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Effects of Water Stress on the Agromorphological Parameters of Two New Maize (*Zea mays* L.) Lines (L36 and L71) Obtained from the Variety EV8728

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Abstract

Maize (*Zea mays* L.) or Indian wheat is the most cultivated cereal in the world and the first in terms of quantity before wheat. Its cultivation is confronted with the climate change which causes drought, and this last one reduces considerably its production. The objective of this experiment is to select maize (*Zea mays* L.) varieties resistant to water stress using gamma irradiation. Its aim is to characterize agromorphologically two maize lines derived from the gamma irradiated variety EV8728. This study took place in Daloa (Ivory Coast). The plant material consisted of maize plants obtained by self-fertilization after five cycles from seeds of the variety EV8728 irradiated

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with gamma rays at a dose of 300 grays. Observations and measurements were made on the number and area of leaves, height and diameter of maize plants, male and female flowering parameters (date of panicle appearance, pollen grains, cob and silks) and number of spikelets, cob insertion height (CIE), panicle height and internode length. At the 58th das, the highest number of leaves (18.76) was observed in the plants of line 36 watered at capacity in field S0. On the other hand, the number of leaves (16.04) was lowest on the plants of the same line under severe stress (S2). Regardless of the type of stress applied, the plants of the control EV8728 always dominate, while the most stunted are those of the line L36. The date of panicle appearance (DAP) was early with the EV8728 control compared to the tested lines (L36 and L71), while the date of pollen appearance (DAGP) was about 4 d after the panicle was visible. Under moderate stress, a delay in flowering (anthesis) is observed in EV8728 and line L71 while there is no change in date for line L36.

Keywords: Maize, variety EV8728, water stress, line, gamma ray, Ivory Coast

Introduction

Cereals have been an important part of human nutrition since the first agricultural crops began (FAO, 2016). The world cereal production is 2791 Mt for the 2021 season (FAO, 2021). Maize (*Zea mays* L.) or Indian wheat is the most cultivated cereal in the world and the first in terms of quantity ahead of wheat (*Triticuma estivum* L. subsp. aestivum) according to Semassa and *al*, (2016). It is also the most energetic cereal (Charcosset and Gallais, 2009), due to its nutritional richness (in starch, presence of proteins, minerals) and the most economical from the production point of view (simple crop to produce, harvest and store) according to Nuss and Tanumihardjo, (2011). Its global production is 1091 Mt for the 2019-2020 period (Hénin, 2019). In sub-Saharan Africa, its production does not cover the demand. This creates a deficit that currently amounts to 23 Mt per year and should reach 35 Mt in 2025, according to the AfDB (2020). Ivory Coast ranks twentieth among maize-producing countries in Sub-Saharan Africa (OECD/FAO, 2015). Maize appears as a cash crop in the South, but production is mainly self-consumed in the North. This makes it one of the most widely used cereals in the family diet and in livestock production in the North. Its national production is estimated at 700,000 t/year and it is second only to rice (Ducroquet *and al.*, 2017).

However, despite the importance of cultivated areas, large quantities of maize are imported to meet the needs of consumers in West Africa, particularly in Ivory Coast, in livestock and industry. This situation is caused by numerous problems affecting maize production, including weeds, declining soil fertility, diseases and pests, poor farming practices and drought. This last

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constraint is becoming a growing concern for producers. It has been reported that drought affects several variables in plant physiology, such as leaf temperature regulation (Patel *and al*., 2001; Luquet *and al*., 2004), stomatal conductance and leaf area (Lowlor and Cornic, 2002), and photosynthesis (Yuan *and al*., 2004). A lack of water also causes a significant drop in crop yield (Fonseca *and* Westgate, 2005). Thus, several studies have been conducted to improve maize production (Goalbaye *and al*., 2014; Naitormmbaide *and al*., 2015; Diallo *and al*., 2016; Goalbaye *and al*., 2017).

In order to contribute to finding a sustainable solution to climate variability and induced fertility loss in response to low maize production, the IAEA-funded maize project initiated the research program on the creation of maize varieties adapted to the soil conditions of northern Ivory Coastsoils through induced mutation techniques. The aim of this study is to investigate the agromorphological characterization under water stress of maize plants derived from seeds of the gamma-irradiated variety EV8728.

