American Journal of Plant Biology
2023; 8(4): 106-112
http://www.sciencepublishinggroup.com/j/ajpb
doi: 10.11648/j.ajpb.20230804.15
ISSN: 2578-8329 (Print); ISSN: 2578-8337 (Online)

Effect of Foliar Application of Boron on Water Stress Tolerance in Pearl Millet (*Pennisetum glaucum* (L.) R. Br.)

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To cite this article:

Soumaila Sounakoye Illiassa, Daouda Ousmane Sani, Mounkaila Boureima Mouhamadou, Sani Daouda Abdou Razak, Lawali Maman Nassourou et al. (2023). Effect of Foliar Application of Boron on Water Stress Tolerance in Pearl Millet (*Pennisetum glaucum* (L.) R. Br.). *American Journal of Plant Biology*, *8*(4), 106-112. https://doi.org/10.11648/j.ajpb.20230804.15

Received: November 17, 2023; **Accepted**: December 5, 2023; **Published**: December 18, 2023

Abstract: Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is presented as one of the best tolerant cereal to abiotic stress. It is an essential component of food security in arid and semi-arid environments like Niger country. However, it is facing increasingly difficulties to withstand the effects of recent climate change. Pearl millet is exclusively cultivated on the coarse textured soils with poor moisture retention capacity and low soil fertility. In addition, the irregularity of rains and the lack of means for additional irrigation have a negative impact on crop productivity and food security for populations. The agricultural production system in Niger is characterized by permanent nutrients export from soil, without equivalent restitution. The very low chemical fertilization, when it exists, concerns the macro-elements (NPK) but never the micro-elements. In view of the eminently important role of these microelements in the plant physiology, the present study aimed to evaluate the effect of boron foliar spray on yield and yield components of pearl millet under drought stress conditions. The field experiment was conducted with 36 treatment combinations, with six genotypes of pearl millet, three levels of boron and two water regimes in a randomized complete block design with three replications. The source of boron was boric acid which content 17.7% boron. The results showed substantial increases in pearl millet growth parameters and yield in water stress condition, after foliar application of Boron. This micro-element contributed to significant changes in growth parameters, especially those related to water use efficiency such as root system development. This work highlights the need to correct fertilization formulas in arid and semi-arid areas, taking into account microelements such as boron.

Keywords: Foliar Spray, Nutrition, Pearl Millet, Water Stress

1. Introduction

Abiotic stressors such as water deficit, salinity and heat are the main causes of crop loss due to their effect on reducing the average yield of most crops by 50–70% [1]. Drought is one of the most influential abiotic stresses [2]. As the human population grows, aggravated with climate change, food accessibility may become a major concern on a global scale [3]. Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the crop that still tolerates the harsh and restrictive conditions of the world's semi-arid and arid environments. With ongoing climate change, the capacity of millet to tolerate drought must be strengthened and this is the major challenge for food security in important regions of the world. Pearl millet is the sixth most important cereal crop in the world next to wheat, rice, maize, barley and sorghum. It is one of the most important staple food crop in many countries of semi-arid zone of the Sahel. It gives also feed and fodder for livestock. In Niger, pearl millet is the first most widely cultivated food crop, with more than 65% of the sown area and contributing to 75% of the country's total cereal production [4-6]. Approximately 40% of global millet production comes from Africa (Samba *et al.*, 2015) [7] and West Africa provides about 80% of this production [8]. Several studies on pearl millet have focused on adaptation to restrictive environmental conditions [9-12]. Other more recent works have focused on genomic design for abiotic stress resistance [13-15], but whose impact on crop productivity in low-income countries is still poor.

Nutrition value of pearl millet is better than many other cereals. It is good source of energy, carbohydrate, fat (5-7%), ash, dietary fiber (1.2 g/100 g), protein (9-13%), and anti-oxidant such as coumaric acids with better digestibility. Pearl millet has higher contents of nutrients of which mainly iron and zinc.

Boron is one of the 17 essential plant nutrients, required for normal plant growth. It is needed by plants in small amounts, but yet crucial to plant development. Boron is required for a number of growth-related metabolic pathways. Because of its mobile nature, it tends to leach down in soil layers. Nigerien sandy soils cultivated with pearl millet is light textured alluvial soils with, rich in aluminum oxides and low content of organic matter, the profile of soils deficient in boron. Translocation of boron is somewhat difficult from actively growing tissue of the plants to other parts as it is relatively immobile in plants. Boron deficiency has been proved to be of the major constraints for crop production [16]. Plants contain boron both in a water-soluble and insoluble form. Several studies have shown that an optimal supply of boron or other microelements such as zinc, iron, silicon or calcium considerably improves crop growth and yield [17-23]. Applying plant growth regulators or micronutrients improves the plant’s resistance to abiotic stresses [24-26]. In Niger country, the fertilization system is essentially based on the three major elements including nitrogen, phosphorus and potassium. The present study aims to better highlight the role of boron bioavailability in improving the response of pearl millet to water stress.

