Quantitative Characteristics of the Okra [*Abelmoschus esculentus* (L.) Moench] Root System Under Water Constraints

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Abstract
      The depth and density of roots play a determining role in the maintenance of the water supply of the plant in a condition of water deficit in the soil. Under water deficit conditions, a root system developing deep in the soil is the most desired character. This study aims to determine adaptive performance of the okra root system under water stress. Thus, the effects of water deficit induced by restriction of soil field capacity (SFC) to 60%, 40% and 20% were studied in two varieties of okra (V1 and V2) and compared to a control water regime (100% SFC irrigation). Results showed that the number of primary roots, the root volume, the root dry matter, the length of the main root and the root fineness varied according to varieties, water regimes and their interaction. However, varietal differences were observed for the characters length of the main root and root fineness. In addition, a significant difference and very highly significant were respectively observed for the interaction * variety hydric regime on the number of primary roots (p = 0.016) and the length of the main root (p ≤ 0.001). Under water regimes at 60% SFC, 40% SFC or 20% SFC, there is an increase in length of the main root of the varietyV2; but for the variety V1, the increase was noted in the plants irrigated

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at 40% SFC. On the other hand, in both varieties, root fineness increased under all restrictive water regimes.

Keywords: Okra, Varieties, Water regime, Roots, Characters

Introduction

In Burkina Faso, agriculture is the main source of economic and social growth. It constitutes the essential sector of jobs because it employs more than 86% of the active population, contributes for more than 40% to the Gross Domestic Product (GDP) (MASA, 2013). However, despite the potential of the country and the efforts made by the various governments to satisfy the population's food demand and ensure sustainable food security, to date Burkina Faso is still far from achieving food self-sufficiency. This is mainly due to low crop productivity which is not consistent with the exponential growth of the population. Other factors explain this situation, particularly the deterioration of climatic conditions, which most often exposes cultivated species to recurrent water deficit. Among the affected crop species, there is Okra of the genus *Abelmoschu*s, a plant neglected and marginalized by research and agricultural structures in Burkina Faso (Ouédraogo et *al.*, 2016 ; Sawadogo et *al.*, 2009); and the challenge of its production is also poorly perceived because of its marginalization in relation to cereal crops (Nana, 2005). Nevertheless, okra is one of the most important vegetable crops in the tropics and subtropics, where it plays a key role in the financial equilibrium of peri-urban farming systems (Tshomba et *al*., 2015).In Burkina Faso, okra plays a significant socio-economic role through its use in food and the generation of financial resources for producers. There is certainly a craze for its production in rural and peri-urban Burkina Faso, but its culture remains low because of climatic constraints characterized by a great heterogeneity of drought forms. Studies on the agro-morphological and physiological characterization of okra have already been carried out (Sani et *al.*, 2019); but the characteristics of the root system of okra related to his resistance to water stress are unknown. Indeed, the absorption and transport of water and mineral elements to the aerial parts of the plant depends on the root system. In addition, the water absorption depends on the number of roots occupying the soil volume, the size and length of roots, the distance that water must travel in the roots of the absorption site up to at the site of use, the age of roots and the rate of new roots produced (Maynard et David, 1987). The overall objective of this work was to understand the adaptive response of okra root system to water constraint. Specifically, it was to determine characteristics of the okra root system under water deficit conditions and to identify okra variety with deep root development under water stress.

Material and methods
Plant material

Two varieties of okra called V1 and V2 were used for this study. The choice of these varieties is justified by the insufficiency of data on their morpho-physiological characteristics under conditions of water stress.

Determination of the soil field capacity

The soil field capacity (SFC) corresponds to the quantity of water retained, after 48 hours of free water dripping to the water table, by a soil previously saturated with water. It has been evaluated to determine water quantities to bring by watering and pot according water treatments. For this, 3 soil samples (substrate) of culture were dried and then weighed and the dry weights DW-S1, DW-S2, DW-S3 noted. These samples were then watered to saturation, then pots were covered with plastics to avoid evaporation and let drain to the cleaning point for 48 hours. Soil samples were weighed again and their saturation weights SW-S1, SW-S2, SW-S3 noted. The soil field capacity was calculated for each sample by the following formula:

$$SFC = \frac{SW - DW}{DW} \ in \ g \ of \ water \ by \ g \ of \ dry \ earth$$

The average of the SFC was calculated by summing SFC of different soil samples divided by the number of samples.

