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RESEARCH ARTICLE

REDUCING OF DROUGHT STRESS-INDUCED DAMAGE ON THE PRODUCTIVITY AND FIBER QUALITY IN COTTON (*GOSSYPIUM HIRSUTUM* L.) USING COMPOSTS

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ABSTRACT

In Togo, the recurrence of pockets of drought during the rainy season and soil degradation pose serious threats to agriculture. Under these conditions, cotton production is strongly influenced, and the quality of the harvested fiber is altered. The purpose of this study is to evaluate the contribution of two types of composts, made with crop residues, on cotton yield and on some technological characteristics of the fiber in conditions of lack of water. The study was carried out in a greenhouse, in a 10 L vegetation pot. The water deficit is induced at the flowering stage of the plant, for 30 days, and consisted of a reduction in irrigation from 70 % to 30 % of the useful water reserve (UWR). The results showed that the water deficit induced a significant decrease in productivity (p = 0.001) in cotton, on the other hand the difference was not significant for the fiber yield at ginning (p = 0.663) and seed index (p = 0.243). The impact of the water deficit on productivity is halved with the use of compost, with rates of change of -26.12 % and -28.78 %, against -47.75 % in the absence of fertilization. Whatever the water regime, the contribution of composts can significantly improve the micronaire index (p = 0.023), the maturity of the fiber (p = 0.019), the length of the fiber (p = 0.003), fiber uniformity (p = 0.006) and tenacity (p = 0.008). Thus, compost appears to be a solution both to the problem of soil infertility and to strengthening the resistance of crops to drought.

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INTRODUCTION

In Togo, rain-fed agriculture still remains the sector that offers the most possibilities for accelerating economic growth, ensuring food security, creating jobs, increasing the income of producers and contributing to the trade balance and the development of the agro -industry. The agricultural sector provides more than 20 % of export earnings and supports more than 60 % of the working population (DSID, 2012). As the country's first cash crop, cotton (*Gossypium hirsutum* L.) plays an important part in overall export earnings (between 1 % and 4.3 % of GDP depending on the year) and makes Togo one of the main producers of fibers and seeds in Africa (NSCT, 2013).

Unfortunately, cotton production in this country has steadily declined in recent years, dropping from 187,000 tons in 1998/99 to 25.000 tons in 2006/2007. This decrease is linked to multiple causes including low soil fertility (Kintche *et al*., 2010), climatic disturbances (Adewi *et al*., 2010; Badameli and Dubreuil., 2010), diseases (Tozoou *et al*., 2015), etc.. Togo is a tropical country and it is known that in the tropical regions, frequently constrained by drought episodes whose frequency and duration are expected to increase under the influence of climate change (IPCC, 2007), water stress remains a major factor affecting crop yields (Benamar *et al.* ., 2009; Ibn Maaoui-Houimli *et al*., 2011) and product quality. In addition, in Togo, more than 50 % of cultivated soils are degraded because of their over-exploitation and the disappearance of fallow under demographic pressure (MERF, 2009).

Only 16 % of cultivated soils are fertilized using chemical fertilizers due to their too high costs for a large part of farmers. The improvement of cotton cultivation in Togo like other crops cannot be envisaged without local alternative solutions in order to increase the cultivable areas and also to reduce the environment constraints this crop face to. Because as with many agricultural products, the production of cotton in a growing area is highly dependent on production conditions. Cotton is cultivated mainly for its fiber. Botanically, the fibers originate from the outermost layer of the seed coat. On the physiological level, the increase in the mass of the fibers takes place initially concomitantly with the elongation, up to 22 days after anthesis1 (JAA) then cellulosic thickening continues at constant length until full maturity, 50 JAA (Benedict *et al*., 1973). In order to have a good yield and a good quality fiber, it is necessary to work on reducing the effect of biotic and abiotic constraints during the various stages of plants growth.
This study aims to evaluate the contribution of two types of composts made using harvest residues, on the yield and on some technological characteristics of the fiber in conditions of induced water deficit.

