EFFECT OF WATER DEFICIT CONDITIONS ON GROWTH AND YIELD OF MAIZE VARIETIES

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ABSTRACT

Drought stress is an abiotic factor affecting maize production. This study was conducted to examine if the growth and development of four maize varieties would be affected by the different water deficit conditions under the vinyl house condition. The experiment was designed using a randomized complete block design (RCBD). The water deficit conditions with four levels were 30% w/w as the control, 25% w/w, 20% w/w and 15% w/w. The maize varieties were CP111, LCH9, NK7328 and NK4300. The results showed that regardless of maize varieties, the reduction of soil water content caused to suppressing maize growth, which led to a decrease of grain yield of maize varieties. The best plant performance was observed in the treatment of 30% w/w of soil moisture content (as control condition), which followed by treatment of 25% w/w of soil moisture content. The lowest growth traits, physiological traits (leaf area, shoot dry weight), yield components, grain yield of maize were observed in plants treated by 15% w/w of soil moisture content (drought stress condition). In particular, NK4300 showed significantly higher physiological traits and grain yield than those of other varities under control condition (30% w/w). However, under drought stress conditions (25% to 15% w/w), LCH9 and NK7328 showed significantly higher physiological traits and grain yield than those of NK430. This result suggests that water deficit condition effect on growth and development of four maize varieties, but the extent of effect of water deficit condition on growth and yield of corn depends on the different maize varieties.

Keywords*: Water deficit condition, maize, growth, yield.*

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1. INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereals broadly adapted worldwide. In Vietnam, it is the second staple food crop after paddy rice. Among cereal crops, maize is an important food crop grown for human consumption, livestock feed, and industrial raw materials. It is estimated that from 2011 to 2050, the demand for maize in developing countries will be doubled, and by 2025 it will become the crop with the highest production demand globally [1].

Rapid global climate change leads to frequent extreme weather events, uneven precipitation, droughts, and foods, resulting in reduced crop yields. Drought stress due to water deficit is considered an important constraint to maize production as it can greatly affect growth and development stages of maize, especially flowering and grain filling, leading the reduced yield of grain [2]. The result of field experiment data published between 1980 and 2015 showed that drought reduced wheat and maize yields by 20.6% and 39.3%, respectively [3], so proper water management is critical to maize growth.

Adapting to such climatic changes is critical for ensuring national food security and economic stability. One such adaptation strategy has been the development of drought-tolerant maize varieties [4]. Drought tolerant in maize could be defined as an ability to maintain stable yield or greater performance under drought condition [5]. However, information is lacking on the performance and variability of drought-tolerant maize variety. Thus, this study was conducted to examine if the growth and development of four maize varieties would be affected by the different water deficit conditions. Based on the evaluation, the best performing drought - tolerant maize varieties would be selected

2. MATERIALS AND METHODS

The pot experiment was conducted at the vinyl house of the Faculty of Agronomy, Vietnam National University of Agriculture during the winter cropping season of 2020. The two - factor experiment was designed using a randomized complete block design (RCBD) with ten replications. The first factor was the water deficit conditions with four levels: 30% w/w as the control, 25% w/w, 20% w/w, and 15% w/w, which were used following the methods of [6]. The water deficit conditions were set up from 15 days after sowing (DAS) until the harvest. Each pot was weighed daily and the amount of water lost was replenished. The second factor was four maize varieties as CP111, LCH9, NK7328 and NK4300, which were drought tolerant maize hybrids (Table 1). All of four maize varieties had the same growth stage and are widely grown in Northern Vietnam.

