Journal of Plant Breeding and Crop Science

Volume 10 Number 2 February 2018
ISSN 2006-9758

Academic Journals

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Vol. 10(2), pp. 33-40, February 2018
DOI: 10.5897/JPBCS2017.0696
Article Number: F5080FC55651
ISSN 2006-9758
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Journal of Plant Breeding and Crop Science

Full Length Research Paper

Phenological, morphological and agronomic characterization of sixteen genotypes of cotton plant (*Gossypium hirsutum* L.) in rainfed condition in Benin

Emmanuel SEKLOKA[1*], Albert Kora SABI[1], Valérien Amégnikin ZINSOU[1], Abib ABOUDOU[1], Cyrille Kanli NDOGBE[1], Léonard AFOUDA[1] and Lamine BABA-MOUSSA[2]

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Received 6 October, 2017; Accepted 22 December, 2017

In Benin, cotton cultivation is rain fed. There is a need to develop varieties adapted to the current diversity of growing conditions caused by climate disruptions. To identify types of varieties that may be used in crossing to adapt varietal offer to climatic disturbances, sixteen genotypes of diverse origins were characterized with a randomized complete block design with four replications. Fifteen agro-morphological variables allowed to describe the genetic variability using descriptive statistics and multivariate analyses. Results showed high genetic variability and a structuration into three groups of genotypes tested. Plant height, length of fruiting branches, height to node ratio, flowering date and opening date of first bolls are the main distinguishing characteristics between groups ($p<0.01$). The first group consists of compact genotypes with stems, fruiting branches and internodes relatively short. These genotypes were early to flowering and opening bolls. The second group is composed of more vegetative genotypes, with medium size stems with long fruiting branches and long internodes; they are late to flowering and opening bolls. The third group consists of a tall genotype with short fruiting branches and long internodes; it is early to flowering and opening bolls. Compact and early genotypes could be used in crossbreeding to produce varieties adapted to the current climate disruptions.

Key words: Republic of Benin, genetic variability, crop maturity, growth habit, cotton breeding.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is the most cultivated fiber plant in the world nowadays. World production of cotton fiber reached 25.74 million tons (International Conference of African Cultures (ICAC), 2017). Cotton is mainly grown for its fiber that is used as raw material for textile industries. But it also produces many byproducts. Indeed, decorticated cotton seed contains a kernel (60% of the weight of the seed) itself composed of 38% oil (Bolek et al., 2016). Cotton oil is used in food after removal of gossypol, a highly toxic alkaloid present in all

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aerial parts except in fibers and seed coat. The kernel also contains 35% protein. This high amount of protein permits the production of cakes occupying an important place in animal feed (12% of world production) and places cotton flour in 2nd place of world plant protein after soybeans (Yue et al., 2012; Camara, 2015). With varieties without gossypol or "glandless", cotton might even become progressively a food plant (Ma et al., 2016; Zhang et al., 2016).

In Benin, cotton sector is the most provider of national currency. It contributes for 14% to Gross domestic product (GDP) and between 30 to 40% of export earnings (Kpadé, 2011; INSAE, 2017). Revenue from cotton cultivation is the main source of cash income for farmers. Unfortunately, for more than ten years, a drastic drop of production was observed (Paraïso et al., 2012). Among other causes, the policy of unique variety so far adopted has shown its limits in view of climatic disturbances becoming recurrent these last years.

Indeed, these disturbances, mainly characterized by rain delays at planting, rather often generate late installations of crop compared to the period recommended by research. This late sowing often limits the operating time of the plant and strongly penalizes the yield. According to Lançon et al. (1989), the potential decline in seed cotton yield is about 20 to 30 kg.ha^{-1} per day for late sowing. But the H279-1 variety grown all over the country since 2003 has been developed within a cropping system based on more regular rainfall. Today, this variety badly fits to an increasingly reduced operating time because of these climatic disturbances. This leads currently in the extension of three new varieties to replace H 279-1 in different agro-ecological zones of country (Hougni et al., 2014). But these new genotypes are still late and are not yet pronounced on morphological and phenological plans to take into account recent research results which have shown that compact and early varietal types could be an alternative when hydrous conditions limit operating time of the culture in case of late sowings (Sekloka et al., 2008). Thus, current climatic difficulties offer new challenges to which varietal research must continue to face by offering varied range of genotypes adapted to the different growing conditions caused by these disturbances. For that, we must not only re-specify the conditions of use of the current late varieties, but also identify relevant genitors in order to achieve the diversification objectives of varietal offer to match the current diversification conditions of culture. This study fits into this framework and proposes to identify relevant genotypes of interest to the cotton plant breeding program in the current situation of cropping system evolution in Benin.

MATERIALS AND METHODS

The study was conducted in 2015 in Benin on the experimental farm of the Faculty of Agronomy of the University of Parakou (9°18'56.87" North latitude and 2°42'4.87" East longitude). The soil type is tropical ferruginous poor in organic matter with C content of 1.43%, C / N ratio of 8.46, clay and silt content of 22.40% (Azontondé et al., 2009). Annual rainfall has been abundant (1100 mm) and well distributed. August and September were the wettest months, corresponding fairly well to active periods of production of cotton plants (Figure 1). The average daily temperature varied between 20 and 25°C with a daily average of 22°C over the period of the study.

The plant material used is composed of 16 genotypes of which 12 are from the genes bank Centre International en Recherches Agronomiques pour le Développement (CIRAD) and multiplied during 2014-2015 campaign. These genotypes are from diverse geographical origins: S 188 (Nicaragua), Stoneville 2B-S9, Stoneville-20, Gregg, Rocket, Acala-44, Mebane-B1, 101-102B and 1-10b (USA), Guazuncho 2 and Chaco 520 (Argentina), Oultan (Uzbekistan), H 279-1 (Togo), H782-3, E956-2 and K768-3 (Benin). These genotypes are contrasted enough on morphological and phenological plans (Bossou, 2014). The last three, H782-3, E956-2 and K768-3 are new varieties from the cotton breeding program of Benin and currently under extension to replace H279-1 (Hougni et al., 2014).

The experimental design was a randomized complete block with four replications. Basic experimental plots (48 m²) were set up with three 20 m rows. Seedlings were thinned to one plant per hole. The stand density was 42 000 plants/ha. We also implemented the crop management sequences generally recommended for cotton-growing areas in Benin (CRA-CF 2015). The observations were carried out on the center lines of the basic plots. They focused on:

(1) First flower opening date (FF), determined by counting the number of flowers daily after flowering onset. This corresponds to the date (expressed in days after planting) when the sum of the daily counts is equal to the number of plants in the row.
(2) First boll opening date (FB), determined by counting the number of open bolls daily after opening of the first bolls. This corresponds to the date (expressed in days after emergence) when the sum of the daily counts is equal to the number of plants in the row.
(3) Production earliness ratio (R1/RT=first harvest/total harvest)
(4) Morphological and boll distribution indicators measured at harvest time on 10 individual plants randomly selected on the center lines of basic plot, using plant mapping technique (Bourland et al., 1990):

(i) Height at harvest (HH), measures the height of the main stem (in cm) from the first cotyledonary node to the tip.
(ii) Height to node ratio (HNR), the ratio of the plant height (in cm) to the total number of nodes counted above the cotyledonary node on the main stem.
(iii) Number of vegetative branches (NBV).
(iv) Length of fruiting branch (LFB), measured (in cm) on the third fruiting branches of the plant, and the length of vegetative branch (LVB) measured (in cm) on the second vegetative branch of the plant, as described by Hau and Goebel (1987).
(v) Height of first fruiting node (HFFN), measures the height on the main stem (in cm) from the cotyledonary node to the first fruiting branch.
(vi) Height of last fruiting node (HFFN), measures the height on the main stem (in cm) from the cotyledonary node to the last fruiting branch carrying a harvestable boll.
(vii) Boll retention at first positions of fruiting branches (RP1) is the ratio of the number of bolls harvested at the first positions of the fruiting branches to the number of fruiting branches.

(5) Boll weight (BW), calculated as mean weight of 3 first position bolls per plants (harvested in low, medium and top part of plant) calculated from 10 plants randomly selected from the central rows of the elementary plots.

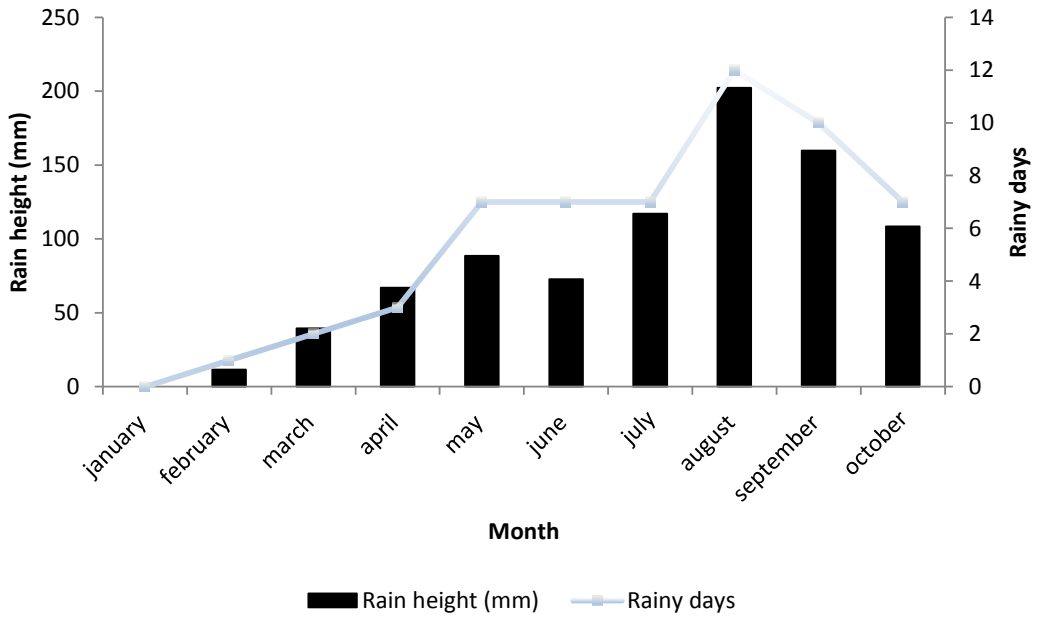

Figure 1. Rainfall data during the test.

(6) Seed cotton yields (Rdt) were also calculated on the basis of boll harvests from the central rows of the elementary plots. The mean productivity of varieties was analyzed.

Variance analyses were performed with the R software version 3.1.3 (2015-03-09). Tukey test (TukeyHSD) was used for comparison of means when differences are significant. Phenological and morphological data were subjected to a Principal Component Analysis (PCA) and a Discriminating Factorial Analysis (DFA). Wilks' Lambda test was then used to extract the quantitative variables most discriminating the groups obtained.

RESULTS

Variability of traits studied

Significant differences were observed between extreme values for most characters and the differences between varieties were highly significant. The differences were more than 10 days for first flower opening date (FF) and nearly one week for first boll opening date (FB). Length of fruiting branch (LFB) and length of vegetative branch (LVB) varied from simple to more than double. Height at harvest (HH), and height to node ratio varied of almost 50% between the two extremes. It was the same for yield parameters like bolls number on fruiting branches (BFB), average boll weight (BW), seed cotton yield (Rdt) (Table 1).