Experimental design and test conduct

Plants were grown in pots; arranged in three randomized blocks. A total of 72 pots (3 pots x 2 varieties x 4 water treatments x 3 blocks) were used for the test. Each block was subdivided into four sub-blocks or crop plots corresponding to the different water treatments. Each plot of culture had six pots with three pots per variety.

The sowing was carried out on March 16, 2019 with three seeds per pot, each containing 17 kg of soil. Unmarking was done two weeks after planting, leaving two plants per pot and another Unmarking at 21 days after sowing (DAS) at one plant per pot, followed by the start of water regimes application. Four water regimes were tested: a water regime at 100% of the soil field capacity (SFC), a 60% SFC water regime, a 40% SFC water regime and a 20% SFC water regime. Thus, water quantities supplied per pot and irrigation were 4.25 liters for the 100% SFC water regime (S0), 2.55 liters, 1.70 liters and 0.85 liters respectively for the water regimes at 60% SFC (S1), 40% SFC (S2) and 20% SFC (S3). Weeding was done manually on demand. The plants were grown under natural conditions of illumination, temperature and hygrometry. During the test, the average daily temperature recorded in the laboratory varied between 28.20°C and 30.70°C; and the relative humidity ranged from 69.67% to 78.33%.

Measured parameters

Parameters were quantitative and were obtained by biometric field and / or laboratory measurements. The measures concerned :

❖ **Leaves fall (LF):** it was evaluated by manual counting of the number of leaves that fell during the period of water stress;

❖ **Characteristics of the root system:** they were evaluated at the end of the water stress after 45 days of application, ie at the 66th days after sowing (DAS). To do this, the soil was separated from roots by a jet of tap water. The roots were then washed in a tank before taking measurements. Parameters of rooting evaluated are as follows:

   ✓ **Number of primary roots (NPR)**, determined by counting root lengths measuring at least 2 cm;

   ✓ **Length of the main root (LMR),** was measured in centimeters (cm) using a graduated ruler

   ✓ **Root volume (RV)**, expressed in cm^3, was evaluated according to the method of Musick et *al.*, (1965) by comparing the water levels, before and after immersion of all roots in a known volume of water;

   ✓ **Dry root mass (DRM)**, expressed in gram (g), was determined after drying in an oven at 60°C for 96 hours using the method of Heitholt (1989);

   ✓ **Root fineness (RF),** expressed in cm/g dry matter, was evaluated by the ratio of root length to dry root weight according to the method of Wilhelm et *al*., (1982).

Data analysis

Data were the subject of graphs with the Excel spreadsheet version 2007. The effect of the water regime on the characters of the root system was appreciated through an Analysis of Variance (ANOVA) using the software XLSTAT version 2016.02.27444. The Dunnett (bilateral) test for comparison of averages was performed at 5% threshold.

Results

Soil water content

At the last day, the soil water content (SWC) showed that the water stress induced by reduction of the soil field capacity, caused a gradual decrease of this parameter according to the water regimes (figure 1). Soil of the water regime S0 recorded the highest moisture content with an average of 12.63% followed by regimes S1 and S2 (9.26%) and the water regime S3 (5.46%).
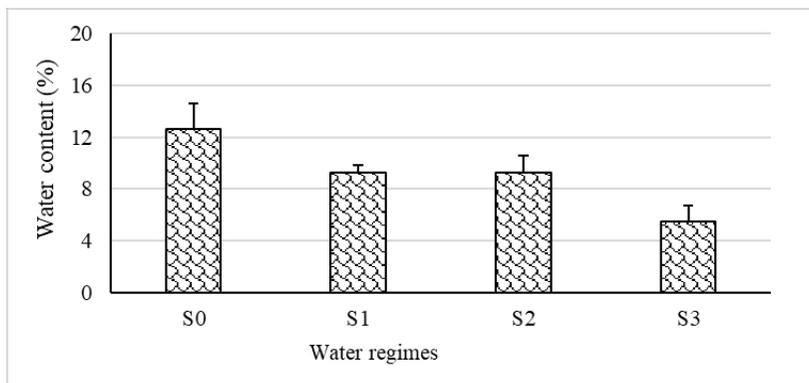
Figure 1 : *Soil water content on the last day of water stress according to water treatments*
Legend : *S0 :plants watered at 100% SFC;S1: plants watered at 60% SFC, S2: plants watered at 40% SFC, S3: plants watered at 20% SFC.*