Tabe 1. Origin and agronomic traits of four maize varieties

Varieties	Origin	Agronomic traits
CP - 111	Maize Research Institute	Drought tolerant maize hybrids, average grain yield: 12 - 15 ton ha^{-1}, growth stage: 95 - 110 days
LCH - 9	Maize Research Institute	Drought tolerant maize hybrids, average grain yield: 8 - 10 ton ha^{-1}, growth stage: 90 - 120 days
NK7328	Syngenta	Drought tolerant maize hybrids, average grain yield: 10 - 12 ton ha^{-1}, growth stage: 105 - 115 days
NK4300	Syngenta	Drought tolerant maize hybrids, average grain yield: 8 - 12 ton ha^{-1}, growth stage: 105 - 115 days

Three pre-germinated seeds were grown in plastic pots (30 cm in height and 35 cm in diameter) filled with 15 kg of air-dried soil. The seedlings were thinned to one seedling per pot at 7 DAS. The amount of fertilizer was calculated and applied for each pot with a base of 120 kg N + 100 kg P_2O_5 + 60 kg K_2O ha^{-1}. Whole phosphate amounts were well-mixed with the soil as a basal application before sowing. Nitrogen and potassium were split equally into three applications at sowing, 3 - 4 full leaves stage and 7 - 9 full leaves stage.

The growth traits including plant height (cm), number of leaves were measured at three stages (7 - 9 leaves, jointing and harvest). The number of leaves were counted from the first true leaf to the final leaf. The leaf area (LA) was determined at the tasseling stage using three-plant samples for each treatment, which calculated by the length × the maximum with × 0.75 × the total number of leaves. At the harvest, the shoots were cut from the base and oven- dried at 80°C for 48 h for determining the shoot dry weight. The yield components including number of kernels per ear, 1000 kernels weight, and grain yield per plant were collected.

The statistical analyses were done using Minitab 16. The data were subjected to ANOVA to detect effects of treatments and their interactions. Treatment mean comparison were subjected to Tukey HSD at 5% probability level.

3. RESULTS AND DISCUSSION

3.1. Plant height and leaves number of four maize varieties as affected by water deficit conditions

Table 2 shows that growth indicators including plant height and leaf number increased over the time and reached the highest values at the harvest stage. Maize varieties differed significantly in terms of plant height and leaf number ($p < 0.05$), except leaf number at the stage of 7 - 9 leaves stage. LCH9 and NK7328 varieties gave higher plant height at the jointing stage and harvest stage. NK7328 showed the maximum leaf number at the last two measured stages. In general, NK7328 gave the best performance in terms of growth indicators compared to the other varieties (Table 2).

Table 2. Effect of water deficit conditions on plant height and number of leaves of four maize varieties

Treatments	Plant height (cm)			Number of leaves		
	7 - 9 leaves stage	Jointing stage	Harvest	7 - 9 leaves stage	Jointing stage	Harvest
Varieties						
CP111	93.5^{a}	151.8^{a}	170.4^{a}	8.5^{a}	14.8^{c}	18.7^{a}
LCH9	93.0^{a}	155.2^{b}	176.3^{b}	8.4^{a}	14.4^{b}	18.8^{ab}
NK7328	92.9^{a}	153.1^{ab}	175.7^{b}	8.3^{a}	14.8^{c}	19.4^{c}
NK4300	93.9^{a}	151.2^{a}	169.0^{a}	8.5^{a}	14.0^{a}	19.2^{bc}
Water deficit conditions						
30% w/w	93.5^{a}	174.0^{d}	199.2^{d}	8.5^{a}	14.5^{d}	19.9^{c}
25% w/w	93.2^{a}	168.9^{c}	192.8^{c}	8.5^{a}	14.9^{c}	19.4^{b}
20% w/w	93.5^{a}	146.5^{b}	169.6^{b}	8.3^{a}	14.2^{b}	18.5^{a}
15% w/w	92.9^{a}	123.1^{a}	141.4^{a}	8.3^{a}	13.4^{aty}	18.3^{a}

Note: Values followed by the same letter in a column are not significantly different at the 5% level.

There was no significant difference of plant growth indicators under water deficit conditions at the stage of 7 - 9 leaves. However, at the jointing stage and harvested stage, plant height was significantly influenced ($p < 0.05$) by water deficit conditions. The height of maize decreased significantly with decreasing soil moisture content from 30% w/w to 15% w/w of soil moisture content. The same trend was recorded in terms of leaf number, when the lowest value was observed under 15% w/w of soil moisture content. The result also showed that the drought stress of 20% w/w and 15% w/w of soil moisture contents gave the lowest leaf number and no difference was found between these two treatments. Sah *et al.* (2020) [7] also showed that water stress occurring during the vegetative and flowering stages reduce plant height and leaf number, leading to reduce grain yield of maize.