MATERIALS AND METHODS

Experimental site and plant material: The trial was conducted at "Centre de Recherche Agronomique de la Savane Humide " (CRA-SH) based in Kolokopé (Togo), from november 2017 to march 2018. The plant material consisted of cotton seed *Gossypium hirsutum* L. variety STAM129A. This variety was selected for testing because of its early maturity (130 days), high field productivity (2.5 $T.ha^{-1}$ seed cotton yield), good pest self-defense (Tozoou *et al*., 2015) and disease resistance (Akantetou, 2013). It is also the variety grown throughout Togo land.

Characteristics of the composts used: For the purpose of agricultural recovery of crop residues in cotton zones in Togo, different types of composts were developed as previously described (Gnofam *et al*., 2019). After windrowing, the heap was covered with a tarpaulin to keep the heat in and prevent insect reproduction. During the composting process, turning and watering are carried out every two weeks, in order to ensure a better mixing, an adequate aeration of the decomposing materials and a drying out which is detrimental to the good progress of biodegradations. The availability of the organic material deposit justifies the frequency of turning during the process. The contents of the heaps were watered to 50-70% of the dry weight of the substrate (Finstein and Miller, 1985) estimated by the handle test, in order to maintain optimal conditions for decomposition. Process monitoring consisted of regular measurements of pile temperature (every 2 days) between 9:00 and 10:00 a.m., and of pile moisture (at each turnover). After a process that lasted 3 to 4 months depending on the types of residues composted, the composts were recovered and analyses on maturity and agronomic potential were performed. Two composts, Cx (compost of cotton stalks + maize straw + goat and sheep manure + ashes) and Cy (compost of maize straw + sorghum straw + *Rottboellia cochinchinensis* straw) were retained because of their good level of maturity [NO3/NH4 (1.07 ± 0.05; 2.93 ± 0.07) and AH/AF (3.93 ± 0.32; 3.46 ± 0.59)], their richness in organic matter (28.97 ± 1.27 %; 32.02 ± 1.29 %) and in major fertilizing elements [N(1.47 ± 0.20 %; 1.33 ± 0.08 %); K(1.10 ± 0.01; 0.79 ± 0.007 %)], and their agronomic performance [plant size (50-57 cm); number of fruiting branches (9-10)] (Gnofam *et al*., 2019).

Growth conditions and induction of water stress: The culture substrate consisted of soil collected from the test site, sieved to 2 mm and sterilized by heating. The compost treatments received an amendment of 1/10, or 100 g of compost per 1 kg of soil (Tartoura, 2010; Bokobana *et al.*, 2019). After potting the growing substrates, a pre-irrigation was carried out every 2 days at the field capacity, until sowing on the 15th day. The survey was carried out under a greenhouse in pots of 10 L (25 cm deep, 25 cm of upper diameter and 16 cm of lower diameter). Each pot was filled with 7 kg of substrate. The bottom of the pots has been drilled with four (04) holes to allow the water to drain after watering. The device was a four-repetitive split-plot (Figure 1) with two interacting factors (fertilization and water regime). The experimental unit consists of four pots. The sowing was carried out at the rate of one four-grain pot per pot. At germination, irrigation was reduced to 70 % of the useful water reserve (UWR). The separation was achieved on the 21^{st} day after sowing (DAS) to maintain one plant by pot. The induction of the water deficit consisted of a decrease in irrigation, from 70 % of the UWR (control treatment) to 30 % of the UWR (stress treatment) from the 45^{th} day DAS. The cycle of lack of water lasted 30 days, corresponding to the average duration of drought pockets in the full rainy season in Togo (Ledi *et al.*, 2020). The UWR was calculated using the following formula (Baize, 2000; Bokobana *et al*., 2019):

$$UWR = (\Theta_{fc}\ 2.5 - \Theta_{wp}\ 4.2) \times T_{fine} \times E \times Da$$

UWR: useful water reserve; ɵfc 2,5: Moisture at field capacity in %, ɵwp 4,2: Moisture at permanent wilting point in %; Tfine: % in fine particles, E: soil depth in dm, Da: apparent soil density.