Leaf fall

Results showed that the leaf fall was variable depending on the water regimes applied to the plants. Indeed, the fall of leaves has been observed only in plants subjected to deficient water regimes S2 and S3 (Figure 2). Plants of water treatment S3 recorded a higher leaf fall with an average of 4.16 ± add the Ecart type of mean leaves per plant in the variety V1 and 3.66 ± add the Ecart type of mean leaves per plant for the variety V2. Analysis of variance revealed no significant difference (p = 0.153) between varieties (Table 1). On the other hand, the difference between control (S0) and water treatments S3 and S2 was significant.
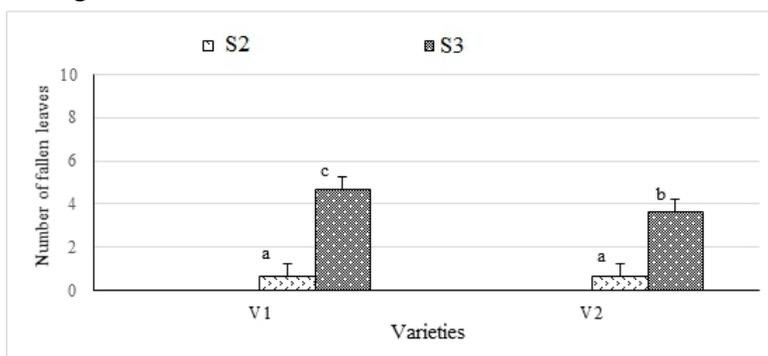

Figure 2 : *Interactions variety*water regime on leaf fall*

Table 1: *Analysis of the differences between Varieties modalities; the control modality Water regime-S0 and the other modalities with a 95% confidence interval on the leaf fall*

Varieties and water regimes	P	Significant
V2 vs V1	0.153	ns
S0 vs S3	**< 0,0001**	***
S0 vs S2	**0.031**	*
S0 vs S1	1.000	ns

Legend:S0: plants watered at 100% SFC, **S1** : plants watered at 60% SFC, **S2** : plants watered at 40% SFC, **S3** : plants watered at 20% SFC, **P**: Probability ; **ns** : not significant difference; ***** : significant difference ; ******* :very highly significant difference at 5% threshold.

Number of primary roots

The number of primary roots (NPR) emitted by plants was variable according to the water regime and the variety (Figure 3). Indeed, the two varieties of okra recorded a higher number of primary roots under the water treatment S2, with respectively an average of 45.66 ± add the Ecart type of mean and 44.66 ± add the Ecart type of mean primary roots. In general, the water regime S2 (40% SFC) had a stimulating effect on the primary root formation of both varieties, whereas the water regime S3 (20% SFC) had a more reducing effect on the number of primary roots. However, the analysis of variance revealed no significant difference (p = 0.829) between V1 and V2 (Table 2). However, there was a significant difference between water treatments; with a water regime S3 (20% SFC) which differs from regimes S0 (p = 0.015) in the number of main roots. The interaction between variety and water regime was statistically significant (Figure 3).
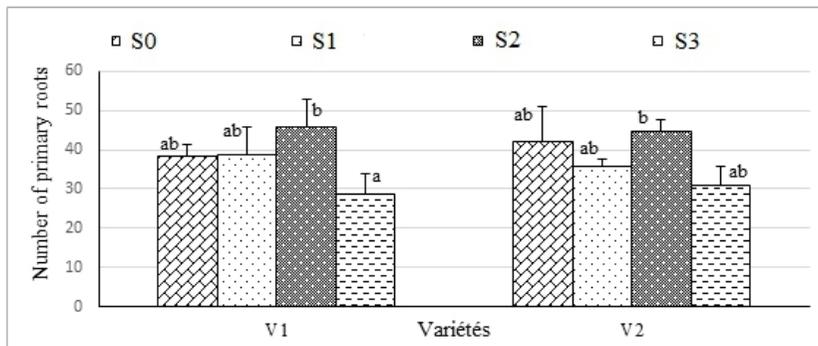

Figure 3: *Interactions variety*water regime on the number of primary roots*

Table 2: *Analysis of the differences between varieties modalities; the control modality Water regime-S0 and the other modalities with a 95% confidence interval on the number of primary roots.*

Varieties and water regimes	P	Significant
V1 vs V2	0,829	ns
S0 vs S3	**0.015**	*
S0 vs S1	0.680	ns
S0 vs S2	0.311	ns

Legend:S0: plants watered at 100% SFC, **S1** : plants watered at 60% SFC, **S2** : plants watered at 40% SFC, **S3** : plants watered at 20% SFC, **P**: Probability ; **ns** : not significant difference; ***** : significant difference ; at 5% threshold.