Table 3. Table 3. Interacting effect of water deficit conditions and varieties on plant height and number of leaves of maize

Treatments		Plant height (cm)			Number of leaves		
		7 - 9 leaves stage	Jointing stage	Harvest	7 - 9 leaves stage	Jointing stage	Harvest
Varieties	Water deficit conditions						
30% w/w	CP111	93.6^{abc}	182.1^{k}	201.6^{j}	8.4^{a}	16.4^{h}	19.2^{de}
	LCH9	93.0^{ab}	179.5^{jk}	202.0^{j}	8.4^{a}	14.8^{ef}	19.2^{de}
	NK7328	92.6^{ab}	174.0^{i}	199.2^{j}	8.4^{a}	15.6^{g}	20.4^{fg}
	NK4300	94.8^{c}	177.1^{ij}	198.4^{j}	8.6^{a}	15.0^{efg}	20.6^{g}
25% w/w	CP111	93.6^{abc}	159.6^{g}	183.2^{h}	8.6^{a}	15.2^{fg}	18.8^{bcd}
	LCH9	93.0^{ab}	162.1^{g}	188.4^{i}	8.4^{a}	14.4^{cde}	19.0^{cd}
	NK7328	92.8^{ab}	168.9^{h}	192.8^{i}	8.4^{a}	15.2^{fg}	19.8^{ef}
	NK4300	93.6^{abc}	168.1^{h}	189.4^{i}	8.6^{a}	14.8^{ef}	20.2^{fg}
20% w/w	CP111	93.6^{abc}	144.2^{d}	163.0^{e}	8.2^{a}	14.0^{bcd}	18.6^{abcd}
	LCH9	92.8^{ab}	152.3^{f}	177.2^{g}	8.4^{a}	14.6^{def}	18.4^{abc}
	NK7328	94.0^{bc}	146.5^{de}	169.6^{f}	8.2^{a}	14.6^{def}	18.6^{abcd}
	NK4300	93.6^{abc}	139.5^{c}	156.6^{d}	8.4^{a}	13.4^{b}	18.2^{ab}
15% w/w	CP111	93.2^{ab}	121.4^{a}	134.0^{ab}	8.6^{a}	13.4^{b}	18.2^{ab}
	LCH9	92.6^{ab}	127.0^{b}	137.6^{bc}	8.2^{a}	13.8^{bc}	18.4^{abc}
	NK7328	92.2^{a}	123.1^{ab}	141.4^{c}	8.0^{a}	13.6^{b}	18.6^{abcd}
	NK4300	93.4^{abc}	120.4^{a}	131.7^{a}	8.2^{a}	12.6^{a}	18.0^{a}

Note: Values followed by the same letter in a column are not significantly different at the 5% level.

The result of ANOVA also indicated that there was a significant two-way interaction between the level of soil moisture contents and varieties on plant height and leaves number (Table 3), excepting leaf number at 7 - 9 leaves stage. Within the same variety, these two growth indicators reduced with the reduction of soil moisture contents at the all three measured stages. At the harvest stage, the plant height was not significantly different among varieties under control condition (30% w/w) but was significantly different under drought stress conditions (15% to 25% w/w). The plant height of NK7328 and LCH9 were significantly higher than that of NK4300 under drought stress conditions (15% to 25% w/w). In terms of leaf number, at the harvest stage, no difference was found between four varieties under 20% w/w and 15% w/w of soil moisture contents. Under 25% w/w of soil moisture content, NK4300 variety produced more leaves, which was at pair with NK7328 variety.