Seedcotton yield analysis

The Beninese selections recorded the best seed cotton yield ($p < 0.01$). H279-1 variety was the most productive followed by H782-3 and K768-3. Oultan, yielding 683 $kg.h^{-1}$ less than H 279-1, was the least yielded variety (Figure 2).

Structure of the genetic diversity tested

The first two axes of the PCA carried out with earliness and morphology variables explained 65.48% of the variability. The first axis is more correlated with the morphological variables, height at harvest (HH), height of first fruiting node (HFFN), height to last fruiting node (HLFN) length of vegetative branch (LVB) and height to node ratio (HNR). So it can be considered as an axis of vegetative development.

The second axis is highly correlated with first flower opening date (FF) and first boll opening date (FB). It can be considered as an axis of precocity (Table 2). The varieties projection in the factorial plan formed by the two axes allowed to distinguish three groups (Figure 3). Group 1 consists of five genotypes (31.25% of the total). These are early varieties with low vegetative growth. The genotypes of this group are of short height. They are earlier for boll opening, seed cotton production, but medium for flower opening. The first fruiting branches are inserted lower on the plant. They produce less vegetative branches, short in length, and short internodes on the main stem (Table 3).

Group 2 made up of ten genotypes (62.5% of the total), includes late maturing genotypes with high vegetative growth: plants had average height at harvest, many and long vegetative branches; they were last ones to bloom

Table 1. Minimal, maximum value and coefficient of variation of the quantitative characters.

Variables	Minimum	(Varieties)	Maximum	(Varieties)	Sd	CV (%)	Prob.
FF (d.a.p.)	57.0	(Oultan)	68.8	(Stoneville-20)	3.2	5.1	0.000
FB (d.a.p.)	112.7	(Oultan)	119.0	(Stoneville-2B-S9)	2.5	2.1	0.000
HFFN (cm)	11.4	(Guazuncho2)	16.0	(K768-3)	2.6	18.6	0.001
HH (cm)	84.5	(Rocket)	132.3	(Oultan)	18.0	17.2	0.000
LFB (cm)	24.5	(Oultan)	56.0	(H279-1)	8.8	19.3	0.000
LVB (cm)	18.4	(Mebane)	74.3	(H279-1)	2.3	32.1	0.000
HNR (cm)	4.8	(Rocket)	6.6	(Oultan)	0.8	13.7	0.000
NBV	0.7	(Mebane)	2.8	(Oultan)	0.7	35.2	0.000
NBF	10.4	(Rocket)	14.1	(Mebane)	2.3	18.4	0.762
BFB	7.6	(Gregg)	14.5	(H279-1)	2.7	25.0	0.033
CBV	0.2	(Mebane)	3.1	(H279-1)	1.2	75.4	0.011
BW (g)	1.1	(H279-1)	1.7	(1-10B)	0.4	28.8	0.397
Rdt (Kg/ha)	1006.0	(Oultan)	1689.0	(H279-1)	36.0	20.4	0.046
RP1 (%)	39.7	(Stoneville-2B-S9)	69.0	(Guazuncho2)	13.3	25.6	0.004
RFB1_7 (%)	29.2	(Stoneville-2B-S9)	50.8	(Guazuncho2)	8.5	22.34	0.000

d.a.p.: days after planting; min: minimum value; max: maximum value; CV: coefficient of variation, FF: First flower opening date, FB: First boll opening date, HFFN: height of first fruiting node, HH: Height at harvest, LFB: Length of fruiting branch LVB: Length of vegetative branch, HNR: Height to node ratio, NBV: Number of vegetative branches, NBF: Number of fruiting branches; BFB: Bolls number on branches fruiting CBV: Bolls number on vegetative branches, BW: Boll weight, yield: seed cotton yield, RP1: Boll retention at first positions of fruiting branches, RBFB1_7: Boll retention over the first 7 fruiting branches.

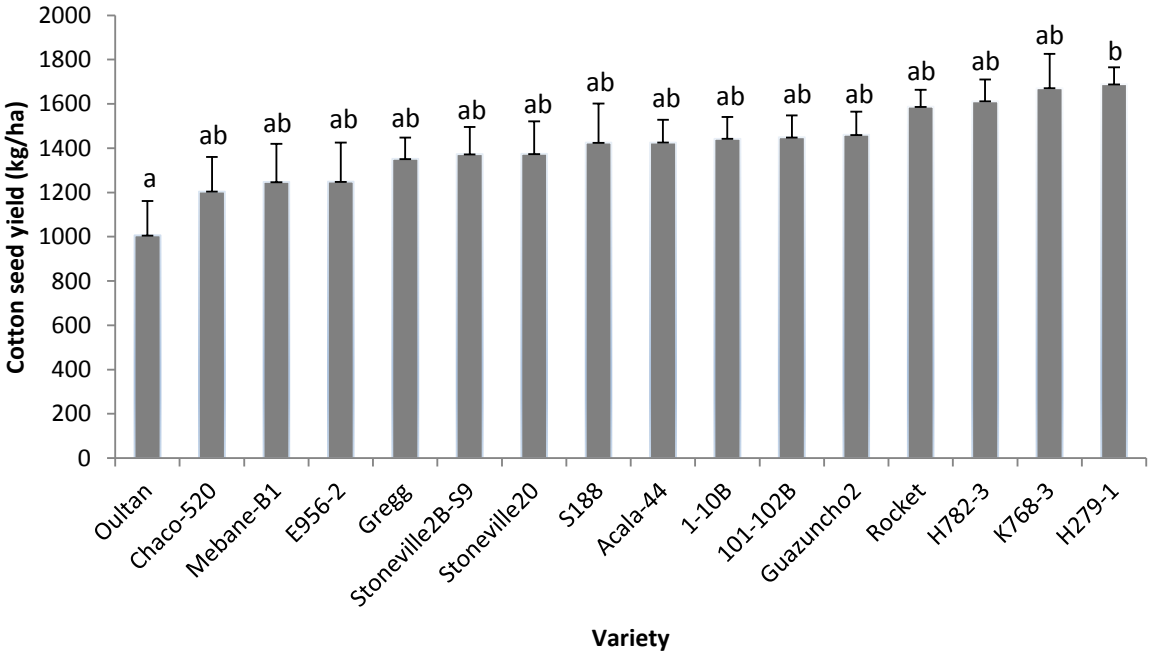

Figure 2. Variation of seed cotton yield of varieties tested.

and to open bolls (Table 3). Group 3 consisted of only one typical genotype (Oultan). It is characterized by early flowering cotton. Plants are very tall, with longest internodes and many long vegetative branches. But fruiting branches are shorter (Table 3).

Discriminant analysis

Discriminant analysis was performed using the three groups obtained from the PCA as categorical variable. Result confirm varieties categorization obtain from PCA

Table 2. Eigenvalues and percentage of variance expressed by the first five axes.

Component	Axis1		Axis2		Axis3		Axis4		Axis5	
Eigenvalue	4.568		2.635		1.75		0.952		0.386	
% of variance	41.53		23.95		15.9		8.652		3.51	
Cumulative % of variance	41.53		65.48		81.4		90.06		93.57	
FF (d.a.p.)	0.45	**	0.83	**	0.14		-0.03		0.24	
FB (jas)	0.49	**	0.73	**	-0.22		-0.11		-0.02	
R1/RT (%)	-0.63	**	-0.22		0.46	**	0.36		0.4	**
HH (cm)	0.82	**	-0.49	**	-0.26		0.04		-0.03	
LFB (cm)	0.28		0.69	**	-0.21		0.56	**	-0.13	
HFFN (cm)	0.84	**	0.29		0.18		-0.18		0.26	
HLFN (cm)	0.77	**	-0.53	**	-0.29		0.04		0.09	
NBF	0.07		-0.27		-0.84	**	0.35		0.22	
NBV	0.62	**	-0.41	**	0.60	**	0.17		-0.07	
LVB (cm)	0.7	**	0.00		0.42	**	0.49	**	-0.14	
HNR (cm)	0.9	**	-0.23		0.09		-0.27		0.08	

d.a.p.: days after planting; FF: First flower opening date, FB: First boll opening date, R1/RT: the production earliness ratio, HH: Height at harvest, HFFN: height of first fruiting node, HLFN: height of last fruiting node, LFB: Length of fruiting branch, LVB: Length of vegetative branch, HNR: Height to node ratio, NBV: Number of vegetative branches, NBF: Number of fruiting branches.

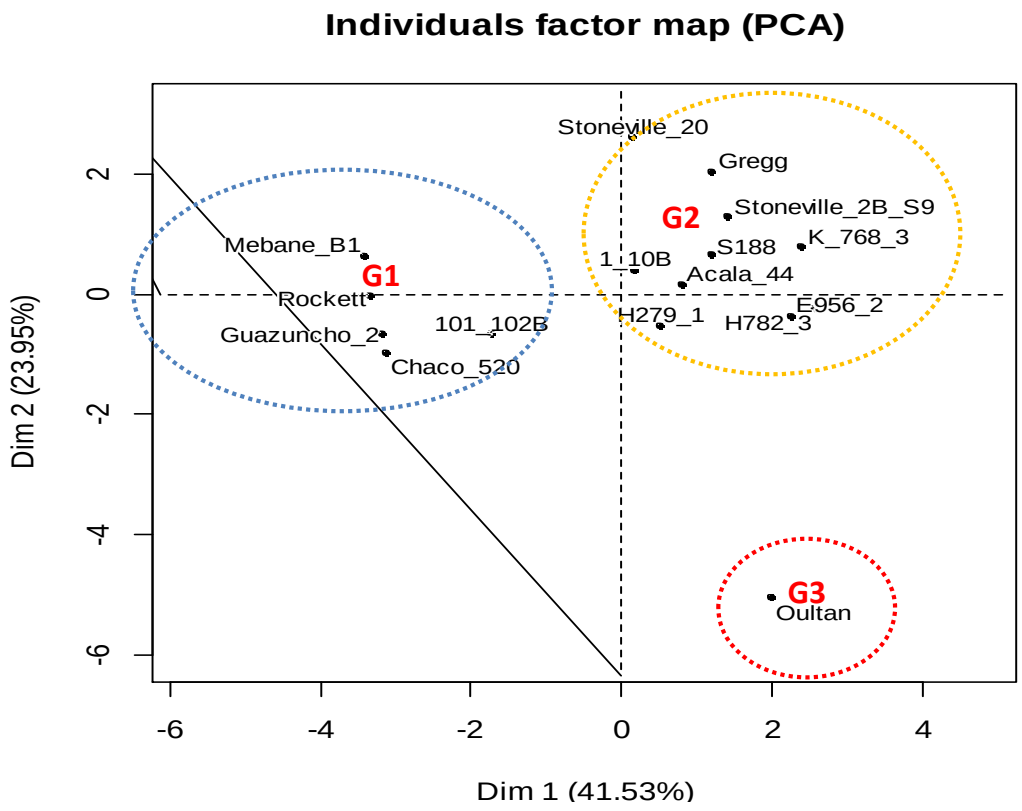

Figure 3. Projection of the varieties in the factorial design formed by the two axes of the principal component analysis (PCA).

at 93.57% and offers a reclassification of certain genotypes analyzed (Table 4). The F-test of Wilks Lambda revealed that five of the eleven characters used allowed to better discriminate genotypes studied (Table

Table 3. Characteristics of different genotypes groups from principal component analysis (PCA).