Root volume

The two varieties of okra are distinguished by a large variation in root volume under water deficit conditions. Indeed, under the deficient water regimes S1 (60% SFC) S2 (40% SFC) and S3 (20% SFC), there was an increase in the roots volume of the variety V2 with respectively 43.33 cm^3 ± add the Ecart type of mean, 46.66 cm^3 ± add the Ecart type of mean, 33.33 cm^3 ± add the Ecart type of mean against 26.66 cm^3 ± add the Ecart type of mean for the control (S0) (figure 4). On the other hand, the increase was only observed in the variety V1 under the water regime S2. Analysis of variance revealed no significant difference between the two varieties (Table 3) and between control regime S0 and the other water treatments.
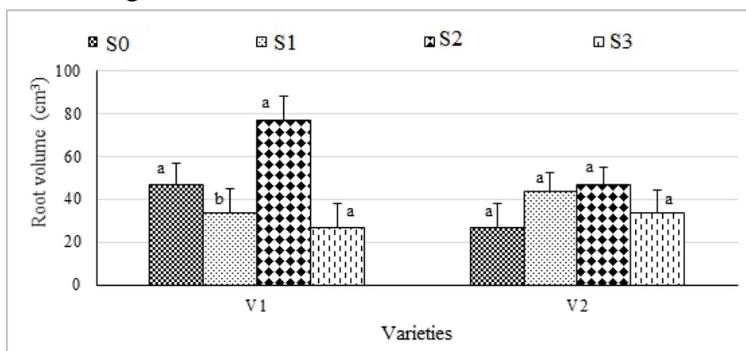

Figure 4: *Interactions variety*water regime on root volume*

Tableau 3: *Analysis of the differences between varieties modalities; the control modality Water regime-S0 and the other modalities with a 95% confidence interval for root volume*

Varieties and water regimes	P	Significant
V1 vs V2	0.250	ns
S0 vs S3	0.840	ns

S0 vs S2	0.056	ns
S0 vs S1	0.996	ns

Legend: S0: plants watered at 100% SFC, **S1** : plants watered at 60% SFC, **S2** : plants watered at 40% SFC, **S3** : plants watered at 20% SFC, **P**: Probability ; **ns** : not significant difference at 5% threshold.

Dry mass of roots

Under the effect of the different water regimes, the root dry mass was variable between varieties but also between treatments. Thus, water regimes S1 and S3 caused a reduction in root dry weight of the variety V1 (Figure 5). However, in the variety V2, the dry mass of roots increased slightly when plants were irrigated to 60% (S1) or 40% (S2) of the soil field capacity. Results of the analysis of variance revealed no significant difference (p = 0.176) between varieties (Table 4). In addition, water regimes S1, S2 and S3 were not significantly different from the control water regime S0 for root dry weight.
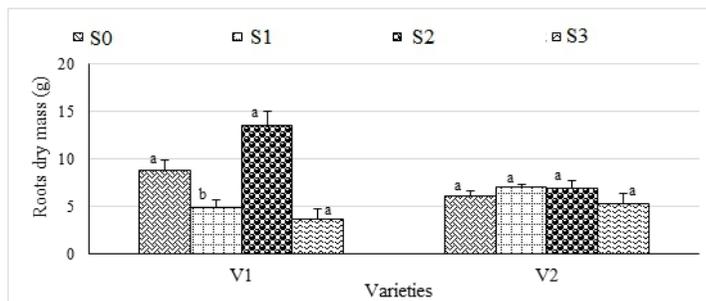

*Figure 5: Interactions variety*water regime on root dry mass*

Table 4: Analysis of the differences between modalities varieties; the control modality Water regime-S0 and the other modalities with a 95 confidence interval for root dry mass

Varieties and water regimes	P	Significant
V2 vs V1	0.176	ns
S0 vs S3	0.117	ns
S0 vs S1	0.616	ns
S0 vs S2	0.132	ns

Legend:S0: plants watered at 100% SFC, **S1** : plants watered at 60% SFC, **S2** : plants watered at 40% SFC, **S3** : plants watered at 20% SFC, **P**: Probability ; **ns** : not significant difference at 5% threshold.

