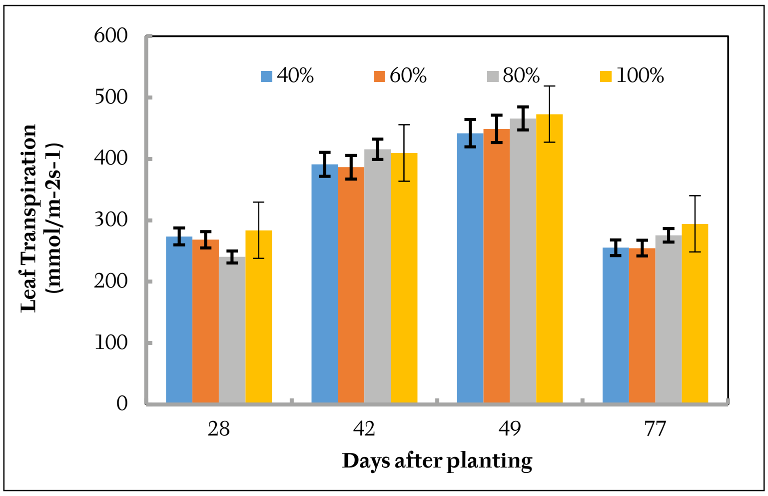

Figure 1. Influence of water stress on leaf transpiration of cucumber

Table 4. Water stress affects male/female flower ratios in cucumber

	Days after sowing										
WS[y]	49		56			63			70		
	MF[k]	FF	MF	FF	M/F	MF	FF	M/F	MF	FF	M/F
40	1.5d	0	14.2b*	7.4a	1.9bc	30.0	11.4b	2.6a	32.9ab	16.0c	2.0a
60	2.0c	0	13.7b	6.2b	2.3a	29.6	13.3a	2.2b	31.9b	18.0b	1.7b
80	2.6a	0	14.5ab	7.6a	1.8c	28.9	13.3a	2.2b	33.6a	19.9a	1.6bc
100	2.3b	0	15.2a	6.9ab	2.2ab	29.6	13.3a	2.2b	32.2b	20.8a	1.5c

*Means followed by same letter or no letter, within columns water are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.005$
[y]WS –Water stress (% pot capacity)
[k]MF; Male flowers: FF; Female flowers: M/F; Male female ratio

example, vines from the plants subjected to 40% water stress had reduced internodes lengths and diameter by 17.3% and 18.8%, respectively, compared to the control (Table 2).

Cucumber leaf growth parameters

Increased water stress reduced the number of leaves per vine, with plants subjected to 40% water stress having the least number of leaves. Leaf area and leaf area indices were also significantly reduced by high levels of water stress (Table 3). The highest water stress (40% PC) reduced RLWC and RLER by 14.3% and 24.3%, respectively, compared to the control.

Transpiration

Water stress levels had significant effect on the leaf transpiration (Figure 1). There was a remarkable increase in leaf transpiration up to the 49th day after planting. Low transpiration rates (mmol m^{-2} s^{-1}) were also observed at high water stress levels (40% and 60% water stress) compared to the control.

Cucumber male and female flowers

Increase in water stress reduced the days to which cucumber produced its first flowers. The cucumber plants subjected to maximum water stress (40%) produced fully opened flowers two days earlier than

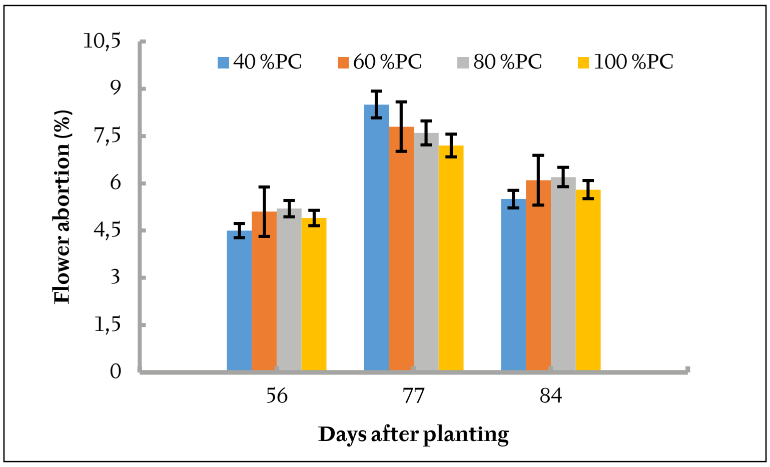

Figure 2. Influence of water stress on flower abortion (%) at different maturity stages