Material and Methods

Study area

The study was carried out on the experimental site of the University Jean LorougnonGuédé (UJLoG) in Daloa, Ivory Coast, between 6°54 North latitude and 6°26 West longitude. This site has a humid tropical climate. There are four types of seasons. A large rainy season from April to mid-July, a small dry season from mid-July to mid-September, a small rainy season from mid-September to November, and a largely dry season from December to March (N'guessan *and al*., 2014). Average annual temperatures range from 24.65 to 27.75 °C. The annual rainfall which was 1868.5 mm in 1968, decreased to 1200 mm of water in 2008, a decrease of 40% (Ligban *and al*., 2009). The soil encountered is of the ferralitic type, highly or moderately altered (Dié, 2006). These ferralitic soils present good agricultural aptitudes and are suitable for all types of crops (Soro *and al*., 2015).

Plant material

The plant material consisted of seedlings of maize lines (L36 and L71) obtained after five cycles by self-fertilization from seeds of the variety EV8728 irradiated with gamma-ray at the dose of 300 grays in Seibersdorf, Austria. This variety EV8728 comes from the CNRA station of Korhogo whose characteristics are recorded in Table 1.

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Table 1. Some characteristics of the variety EV8728 (CNRA, 2006)

Variety name	Characteristics			
	Cycle time (days)	Color and texture	MainCharacteristics	Yield (t/year)
EV8728	105	yellow, toothed	Tolerance to stripeand root lodging	3-5

Methods

Experimental conditions

The experiment took place under a shelter covered with transparent plastic film. The dimensions were 16 m long, 12 m wide and 3 m high. It allowed controlling the water supply. During this trial, 270 PVC pots of 25 cm height and 22.5 cm diameter with a capacity of 10 liters were used. These pots were perforated at the base and covered with a thin layer of gravel to ensure water and air drainage.

Determination of the different water regimes

The different levels of water supply are referred to the determination of the field capacity (FC) of the soil (substrate used). For this purpose, 10 kg of growing mediumP1 (dry weight of soil) were potted. After watering the substrate to saturation, the pot-substrate system was covered with aluminum foil to prevent water evaporation. Every 24 h, the pots were weighed until a constant mass P2 (saturation weight) was obtained. The field capacity (FC) is calculated by the following formula:

$$FC = \frac{P2 - P1}{P1} \times 100$$

FC : Field capacity
P2 : Saturation weight
P1 : Dry weight of soil

Field capacity is variable depending on soil texture. Three treatments were selected :

- 100% FC (the field capacity) or the control
- 50% FC
- 25% FC

Experimental design

The essay was conducted in a split-plot design with three replications. Each replication was represented by a block subdivided into three sub-blocks. The main factor was water stress and the second was the lines tested. The sub-block contained ten (10) plants per line, i.e. 30 per treatment, with 270 pots. The spacing between the pots was 20 cm on the row and 20 cm between the

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rows. The distance between the two elementary blocks was 50 cm and the distance between the repetitions was 60 cm.

Substrate treatment and seeding

First of all, a substrate treatment with VYTAL 3G (Oxamyl 30 g/kg) against nematodes was performed, after a contribution of 3 g of NPK fertilizer formulation (15-15-15), 0.3 S + 4.5 MgO + 6.7 CaO per pot as a bottom fertilizer. Sowing was done with two seeds per pot. Two weeks after sowing, the plants were removed, leaving one plant per pot. A treatment with PYRICAL 5G (Chlorpyriphos-ethyl, 50 g/kg) against insects was made when they appeared. Urea (46%) was applied at the 4 leaf stage at a rate of 2 g/plant. Finally, on day 60, a cover fertilizer was applied.

Application of water stress

Before the application of different treatments (water regime), the device was watered every two days with the field capacity until the bolting stage, i.e. 30 days. Thus, from this date, the different water regimes (S0: 100% FC, S1: 50% FC, S2: 25% FC) were applied to each maize plant until the maturity of the ears on the plants.

Data collection

Number of leaves

The rate of leaf emission is determined by counting the number of leaves emitted every week until the male flower appears.

Stem height

Stem height is measured with a tape measure from the collar to the V formed by the last two leaves.