Groupe	Group 1	Group 2	Group 3	F	P
Number of Génotypes	5	10	1		
FF (jas)	61.2±2.2^{b}	65.0±2.2^{c}	57.0±1.2^{a}	38.73	<0.001
HH (jas)	92.3±11.7^{a}	108.3±15.0^{b}	132.0±28.3^{c}	14.80	<0.001
LFB (cm)	40.2±6.6^{b}	47.6±7.4^{c}	27.5±3.1^{a}	19.04	<0.001
FB (cm)	113.8±1.8^{a}	116.0±2.0^{b}	113.0±1.3^{a}	20.87	<0.001
R1/RT (%)	2.2±0.0^{a}	1.7±0.0^{b}	1.7±0.0^{ab}	8.56	<0.001
HFFN (cm)	11.8±1.6^{a}	14.8±2.3^{b}	13.4±3.2^{ab}	12.50	<0.001
HLFN (cm)	84.3±14.2^{a}	97.5±15.4^{b}	122.0±29.6^{c}	10.59	<0.001
NBF	12.4±2.1^{a}	12.5±2.4^{a}	13.1±2.5^{a}	0.14	**0.873**
HNR (cm)	4.9±0.5^{a}	5.8±0.6^{b}	6.6±0.6^{c}	23.65	<0.001
NBV	1.7±0.8^{a}	2.1±0.6^{b}	2.8±0.7^{b}	6.05	<0.005
LVB (cm)	43.0±18.9^{a}	62.3±12.6^{b}	66.2±26.7^{b}	10.85	<0.001

FF: First flower opening date, FB: First boll opening date, R1/RT: the production earliness ratio, HH: Height at harvest, HFFN: height of first fruiting node, HLFN: height of last fruiting node, LFB: Length of fruiting branch, LVB: Length of vegetative branch, HNR: Height to node ratio, NBV: Number of vegetative branches, NBF: Number of fruiting branches.

Table 4. Groups classification matrix on the basis of characters of phenology and morphology.

Group	% of classification	Group1	Group2	Group3	Total
Group 1	85,71	18	2	1	21
Group 2	95,00	2	38	0	40
Group 3	100,00	0	0	3	3
Total	93,57	20	40	4	64

Table 5. Discrimination power of different variables.

Variables	cor_ratio	wilks_lamb	F_statistic	p_values
FF	0.56	0.44	38.73	1.39E-11
HH	0.33	0.67	14.80	5.75E-06
LFB	0.38	0.62	19.04	3.76E-07
FB	0.41	0.59	20.87	1.24E-07
R1/RT	0.22	0.78	8.56	5.28E-04
HFFN	0.29	0.71	12.50	2.82E-05
HLFN	0.26	0.74	10.59	1.13E-04
NBF	0.00	1.00	0.14	8.73E-01
NBV	0.17	0.83	6.05	4.00E-03
LVB	0.26	0.74	10.85	9.32E-05
HNR	0.44	0.56	23.65	2.49E-08

FF: First flower opening date, FB: First boll opening date, R1/RT: the production earliness ratio, HH: Height at harvest, HFFN: height of first fruiting node, HLFN: height of last fruiting node, LFB: Length of fruiting branch, LVB: Length of vegetative branch, HNR: Height to node ratio, NBV: Number of vegetative branches, NBF: Number of fruiting branches.

5). These are first flower opening date (FF), first boll opening date (FB), height at harvest (HH), length offruiting branches (LFB) and height to node ratio (HNR).

DISCUSSION

Suitable cotton variety selection is imperative to cope

with climatic variations for yield enhancement and sustainability under unpredictable climatic conditions (Habib ur Rahman et al., 2016). Under rainfed conditions where climatic variations are unpredictable like that occurs in Benin, the demonstration of a genetic variability for the morphological and phenological characters in selected genotypes is a guarantee of future genetic progress (Mergeai, 2006; Hajjar et al., 2008). Our study, showed a strong phenological and morphological heterogeneity of the studied collection, thus providing usable genetic variability to achieve the objectives of adaptation of the cropping system to current evolutions on the climatic conditions. The results distinguish three groups of which one consisted of compact and early genotypes. These could be used in crossbreeding to produce varieties adapted to limiting hydrous conditions. Compact and early genotypes were found able to adapt to a more reduced cycle of precipitations (Sekloka et al., 2016; Lu et al., 2017) and their low spatial extent allows for high planting density (Sekloka et al., 2008, 2016; Sahito 2016). These genotypes could be backcrossed to cultivated varieties already adapted to local growing conditions in order to improve the precocity and plant shape in the new varieties.

Results also showed that the Beninese selections, late maturing varieties with high vegetative growth, gave the best yields in cotton seed. In a previous study comparing varieties of different geographical origins and different agro morphological characters, Beninese varieties H279-1, Stam 18 A also gave the best yields in cotton seeds when the water conditions are not limiting (Sekloka et al., 2008, 2016). Our results, consistent with these, validate that in African rainfed conditions, late maturing varieties with high vegetative growth continues to be interesting when rains are regular, abundant and well distributed (Lancon et al., 2007) as was during our study. However, previous work had shown that when water conditions are limiting (late sowings for example), these indeterminate varieties were capable of the best and the worst: they maintain irregular yields that can be found both in the low yield classes and in high yield classes (Sekloka, 2008). Furthermore, it is known that in rainfed, water deficit is the most limiting abiotic factor for productivity and yield in several crops (Loison, 2015). Several authors have shown that water stress particularly affects flowering and boll formation and consequently the fiber yield (Kouakou et al., 2008; Loison 2015; Huang, 2016). The present studies must be repeated in more northern areas of the country where water stress may be stronger. This would allow to better specify the responses of these different genotypes to changes in the environment and to better justify the value of their use in selection.

The most structuring criteria of the genetic variability have been the plant height at harvest, the length of fruiting branches, the height to node ratio, the first flowers opening date and the first boll opening date. Although the number of varieties studied is not very large, the result is similar to those fairly often reported in the literature with respect to the analysis of genetic diversity in the species cotton *G. hirsutum* L. In an earlier study on three years of collection, Djaboutou et al. (2000) have also highlighted three genotype groups contrasted by the same criteria of morphology and precocity. On the other hand, our works differ from those of Bourgou et al. (2014) that highlighted six diverse groups at the end of the evaluation of 336 accessions collected across Burkina Faso. Indeed, the collection described by these authors was larger and contained ecotypes of all grown species, diploid (*G. arboreum* and *G. herbaceum*) as tetraploid (*G. hirsutum* and *G. barbadence*). The variability described by these authors was therefore necessarily larger. The varieties tested in our study, all of the species *G. hirsutum*, were not enough representative of the genetic pool potentially available for improving the cultivated varieties in cotton. Wild cotton previously neglected may be useful in the current context of climate change and continuous narrowing genetic base of cultivated varieties (Mergeai, 2006; Sarr and Mergeai, 2009; Bourgou et al., 2014).

CONCLUSION AND SUGGESTIONS

The different analyzed genotypes have variability for all characters used, particularly those related to phenology, morphology and distribution of production throughout the plant. Compact and early varieties described could be used in crossing to create new improved varieties for earliness and compactness of the port, adapted thus to limiting water conditions. However, this variability is far from being representative of the genetic pool potentially available to improve the varieties grown in cotton.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

Authors thank "Centre International en Recherches Agronomiques pour le Développement (CIRAD)" for providing the seeds of many of the varieties used in this study.

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Vol. 10(2), pp. 41-47, February 2018
DOI: 10.5897/JPBCS2017.0691
Article Number: 7D4B81D55653
ISSN 2006-9758
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Journal of Plant Breeding and Crop Science

Full Length Research Paper

Production of groups of tomatoes in substrate at different concentrations of phosphorus

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Received 8 September, 2017; Accepted 7 December, 2017

The development of production technologies, such as greenhouses, was highlighted in the growth of horticultural crops. However, these products are often offered without basic instructions to farmers who can generate financial losses. One outstanding production technology is substrate cultivation, which would be very useful in the cultivation of protected plants. Like this, in order to evaluate the effects of different doses of phosphorus on the production of tomato groups grown in substrate under greenhouse conditions, a randomized complete block design was used in a 2 x 5 factorial scheme, with two tomato groups: Santa Cruz "Debora Max" and Cherry "Coco" x five rates of P_2O_5 (0; 33; 66; 99 and 132 g; 10 L of nutrient solution) with four replicates. The results showed that the electrical conductivity inside the Slabs is not homogeneous, being recommended to wet the substrate inside the slabs, before the planting to reduce the electrical conductivity. In relation to phosphorus efficiency, the highest tomato yield was for the 6.6 g L^{-1} phosphorus dose for the two Santa Cruz and Cherry groups. The main advantage of using slabs in tomatoes is the efficiency of the phosphorus used in the first planting.

Key words: *Lycopersicon esculentum*, substrate, slabs, phosphorus, fertilization.

INTRODUCTION

The tomato *Lycopersicon esculentum* Mill is one of the main vegetables produced in Brazil, arriving at the market in an in natura or processed way. The tomato production chain reached more than 37 million tons in 2010, for global parameters, consolidating the chain as one of the main agribusiness. By 2016, according to estimates by the World Tomato Processing Council, the amount should reach more than 39.3 million tonnes. Most of the production, near 97%, is concentrated in the 10 largest producers, which accumulate around 34.1 million tons. Brazil is in eighth place with 1.25 million tons produced (Carvalho et al., 2016).

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In order to improve tomato yield and meet increasing demand, new technologies have been adopted, among which the production in a protected environment stands out (Cararo and Duarte, 2002). The cultivation in a protected environment provides better accommodation of the plants against undesirable climatic factors, reducing the risks of tomato cultivation, besides allowing the production of fruits in times not favorable to the conduction of planting in the open field (Alvarenga, 2004). The technique of cultivation in protected environment using substrate has been generalized to allow better nutrient absorption, higher productivity, better product quality and facilitation of the implementation of cultural practices (Gul et al., 2005).

Gualberto et al. (2002) comments that this system has many advantages that include the high quality and yield of the crop, lower fertilizer losses and the better use of water, besides the reduction in environmental pollution and greater control and efficiency in the process productive. Riviere and Caron (2001) report that substrate cultivation is effective in protecting crop pathogens from soil and, despite the high cost and demanding a better technological level, this technique has attracted producers from several countries.

The material that is used in this research is ‘’slabs’’ that are bags with dimensions that vary from 1.50 x 50 cm in width that, when filled, are 30 cm in diameter. The material was designed in 2010, after several attempts of cultivation in pots, bags for seedlings, cultivation channels, the system is widely used in developed countries (Holler, 2015). The research carried out in Brazil indicated the possibility of tomato production on substrate (Loures et al., 1998). However, regarding the correct supply of nutrients in the substrate, there are still many problems related to fertilization, which can increase the electrical conductivity in canopy plants (Blanco et al., 2002).

Although irrigation water in protected crops is of good quality, the addition of fertilizers, when using the fertigation technique, makes it saline, increasing the risk of salinization, especially potassium chloride, which has high salinity (Marques et al., 2014). This conclusion is confirmed by Fontes et al. (2004), which reports the accumulation of salts, the presence of soil pathogens and allopathic substances, as a limiting factor for the tomato crop economy.