The irrigation of the plants is done by successive weighing of the pots, at a periodicity of 3 days. During each weigh-in, the control is reduced to the same weight corresponding to 70 % of the UWR, while water-deficient treatments maintain the restriction of water content to 30 % of the UWR (Bokobana, 2017). Ambient air temperature and relative humidity were measured daily below the greenhouse at 8:00 a.m. / 2:00 p.m. / 5:00 p.m. throughout the test period. Average environmental conditions are: a 12-hour photoperiod, an average temperature of 24 °C / 35 °C / 20 °C at 8:00 a.m. / 2:00 p.m. / 5:00 p.m. and an average relative air humidity of 65 % / 41 % / 55 %, respectively. At the cotton harvest (130 DAS), agronomic parameters were measured.

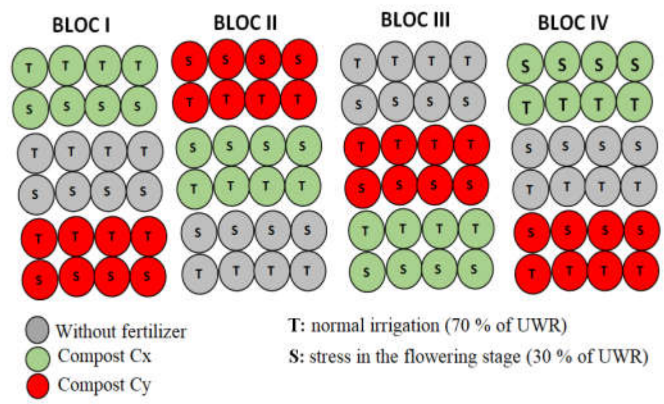


Figure 1. Test device (Split Plot 4 x 4) UWR: useful reversion in water

Yield components measurement: They consist in the productivity of cotton plants defined by the mass of cottonseed harvested per plant, the fiber yield at ginning (calculated after ginning by the following formula % F = Quantity of fiber / ginned cotton), and the weight of 100 seeds or seed index which enables to assess the size of cotton seeds. Weight measurements were made using a precision balance (near 0.1).

Technological analysis of the fiber: They were measured on samples of fiber obtained from ginning. The analyzes were carried out in the laboratory of technology and Characterization of natural fibers (LTC) UR 115 AÎDA, CIRAD-PERSYST, in Montpelier (France) with the HVI MIL ® 700 chain, according to ISO-139-2005 standards (20 °C + / -2 °C; 65 % humidity +/- 4 %), and according to the standards ASTM D3818-92 and D5867-05.
The parameters measured are: fiber micronaire number, fiber maturity, fiber length, fiber uniformity and fiber tenacity / strength.

Statistical analysis: Statistical analyzes of the data collected were carried out using the XLSTAT version 7.5.0 software. Fisher test was used for comparison of means when analysis of variance revealed significant differences between treatments, at the 5 % level. The calculation of the rate of change (S) of the measured parameter was performed according to the formula:

$$S = [(Vs - Vt) / Vt] \times 100$$

S = Incidence of water deficit (or rate of decrease or increase of the parameter); Vs = Gross value of the stressed treatment; Vt = Gross value of the control treatment.

RESULTS

Yield components

Change in productivity: The water deficit during the flowering period induces a significant decrease in productivity in the cotton plant (Table 1). However, the incidence is reduced by half with the use of compost, with variation rates of -26.12 % and -28.78 % respectively with composts Cx and Cy, compared to -47.75 % in the absence of fertilization (figure 2).

Variation in fiber yield and weight of 100 seeds (seed index): No significant difference was observed for the different treatments fiber yields (p = 0.663), and for their 100 seed weights (p = 0.243). Compared to the varietal standard, it should be noted that the stressed treatments presented the best fiber yields at ginning (42 %) against an average of 41 % for the irrigated treatments (Table 1). The weight of 100 seeds of the stressed treatments remains slightly lower than that of the irrigated treatments.

Variation in fiber quality parameters

Variation in fiber micronaire index and fiber maturity: Water deficit induced a significant decrease in micronaire index (p = 0.023) and maturity ($p = 0.019$) of the fibers of the different treatments (Table 2). According to these data the composts contributed to increase both parameters of fiber quality, to reduce the incidence of water deficit. Only small variations, without precise trends, were recordered, with rates varying from -13.93 % to -17.70 % for the micronaire index (Figure 3), and from -1.42 % to -1.75 % for maturity (Figure 4).