3.2. Leaf area and shoot dry matter of four maize varieties as affected by water deficit conditions

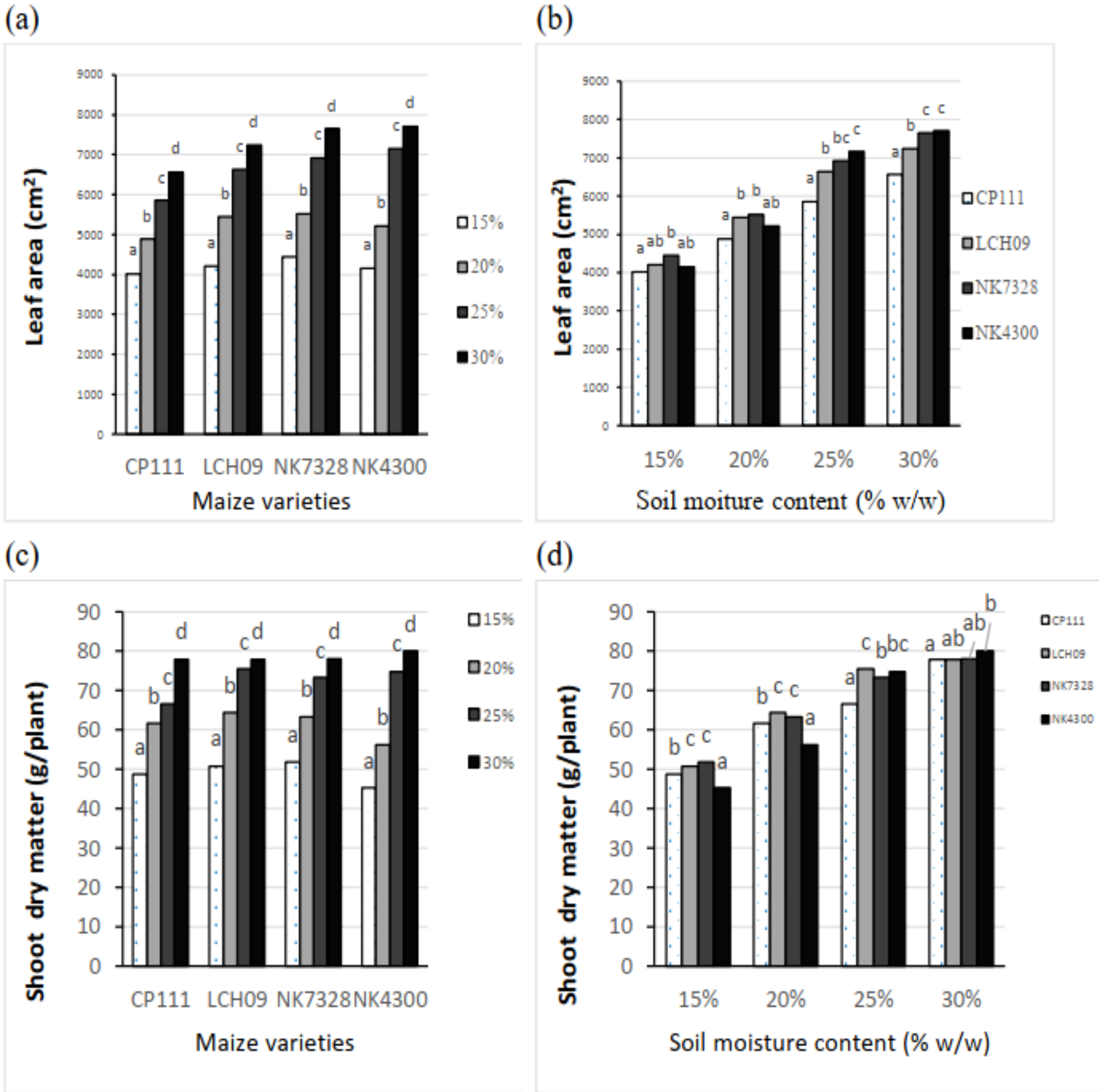

Figure. Effect of water deficit conditions on leaf area (a, b)
and shoot dry matter (c, d) of four maize varieties

Note: Columns with the same letter within each treatment are not significantly different the 5% level.

Leaf area and shoot dry weight significantly different under different maize varieties and water deficit contents [7 - 8] found that water stress occurring during the vegetative and tasseling stages reduced considerable shoot dry matter and leaf area index. In this study, there was the significant reduction of leaf area and shoot dry weight due to the decrease of soil moisture regardless of varieties. These two indicators were significantly higher under 30% w/w of soil moisture content compared to other treatments and lowest under 15% w/w of soil moisture content. It can be found that, CP111 variety showed the lowest leaf area in any cases of water deficit conditions. Interestingly, NK4300 variety gave highest leaf area under 25% and 30% w/w of soil moisture contents, however under 15% and 20% w/w of soil moisture contents, this variety produced lower leaf area, which indicated that NK4300 variety was more sensitive to drought condition. LCH9 and NK7328 varieties produced higher leaf area, even in the condition of 15% and 20% w/w of soil moisture contents.