Diameter of the stem

The measurement of the diameter is made with a caliper during the culture.

Leaf area SF (cm^2)

The total leaf area (cm^2) per plant was determined weekly. It was determined by the method of Mokhtarpour *and al.,* (2010) which consists of taking the measurement of the length and width of the leaves, and then deducting the leaf area (LA) by the following formula:

$$SF = \Sigma\ i=1\ (L \times l \times 0.75)$$

SF: Total leaf area per plant, L: leaf length, l: large leaf width and i: leaf sequence number in the plant.

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Flowering parameters

The dates of appearance of male and female organs (panicle, pollen grains, spike, and silks) were determined by simple observation of 50% of flowering plants per line.

Spike insertion height

The measurement of the spike insertion height was done with a measuring tape from the collar to the base of the spike.

Length between nodes

The length between two nodes was taken using a carpenter's tape measure.

Statistical analysis

Data were submitted to analysis of variance (ANOVA) using STATISTICA 7.1 software. The means of the different parameters were separated by the Newman-Keuls multiple comparison test.

Results

Number of leaves emitted

Table 2 shows the influence of water stress on leaf emission. Under the non-stressed conditions, the highest number of leaves (12.09 leaves) is observed under the 50% CC regime and the lowest (09.69 leaves) under CC with line L36. There was no significant difference at the 5% threshold (p =0.17). After one week of stress (37 days), the control EV8728 was the line that produced more leaves under the moderate stress condition (14.29 leaves). The lowest average is shown with L36 under the same stress (11.67 leaves). There is a clear significant difference at the 5% threshold with p = 0.03. On the 44th day, the highest mean is recorded with the control EV8728 under the favorable S0 conditions (16.78 leaves), while the lowest (14.58 leaves) is identified in L36 when the stress becomes severe. Nevertheless, no significant difference is recorded (p = 0.32). At 51 days, the number of leaves is highest in line L71 (17.58 leaves) under normal condition S0 and the lowest with line L36 (15.09) under severe stress S2. There is a highly significant difference with p = 0.007. On the 58th day, the highest number of leaves (18.76) on the plants of line 36 was watered at the field capacity S0. On the other hand, the number of leaves is 16.04 is the lowest among the plants of the same line put under severe stress (S2). There is a very significant difference at the 5% threshold (p=0.0001).

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Table 2. Average number of leaves of maize plants under the effects of water

Treatments		30 DAS	37 DAS	44 DAS	51 DAS	58 DAS
	EV8728	11.87± 0.84^{a}	14.20 ±1.14^{bc}	16.18 ± 1.45^{a}	16.78 ± 1.44^{a}	17.00 ±1.43^{bc}
S0	L36	12.09 ± 1.12^{a}	14.29 ± 1.62^{c}	15.82 ± 1.89^{a}	16.91 ± 1.83^{a}	17.36 ± 1.90^{bcd}
	L71	11.51 ± 1.31^{a}	13.78 ±1.31^{bc}	15.33 ± 1.69^{a}	15.80 ± 1.24^{b}	16.16 ± 1.15^{a}
	EV8728	09.69± 1.12^{a}	12.27 ±1.45^{ab}	14.76 ± 1.85^{a}	17.44 ± 2.09^{a}	18.76 ± 1.52^{e}
S1	L36	09.76 ± 1.07^{a}	11.67 ± 2.11^{a}	13.78 ± 1.89^{a}	15.93 ± 1.76^{b}	17.60 ±1.32^{cd}
	L71	09.89 ± 1.23^{a}	12.36 ±1.43^{ab}	13.91 ± 1.55^{a}	15.09 ± 1.49^{b}	16.04 ± 1.17^{a}
	EV8728	10.14 ± 0.94^{a}	12.91 ± 1.29^{b}	15.35 ± 1.60^{a}	17.58 ± 1.56^{a}	18.65 ± 1.34^{e}
S2	L36	10.02 ± 1.27^{a}	12.40 ±1.07^{ab}	14.58 ± 1.53^{a}	16.73 ± 1.57^{a}	17.84 ± 1.36^{d}
	L71	09.79 ± 0.80^{a}	12.09 ±1.06^{ab}	13.86 ± 1.26^{a}	15.58 ± 1.20^{b}	16.72 ±1.39^{ab}
p		**0.17**	**0.03**	**0.32**	**0.007**	**0.0001**
F		**1.60**	**2.77**	**1.17**	**3.57**	**5.84**

DAS: days after sowing;S0, S1 and S2 (100%, 50%, 25% of field capacity respectively); mean values with the same letters in the same column are not significantly different (5% Newman-Keuls test).