Length of the main root

The length of the main root (LRP) of the variety V1 was reduced under deficient water regimes S1, S2 and S3; while under these same water regimes, the main root of the variety V2 recorded an increase in its length (Figure 6).

Indeed, the length of the main root of the variety V1 of treatments S1, S2 and S3 was on average 52 cm ± add the Ecart type of mean, 75 cm ± add the Ecart type of mean and 35 cm ± add the Ecart type of mean, compared to 82 cm ± add the Ecart type of mean for the length of control plants (S0). In the variety V2, it was 29.33 cm ± add the Ecart type of mean in the control plants (S0), 38 cm ± add the Ecart type of mean in the treatment plants S1, 49.66 cm± add the Ecart type of mean in the treatment plants S2 and 45.33 cm ± add the Ecart type of mean in the treatment plants S3. The results of the analysis of variance indicated a highly significant difference at the 5% threshold between the two varieties of okra (p = 0.001) for the length of the main root (Table 5). However, the differences between water regime modalities were not significant.
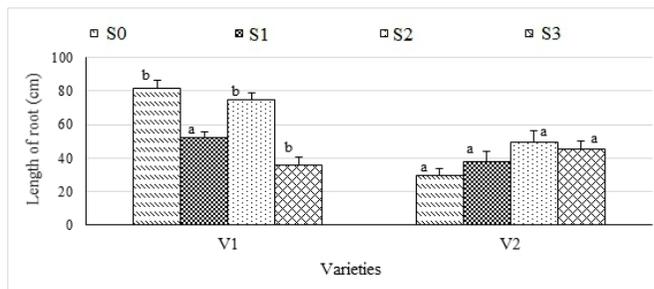

Figure 6 : *Interactions variety * water regime along the length of the main root*

Table 5: *Analysis of differences between varieties modalities; the control modality Water regime-S0 and the other water treatments modalities with a 95% confidence interval for the length of the main root*

Varieties and water regimes	P	Significant
V2 vs V1	**0.001**	**
S0 vs S3	0.095	ns
S0 vs S1	0.296	ns
S0 vs S2	0.641	ns

Legend: S0: plants watered at 100% SFC, **S1** : plants watered at 60% SFC, **S2** : plants watered at 40% SFC, **S3** : plants watered at 20% SFC, **P**: Probability ; **ns** : not significant difference at 5% threshold.

Root fineness

Varieties showed variable root fineness depending water regimes. In the variety V2, root finesse increased progressively with decreasing soil field capacity (Figure 7). In addition, in the variety V1, the increase of the root fineness was observed on plants irrigated at 60% SFC (S1) or 20% SFC (S3). Analysis of variance showed a significant difference between V1 and V2 (p = 0.029) for root fineness (Table 6). On the other hand, no significant difference

was noted between water treatments. The interaction between variety and water regime was statistically insignificant (Figure 7).
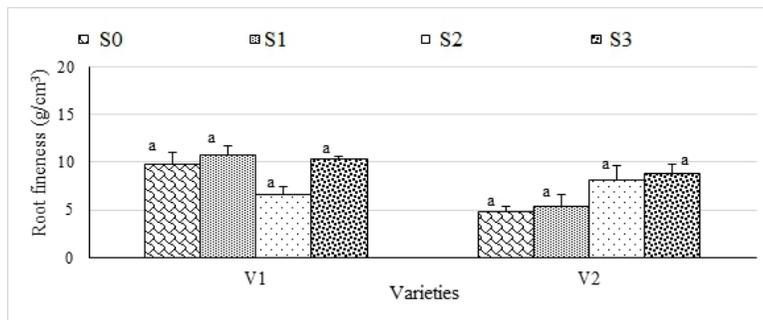

Figure 7: Interactions variety * water regime on root fineness

Table 6 : *Analysis of the differences between varieties modalities the control modality Water regime-S0 and the other modalities with a 95 confidence interval on root fineness*

Water regimes	P	Significant
V2 vs V1	**0.029**	*
S0 vs S3	0.340	ns
S0 vs S1	0.921	ns
S0 vs S2	1.000	ns

Legend: S0: plants watered at 100% SFC, **S1** : plants watered at 60% SFC, **S2** : plants watered at 40% SFC, **S3** : plants watered at 20% SFC, **P**: Probability ; **ns** : not significant difference at 5% threshold.