Shoot dry weight of maize plants grown under the same water deficit condition varied dramatically between four selected varieties. LCH09 and NK7328 varieties produced significantly higher shoot dry weight compared to other varieties under 15% and 20% w/w of soil moisture contents. Under 25% w/w of soil moisture content, LCH09 also gave the highest shoot dry weight. Shoot dry weight of NK4300 variety was the highest under 30% w/w of soil moisture content, but under the reduction of soil moisture from 25% to 15% w/w of soil moisture content, this value significantly decreased compared to other varieties. It can be suggested that LCH09 and NK7328 varieties was able to adapt well to the drought stress condition.

3.3. Root traits of four maize varieties as affected by water deficit conditions

Table 4. Effect of water deficit conditions on root traits of four maize varieties

Treatments	Number of primary roots	Primary root length (cm/plant)	Root dry weight (g/plant)
Varieties			
CP111	35.0[c]	78.7[b]	19.7[b]
LCH9	32.8[b]	81.6[c]	20.3[c]
NK7328	29.8[a]	82.3[c]	20.4[c]
NK4300	29.9[a]	74.5[a]	18.1[a]
Water deficit conditions			
30% w/w	37.3[c]	92.6[c]	24.4[c]
25% w/w	32.2[b]	85.1[b]	21.4[b]
20% w/w	30.0[b]	71.3[a]	18.8[b]
15% w/w	26.6[a]	68.1[a]	14.0[a]

Note: Values followed by the same letter in a column are not significantly different at the 5% level.

Table 4 illustrates the effect of four levels of soil moisture contents and four maize varieties on root characteristics of maize. The results indicated that number of primary roots, primary root length and root dry weight differed significantly ($p < 0.05$) among the four soil water content treatments as well as four chosen varieties. CP111 produced the highest number of primary roots with 35.0 roots, meanwhile LCH9 and NK7328 had the significantly higher primary root length and root dry weight compared to other varieties. In terms of water deficit conditions, 30% w/w of soil moisture content was the best condition of soil moisture for maize plants, so this treatment gave the best values of all root characteristics. Reducing the soil moisture caused to the reduction of root traits of maize, which was lowest under the treatment of 15% w/w of soil moisture contents. Tran *el al.* (2017) [6] and Zhao J *el al.* (2018) [9] also showed that root traits as number of lateral root, lateral root length decreased remarkably under drought stress condition.

Table 5. Interacting effect of water deficit conditions and varieties on root traits of maize

Treatment		Number of primary roots	Primary root length (cm/plant)	Root dry weight (g/plant)
Varieties	Water deficit			
30% w/w	CP111	39.0^{j}	93.1^{f}	23.4^{fg}
	LCH9	37.3^{hij}	98.6^{g}	24.2^{fg}
	NK7328	36.0^{hi}	98.7^{g}	25.3^{g}
	NK4300	36.7^{hij}	79.8^{c}	24.6^{g}
25% w/w	CP111	37.3^{hij}	86.8^{de}	21.2^{de}
	LCH9	34.3^{gh}	82.0^{cd}	21.2^{de}
	NK7328	30.3^{ef}	88.3^{ef}	22.6^{ef}
	NK4300	32.0^{fg}	83.2^{cde}	20.7^{de}
20% w/w	CP111	32.3^{fg}	68.2^{a}	20.5^{d}
	LCH9	31.7^{ef}	74.4^{b}	19.9^{d}
	NK7328	29.3^{de}	73.9^{b}	19.5^{d}
	NK4300	26.7^{bc}	68.5^{ab}	15.1^{bc}
15% w/w	CP111	31.2^{ef}	66.8^{a}	13.6^{ab}
	LCH9	27.7^{cd}	71.3^{ab}	15.9^{c}
	NK7328	23.3^{a}	68.0^{a}	14.3^{bc}
	NK4300	24.3^{ab}	66.5^{a}	12.0^{a}

Note: Values followed by the same letter in a column are not significantly different at the 5% level.