Other limitations that occur in agricultural production in acidic soils of tropical and subtropical regions are the low availability of phosphorus in the soil, due to the high adsorption capacity and / or low content of the nutrients in the source material, and the low efficiency of absorption and use of phosphorus presented by most modern varieties commercially used (Novais and Smyth, 1999). These conditions have required the application of high doses of phosphate fertilizer. As a result of these facts, the use of efficient cultivars in the absorption and utilization of nutrients under low phosphorus availability conditions has been suggested (Silva and Gabelman, 1992).

Facing this national scene, fertilizer doses exceeding 300 kg P_2O_5 per hectare have been associated with maximum yield in the tomato plant, being frequently used doses that reach 1200 kg of P_2O_5 per hectare. A reduction of only 100 kg P_2O_5 per hectare in the use of this nutrient by tomato plants would represent savings of more than R$ 200.00 per hectare which, represents the national tomato production level, a savings of more than R$ 11 million (Silva and Maluf, 2012).

Despite the wide knowledge of the effects of phosphorus (P_2O_5) in tomato cultivation in the soil, a poor understating of the effects in the protected cultivation, especially when grown in plastic containers, tubes type "slabs" filled with commercial substratum and conducted under fertigation. The research objective was to evaluate the effects of different doses of phosphorus on the production of cultivated tomato groups in substrate under greenhouse conditions.

MATERIALS AND METHODS

The experiment was carried out in the Olericultura and Experimentation Sector of the José do Rosário Vellano University - UNIFENAS located in the city of Alfenas - Minas Gerais, Brazil, located in the geographical coordinates: 21° 25 '45 "south, 45º 56' 50 " west, and average altitude of 881 m.

The annual average temperature is 19°C in the summer and in the spring are the hottest seasons, with daily maxima varying from 28 to 30°C, October and November are the hottest months coming from 36 to 37°C (CPTEC / INPE, 2017). Two groups of tomato (Santa Cruz, 'Débora Max' and Cereja, 'Coco' cultivar) were used in the research. The seedlings were produced in styrofoam trays with 128 cells using commercial Plantmax® substrate and transplanted into the 'slabs' with four final leaves. The 'slabs' were made with polyethylene bags, with dimensions of 0.25 m wide by 2.80 m long and filled with commercial substrate. The 'slabs' were distributed in 0.30 m spacing between plants and 0.40 m between lines, 9 meters long, where they remained until the end of the experiment. It was standardized using four plants per treatment by removing two plants from the border.

Table 1 shows the chemical analysis of the substrate within the ‘slabs’ where the tomato groups were conditioned during the experiment. A randomized block design in a factorial 2 x 5 was used, consisting of two tomato groups, "Santa Cruz and Cereja” commercial lines “Débora Max" and Coco" respectively x five doses of P_2O_5 (0; 33; 66; 99 and 132 g P_2O_5 to 10 L of nutrient solution, with four replications.

In addition to the phosphorus (P_2O_5), the other nutrients necessary were applied according to the suggestion of Silva et al. (2005), adapted to tomato plants. The amount of fertilizer was divided into 10 applications through fertigation being initiated at 5 days after transplanting (DAT). Tanks with airtight lids connected to the irrigation system in two locations was used, and the water, going through the tank, received fertilizers forming the nutrient solution, which was conducted by drip line to the canopy of the tomato crop. During this experiment, the handling and cultural practices as recommended for the tomato crop was used.

After 0, 60 and 110 DAT, aliquots of solution used on the substrate was collected, to quantify the electrical conductivity (EC). For both, trays in the plant canopy to collect the solution drained after fertigation was placed. Suddenly, the solution was stored in

Table 1. Chemical analysis of substrate in “slabs” before fertigation.

Macronutrients and micronutrientes	mg dm³
Aluminum (Al)	< 0.1
Calcium (Ca)	2.0
Magnesium (Mg)	1.0
Potassium (K)	7.0
Phosphorus (P)	55.0
Sulfur (S)	170.0
Sodium (Na)	42.0
Boron (B)	1.2
Iron (Fe)	5.0
Manganese (Mn)	0.1
Copper (Cu)	0.2
Zinc (Zn)	0.2
Chlorine (Cl)	260.0
Nitrogen (N)	0.78*
Eletrical Conductivity (25°C)	0.815**

(%)*; (mS m^{-1})**.

Table 2. Summary of variance analysis for the electrical conductivity (EC), dry matter of aerial part (MSPA), number of fruits (NF), tomato production, P rates (TP) in relation to P_2O_5 doses and two tomato groups (Santa Cruz "Debora Max" and Cereja cultivar "Coco" in tomato plants.

Variation source	GL	Mean square				
		EC	MSPA	NF	Production	TP
Rate P_2O_5 (D)	4	0.62*	21.66*	53*	10857*	45.37*
Tomato groups (TG)	1	1.17*	0.09*	416*	62400*	42.43*
D x TG	4	1.23*	8.94*	11*	11176*	43.58*
Block	3	0.92	0.12	1	112	0.53
Residue	27	0.13	0.35	1	170	0.13
CV%	-	**7.5%**	**5%**	**7%**	**8%**	**3%**

*= Probability significant 5%; ns = probability not significant a 5%.

Falcon Tube and sent to the laboratory where the electrical conductivity (EC) measurement was performed. A digital conductivity meter was used (Lutron, mod. CD-4303).

The aerial part (stem + leaves) (g $plant^{-1}$) was collected on 130 days after transplanting (DAT), for the determination of the dry matter of the aerial part (MSPA). The material was dried at 70°C with forced ventilation, until constant weight. The part aerial + stem was processed together. The phosphorus concentration in leaf tissue (g kg^{-1}) was measured at 90 DAT in the leaf analysis laboratory of the Department of Soil Science of the Federal University of Lavras, MG, determined according to the methodology described by Malavolta et al. (1997).

The efficiency of the acquisition and use of P (EAQ and EUTIL) and its components were obtained by means of the following expressions (Moll et al., 1982). For the efficiency of the P acquisition, we used the equation: EAQ = (Total content of P in the leaflet / Quantity of soluble P in the solution) and EUTIL = (Tomato production / total P in the leaflet). The phosphorus content in the nutrient solution was quantified at 90 DAT (mg L^{-1}) in Natural Resources Laboratory, for spectrophotometer (HACH mod. DR 6000) and flame photometer (Analyser mod. 910 M) was used according to Okumura et al. (2004). During the experiment, six harvests of ripe fruit was carried out, compared to tomato groups.

The results were submitted to analysis of variance. According to the theories recommended by Steel et al. (2006), the Scott-Knott test or t-test in order to evaluate the average was applied. The standard deviations were calculated and applied estimators of regression and correlation (Pearson or Spearman), using the SISVAR software (Ferreira, 2011).

RESULTS AND DISCUSSION

Significant interactions between all the evaluated characteristics of phosphorus levels and tomato groups have been observed (Table 2). The EC has risen with the increase of doses of P_2O_5 for the groups "Santa Cruz and Cereja", to a maximum of 1.5 and 1.40 dS m^{-1}.

From the dose of 66 g P_2O_5 10 L^{-1}, it was observed a

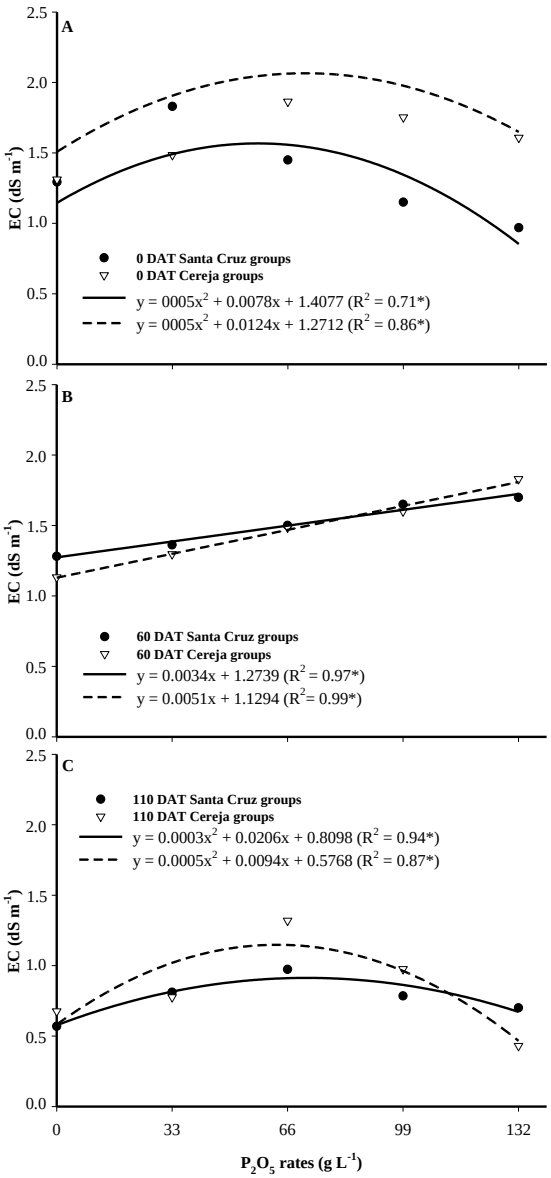

Figure 1. Electrical conductivity (EC) (dS m^{-1}) of the substrate within the "slabs" in relation to P_2O_5 levels and tomato groups "Santa Cruz and Cereja" in 0 (A), 60 (B) and 110 (C) days after transplanting.

decrease in EC (Figure 1A). At 60 DAT, regardless of tomato group, EC rose with increasing rates of P_2O_5. However at 110 DAT, the EC showed the maximum increase, 1.32 mS dm^{-1} at a dose of 66 g P_2O_5 10 L^{-1}, from this value there was a decrease in EC for the "Cereja". The same trend of maximum increase of EC at a dose of 66 g P_2O_5 10 L^{-1} was observed for "Santa Cruz", reaching 0.97 dS m^{-1} in higher rates where there was a reduction in the EC. It has been noted that there was a difference of EC between the tomato groups, especially when compared to EC in "Cereja", which was higher than the EC in "Santa Cruz". This may be related to the lack of homogeneity of the substrate, since the electrical conductivity is directly associated with the ionic concentration and the absorption of the nutrients by the culture during its development (Marschner, 1995).

For Li and Stanghellini (2001) studying the effects of electrical conductivity and the potential of perspiration in the production of tomato plants cultivated in greenhouses, observed that with increasing concentration of nutrients in the nutritive solution, there was a significant decrease of production, mainly due to reduction of the size of the fruit, this is because of the lowest amount of water absorbed by the fruit. Since the dry mass of the fruits was not affected by high EC in the root zone. Researches related to the effects of EC in the production of roots and its effect on the decrease in production of eggplant fruits, and plant from the same access of tomatoes was reported by Marques et al. (2011).

With the growth of tomato plants, there was a reduction of EC, which is associated with greater cellular respiration, which provided higher absorption of P. The extraction and accumulation of nutrients by plants depends on other factors, from the EC, whose values are proportional to the concentration of the various ions responsible for the osmotic potential of the solution (Figure 1).