Discussion

In view of results obtained, the effect of water regimes on plants of the two varieties of okra from the 21st DAS to the 66th DAS was variable according to parameters measured. Thus, the water deficit induced by irrigation at 40% SFC or 20% SFC caused yellowing of the basal leaves of plants and subsequently their fall. This leaf loss could be an alternative for seedlings to reduce the transpiring surface through the number of leaves. In addition, the number of primary roots (NPR) of varieties of okra was reduced when plants were irrigated at 20% of the soil field capacity (S3). On the other hand, when the water restriction was carried out at 40% SFC, plants of the varieties have seen an increase in the number of their primary roots. Water restriction at 20% SFC seems to cause a more pronounced water deficit. Daaloul et *al.* (2002) found that in some wheat varieties, the number of primary roots is reduced about 40% under water deficit conditions, and that the maintenance of high primary root numbers under water stress in other varieties allows better

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accessibility to the water of the plant. In both varieties studied, the restriction water deficit at 60% SFC (S1), 40% SFC (S2) and 20% SFC (S3) positively affects the root volume (RV) of the variety V2 while in the variety V1, the increase in root volume was recorded under the regime S3. Indeed, the root volume reflects an extension and / or branching of the root system that favors the colonization of a larger volume of soil, making the soil's water (and nutrient) reserves more accessible to the soil (Benlaribi et *al.* 1990). The increase in the root volume of the variety V2 under water stress is probably related to the increase in the length of its main root under water stress. Indeed, El Fakhri et *al.*, (2010), found a positive correlation between the length of the main root, the number of primary roots and the root volume in wheat varieties. The characteristics expressed by the variety V2 seem to have a genetic origin. Under different water restrictions, the variety V2 tends to accumulate more dry matter in its roots than the variety V1. According to Daaloul et *al.* (2002), the most important characteristic is not the quantity of dry matter accumulated in the roots but their destination. Thus, this dry matter is used for the production of new roots, their proliferation (root volume), their elongation (increase in length) and their maintenance (El Fakhri et *al.*, 2010). Low translocation of photo-assimilates causes a decrease in root mass. Under water deficit, the variety V2 seems to be more consuming photo-assimilates by orienting them more towards the roots, which would be at the origin of the increase the root dry mass.

In addition, under the three restrictive water regimes 60% SFC (S1), 40% SFC (S2) and 20% SFC (S3), the variety V2 was successful in terms of increasing the length of the main root (LMR).When the water conditions are favorable, there may be a balance between the different root parameters with a tendency to elongation(El Fakhri et *al.,* 2010). Also, the increase of the LMR under water deficit would be an interesting characteristic to facilitate deep soil exploration.Indeed, this increase indicates a deep rooting process that makes it possible to draw water at depth when it is limited in the upper layers of the soil (Brown et *al.,* 1985); and even if this depth is reached only by a single main root (Dib et *al.,* 1992).Our results seem to corroborate those of Sayar et *al.* (2008) who showed that the water deficit applied to durum wheat at the 1/3 SFC irrigation dose causes a reduction in the number of primary roots.

The root fineness increased progressively with the decrease in soil field capacity (S1, S2, S3) in the variety V2; but this increase has been observed in plants of the variety V1 in water treatments S1 or S3.The root finesse seems to be an important characteristic because it allows a better adaptation of the plant to the hydric conditions of the environment. The increase in root fineness could be explained by a larger allocation of dry matter for the production of branched roots. The more roots there are, the finer they are that can result from a compensatory effect (Sayar et *al.*, 2008).

Conclusion

The results showed a variability in the characters of the okra root system depending on varieties and water regimes.The effect of water deficit on root parameters was a function of the degree of deficit.Indeed, the plants irrigated at 20% of the soil field capacity (SFC) had a reduced primary root number and reduced root mass in the two varieties. However, an increase in the length of the main root was noted under water regimes at 60% SFC (S1), 40% SFC (S2) and 20% SFC (S3) in the variety V2, but only under the water regime at 40 % SFC in the variety V1.In addition, under water restrictions S1, S2 and S3, the root fineness increased in the two varieties.The length of the main root (LMR) and root fineness (RF) appear to be the most relevant okra root traits for water stress resistance and can be used as an indicator of tolerance to water stress in okra. In terms of results, the variety V2 would present the best adaptive performance of the root system to the water deficit. This study allows a rational use of these varieties in the Okra improvement programs of Burkina Faso and other countries.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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