Stem height

Figure 1 shows the results on corn plant height. Without the water stress, the control has the highest plants while the lowest are those of line L36. Regardless of the type of stress applied, the control EV8728 plants always dominate while the stunted ones are from line L36. However, the height of the plants of each line decreased significantly with the severity of the stress. There was a significant difference between the treatments (stress) and the control with p = 0.0000, between the lines tested and the control EV8728 where p = 0.0000. The stress-line interaction also shows us a clear significant difference (p = 0.0000).

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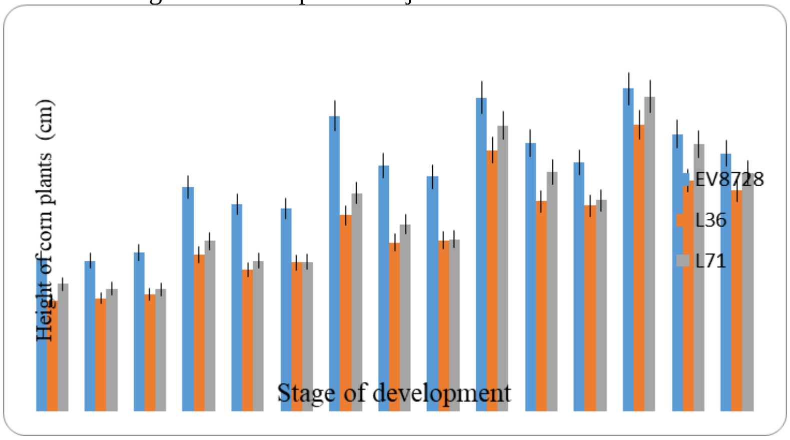
Figure 1. Stem heights of maize plants subjected to different water stress modalities

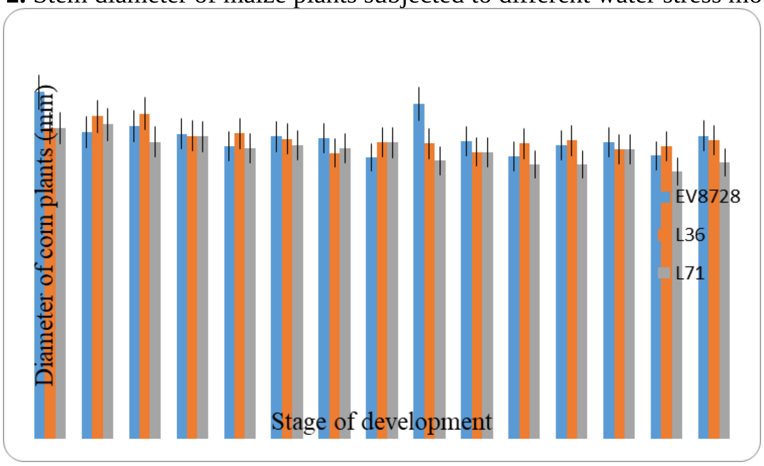


S0, S1 and S2 (respectively 100%, 50%, 25% of field capacity); EV8728: non-irradiated control; L36 and L71 (tested lines); DAS: day after sowing

Stem diameter

The effect of water stress on plant diameter is shown in Figure 2. Under normal conditions, the largest diameter is recorded with the control ranging from 17.01 ± 13.21 mm to 14.56 ± 2.80 mm. On the other hand, the smallest is observed with the L36 line ranging from 14.89 ± 3.54 mm to 14.07 mm. Under moderate stress, the thickest diameter is mentioned by line L36 with values ranging from 14.99 ± 2.98 to 14.34 ± 3.25 mm, while the thinnest is with line L71 (14.24 ± 2.95 to 13.11 ± 285 mm). With severe stress, the largest diameter is marked by L36 with 15.72 ± 4.04 mm decreasing to 14.48 ± 3.37 mm. The line L71 has the smallest diameter which decreased from 14.57 ± 2.66 mm to 13.45 ± 2.36 mm. However, the difference was not significant at the 5% level ($p > 005$).