2. Material and Methods

This experiment was conducted during year 2022 at Agronomy Farm, Radio-Agronomy Institute of the University Abdou Moumouni of Niamey, in Niger (13°29’ N, 02°10’ E) (Figure 1), and at an altitude of 207 meters above mean sea level. The soil is sandy and acid. The climate is tropical, Sudano-Sahelian type, with average rainfall of 452 mm and high daily temperature of 35-44°C in the rainy season (May-September) and cool in the dry and cold season (16°C in January). The field experiment comprised a combination of 36 treatments, in a split-plot device with three replications and three factors, the genotype (six varieties: MI1363, MI1272, MI1054, ANKOUTESS, H80-10GR and HKP), the water regime (Irrigation and Stressed) and three doses of boron D0 (without boron), D1 (standard dose = 2 mg Boron/plant) and D2 (twice the standard dose). Water stress was applied 66 days after sowing (DAS), by stopping irrigation. The two irrigated and stressed sub-blocks are separated by a width of 3 meters. The experimental unit corresponds to a seeding line 4 meters long and one meter wide. Each genotype has three lines per sub-block which correspond respectively to doses D0, D1 and D2. The foliar spray was done at flowering initiation as par treatments.

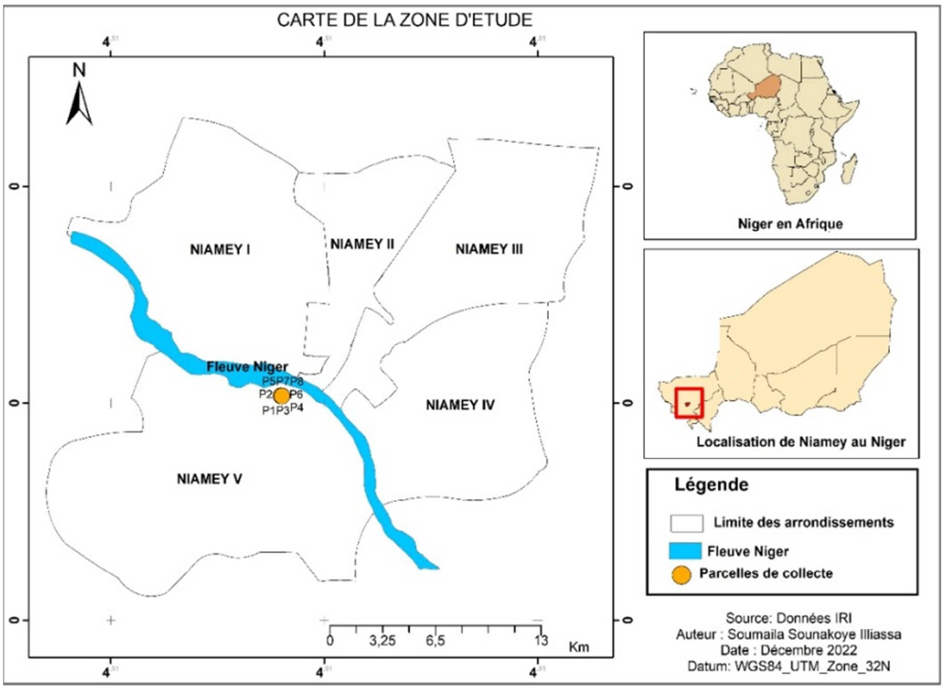

Figure 1. *Location of the study area..*

Seeds of pearl millet were sown on 5th August 2022, after a rain of 27.8 mm in rows spaced at 100 cm apart at the depth of 4-5 cm, using a seed rate of 5 kg/ha. A graduated rower allowed to obtain a good seeding density of 1m x 1m.

The rains stopped on October 10, 2022 (JAS 66), corresponding to the date of application of the water constraint and the watering's began on the same date on the irrigated block, at the rate of three watering's per week. The stressed block then receives no watering (Figure 2). The date of sowing, the start of irrigation and the date of harvest are shown in Figure 2.