For the concentration of P in leaf tissue (Figure 2), independent of P rates, the "Cereja" has accumulated the highest concentrations of P compared to the "Santa Cruz". The amount of nutrients absorbed by the tomato plant and its partitioning are usually associated with plant growth, production and depends on abiotic factors, including the fertilizer and tomato groups. The phosphorus (P) concentration in the nutritive solution drained from “slabs” quantified at 90 DAT for different groups of tomatoes is presented in Figure 2 (B).

For the concentration of P in the control treatment, there was no significant difference between the groups of tomato plants. It is notable that although no addition of P in this treatment was detected, a trace of this element in solution P came from the substrate (Table 1) which did not affect the search results. With increasing concentrations of P in rates of 33 and 66 g P_2O_5 to 10 L^{-1} nutrient solution, the tomato "Cereja" showed the highest concentration of P in the solution.

However, for the P concentration in the dose 99 g P_2O_5 to 10 L^{-1} in solution of “Cereja” was higher. On the other hand, for the dose of 132 g P_2O_5 to 10 L^{-1} a higher production for the "Santa Cruz" was noted (Figure 2). The dry matter production of aerial part (MSPA) expressed in grams $plant^{-1}$, the tomato "Cherry and Santa Cruz" at rates of 0; 33 and 132 g of P_2O_5, when using 10 L^{-1} of nutrient solution provided no significant difference between the tomato groups.

However, with a dose of 66 g of P_2O_5 10 L^{-1} of nutrient solution, the production was higher in the group "Cherry". At rates 99 and 132 g of P_2O_5 10 L^{-1} of nutrient solution,

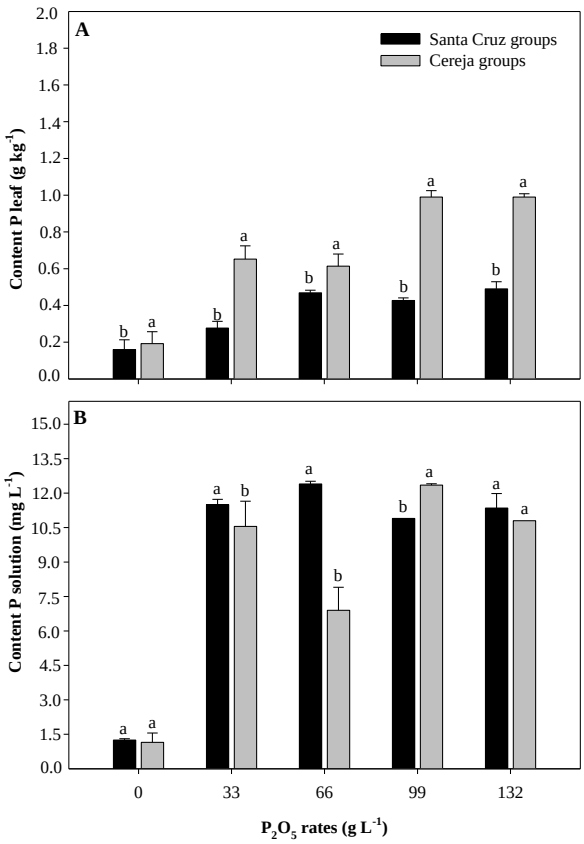

Figure 2. Content of P in the nutrient solution drained of "slabs" during fertigation (A) and P content in the leaf (B) according to P_2O_5 rates used in tomato groups "Santa Cruz and Cereja".

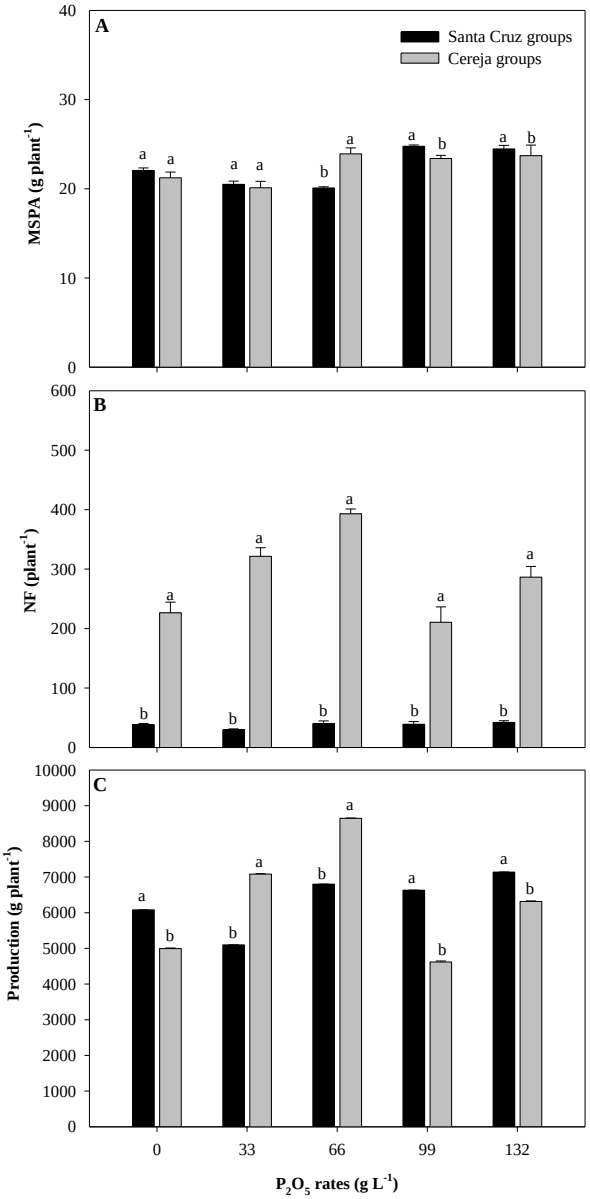

Figure 3. Aerial part dry matter (A), number of fruits (B) and tomato production (C) associated to the rates and groups of tomato grown in "slabs" of increasing concentrations of P_2O_5.

the highest MSPA production was for Santa Cruz (Figure 3A). As for the number of fruits per plant (Figure 3B) Cherry "Cocco" was larger when compared to "Santa Cruz". According to Genuncio et al. (2010), the dry matter (leaflet + stem) for the Cherry tomato group is 93 g plant^{-1}, and for the Santa Cruz group it was 64 g plant^{-1}. For tomato yield it reaches 95%, the level of P in leaves should be between 1.7 to 3.0 g kg^{-1} (Silva et al., 2005).

However for commercial tomato production (Figure 3C), the control treatment was higher for the "Santa Cruz" group. With the increase of the concentration of P in rates of 33; 66 g of P_2O_5 10 L^{-1} of nutrient solution, "Cherry" was the most productive when compared to "Santa Cruz". The highest production of fruits was observed with doses of 66 and 132 g of P_2O_5 10 L^{-1} of nutrient solution, where the maximum production was 8646 g plant^{-1} for the Cherry group and 6800 g plant^{-1} for Santa Cruz. It was observed that, at 0 and 132 g of P_2O_5 10 L^{-1} of nutrient solution, the phosphorus content in the ‘’slabs’’ (Table 1) was sufficient for the production of 6 and 5 kg of plant^{-1} of fruit for "Santa Cruz and Cherry", respectively. It was observed that "Cherry" was the most sensitive to the lack of phosphorus in the control treatment and to the dose of 132 g of P_2O_5 10 L^{-1} of nutrient solution.

This difference may be related to greater nutritional needs of the "Santa Cruz" group, whose fruits are larger and, consequently, with greater nutritional need in relation to the "Cherry". These results corroborate the data of Alvarez et al. (2008), citing that plant species have different abilities to absorb P_2O_5, which allows the use of this characteristic to distinguish genotypes with high efficiency for absorption of P_2O_5 in soil solution or genotypes that have tolerance to low levels of this nutrient.

In order to evaluate the adaptation of cultivars and / or

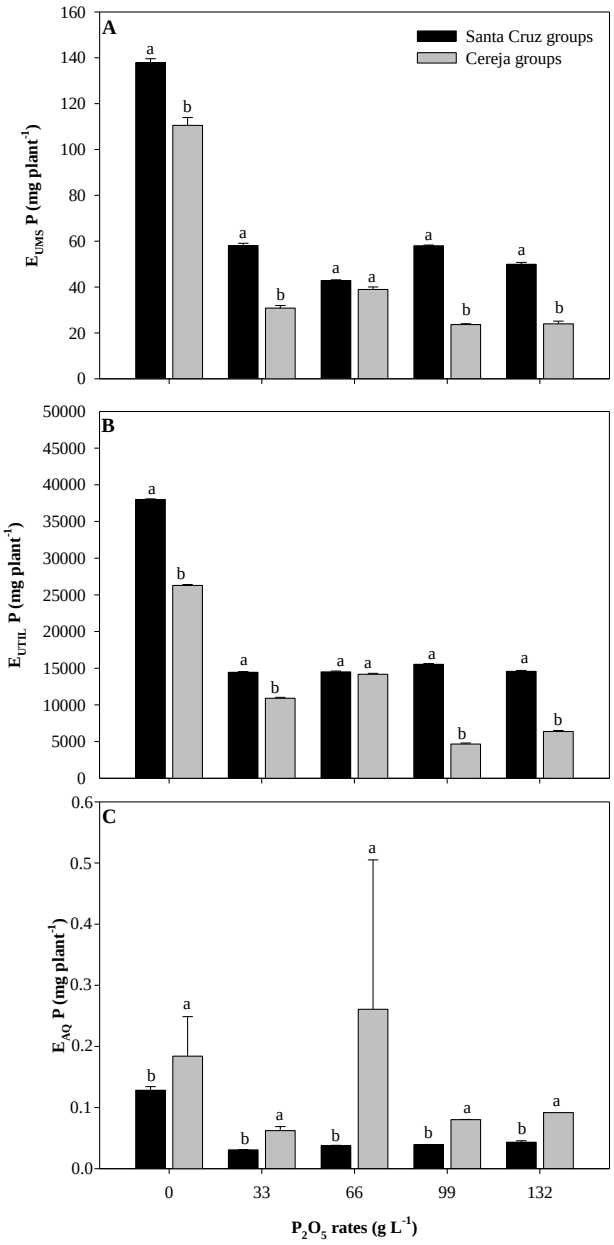

Figure 4. Efficiency in use in dry matter (A), production of tomatoes (B) and absorption of P (C) in rates and tomato groups cultivated in slabs on increasing concentrations of P.

hybrids to the protected cultivation of tomatoes, variations in productivity were verified due to interactions between genotypes and environments and cultural practices adopted in different trials (Caliman et al., 2005). When genotypes with high productive potential and management of favorable environmental conditions are associated, high yields are obtained, increasing production from 25 to 40% due to early maturation, better uniformity, higher initial vigor and development, better fruit quality and resistance to diseases (Melo et al., 2009).

The occurrence of genotypic variability, due to its tolerance to low phosphorus content has been reported in several economically important crops, including tomato. However, information on use efficiency phosphorus and nutrients for these varieties are very small. According to Moraes (1997), there is a need for more detailed information on the mineral nutrition of tomato in protected cultivation, since these are essential for the definition of adequate doses of fertilizers, aiming at maximum efficiency and high quality of fruits.