Figure 2. Stem diameter of maize plants subjected to different water stress modalities



S0, S1 and S2 (100%, 50%, 25% of field capacity respectively); EV8728: non-irradiated control; L36 and L71 (lines tested); das: day after sowing

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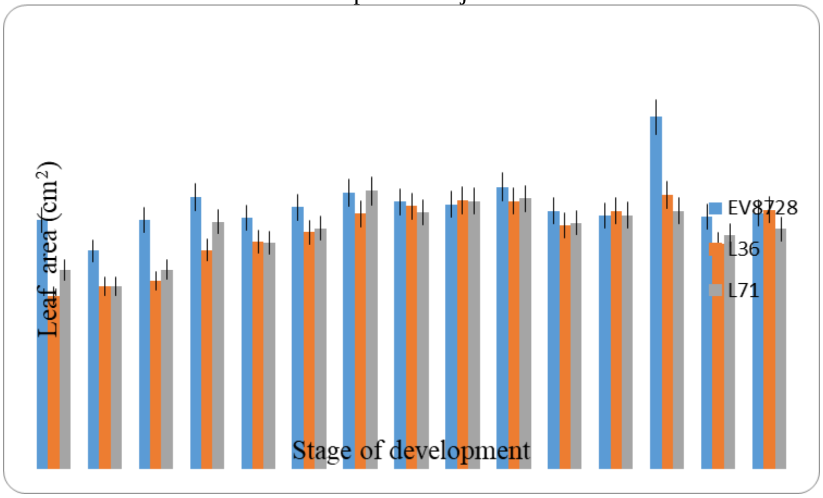
Leaf area

Figure 3 shows the change in leaf area of water-stressed corn plants. Before the application of water stress, the largest leaves are observed on control plants with 452.98 ± 106.72 cm^2 and the smallest online L36 (315.66 ± 87.15 cm^2). After the application of the stress, the leaves continue to grow until reaching a threshold at the 44th das. At this date, the largest leaf is observed on the control EV8728 plants (486.42 ± 98.24 cm^2) and the smallest with L71 (467.05 ± 109.32 cm^2) under moderate stress. Yet, under severe stress, the largest is recorded with L36 (488.90 ± 111.36 cm^2) and the smallest with control EV8728 (481.97 ± 104.72 cm^2). No difference is observed (p = 1.025). After the 44th day, the leaves are rapidly reduced under water stress. However, they continue to grow under favorable conditions, but without significant difference.

Figure 3. Evolution of leaf area of corn plants subjected to different water stress modalities



S0, S1 and S2 (respectively 100%, 50%, and 25 % of field capacity) ; EV8728: non-irradiated control; L36 and L71 (tested lines)

Flowering parameters

Table 3 shows the effect of water stress on flowering parameters of maize plants.

Panicle onset date

The panicle emergence date (PAD) is early with the control EV8728 compared to the tested lines (L36 and L71). It increases from 51 days under S0 stress to 56 days under S2 stress. This date is late in line L71 going from 63 das under S1 stress to 65 das under S0 and S2 stress respectively. The stress delays panicle emergence as it becomes more and more severe. A significant difference is observed with p = 0.0000.

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Date of appearance of pollen grains

The appearance of pollen grains (DAGP) took place at about 4 d after the panicle was visible. On the control plants, they were visible at 55 d under S0, 2 d later under S1 stress (57 d), and 3 d under S2 stress (58 d). With the plants of line L36, pollen grains emerged on the 66th day under stress S0 and S1. On the other hand, they are visible 4 d later (70 d) under the S2 stress. They are observed on the 67th day under S1 stress in line L71, while 68 days under S0 and 72 days under S2. There is then a clearly significant difference with p = 0.0000.

Date of appearance of the ear

Appeared early on the EV8728 plants, whereas it was late on the plants of the lines tested (L36 and L71). Thus, under S0 stress, it appears 55 das in EV8728 against 67 das in L36 and L71. Under S1 stress, it is always visible rather with EV8728 (57 das). On the tested lines L36 and L71, the plants emit the ear respectively 67 and 68 das. With S2 stress, the EV8728 plants release the cob 58 das, while the tested lines L36 and L71 emit 71 das and 74 das respectively. There is a highly significant difference with p = 0.0000.