Variation in fiber length: Fiber length analysis revealed a very significant difference (p = 0.0003) between the treatments. The fibers from cotton produced on substrate without compost resulted in short length under stress conditions (24.1 mm) with a varietal standard greater than 27 mm (Table 2). For the other treatments the fibers lengths were statistically identical. The effect of the water deficit on the length of the silk was greatly reduced by the application of the compost, with variation rates of only -2.67 % and -2.02 % respectively for the composts Cx and Cy, compared to -13.62 % for the treatment without fertilization (Figure 5).

Variation in fiber uniformity: The analysis of the uniformity of the fiber showed a significant difference between the different treatments (p = 0.006). Applying water deficit during flowering resulted in a decrease in fiber uniformity (Table 2). Using of compost enabled to have a better uniformity compared to controls without compost and reduced the effect of water stress, with variation rates of -1.17 % and -1.40 % respectively for the composts Cx and Cy, compared to -1.90 % for the treatment without composts (Figure 6).

Variation in fiber strength / tenacity: The tenacity of the fiber was significantly influenced by the water deficit (p = 0.008). All the treatments with the water deficit showed low tenacity. In contrast under water stress conditions, the treatments with compost showed a higher toughness than those without compost (Figure 7). It cleary appeared that composts reduced the impact of the water deficit on the fiber tenacity.

DISCUSSION

The water deficit, applied during the flowering phase in cotton, induced a decrease in productivity regardless of the substrate used. Similar results were reported by Azevedo *et al.* (1993) et Nunes *et al*. (1998). The cotton plant needs an adequate amount of water for its growth and development, depending on the soil, the climate and the crop itself. Lack of water during critical periods of the cycle compromises photosynthetic activity of crops (Hussein *et al*., 2011; Luo *et al*., 2013). Beltrão *et al*. (2001) state that water scarcity affects cotton growth, with the most critical effects occurring at the flowering, boll formation and development stages. The results also showed that the treatments that received compost gave the best productivity regardless of the water regime. According to ADEME (2008), the addition of compost ensures the presence of nutrients to feed plants for a long period. Pagliai *et al.* (2004) showed that the addition of compost to the soil improves its porosity and structure. Stable organic matter amendments increase the buffering capacity and the exchange capacity of soils, two parameters that condition the mineral nutrition of plants (CEFREPADE, 2008). Improving the porosity, structure and exchange capacity of the soil therefore increases the productivity of the soil and therefore of the crops. The fiber yield at ginning of the stressed plants is slightly higher (but without significant difference) than that of the irrigated plants and is beyond the varietal norm. The distribution of carbohydrates produced by photosynthesis among carpels, seeds and fiber corresponds to the growth rate of these three components of the capsule. However, according to Dessauw (2006), in a stress situation, when the demand for carbohydrates for the growth of all the components of the boll is higher than the supply of carbohydrates from photosynthesis, it is the growth of the fiber that is favored over that of the seeds, which is much more costly in energy. Therefore, it is easy to understand why the fiber yield at ginning is relatively high. The weight of 100 seeds, an important parameter for ginners and crushers, was not significantly affected by the water deficit, although it seemed to decrease. The individual mass of the seeds depends on their filling level, i.e., the quantity of accumulated carbohydrate. Under water deficit conditions, there is a poor filling of the seeds (Cretenet, 2006; Gawrysiak and Gourlot, 2008). Seeds weighing less than 8 g generally pass between the bars of the gin and thus contribute to the soiling of the fiber. The technological characteristics of cotton fiber are intrinsically linked to the variety, but they are influenced by the