The efficiency in the use of P in dry matter, the leaf and the EUMS (efficient use of P in dry matter) was superior to the control treatment, in the group "Santa Cruz". The "Santa Cruz" presented higher EUMS in comparison to the "Cereja" due to increase in the P_2O_5 levels. There was no significant difference at the dose of 66 g P_2O_5 10 L^{-1} of nutrient solution (Figure 4A).

In the Figure 4 (B), the same trend was observed for "Santa Cruz", regardless of P_2O_5 rate, there was a higher EUTIL (tomato production/total P in the leaf) compared to the “Cereja”. For the absorption efficiency of P (EAQ), regardless of the phosphorus levels used, “Cereja” was superior compared to the “Santa Cruz” (Figure 4 C). Studies on the efficiency in the use of P, based on the genotypic variability, aimed at tolerance to low phosphorus content has been reported in several crops of economic importance (Silva and Gabelman, 1992).

In Brazil, countless works were conducted to evaluate the morphological and agronomical characteristics, fruit quality and edaphoclimatic adaptation of tomato cultivars, including cultivars “Santa Cruz and Santa Clara” configured as progenitor of important genotypes (Silva, 1996; Peixoto et al., 1999).

Conclusion

The electrical conductivity on the slab substrate was not homogeneous. The correct supply of nutrients in the substrate can increase the electrical conductivity, so it is necessary to recondition the substrate before sowing, in order to reduce the electrical conductivity. For the tomato group “Cereja and Santa Cruz”, phosphate fertilizer provided the best yields when applying the dose of 66 g P_2O_5 to 10 L^{-1} of nutrient solution to the "slabs". An important advantage of using "slabs" in tomato plants is the efficiency of the use of phosphorus in the first sowing, providing a better crop yield and better plant growth.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Vol. 10(2), pp. 48-57, February 2018
DOI: 10.5897/JPBCS2016.0589
Article Number: 1AA1E7C55880
ISSN 2006-9758
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http://www.academicjournals.org/JPBCS

Journal of Plant Breeding and Crop Science

Full Length Research Paper

Screening cotton (*Gossypium hirsutum* L.) genotypes for drought tolerance under screen house conditions in Malawi

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Received 1 June, 2016; Accepted 25 July, 2017

Drought stress is a major factor decreasing cotton productivity in Malawi. To identify drought tolerant cultivars, a study was conducted in 2012 at Bunda College to evaluate the performance of 20 cotton genotypes under water stress conditions. A screen house pot experiment was carried out using a randomized complete block design and data were recorded on tap root length, lateral root number, fresh root weight, dry root weight, fresh shoot weight, dry shoot weight, shoot length, root volume, number of leaves per plant, and stem diameter. Results revealed significant differences among genotypes for response to drought stress. Six genotypes (06K485, 06K486, SPAN 837, FQMA (05) 5 bcp, Chureza, and RASAM 17) showed drought tolerance. The inclusion of these genotypes as parents in the drought tolerance breeding programme can have a significant impact to minimize the adverse effects of drought on cotton in Malawi.

Key words: Cotton, genotypes, water stress, growth, productivity traits.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is the most important fiber crop, providing half of the global fibre requirement (Pretorius, 2009; Poehlman and Sleper, 1995). Despite the availability of synthetic alternatives, it continues to serve as the most important source of fiber for textiles (Sunilkumar et al., 2006; Martin et al., 2006). The seed is also of economic importance (Pretorius, 2009) and used as a primary source of vegetable oil for culinary purposes, with the oilcake residue as a protein-rich feed for ruminant livestock (FAO, 1994). Cottonseed contains 21% oil and 23% protein, both of which are of relatively high quality (Rathore, 2007). Cotton seed oil is also used in products such as soap, margarine, emulsifiers, cosmetics, pharmaceuticals, rubber, and plastics (USDA, 2008).

In Malawi, cotton is one of the most important cash crops (MoAFS, 2006). Rural households planting cotton rely almost solely on the crop for their cash income, which is used for buying food items for family consumption (Fortucci, 2002). Despite its importance as a cash crop for a considerable proportion of the country's farming community, farmers generally obtain very low yields, which are about 25 to 30% of the potential production. Drought is one factor contributing to the huge

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disparity in yields (MoAFS, 2005). Drought stress has the highest percentage (26%) when the usable areas on the earth are classified in view of stress factors (Farshadfar et al., 2012). Genetically, equivalent cotton plant populations, when subjected to water deficit show reduction in yield of up to 50% if compared to those that have been irrigated (Brito et al., 2011). Malawi depends on rain-fed agriculture which is vulnerable to extensive dry spells and droughts. The country has experienced changing rainfall patterns in recent years, including changes in the on-set of rains and irregular and uneven rainfall distribution (Ministry of Mines, Natural Resources, Energy and Environment, 2006). Irrigation has the potential to increase crop production; however, many farmers do not have access to adequate irrigation facilities. Cotton varieties with acceptable levels of drought tolerance are the only cost-effective drought management tactic available to small-scale farmers. Genotypic selection for adaptation to different water regimes is an important strategy in breeding programmes to develop drought tolerant varieties (Monneveux and Ribaut, 2011).

A lot of work has been done to develop drought tolerance in cotton, that is, Basal et al. (2005) reported that root characteristics play an important role in determining the response of plants to drought and that water deficit decreases shoot growth rate, plant height and yield, but root growth is less sensitive to drought than shoot growth. Root elongation during drought may help plants get deeper water, thus avoiding water deficits near the soil surface (Pace et al., 1999). Basal et al. (2005) reported that drought-stressed cotton seedlings showed some increase in root length but reduced diameter. Iqbal et al. (2011) found out that the differing measurement of root and shoot lengths of *G. hirsutum* seedlings indicated variability among varieties/lines to the adverse effect of water stress. Basal et al. (2005) indicated that root growth is a reliable indicator of the response to drought tolerance. Significant variability for taproot length and number of lateral roots among exotic cotton germplasm has been reported. It has been indicated that the day-neutral converted race stocks (CRS) accessions have useful genetic variability for root growth parameters which were root length (RL), lateral root number (LRN), root fresh weight (RFW), lateral root dry weight (LRDW) and total root dry weight (TRDW) (Basal and Unay, 2006). Kohel and Lewis (1984) reported that significant genetic variability exists among the exotic strains of *G. hirsutum* for dry matter accumulation, heat tolerance and root growth; and that root growth and vigorous growth of root laterals are important to the adaptation of cotton to limited supplies of soil water. Ali et al. (2011) reported that the information about significant correlation among the traits is important for initiation of any breeding programme because it provides a chance for selection of desirable genotypes with desirable traits. Basal et al. (2005) found that root length, lateral root number, total dry root weight, and shoot dry weight were all positively and significantly correlated.

Currently, there is no information on the performance of cotton genotypes under water stress conditions; hence, the screening of cotton varieties grown in Malawi is needed to identify drought tolerant varieties. The present study was carried out to determine the genotypic variation among 20 cotton genotypes for growth and productivity traits in response to water stress to identify drought tolerant varieties.

MATERIALS AND METHODS

Because there is no information available on drought tolerance for cotton varieties grown in Malawi, 20 genotypes were randomly chosen from released varieties, promising lines and working accessions. The genotypes were SZMA (04) 4bcp, FQMA (05) 5bcp, MAP85 (05) 18bcp, Acala glandless, CHUFQ (06) 1bcp, Glandless NC-1, CHUMA (04) 17 bcp, 06K485, K502MA (05) 1bcp, IRMSZ (06) 3bcp, MACHU (06)1, BF26 (03) 4bcp, SPAN 837, MTB (84) 2, SZ9314, 06K486, Makoka 2000, RASAM 17, IRM 81, and Chureza. The genotypes varied for leaf colour, yield potential (seed cotton yield), ginning out turn, tolerance to jassid insect attack and bacterial blight disease, gossypol levels, and fibre colour (Table 1). Seeds were obtained from the Department of Agricultural Research Services (DARS) national cotton breeding programme in Malawi.

The study was conducted in a translucent plastic screen house at the Student's Research Farm of the Department of Crop and Soil Sciences, Bunda College of Agriculture (14°11´ S and 33°46´ E, 1100 m above sea level), Lilongwe, Malawi from March to June 2012. The experiment was a randomized complete block design with two watering regimes (well - watered and water - stressed), and 20 genotypes, making a total of forty treatment combinations. The treatments were replicated three times. Each experimental unit composed of two pots with three plants per pot, giving a total of 240 pots.

Five-litre plastic pots, perforated at the base, were filled with 4.0 kg of soil composed of 2 parts loam soil and 1 part river sand. Pots were watered to field capacity before planting. NPK fertilizer (23:21:0 + 4 S) was thoroughly mixed in water and added to each pot prior to planting at rates equivalent to 34 kg ha^{-1} N, 45 kg ha^{-1} P_2O_5, and 22 kg ha^{-1} S (Sarrantonio, 1991). Eight fuzzy cotton seeds per pot were sown on 13 March, 2012. Seedlings were thinned to three plants per pot, three weeks after planting. Plants were allowed to grow under optimum water regime from sowing to 38 days after emergence (DAE). Thereafter, pots were divided into two sets; one set was treated as the well-watered (W1) control and the other set was the water-stressed (W2) treatment. For the non-stressed water regime, pots were maintained at field capacity throughout the growing period by irrigating four times a week with 500 ml of water per pot. In the water-stressed regime, stress was imposed by withholding water from the pots until 50 % of the plants showed signs of stress. Drought stress was determined by visually evaluating plants for wilted or rolled leaves where the rolled leaf rim covered part of the leaf blade (Monneveux and Ribaut, 2011). These signs of drought stress appeared after four days, after which pots were irrigated four times per week with 250 ml of water per pot. Therefore, the water-stressed treatments received 50% of the quantity of water compared to the well-watered controls needed in the non-stress condition (Ali et al., 2011) in order to relieve the signs of wilting, but not enough water to reach soil field capacity (Loka and Oosterhuis, 2009). The treatments were maintained for 21 days. The effects of drought stress were determined by measuring 11 parameters including tap root length (TRL),

Table 1. List of cotton genotypes evaluated under translucent plastic screen house conditions at Bunda College, 2012.