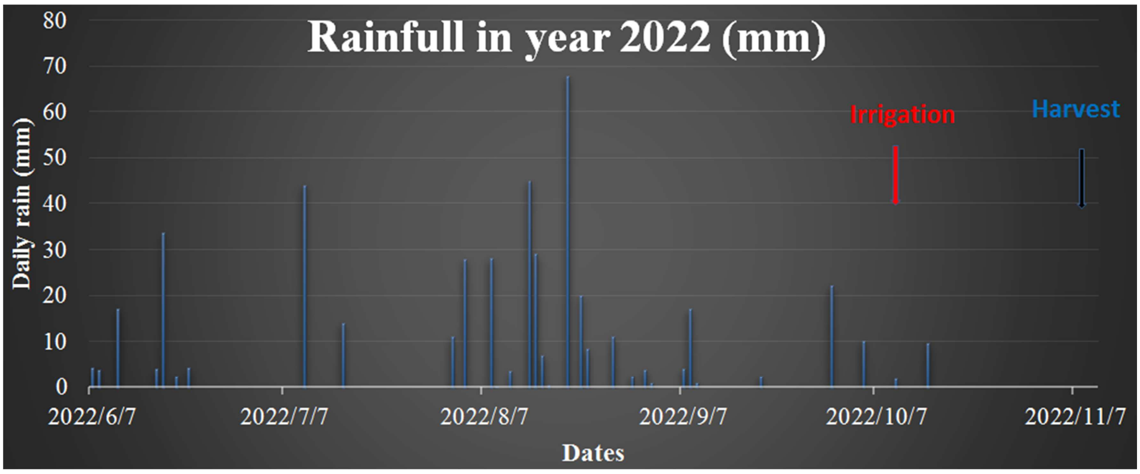

Figure 2. *Rainfall in the study area and dates of sowing, start of irrigation and harvest.*

Fertilization in the form of 15-15-15 was applied at a dose of 100 kg.ha^{-1} before sowing on 5th July, 2022 and incorporated immediately by light plowing. A contribution of 100 kg.ha^{-1} of urea was applied in 3 fractions 25-25-50. Maintenance weeding was done with traditional agricultural tools (*îler*), on demand. The thinning of a plant before tillering is carried out on 20th August, 2022. All phytosanitary monitoring operations have been carried out on request in accordance with the standards prescribed for agricultural extension in Niger.

Boron was supplied in the form of boric acid by leaf spraying as indicated in Table 1, on September 27, 2022 (JAS 53) around 6 p.m., using mini-sprinklers.

Table 1. *Boron doses tested by foliar spraying.*

	D0 (No boron)	D1 (2 mg of boron per plant)	D2 (4 mg of boron per plant)
Per ha	Distilled water	20g/ha	40 g/ha
Per plant	0	2 mg	4 mg
concentration	0	200 mg/l	

The following observations were made on the central pockets of each line: emergence rate, tillering, number of ears, diameter of stems and ears (on the main strand), height of the stem, spike length. At harvest, the weight of the stems, the weight of the cobs, the fresh aerial and root biomasses were determined. The fresh root biomass was determined on a cylinder of 0.4 m in diameter and 0.5 m deep, centered on the axis of the pocket. The roots were recovered using a 2 mm sieve, by rinsing with a water jet. The length of the roots corresponds to the longest root of each pocket. The weight of the seeds was determined by threshing the ears after their passage in the oven for 48 hours. The 1000 grain weight was determined by counting and weighing.

Statistical analyzes were performed using STATISTIX 8.1 software. The experimental device is in split-plot and the LSD test at the 5% threshold was used to separate the means. The XL stat software was used for the table of means, variances, standard deviations, coefficients of variation and for calculating the correlation between the different parameters.

3. Results

3.1. Variance Analysis

The ANOVA on pearl millet genotypes, water regime and boron dose is summarized in Table 2. It shows a significant difference between genotypes for parameters such as aboveground fresh and dry biomass, root fresh and dry biomass, cob length and weight and yield. The boron dose factor is significant for parameters such as yield, fresh and dry root biomass. The water regime effect had a significant influence for the parameters aboveground fresh biomass, root dry biomass, yield, cob weight and root length. The interaction between genotypes and boron doses was significant only for root dry biomass. The interaction of boron dose, water regime and genotypes is significant only for the length of the root.