Table 1. Measurements of some yield components under induced water stress

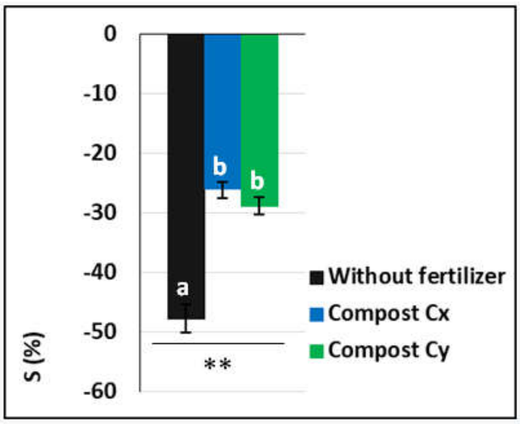
Water Regime	Fertilization	Productivity Cotton-seed (g)	Cotton fiber yield (% F)	100 grain weight (g)
Normal irrigation	Without fertilizer	124.6 ± 11.36[a]	41,25± 05,13[a]	08.15 ± 01.63[a]
	Compost Cx	138.2 ± 17.42[a]	41,4 ± 08,61[a]	08.65 ± 01.12[a]
	Compost Cy	147.1 ± 13.68[a]	40,88± 04,47[a]	08.20 ± 02.46[a]
Water deficit	Without fertilizer	65.1 ± 08.37[b]	42.78± 07.32[a]	07.11 ± 02.24[a]
	Compost Cx	102.1 ±10.75[ab]	42.68± 06.48[a]	07.76 ± 01.63[a]
	Compost Cy	104.75±12.23[ab]	41.98± 03.65[a]	08.10 ± 01.31[a]
	p	0.001	0.663	0.243
	Standard		> 41 %	> 08 g

The numbers with the same letter(s) in the same column are not significantly different at the probability threshold of 0.05 (Fisher). Cx: Compost of cotton stalks + maize straw + goat and sheep manure + ash, Cy: Compost of maize straw + sorghum straw + *Rottboellia cochinchinensis* straw.

Table 2. Measures of some fiber quality parameters under drought stress-induced

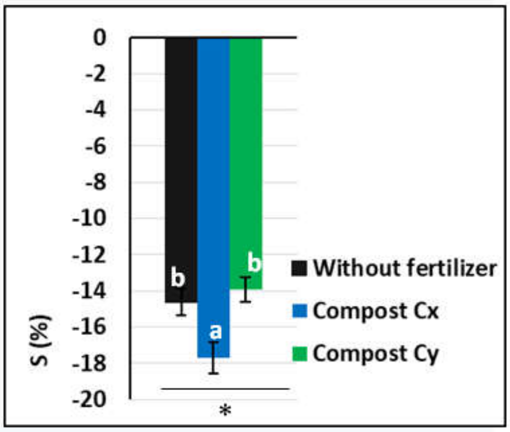
Water regime	Fertilization	Micronaire index	Maturity (%)	Length (mm)	Uniformity (%)	Tenacity HVI (Str-g/tex)
Normal irrigation	Without fertilizer	03.42± 0.02[ab]	84.20± 0.95[ab]	27.90 ± 01.02[a]	83.90± 0.09[ab]	31.19± 01.63[a]
	Compost Cx	04.18 ± 0.31[a]	86.20 ± 0.13[a]	29.90 ± 01.10[a]	85.40 ± 0.10[a]	32.64± 01.63[a]
	Compost Cy	04.02 ± 0.20[a]	85.50 ± 0.34[a]	29.70 ± 01,27[a]	85.40 ± 0.08[a]	32.20 ±01.63[a]
Water deficit	Without fertilizer	02.92 ± 0.56[b]	83.00 ± 0.47[b]	24.10 ± 01.09[b]	82.30 ± 0.11[b]	28.06 ±01.63[b]
	Compost Cx	03.44 ± 0.15[ab]	84.40± 0.65[ab]	29.10 ± 01.12[a]	84.40 ± 0.06[a]	30.72±01.63[ab]
	Compost Cy	03.46 ± 0.38[ab]	84.00 ± 0.28[ab]	29.10 ± 01.29[a]	84.20± 0.13[ab]	30.26±01.63[ab]
	p	0.023	0.019	0.003	0.006	0.008
	Standard	03.60- 04.20	> 83	> 27 mm	-	> 26

The numbers with the same letter(s) in the same column are not significantly different at the probability threshold of 0.05 (Fisher). Cx: Compost of cotton stalks + maize straw + goat and sheep manure + ash, Cy: Compost of maize straw + sorghum straw + *Rottboellia cochinchinensis* straw.