Genotype name	Source	Status	Description
SZMA (04) 4bcp	DARS, Malawi	Promising line	Selection from a cross between SZ9314 and Makoka 2000. Green, palmate, hairy leaves. Seed cotton yield potential of 2400 kg ha^{-1}, mean GOT of 40%. Tolerant to jassid insect attack.
FQMA (05) 5bcp	DARS, Malawi	Promising line	Selection from a cross between a Zimbabwe variety FQ902 and Malawi variety Makoka 2000. Pale green, palmate hairy leaves. Seed cotton yield potential of 2300 kg ha^{-1}, mean GOT of 41%. Tolerant to jassid insect attack.
MAP85(05) 18bcp	DARS, Malawi	Promising line	Selection from Malawi panmixes bulk of chosen potential commercial varieties in Malawi. Pale green, palmate hairy leaves with compact growth habit and an open canopy. Seed cotton yield potential of 2300 kg ha^{-1}, mean GOT of 39%. Tolerant to jassid insect attack.
Acala glandless	DARS, Malawi	Working accession	Palmate hairy leaves with pale green plant colour. Has low levels of gossypol, seed cotton yield potential of 1700 kg ha^{-1}, mean GOT of 38%. Tolerant to jassid insect attack.
CHUFQ (06) 1bcp	DARS, Malawi	Advanced line	A selection from a cross between Zambian and Zimbabwe commercial varieties. Seed cotton yield potential of 2200 kg ha^{-1}, mean GOT of 39%. Tolerant to jassid insect attack.
Glandless NC-1	DARS, Malawi	Working accession	Palmate hairy leaves, pale green colour, not tolerant to early jassid attack. Has low levels of gossypol. Seed cotton yield potential of 1800 kg ha^{-1}, mean GOT of 36 %. Tolerant to jassid insect attack.
CHUMA(04) 17bcp	DARS, Malawi	Promising line	Palmate hairy pale green leaves with open canopy. Seed cotton yield potential of 2000 kg ha^{-1}, mean GOT of 39%. Tolerant to jassid insect attack.
06K485	DARS, Malawi	Newly released	Originated from Albar stocks; compact growth habit with pale green, palmate hairy leaves; GOT around 41%, seed cotton yield potential above 3000 kg ha^{-1}. Tolerant to jassid insect attack.
K502MA(05) 1bcp	DARS, Malawi	Promising line	Pale green, palmate hairy leaves with an open canopy. Has seed cotton yield potential of 2000 kg ha^{-1}, mean GOT of 38 %. Tolerant to jassid insect attack.
IRMSZ(06) 3bcp	DARS, Malawi	Promising line	A selection from a cross between a Malawi and Zimbabwe commercial varieties. Pale green, palmate hairy leaves with open canopy. Seed cotton yield potential of 2000 kg ha^{-1}, mean GOT of 40%. Tolerant to jassid insect attack.
MACHU(06)1	DARS, Malawi	Promising line	Green palmate hairy leaves with compact growth habit. Seed cotton yield potential of 2000 kg ha^{-1} and mean GOT of 40%. Tolerant to jassid insect attack.
BF26 (03) 4bcp	DARS, Malawi	Working accession	Pale green hairy leaves and stems. Brown fibre with seed cotton yield potential of 2500 kg ha^{-1} and mean GOT of 37%. Tolerant to jassid insect attack.

Table 1. Contd.

SPAN 837	DARS, Malawi	Working accession	Palmate green light hairy leaves. Seed cotton yield potential of 2000 kg ha^{-1}, mean GOT of 38%, susceptible to jassid insect attack during early crop growth.
MTB (84) 2	DARS, Malawi	Working accession	Has high tolerance to jassid insect attack during early crop growth. Compact growth habit with open canopy. Seed cotton yield potential of 1800 kg ha^{-1}, mean GOT of 38%.
SZ9314	DARS, Malawi	Released variety	Pale green, palmate hairy leaves and stems. Introduced from Zimbabwe with seed cotton yield potential above 3000 kg ha^{-1} and mean GOT of 43%. Tolerant to jassid insect attack.
06K486	DARS, Malawi	Newly released	Selection from Albar stocks; closed growth habit with pale green, palmate hairy leaves ; mean GOT of 41%, seed cotton yield potential above 3500 kg $ha^{-1.}$ Tolerant to jassid insect attack.
Makoka 2000	DARS, Malawi	Released variety	Bred in Malawi for low altitude areas. Developed from a selection of Albar stocks from Chad and Cote d'Ivoire. Seed cotton yield potential of 3000 kg ha^{-1}, tolerant to jassid insect attack, mean GOT of 39%.
RASAM 17	DARS, Malawi	Released variety	Bred in Malawi for lakeshore areas. Developed from Albar stocks imported from West Africa. Resistant to bacterial blight disease and jassid insect attack. Seed cotton yield potential of 3000 kg ha^{-1}, tolerant to jassid insect attack, mean GOT of 38%.
IRM 81	DARS, Malawi	Released variety	Bred in Malawi for medium and high altitude areas. A selection from Albar stocks imported from Chad. Tolerant to jassid attack and bacterial blight disease. Seed cotton yield potential of 3500 kg ha^{-1}, tolerant to jassid insect attack, mean GOT of 38%.
Chureza	DARS, Malawi	Released variety	An introduction from Zambia. Tolerant to jassid insect attack. Erect and compact growth habit with pale green, lobed and hairy leaves; seed cotton yield potential of 3000 kg ha^{-1}; mean GOT of 42%.

lateral root number (LRN), root fresh weight (RFW), root dry weight (RDW), shoot fresh weight (SFW), shoot dry weight (SDW), shoot length (SL), root volume (RV), total biomass (TBM), stem diameter (SD), and number of leaves per plant. A mean of three plant measurements of each genotype was used for statistical analyses for all the parameters in each replicate under non-stress and stressed conditions. The methods of measurements are subsequently described in detail.

Taproot length (TRL) of each plant was determined by removing the soil together with the plants from the pot, uprooted the plants carefully as the soil was loose, washed them free of soil and then directly measured the tap roots in centimeters (cm), before oven drying, from the junction of the shoot and root to the terminal of the root with a measuring tape. Lateral root number (LRN) was determined by direct counting of roots before oven drying. Roots were washed free of soil, spread on a paper for determination of lateral root number, a technique similar to the one used by Basal et al. (2005). Plants were cut at the junction of the root and shoot to measure fresh weight of the roots. Fresh weight of the roots (RFW) was recorded in grams (g) before oven drying, using an electronic balance. In order to measure root volume (RV) in mm^3, roots were washed free of soil and a graduated measuring cylinder with known water volume was used as the following.

Root volume = (Water + roots volume) – water volume. Root dry weight (RDW) was determined by placing the roots in paper bags and oven drying for 48 h at 75°C (Ali et al., 2011), to have the roots completely dried. Root dry weight (g) was weighed with the help of an electronic balance. Shoot fresh weight (SFW) was determined after shoot was separated by cutting at the junction of root and shoot. SFW was obtained with an electronic balance in grams, a procedure as was used by Iqbal (2010). Shoot length (SL) was obtained after the shoot was separated by cutting at the junction of root and shoot (Iqbal, 2010). A measuring tape was used to measure SL (cm) from the cotyledonary node to the apical bud.

Shoot dry weight (SDW) was obtained after recording fresh weight. Shoot samples were then placed in paper bags and oven dried for 48 h at 75°C to get the shoots completely dried. Shoot dry weight (g) of each treatment was recorded with the help of an electronic balance. Weight of each plant (dry root weight + dry shoot weight) after oven drying was recorded after weighing on a digital balance to obtain total biomass (TBM). Stem diameter (SD) was measured on the shoot which was earlier separated from the root using a ruler from the middle of the lower first and second node of the plants (Iqbal, 2010). Number of leaves per plant was obtained by direct counting of leaves of each plant before uprooting (Mahmood et al., 2006).

Data analysis

The mean of three plant measurements of each genotype was used for statistical analyses for all the parameters in each replicate under non-stress and stressed conditions. Data were subjected to analysis of variance using General Statistics (GenStat 14th edition) to test for differences among genotypes, water regimes and interactions between cotton genotypes and watering regimes. Significant means were separated using the least significant difference at 5% probability level ($LSD_{0.05}$). Correlation analysis for the traits was performed using GenStat 14th edition computer package to assess the relationships among them.

Percent change in parameters measured under water-stress was derived from the difference in parameters between non-stress and stress conditions as follows:

$$\text{Percent change (\%)} = \frac{(\text{Nonstress water regime} - \text{water stressed regime}) \times 100}{\text{Non-stress water regime}}$$

Positive values indicated reduction of the parameter under water stress in relation to non-stress water regime; negative values represent an increase and zero indicated that there was no change in the parameter under water stress.

RESULTS AND DISCUSSION

Mean squares computed through analysis of variance are presented in Table 2. The genotypes were highly significant with respect to the majority of the measured parameters. Water regimes were also highly significant for all the measured parameters. The results showed high significant differences for interactions between water regime and cotton genotypes except root dry weight. All the 11 parameters which were evaluated were affected by water stress. The variable expressions of 20 cotton genotypes for various traits under water stress indicated that there was genotypic variability for drought tolerance. The presence of variability among genotypes for different traits under water stressed conditions has been reported (Basal et al., 2005; Iqbal, 2010; Bibi et al., 2012).

TRL and LRN have been shown to be increased by water stress (Pace et al., 1999; Chaturvedi et al., 2012). Increased TRL in response to water stress may permit cotton plants to survive drought by accessing water from deeper layers in the soil profile during periods of limited water supply. The majority of the genotypes in the present study showed a reduction in TRL and LRN (Table 3). Only two genotypes (BF26 (03) 4 bcp and SPAN 837) showed a significant increase in TRL under drought stress; whereas, nine genotypes showed no significant change in TRL between the water regime treatments. For LRN, two genotypes (SPAN 837 and MTB (84) 2) showed a significant increase under stress with 11 genotypes showing no significant change in LRN. Root growth has been reported as a reliable indicator of the response to drought tolerance due to significant variability for TRL and LRN (Basal et al., 2005; Kohel and Lewis, 1984). Additionally, nearly all genotypes showed a reduction in RFW under stress with only genotype SPAN 837 showing a significant increase (Table 3). All genotypes showed a reduction in RDW under stress; although, genotypes SPAN 837 and MACHU (06) 1 were less affected by water stress due to minimum reduction in RDW (Table 3).

Nearly all genotypes showed large reductions in SFW and SDW (Table 4). Only one genotype 06K486 showed no significant reductions in these two traits. SFW and SDW were much lower under water stressed conditions, suggesting that shoot growth was more sensitive to water stress than root growth. Basal et al. (2005) reported that SFW and SDW could be used as selection criteria for drought tolerance because of their ease of measurement and reliability. All genotypes showed a reduction in SL under drought stress (Table 4). The reduction of SL could be attributed to decrease in cellular expansion resulting from lower plant water content and turgor pressure under water stress (Abayomi and Abidoye, 2009). The majority of the genotypes also showed a reduction in RV; although, two genotypes showed a significant increase in RV under stress. Shoot length and root volume have been used as selection parameters for drought tolerance by Iqbal (2010) and Chaturvedi et al. (2012).

Total biomass was significantly reduced under drought stress for all genotypes except 06K486 (Table 5). Genetic variability has been reported to exist for dry matter accumulation (Poehlman and Sleper, 1995); however, no significant variation was observed in the present study. Genotypes with higher biomass under water stress conditions are able to develop sufficient biomass early, as such, the available moisture would be utilized before it is lost through deep drainage and soil evaporation (Taiz and Zeiger, 2006). Stem diameter and number of leaves per plant were significantly decreased for all genotypes due to water stress (Table 5). Taiz and Zeiger (2006) indicated that for indeterminate plants, water stress limits leaf number. Akıncı et al. (2012) indicated that water stress caused major reductions in leaf number of cotton plants.

Correlations among the traits (Table 6) revealed a lot of positive and significant associations among root traits as well as between root and shoot related traits. Taproot length, lateral root number, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, shoot length, root volume, stem diameter and number of leaves per

Table 2. Mean squares of 20 cotton genotypes for different traits measured under non stressed and stressed water regimes in translucent plastic screen house at Bunda College, March to June, 2012.