Date of silk appearance

The time interval between heading and silk emergence is about 2 d under S0 and S1 stresses. Exceptionally, this interval in the control EV8728 under S0 is 3 d. Under S2 stresses, it is 3 days. Under all stresses, silk is earliest (57 d) with EV8728 while the latest 69 d is with line L71. Under S1 and S2 stresses, silks appear faster on EV8728 plants compared to the tested lines L36 and L71 released late. There is a significant difference with p = 0.015.

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Table 3. Date of appearance of panicle, pollen grains, ear and silk in 50% of maize plants underdifferent stress conditions

Stress × line		Parameters			
		DPA	DPGA	DEA	DSA
	EV8728	51±3.32**a**	55±3.24**a**	55±5.03**a**	57±5.06**a**
S0	L36	62±2.75**d**	66±2.80**c**	67±2.69**b**	68±3.20**d**
	L71	65±2.77**e**	68±2.92**d**	67±3.05**b**	69±4.13**d**
	EV8728	54±3.35**b**	57±4.30**b**	56±4.05**a**	59±4.66**b**
S1	L36	62±2.83**d**	66±3.07**c**	67±2.77**b**	68±3.20**d**
	L71	63±1.92**d**	67±1.89**c**	68±2.31**bc**	68±2.38**d**
	EV8728	56±3.45**c**	58±3.58**b**	58±3.89**a**	61±4.39**c**
S2	L36	64±2.65**e**	70±2.57**d**	71±2.02**c**	74±2.34**e**
	L71	65±2.76**e**	72±2.75**d**	74±2.46**c**	77±3.23**e**
P		**0.000**	**0.000**	**0.000**	**0.015**
F		**5.1**	**6.8**	**2.1**	**3.1**

DPA: date of panicle appearance of 50% of plants; DPGA: date of pollen grain appearance of 50% of plants; DEA: date of ear appearance of 50% of plants; DSA: date of silk appearance of 50% of plants;das: day after sowing; S0, S1 and S2 (100%, 50% , 25% of field capacity, respectively); EV8728: Control; L36 and L71 (lines tested); mean values with the same letters in the same column are not significantly different (5% Newman-Keuls test).

Number of spikelets

Table 4 shows the effect of water stress on the number of spikelets. Regardless of the severity of the water stress, the number of spikelets did not vary in the plants of the tested lines L36 and L71. This number remains 16 for L36 and 14 for L71. However, a variation is observed in the plants of the control EV8728. Under normal conditions, the plants bear 13 spikelets, while it decreases to 12 under moderate stress. Under severe stress, it decreases to 12 spikelets. However, no difference was observed with p = 0.123.

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Table 4. Number of spikelets, ear insertion height, panicle height, internode length of maize plants under water stress modalities

Stress × line		Parameters			
		NS	EIH (cm)	HP (cm)	IL (cm)
	EV8728	13±4.04**a**	66.65±16.56**d**	41.58±9.11**d**	12.65±2.5**a**
S0	L36	16±3.92**a**	73.55±22**e**	33.13±8.22**b**	11.93±11.91**a**
	L71	14±2.87**a**	74.43±15.11**e**	37.78±8.16**cd**	12.35±2.67**a**
	EV8728	12±3.54**a**	66.33±12.77**d**	37.85±8.3**cd**	11.4±2.09**a**
S1	L36	16±2.92**a**	61.15±15.08**c**	34.63±7.21**bc**	9.56±1.92**a**
	L71	14±2.45**a**	62.43±15.55**c**	37.33±7.26**c**	10.32±2.21**a**
	EV8728	12±3.25**a**	59.73±15.09**b**	38.65±7.45**cd**	10.51±2.37**a**
S2	L36	16±3.63**a**	66.01±19.89**d**	28.1±8.63**a**	8.96±2.61**a**
	L71	14±3.62**a**	55.76±14.03**a**	28.5±10.68**a**	8.93±2.38**a**
P		**0.123**	**0.033**	**0.000**	**0.905**
F		**1.821**	**2.637**	**6.059**	**0.257**

NS: Number of spikelets; EIH: ear insertion height; HP panicle height; IL: internode length; S0, S1 and S2 (respectively 100%, 50%, 25% of field capacity); EV8728: Control; L36 and L71 (lines tested); mean values with the same letters in the same column are not significantly different (5% Newman-Keuls test).