The interaction of different varieties and water deficit conditions statistically differed the root traits of maize (Table 5). Each variety showed the decrease of number primary roots, primary root length and root dry weight under the reducing soil moisture contents. Under 30% w/w of soil moisture content, all varieties produced more primary roots with higher roots length compared to other treatments of water deficit conditions. It can be found that, CP111 and LCH9 had higher number of primary roots as compared to other varieties under the drought stress conditions (15% to 25% w/w). In addition, NK4300 showed longer primary root under 25% w/w and 20% w/w of soil moisture contents, whereas this indicator of LCH9 was higher under the treatments of 20% w/w and 15% w/w of soil moisture contents. In terms of root dry weight, under 30% or 25% w/w of soil moisture content, no statistical difference was found between four varieties. However, under 20% w/w of soil moisture content, CP111, LCH9, NK7328 varieties had significantly root dry weight compared to NK4300. Under 15% w/w of soil moisture content, LCH9 gave the highest root dry weight, which was at pair with NK7328. Generally, LCH9 and NK7328 was the two varieties with better performance of root traits under drought stress conditions.

3.4. Yield components of four maize varieties as affected by water deficit conditions

The results showed that there was a significant difference in the number of kernels per ear, weight of 1000 kernels and grain yield among four levels of soil water condition as well as different varieties (Table 6). LCH9 gave the highest number of kernels per ear, meanwhile CP111 gave the statistically higher weight of 1000 kernels compared to the rest varieties. LCH9 and NK7328 varieties gave significantly higher grain yield as compared to other chosen varieties. In addition, decrease soil moisture content caused to the dramatically reduction of yield component, causing to the lowest grain yield of maize under 15% w/w of soil moisture contents. This result was consistent with the report of [8], who showed that grain yield was significantly reduced by progressive drought during the growth stage. In addition, [7] also reported that an exposure of water deficit stress at flowering and grain filling stage brought severe negative effects on phenological and yield traits attributes of the maize.

Table 6. Effect of water deficit conditions on yield components and grain yield of four maize varieties

Treatments	Number of kernels per ear	1.000 kernels weight (g)	Grain yield (g/plant)
Varieties			
CP111	267.5^{a}	283.2^{c}	80.5^{a}
LCH9	306.6^{d}	262.2^{b}	86.5^{a}
NK7328	296.6^{c}	263.0^{b}	83.5^{a}
Nk4300	284.6^{b}	251.2^{a}	78.0^{a}
Water deficit conditions			
30% w/w	403.2^{d}	311.8^{d}	129.0^{d}
25% w/w	352.7^{c}	292.9^{c}	105.0^{c}
20% w/w	247.0^{b}	256.0^{b}	64.5^{b}
15% w/w	152.4^{a}	198.8^{a}	30.0^{a}

Note: Values followed by the same letter in a column are not significantly different at the 5% level.

Table 7. Interacting effect of water deficit conditions and varieties on yield components and grain yield of maize

Treatment		Number of kernels per ear	1000 kernels weight (g)	Grain yield (g/plant)
Varieties	WD			
30% w/w	CP111	384.0^{g}	321.3^{h}	126^{k}
	LCH9	411.0^{hi}	306.3^{g}	130^{lm}
	NK7328	401.7^{h}	311.1^{g}	128^{kl}
	NK4300	416.0^{i}	308.6^{g}	132^{m}
25% w/w	CP111	326.7^{e}	307.9^{g}	102^{h}
	LCH9	363.3^{f}	292.4^{f}	108^{j}
	NK7328	357.3^{f}	289.1^{ef}	106^{i}
	NK4300	363.3^{f}	282.1^{e}	104^{hi}
20% w/w	CP111	220.3^{c}	285.8^{ef}	64^{c}
	LCH9	276.0^{d}	260.3^{d}	74^{g}
	NK7328	264.0^{d}	252.8^{d}	68^{f}
	NK4300	227.7^{c}	225.3^{c}	52^{d}
15% w/w	CP111	139.0^{a}	217.8^{c}	30^{b}
	LCH9	176.0^{b}	189.9^{a}	34^{c}
	NK7328	163.3^{b}	199.1^{b}	32^{bc}
	NK4300	131.3^{a}	188.6^{a}	24^{a}

Note: Values followed by the same letter in a column are not significantly different at the 5% level.