Table 2. *Analysis of variance on the 15 quantitative parameters studied in millet (Pennisetum glaucum (L) R. Br.*

Source of variation	**ddl**	**DEP**	**DTG**	**LEP**	**LTG**	**BFA**	**BSA**	**BFR**	**BSR**
		F	**F**	**F**	**F**	**F**	**F**	**F**	**F**
Genotypes	5	34,59***	3,31*	25,71***	3,94*	1,39^{ns}	1,36^{ns}	1,72^{ns}	3,05*
Boron Dose	2	0,15^{ns}	0,76^{ns}	0,26^{ns}	0,40^{ns}	2,00^{ns}	2,45^{ns}	6,49*	9.61**
Water Regime	1	0,19^{ns}	0,61^{ns}	0,60^{ns}	0,49^{ns}	7,10*	3,88^{ns}	2,95^{ns}	4,22*
Bloc	2	0,46^{ns}	1,97^{ns}	0,05^{ns}	3,63*	1,72^{ns}	0,52^{ns}	1,05ns	5,31*
Genotypes*Boron Dose	10	1,05^{ns}	0,50^{ns}	0,91^{ns}	1,18^{ns}	1,08^{ns}	0,70^{ns}	1,96^{ns}	2,08*
Genotypes*Water Regime	5	0,72^{ns}	1,10^{ns}	0,16^{ns}	1,31^{ns}	2,78*	2,47*	2,14^{ns}	1.85^{ns}
Water Regime*Boron Dose	2	0,15^{ns}	1,27^{ns}	0,87^{ns}	0,16^{ns}	0,04^{ns}	0,49^{ns}	0,87^{ns}	4,79*
Genotypes*Water Régime*Born Dose	10	0,52^{ns}	0,17^{ns}	0,69^{ns}	0,56^{ns}	0,74^{ns}	1,02^{ns}	0,51^{ns}	1,19^{ns}

Source of variation	**ddl**	**NEP**	**RDT**	**NTL**	**PEP**	**PGR**	**LGR**	**WBA**
		F	**F**	**F**	**F**	**F**	**F**	**F**
Genotypes	5	2,71*	0,43^{ns}	2,23*^{ns}	0,51ns	0,10^{ns}	1,58^{ns}	1,33^{ns}
Boron Dose	2	0,77^{ns}	4,03*	1,04^{ns}	1,59^{ns}	6,44**	2,42^{ns}	3,26*
Water Regime	1	1,27^{ns}	4,62*	1,74^{ns}	11,78**	5,72*	8,41*	0,07^{ns}
Genotypes*Boron Dose	10	1,65^{ns}	0,99^{ns}	1,89^{ns}	1,31^{ns}	0,08^{ns}	0,92^{ns}	0,90^{ns}
Genotypes*Water Régime	5	1,98^{ns}	2,03^{ns}	2,42*	1,07^{ns}	0,06^{ns}	1,26^{ns}	0,71^{ns}
Water Régime*Boron Dose	2	0,52^{ns}	1,02^{ns}	0,24^{ns}	0,22^{ns}	5,41*	0,25^{ns}	0,80^{ns}
Genotypes*Water Régime*Boron Dose	10	0,88^{ns}	1,91*^{ns}	1,14^{ns}	0,58^{ns}	0,11^{ns}	2,06*	1,27^{ns}

DEP: Ear Diameter; *DTG:* Stem Diameter; *LEP*: Ear Length; *LTG*: Stem Length; *NEP:* Number of Ears; *BFA*: Shoot Fresh Biomass; *BSA*: Shoot Dry biomass; *WBA*: Shoot Water Content; *WBR*: Root Water Content; *PGR*: 1000 grains Weight; *RDT*: Grain Yield; *NTL*: Number of Tillers; *PEP*: Ear Weight; *LGR*: Root Length; *ns*: not significant; * *(0,01)*: Significant; ***(0,001)*: Highly significant; *** *(0,0001)*: Very Highly Significant; *F*: Fisher Value; *ddl:* degree of freedom; LSD: Least Significant Difference at 5 % level

3.2. Grain Yield and Root Biomass

Pearl millet grain yield varied from 257.29 to 341.43 g/pocket with a general average of 306.13. The ANOVA indicates a significant difference between boron doses (p = 0.0220) (Table 3). The D1 and D2 doses have produced the best yields. The D0 dose (without boron) had the lowest yield. The dry root biomass varied from 55.64 to 86.78 g/pocket for a general average of 72.87 g. The ANOVA indicates a highly significant difference between boron doses for dry root biomass (p = 0.0002). As in the case of grain yield, doses D1 and D2 have still recorded the best biomass, the lowest being with the D0 dose. We note that an increase in the boron dose leads to a significant increase in the production of root dry biomass and yield.