Height of ear insertion

Table IV shows the impact of water stress on-ear insertion height. Under the ideal situation, the largest insertion height 74.43 cm is observed online L71 while the smallest (66.65 cm) is with control EV8728. During moderate stress, the largest HIE (66.33 cm) is recorded in EV8728 while the smallest (61.15 cm) is with L36. When conditions become very stressful, L36 has the largest HIE (66.01 cm) and L71 has the smallest HIE (55.76 cm). The water stress had an impact on the ear insertion height. Thus, there is a highly significant difference between the tested lines and the control and between the different water regimes with p = 0.033.

Panicle height

The effect of water stress on panicle height is mentioned in Table IV. Under the favorable conditions, the highest panicle 41.58 cm is observed in EV8728 plants, while the lowest panicle 33.13 cm with line L36. With the application of moderate stress, the height decreases slightly with EV8728 (37.85 cm) but remains the tallest panicle. It increases with L36 (34.63cm)

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which nevertheless represents the small one. Under severe stress, panicle size decreased with all lines. However, EV8728 has the largest panicle 38.65 cm, while line L36 (28.1 cm) has the shortest. Water stress had a negative effect on panicle size. Thus, there is a clearly significant difference with p = 0.000.

Internode length

Table 4 shows the effect of water stress on internode length. Under moderate stress, internode length (LEN) decreased by about 2 cm for the test lines L36 and L71 and by 1 cm for the control line EV8728. When the stress conditions become extreme, the NEL decreases significantly. This reduction is 2.14 cm for EV8728, followed by 2.97 cm for L36 and 3.42 cm for L71. However, the control EV8728 has the highest internode elongation and the lowest with L71. No significant difference is observed with p = 0.905.

Discussion

Reduction in plant growth is one of the first manifestations of water deficit. It is manifested in many species by a modification of the plant architecture. Morphological parameters of maize plants of the variety EV8728 derived from irradiated seeds were influenced by water stress.

Leaf emission was more active with all lines when under the S0 field capacity regime. Indeed, the rate of leaf emission is significant with all lines under S0. Water stress negatively influenced this foliar emission of maize plants. It is delayed when the stress becomes more and more severe up to 25% of the field capacity. Our results are similar to those of Attia (2007) who noted a significant decrease in the number of leaves of plants under water stress.

As for the height of the plants, all lines grew perfectly under S0. It decreased dramatically when the plants were subjected to water stress corresponding to 25% of the field capacity. This could be explained by the fact that the plant metabolism is disturbed by the reduction of the amount of water supplied to the plants. Our results corroborate those of El-Zohiri and Abd El-Aal (2014) who observed a reduction in the height of taro (*Colocassia esculenta* (L.) Schott) plants subjected to a 25% watering dose compared to plants treated at the field capacity of the soil (100%). Similarly, Lauer (2005) observed that reducing water during vegetative development diminishes stem expansion in corn. According to Hopkins (2003), growth reduction is an adaptive capacity necessary for the survival of a plant exposed to water stress. Other studies had shown the reduction in height growth of plants subjected to different water stresses on some species such as argan, casuarina, cedar, and citrus rootstocks (Aussenac and Finkelsten, 1983; Albouchi *and al.*, 2003; Berka and Aïd, 2009; Beniken, 2011). Seed irradiation at the dose of 300 grays would not have positively influenced water stress resistance in the tested lines. Our work is in agreement with studies conducted by Sengupta *and al.*, (2013)

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and Macovei *and al.*, (2014). These authors had shown that a reduction in growth is commonly observed in irradiated plants and is generally attributed to alterations in the cell cycle in meristematic tissues, degradation of photosynthetic pigments, and thus decreased photosynthetic capacity.