There was statistical difference of yield component and grain yield of maize under the effect of interaction of different maize varieties and water deficit conditions (Table 7). Interestingly, CP111 variety contained the highest weight of 1000 kernels in any case of water deficit conditions. In terms of number of kernels per ear and grain yield, all varieties gave higher values under 30% w/w of soil moisture content. Therein, NK4300 and LCH9 varieties achieved the highest number of kernels per ear as well the maximum grain yield. Under the condition of 25% w/w of soil moisture content, LCH9, NK7328 and NK4300 produced significantly higher kernels per ear as compared to CP111, meanwhile under conditions of 20% w/w and 15% w/w of soil moisture content, this indicator was dramatically higher in LCH9 and NK7328 varieties. Under the conditions of water deficits (15 – 20 - 25% w/w), LCH9 and NK7328 varieties gained higher grain yield compared to other varieties. These suggested that LCH9 and NK7328 were the varieties adapted with the drought stress condition.

4. CONCLUSION

The results showed that regardless of maize varieties, the reduction of soil water content caused to suppressing maize growth, which led to a decrease of grain yield of maize varieties. The best plant performance was observed in the treatment of 30% w/w of soil moisture content (as control condition), which followed by treatment of 25% w/w of soil moisture content. The lowest growth traits, physiological traits (leaf area, shoot dry weight), yield components, grain yield of maize were observed in plants treated by 15% w/w of soil moisture content (drought stress condition). In particular, NK4300 showed significantly higher physiological traits and grain yield than those of other varities under control condition (30% w/w). However, under drought stress conditions (25% to 15% w/w) LCH9 and NK7328 showed significantly higher physiological traits and grain yield than those of NK430. This result suggests that water deficit condition effect on growth and development of four maize varieties, but the extent of effect of water deficit condition on growth and yield of corn depends on the different corn varieties.

REFERENCES

1. CIMMYT (2011). Maize global alliance for Improving food security and the livelihoods of the resource - poor in the developing world". Proposal submitted by CIMMYT and IITA to the CGIAR Consortium Board. 1 June 2011.

2. Lobell D. B., Roberts M. J., Schlenker W., Braun N., Little B. B., Rejesus R. M. and Hammer G. L. (2014). Greater sensitivity to drought accompanies maize yield increase in the U.S. Midwest. *Science,* 344 - 519.

3. Daryanto S., Wang L., Jacinthe P.A. (2016). Global synthesis of drought effects on maize and wheat production. PLoS ONE , 11, e0156362.

4. Habte E., Marenya P., Beyene F., Bekele A. (2022). Reducing susceptibility to drought under growing conditions as set by farmers: The impact of new generation drought tolerant maize varieties in Uganda. *Frontiers in Sustainable Food Systems* Vol 6.

5. Blum A. (2009). Effective use of water (EUW) and not water-use ef ciency (WUE) is the target of crop yield improvement under drought stress. Field Crops Research, 112, 119 - 123.

6. Tran T. T. & Akira Y. (2017). Nitrogen applicaiton levels affect root system development of rice under water deficit conditions. Vietnam *J.Agri.Sci.*, vol. 15, no. 3: 181 - 188.

7. Sah R. P., Chakraborty M., Prasad K., Pandit M., Tudu V. K., Chakravarty M. K., Narayan S. C, Rana M, Moharana D. (2020). Impact of water deficit stress in maize: Phenology and yield components. Scientific reports 10: 2944.

8. Song L., Jin J. and He J. (2019). Effects of severe water stress on maize growth processes in the field. *Journal of sustainability,* 5086. doi:10.3390/su11185086.

9. Zhao J., Xue Q., Jessup K. E., Hou X., Hao B., Marek T. H., Xu W., Evett S. R., Shaughnessy S.A.O, Brauer D. K. (2018). Shoot and root traits in drought tolerant.