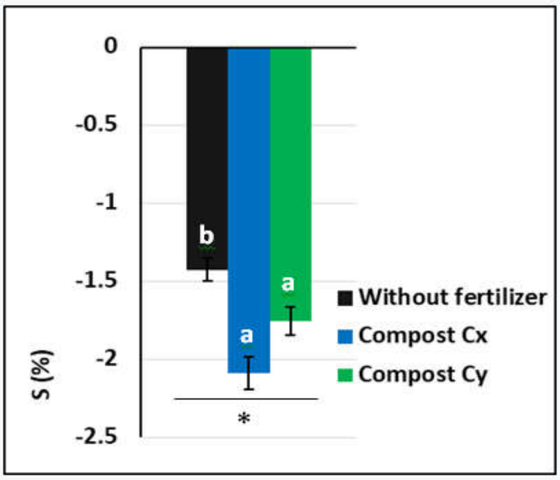
* *p*≤ 0.05 ; ** *p*≤ 0.01 ; *** *p*≤ 0.001 ; ns : non significative.

Figure 2. Rate of change in productivity under water deficit



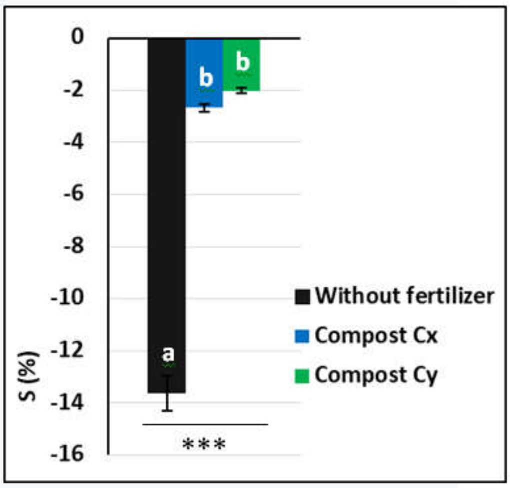
* *p*≤ 0.05 ; ** *p*≤ 0.01 ; *** *p*≤ 0.001 ; ns : non significative.

Figure 3. Rate of change in fiber micronaire index under water deficit



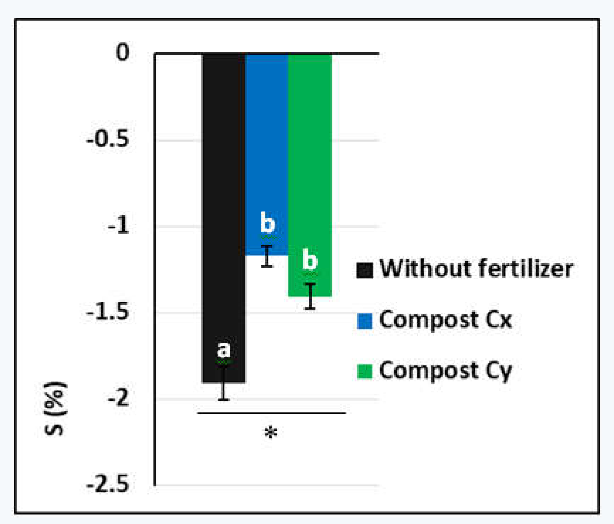
* *p* ≤ 0.05 ; ** *p* ≤ 0.01 ; *** *p* ≤ 0.001 ; ns : non significative

igure 4. Rate of change in fiber maturity under water deficit



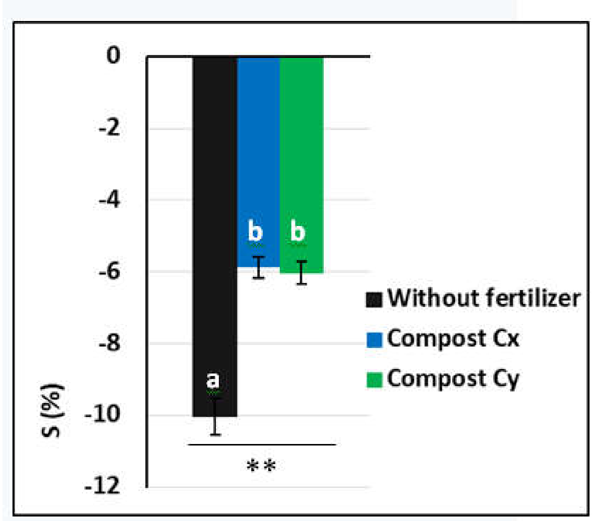
* p≤ 0.05 ; ** p≤ 0.01 ; *** p≤ 0.001 ; ns : non significative

Figure 5. Rate of change in fiber length under water deficit



* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; ns : non significative.