The results obtained on diameter show that water stress did not cause significant reductions. Regardless of the severity of stress, the plants had diameters almost identical to those of the plants irrigated with field capacity (S0). This would be due to the adaptation of these plants to water stress. Our work is in agreement with Farooq *and al*., (2008); Razmjoo *and al.,* (2008) and Reynolds and Tuberosa, (2008). For these authors, during a water deficit, plants adopt adaptation strategies that differ from one species to another and that involve a large combination of morphological, physiological, and biochemical factors.

The leaf area of maize plants was reduced with the application of water stress. However, there was no significant difference. The control EV8728 performs better compared to the tested lines. Our work is consistent with that of Ouiam *and al*., (2002) who showed a reduction in leaf area depending on the water regimes in four potatoes (*Solanum tuberosum* L.) varieties. These results are consistent with those of Lauer (2005), who working on the behavior of maize during the dry season, observed that the application of water stress during vegetative development reduced leaf area. Seed irradiation at a dose of 300 grays would have triggered an adaptive mechanism in the two lines tested in response to water stress. Our results also corroborate those of Lebon (2006). This author showed that the reduction of the leaf area under the limiting water regime is an adaptive mechanism of the plants aiming to limit their leaf transpiration when the water conditions become unfavorable. Indeed, this reduction of leaf area is a judicious way to control water losses, by adjusting water consumption in cereals, and the latter is said to be water-saving plants. Our work agrees with that of Chaves *and al*., (2009). These authors state that the decrease in leaf area of the leaves is considered as a response or adaptation to water shortage.

The effects of water stress were observed on all four flowering parameters in maize. Under moderate stress, a delay in flowering (anthesis) was observed in EV8728 and line L71 while there was no change in date for line L36. Nevertheless, the panicle of the plants of line L71 is early, i.e. 63 das against 65 das for those irrigated with 100% of the field capacity. Under severe stress, all lines experienced a more pronounced delay in flowering of at least 2 d. This delay would be due to the fact that the plant would first respond to the metabolic disturbances caused by the water stress before carrying out its own functions. Our results are similar to those of Harou *and al.*, (2018) who showed that water stress delays the 50% flowering date by an average of 5 d in cowpea [*Vigna unguiculata* (L) Walpers]. Our work corroborates that of

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Wopereis *and al*., 1996 and Winkel *and al*., 1997. These show that in cereals, a water deficit during the vegetative growth period or during floral induction and inflorescence development reduces the speed of inflorescence development and that this leads to a delay or complete inhibition of flowering (anthesis). Other work has shown that the effects of water stress at the heading and filling stages of the grain are more detrimental than those occurring at the tillering and bolting stages (Thompson and Chase, 1992).

Water stress negatively impacted internode length. It decreased as the stress became severe. Our results are in agreement with Chafai (2012) who claimed that the rate of reduction in internode length under water stress is 19% in *Medicago truncatula*. Other authors claim that water stress resulted in a reduction in stem growth of cotton from the 65th day of the year and in internode length on the 75th day of the year (Gnofam *and al*., 2014).

As for insertion height, it gradually decreases as stress increases. This would be due to the fact that lack of water would prevent the absorption of nutrients by the plant hence the reduction in height. Our work is in agreement with Kasongo *and al*., (2019). These authors showed that ear insertion height in maize varies from 67.17 cm without chicken droppings to 82.08 cm with 7500 kg/ha of chicken droppings.

Regarding panicle height, water stress affected this parameter in all lines. However, the control line EV8728 had the longest panicle under all regimes followed by L71. Our results are in line with those of Doucet and Soenen (2016) who showed in maize that water stress leads to a reduction in panicle development affects pollen potential and increases the rate of pollen blocked in flowers.

As for the number of spikelets, the control EV8728, the early line, has very few spikelets compared to the lines tested. Our work confirms that of Chafai (2012) in Medicagotruncatula. This author states that the earliest lines (including the control) have the least branching.

Conclusion

This study revealed the effect of water stress on maize plants. Upon application of water deficit, the different agro morphological parameters were affected except for the diameter. However, prolonged water deficit significantly reduced all morphological components, as well as phenological and post-flowering parameters. The results obtained show an important intra-specific variation between the two lines on all their agro morphological characters. It should be noted that gamma irradiation had no impact on the agromorphological behavior of the lines with respect to water stress. Our tested lines have therefore been agromorphologically sensitive to water stress as the variety EV8728.

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