Table 3. *Grain yield and root biomass of six millet genotypes subject to variable boron doses by foliar application. D0: without boron, D1: 2 mg of boron by plant; D2: 4 mg of boron by plant; LSD: Least Significant Difference (5 % level); Means with the same letter are not significantly different.*

Boron Doses	**BSR (g/pocket)**	**RDT (g/pocket)**
D0	55,64^{b}	257,29^{b}
D1	75,20^{a}	319,66^{a}
D2	86,78^{a}	341,43^{a}
Average	72,87	306,13
LSD	14,32	61,354
P	0,0002	0,0220

3.3. Boron and Pearl Millet Root Biomass in Water Stress Conditions

The effect of boron on pearl millet root growth under water stress is summarized in Table 4. The production of dry root biomass for the different genotypes varied from 53.17 to 93.67 g/pocket, with a general average of 72.54 g all doses and all treatments combined. The ANOVA shows the existence of significant differences between combinations of boron doses and water regimes (*p = 0.0112*). Up to a dose of 2 mg of boron per plant (D1), no effect of water stress on root growth was observed. From a dose of 4 mg per plant, a drastic and significant reduction in root growth linked to water stress is observed (Table 4). Boron at a dose of 2 mg per plant leads to an increase in root growth, both under irrigated and stressed conditions. But with higher doses (4 mg per plant) the effect of water stress appears which slows down the production of root biomass.

Table 4. *Roots, water regimes and boron doses in pearl millet. D0: without boron, D1: 2 mg of boron by plant; D2: 4 mg of boron by plant; LSD: Least Significant Difference (5 % level); Means with the same letter are not significantly different.*

Boron doses X water regime	**Root biomass (g)**	**Root biomass variation relative to stress**
D0 x Irrigated	58,11^{b}	-9%
D0 x Stressed	53,17^{b}	
D1 x Irrigated	83,89^{a}	+7%
D1 x Stressed	89,67^{a}	
D2 x Irrigated	93,67^{a}	-39%
D2 x Stressed	56,72^{b}	
average	72,54	
LSD	20,25	
P	0,0112	

4. Discussion

During this study, foliar boron spraying showed significant effects on the different growth and yield parameters in the six millet genotypes tested. In General, a good supply of water and nutrients to a crop leads to good growth and good yields [27-34, 23]. But this good supply, especially in microelements, can provide the plant with good capabilities in the face of abiotic stress. Our results show that boron, as a micronutrient, can play a key role in the production of root biomass and yield of pearl millet (*Pennisetum glaucum*), with spray application ranging from 2 to 4 mg per plant. A more abundant root system should allow better exploitation of a larger volume of soil and therefore better nutrition of water and minerals for the plant, especially in the event of drought. Results consistent with ours were found by several previous authors who showed the positive effect of boron on water stress mitigation. Shehzad *et al.* [35], working on sunflower (*Helianthus annuus*), obtained an improvement in drought tolerance (maintenance of growth) with a foliar supply of boron at a concentration of 30 mg.L^{-1}. They found that boron application increased root length and number, and improved root hair development. Quirogo *et al.* [36] found no adverse physiological effects on a corn crop subjected to water stress, in the presence of boron. Abdullah *et al.* [17], studying the mitigation of water stress by foliar application of boron in coriander (*Coriandrum sativum*), reported that spraying 150 ppm of boron under conditions of moderate stress (80% ETP), made it possible to maximize the yield. Alijani *et al.* [37] and Shahgholi *et al.* [22] obtained a significant positive effect on the grain yield of soybean and wheat under water stress conditions, by combined foliar application of iron, zinc and boron.

Boron also plays a leading role in the movement of water and nutrients from roots to aerial parts [38]. The root is an important organ for plants to fix and absorb nutrients from the soil.

5. Conclusion

Among abiotic factors, drought stress is one of the major abiotic stresses, adversely affecting crop growth and mostly limits agricultural productivity worldwide, particularly in arid and semiarid regions. In this part of the world, crop productivity is constantly declining and this is rightly or wrongly attributed to climate change. Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is one of the crops most tolerant to arid environmental conditions but does not escape this drop in productivity. In Niger, a very arid, poor and indebted country, agricultural fertilization is essentially based on the main major nutrients; nitrogen, phosphorus and potassium. No compensation for microelements has been applied for decades, even for so-called cash crops. The data collected in this study show that the foliar spray of boron (2 to 4 mg per plant) enhances pearl millet plant and roots biomass in reaction to drought stress, improving plant tolerance to this stress. It can be concluded that the foliar application of boron is a good strategy to reduce the negative effects of drought. We recommend a more in-depth study to specify the most effective dose for drought tolerance and also the toxicity threshold.

Conflicts of Interest

The author(s) have not declared any conflict of interest.

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