Figure 6. Rate of change in fiber uniformity under water deficit



* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; ns : non significative.

Figure 7. Rate of change in fiber tenacity under water deficit

amounts of water applied at different stages of crop development (Davidonis *et al*., 2004; Bradow *et al*., 2010). Micronaire index, maturity, silk length, uniformity and tenacity were negatively influenced by water deficit. The micronaire index is generally used as a measure of maturity, which is valid for a given variety of cotton (cultivar) and under specific production conditions. However, it is more generally a function of maturity and fineness, which affect spinning behavior and quality independently and differently (CCI, 2007). The micronaire index allowed for good spinning and good appearance for dyed fabric is between 3.8-4.2. However, values between 3 and 3.8 are still preferable provided the cotton is mature, especially for spinning. The control without compost subjected to water stress gave a very low micronaire index (2.92) and therefore a fiber unsuitable for spinning and dyeing. The addition of compost under irrigated conditions resulted in a very good micronaire index compared to the control. Under water deficit conditions, the micronaire index of fibers obtained with composted substrates, although higher than that of the control, remained below the desired standard.

Water deficit during secondary wall synthesis alters cellulose accumulation and reduces fiber maturity and micronaire (Wang *et al*., 2005). Water stress in the plant affects photosynthesis during which glucose is produced and converted to starch, lignin and cellulose. The latter is the major constituent of cotton fiber. Any effect on photosynthesis impacts cellulose production and consequently secondary wall formation and thus influences fiber maturity and diameter (Nafissatou *et al*., 2014). The mechanisms that govern cell expansion are therefore involved in the determination of diameter. For Cretenet (2006), poor growing conditions correspond to poor seed filling, and poor fiber filling, favor ginning yield, which is all the stronger when maturation conditions are poor. Growth occurs through a cell turgor mechanism that requires the availability of potassium, water, and heat. Unavailability of any of these elements leads to less fiber development (Nafissatou *et al.*, 2014). The application of water stress shortly after flowering and during the elongation phase of the fiber reduced its length due to the direct connection to the physiological mechanisms of cell expansion (Pettigrew, 2004; Davidonis *et al*., 2004). The increase of soil moisture level leads to the increase of fiber lengths (Balkcom *et al*., 2006; Beltrão *et al*., 2008). Water deficit reduces fiber strength and fineness (Nunes *et al*., 1998; Cordão *et al*., 2007). According to Zhao *et al*. (2012), as the strength of the fiber increases its commercial value increases, thus improving weaving performance. According to Freire (2015), the process of fiber formation occurs during the fertilization of the flower, for this reason, the lack of water at this stage can negatively affect the quality of the fiber. From an agronomic point of view, drought tolerance is the capacity of the plant to grow and give satisfactory yields in areas subject to episodic water deficits (Chaves and Oliveira, 2002). Soil amendment with compost had a positive effect on the resilience of the cotton plant to water deficit. Indeed, the damage caused on the productivity of the cotton plant and on the quality of the produced fiber was limited with the use of compost. Similar results have been reported in wheat (Tartoura, 2010) and maize (Bokobana, 2017). Compost improves stability through its effectiveness in increasing the organic matter present in the soil. The latter increases the cohesion of aggregates and makes them more hydrophobic and thus allows them to better resist water stress. The use of compost from agricultural residues in soil fertilization would be an economically beneficial and strategically sustainable approach in the current environmental and economic crisis (Prabu *et al*., 2003).

CONCLUSION

Fertilization of the culture substrate and water regime were the two interacting factors in this study. Compared to the fertilization of the culture substrate, the contribution of composts has improved the productivity of the cotton plant and the technological parameters which are criteria that influence the purchase price of cotton fiber. Compared to the water regime, the fiber yield at ginning is higher under water deficit conditions, but the other technological parameters of the fiber are negatively impacted. However, the composts used made it possible to reduce the impact of water deficit on various measured parameters. Thus, beyond their fertilizing power, composts would protect crops against environmental stress.

Author Contribution: All authors contributed equally.

Conflict of Interest: There is no conflict of interest in this case report.

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