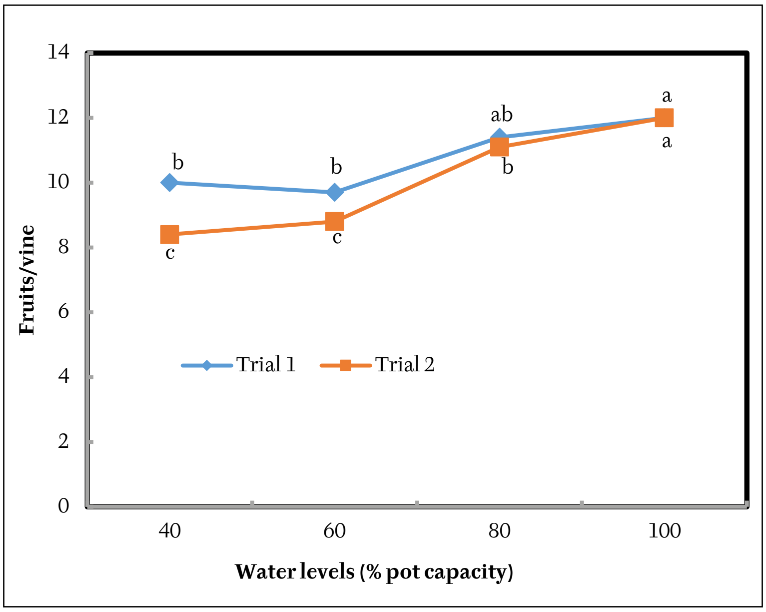

Figure 3. Effect of water stress on the number of fruits per main vine of cucumber

those continuously supplied with water (100% PC). The number of male flowers increased steadily and then declined on day 56. High levels of water stress reduced the number of female flowers thus increasing the male/female ratio (Table 4).

Effects of water stress on selected yield parameters of watermelon

Flower abortion

Water stress levels increased the number of flower aborted (Figure 2). A high number of abortions was exhibited at maximum water stress (40%) compared to the control. Flower abortions increased with plant maturity and reached a maximum at 77 d after planting before starting to reduce

Yield parameters

There was a remarkable reduction in average fruit weight with increase in water stress. Cucumber plants were maintained with less than 60% of the control (100% PC) had the lowest number of fruits/vine in both seasons. Plants from the control plots (100% PC) had significantly higher (16.7% and 39.7%) fruits/vine in the first and second trial, respectively (Figure 3).

Average yield per plant, fruit length and diameter

Increased water stress reduced the cucumber fruit length and diameter compared to control. Maximum

Table 5. Water stress affects length and diameter of cucumber fruit

WS (%PC)	Fruit length (cm)		Fruit diameter (cm)	
	Trial 1	Trial 2	Trial 1	Trial 2
40	15.8c*	14.4b	3.9b	3.5c
60	17.3a	14.9b	3.9b	3.8b
80	16.7b	16.8a	4.2a	4.1a
100	17.4a	17.5a	4.1a	4.3a

*Means followed by same letter or no letter, within a columns are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.005$

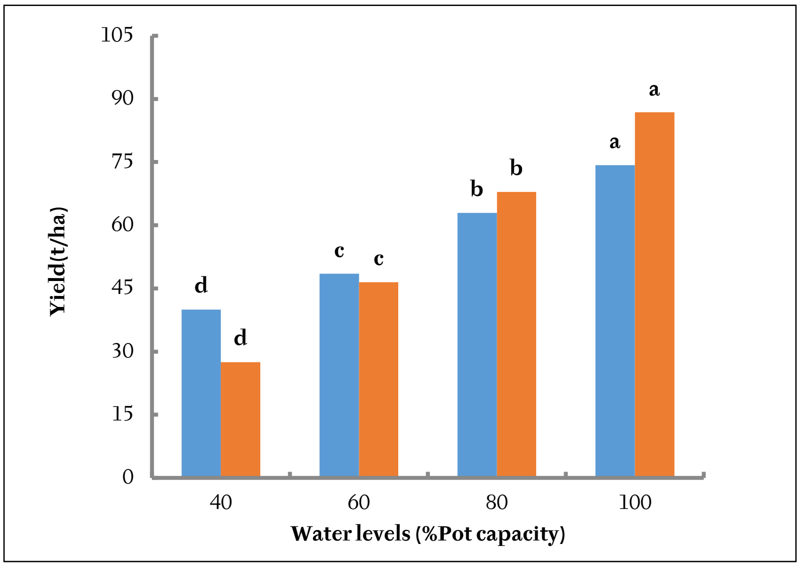

Figure 4. Effect of water stress on the yield (t/ha) of cucumber

water stress reduced fruit length by 10.1% and 17.6% in the 1st and 2nd trials, respectively. Fruits harvested from water-stressed plots had smaller diameters compared to the control in both trials. Slightly larger fruits were observed where cucumbers were subjected to more than 80% pot capacity (Table 5). The lowest yield of 0.78 kg of fruits per plant were obtained from the plants that were subjected to 40% PC of soil moisture. Plants subjected to soil moisture at field capacity had significantly higher yield of 2.48 kg/per (Table 5).

Total yield per hectare

Cucumber yield reduced with the increase in water stress. In both trials, the lowest yield was obtained in the most stressed plants compared to the control. The highest fruit yield of between 74 and 87 t/ha was observed in plants subjected to 100% PC. Yield of the plants subjected to the highest water stress (40% PC) was less by between 46 to 68% compared to the control. The lowest yield of 27 t/ha was observed in the second trial (Figure 4).

DISCUSSION

Water stress affects the physiological functions of plants. In this research, water stress reduced the ultimate vine growth throughout the growing period. The reduced cucumber shoot growth under water stress conditions could be due to reduced turgor which affected cell division and expansion. Although cell division has been reported to be less sensitive to water deficit than cell expansion or enlargement, Luvaha et al. (2008) reported that severe water deficit reduced stem elongation in mango seedlings, in our case cucumber internodes and ultimate plant height was affected.

Relative leaf expansion rate (RLER) was reduced with increase in water stress. These results supports the findings of Kirnak et al. (2001) and Sibomana et al. (2013) who reported reduced growth and leaf expansion in eggplant and tomato, respectively, at low water applications rates. The decrease in growth observed in this research might be attributed to turgor loss in the earlier expanded cells of the plants. It is also possible that the growth inhibition observed in the stem internodes and leaves is a metabolically regulated adaptive mechanism that restricts development at low water potential as a result of osmotic adjustments. Earlier studies indicate that water deficit decreased the number of leaves, leaf area and leaf water content. Relative leaf water content (RLWC) in our research was reduced with increase in water stress. This is in agreement with Yuan et al. (2003) who reported that leaf blade water content responded directly to applied irrigation and soil water content.

Flower and fruit abortions were greatly affected by water stress. The environmental temperatures under which the plants were grown within the greenhouse were high (about 35 °C). This might have increased the flower drops, particularly in the stressed plants. Our finding supports the earlier finding by Sibomana et al. (2013) on tomato who reported a 22% abortion of flower in the most water stressed tomato plants. In this research, the number of flower buds that failed to form fruit premodia increased with a decrease in water levels (R^2 = 82%). The authors attributed the high percent abortion observed in severely stressed plants to a possible decrease in the number of ovules per floret as water stress increases. Yield of cucumber plants under high water stress was substantially reduced. The research confirms the hypothesis that soil moisture level affects the growth and yield of cucumber.

CONCLUSION

The growth and yield of cucumber are affected by the amount of moisture in the soil by significantly reducing leaf area, shoot height, chlorophyll concentration and flower formation of the plant. Plants subjected to high water stress (40% field capacity and below) had a reduced number of female flowers, the highest level of flower abortion and a reduced yield. The highest yield of between 74 t/ha to 87 t/ha was observed in the plants subjected to soil moisture level of 100% field capacity. From the results, it can be concluded that soil moisture levels affect the growth and yield of the crop. To optimise the productivity of cucumber, the soil moisture level should be maintained to at least 80% of the field capacity throughout its productive phase.

CONFLICT OF INTEREST

The authors declared no conflicts of interest with respect to research, authorship and publication of this article.

ETHICAL COMPLIANCE

The authors have followed the ethical standards in conducting the research and preparing the manuscript.

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