Source	Df	TRL	LRN	RFW	RDW	SFW	SDW	SL	RV	TBM	SD	NL
W	1	245.67 ***	134.20***	6.47***	2.12***	766.75***	107.88***	783.36***	5.94***	140.26***	9.86***	963.33***
G	19	36.37***	78.31***	0.41***	0.06	11.13**	0.9	17.63***	0.91***	1.14	0.40 ***	7.03 **
W × G	19	35.48***	48.27***	0.29*	0.04	9.54*	1.24*	14.74***	1.10***	1.49*	0.47***	6.44*
Error	80	2.96	4.24	0.14	0.04	5.16	0.6	2.8	0.31	0.72	0.09	3.11

W: Water regime; G: genotype; W × G: water regime × genotype interaction, df : degrees of freedom, TRL: tap root length; LRN: lateral root number; RFW: root fresh weight; RDW: root dry weight; SFW: shoot fresh weight; SDW: shoot dry weight; SL: shoot length; RV: root volume; R/S: root: shoot ratio; TBM: total biomass; SD: stem diameter; NL: number of leaves per plant. ***, **, *Significant at P< 0.001, P<0.01, P<0.05, respectively.

Table 3. Effect of water stress and associated percent change in taproot length, lateral root number, root fresh weight and root dry weight of cotton genotypes.

Genotype	Tap root length (cm)			Lateral root number			Root fresh weight (g)			Root dry weight (g)		
	W1	W2	% Change	W1	W2	% Change	W1	W2	% Change	W1	W2	% Change
SZMA(04) 4bcp	30.83	25.83	16.22	41.67	37.67	9.50	3.27	1.95	40.22	1.32	0.78	40.80
FQMA(05) 5bcp	29.03	23.33	19.20	37.67	37.10	1.57	2.80	2.47	10.90	1.18	1.09	3.80
MAP85(05) 18bcp	25.27	21.33	15.30	43.67	37.33	14.37	2.92	2.48	13.50	1.16	1.02	12.31
Acala glandless	25.03	20.70	17.30	34.67	36.77	-6.00	2.46	2.29	6.94	1.08	0.76	29.13
CHUFQ(06) 1bcp	28.27	25.37	9.90	39.43	36.67	6.77	2.67	2.10	21.00	1.07	0.79	26.68
Glandless NC-1	24.73	26.47	-7.20	33.67	29.67	11.70	2.48	2.23	10.19	0.92	0.82	11.15
CHUMA(04) 17bcp	30.63	17.10	44.20	45.67	44.17	3.28	3.22	2.09	32.40	1.33	0.83	37.35
06K485	30.10	30.13	2.60	44.00	40.67	13.40	3.62	3.00	17.12	1.38	1.18	14.77
K502MA(05) 1bcp	30.47	25.73	15.50	43.43	40.77	5.90	3.37	2.23	33.94	1.35	0.84	37.53
IRMSZ(06) 3bcp	29.27	27.03	7.30	38.33	29.67	22.47	2.94	2.93	0.24	1.13	0.94	17.02
MACHU(06)1	27.83	21.73	21.00	41.10	31.67	22.97	2.54	2.66	-4.57	1.13	1.09	3.36
BF26 (03) 4bcp	20.47	25.57	-25.00	37.33	36.00	3.50	2.85	2.35	16.80	1.20	0.88	24.30
SPAN 837	22.17	30.80	-42.10	37.10	47.10	-26.90	2.89	3.19	-10.80	1.06	1.01	1.70
MTB (84)2	25.70	25.10	2.30	34.67	44.00	-26.93	2.71	2.54	6.28	1.10	0.93	12.50
SZ9314	27.03	19.80	26.60	42.77	29.67	30.67	2.49	2.41	3.37	1.06	0.87	18.07
06K486	25.10	23.87	4.90	41.33	41.10	0.20	2.85	2.62	7.90	1.17	1.02	11.40
Makoka 2000	25.37	25.00	1.10	37.33	41.33	-10.20	2.96	2.27	23.00	1.20	0.92	23.19
RASAM 17	34.87	27.90	19.70	46.23	39.43	14.43	2.90	2.63	7.50	1.19	0.98	17.60
IRM 81	32.77	25.10	23.10	45.33	45.33	0.07	3.28	2.42	26.23	1.40	0.85	39.00
Chureza	28.10	27.90	0.50	43.67	40.67	6.87	3.71	2.78	24.60	1.52	1.03	30.00
Mean	27.65	24.79	8.60	40.45	38.34	4.85	2.95	2.48	13.80	1.20	0.93	19.70
CV (%)	6.80		20.40	5.20		26.40	13.90		32.20	19.40		15.20

Table 3. Contd.

	W	0.63***	-	0.75***	-	0.14***	-	0.08***	-
$LSD_{0.05}$	G	2.00***	15.85***	2.37***	11.50***	0.43***	NS	NS	NS
	W × G	2.80***	-	3.35***	-	0.61***	-	NS	-

W1: Non-stressed water regime, W2: stressed water regime, G: genotype, W: water regime, bcp: bulk of chosen plants. NS, *** Not significant, significant at P< 0.001 respectively.

Table 4. Effect of water stress and associated percent change in shoot fresh weight, shoot dry weight, shoot length and root volume of cotton genotypes.

Genotype	Shoot fresh weight (g)			Shoot dry weight (g)			Shoot length (cm)			Root volume (mm^3)		
	W1	W2	% Change	W1	W2	% Change	W1	W2	% Change	W1	W2	% Change
SZMA(04) 4bcp	20.93	14.40	31.22	7.09	5.42	23.53	42.97	36.97	13.96	3.73	3.97	-6.27
FQMA(05) 5bcp	19.29	15.29	20.10	6.82	5.59	17.20	44.63	37.57	15.82	5.10	3.57	30.06
MAP85(05) 18bcp	23.14	16.00	30.82	8.38	4.75	43.33	49.40	43.37	12.21	4.33	3.63	16.16
Acala glandless	19.19	12.40	35.38	6.65	4.43	33.35	46.60	37.10	20.39	3.57	3.77	-5.61
CHUFQ(06) 1bcp	21.45	15.30	28.67	7.10	5.40	24.01	47.17	38.70	17.96	4.47	3.33	25.39
Glandless NC-1	18.91	14.86	21.39	6.34	4.91	22.49	44.37	37.80	14.81	4.47	4.43	0.76
CHUMA(04) 17bcp	22.17	14.14	36.22	7.40	4.29	42.08	45.57	35.20	22.76	4.57	3.97	13.14
06K485	20.33	16.53	18.71	6.50	5.50	15.34	43.53	42.10	3.29	5.67	4.57	19.41
K502MA(05) 1bcp	19.55	14.45	26.20	6.82	5.09	25.37	43.50	38.90	10.57	5.43	3.40	37.42
IRMSZ(06) 3bcp	15.85	12.75	19.56	6.65	5.03	24.36	41.93	41.10	1.98	4.57	4.43	2.93
MACHU(06)1	16.98	14.48	14.74	6.12	4.30	29.78	45.50	41.00	9.89	4.10	4.93	-20.32
BF26 (03) 4bcp	22.13	15.37	30.40	8.03	5.06	36.90	46.67	39.40	15.58	5.90	3.40	41.10
SPAN 837	18.98	15.19	18.00	7.08	5.35	19.90	40.53	37.77	6.81	4.77	4.33	9.10
MTB (84)2	21.16	14.97	28.60	7.32	5.27	27.40	45.60	40.40	11.40	4.10	3.87	5.68
SZ9314	17.93	14.63	18.43	6.29	5.05	19.68	45.87	36.10	21.30	3.83	4.13	-7.83
06K486	16.75	16.01	4.48	5.99	5.80	3.17	39.43	38.17	3.19	3.97	3.80	3.40
Makoka 2000	20.04	15.50	20.90	7.07	5.28	24.30	45.10	40.73	9.63	3.77	4.00	-6.19
RASAM 17	19.27	18.26	5.22	6.55	5.41	16.80	44.33	40.63	8.33	3.77	4.30	-16.00
IRM 81	23.61	13.33	42.60	8.03	4.58	42.50	41.77	39.10	6.33	5.07	4.60	9.20
Chureza	23.83	15.76	33.40	8.14	5.56	31.50	42.30	39.93	5.57	4.77	4.60	2.10
Mean	20.07	15.02	23.80	7.01	5.05	25.80	44.27	39.16	11.21	4.50	4.05	8.20
CV (%)	13.00		15.50	12.70	-	7.40	4.00		8.90	12.90		54.80
W	0.83***		-	0.28***	-	-	0.61***		-	0.20***		-
$LSD_{0.05}$ G	2.61**		NS	-	-	22.17*	1.92***		9.49***	0.64***		23.11***
W × G	3.69*		-	1.25**	-	-	2.72***		-	0.90***		-

W1: Non-stressed water regime, W2: stressed water regime, G: genotype, W: water regime, bcp: bulk of chosen plants NS, *, **, ***Not significant, significant at P< 0.05, 0.01, 0.001, respectively.

Table 5. Effect of water stress and associated percent change in total biomass, stem diameter and number of leaves per plant for cotton genotypes.

Genotype	Total biomass (g)			Stem diameter (mm)			Number of leaves per plant		
	W1	W2	% Change	W1	W2	% Change	W1	W2	% Change
SZMA(04) 4bcp	8.41	6.20	25.60	5.70	3.90	31.58	20.70	16.00	22.71
FQMA(05) 5bcp	8.00	6.68	15.50	5.60	4.90	12.50	21.30	14.00	34.27
MAP85(05) 18bcp	9.54	5.77	39.00	5.80	5.30	8.62	22.30	12.70	43.05
Acala glandless	7.73	5.20	31.70	5.90	4.60	22.03	18.00	13.30	26.11
CHUFQ(06) 1bcp	8.18	6.18	23.80	5.90	5.10	13.56	18.70	16.00	14.44
Glandless NC-1	7.26	5.73	21.05	5.60	5.20	7.14	20.00	14.00	30.00
CHUMA(04) 17bcp	8.73	5.12	41.36	6.00	5.30	11.67	19.70	13.00	34.01
06K485	7.88	6.68	15.22	6.10	5.20	13.70	20.70	16.30	21.26
K502MA(05) 1bcp	8.17	5.94	27.34	5.80	5.30	8.62	19.30	15.30	20.73
IRMSZ(06) 3bcp	7.77	5.97	23.20	5.90	5.10	13.97	20.00	14.67	26.65
MACHU(06)1	7.25	5.39	25.63	5.40	5.20	3.70	22.00	11.70	46.82
BF26 (03) 4bcp	9.24	5.93	35.79	5.40	5.10	5.56	19.00	15.00	21.05
SPAN 837	8.13	6.36	18.00	5.30	5.20	1.89	19.30	14.30	24.80
MTB (84)2	8.42	6.21	26.29	5.40	4.40	18.52	20.00	15.70	20.70
SZ9314	7.35	5.92	19.47	5.90	4.80	18.64	19.00	13.30	30.00
06K486	7.01	6.57	6.27	6.10	6.00	1.64	22.30	16.00	27.90
Makoka 2000	8.28	6.21	24.40	5.70	5.10	10.53	24.30	16.00	33.90
RASAM 17	7.73	6.39	16.90	5.60	5.40	3.57	22.30	15.30	31.00
IRM 81	9.43	5.43	42.00	6.00	5.50	8.33	18.70	14.70	21.30
Chureza	9.66	6.58	31.80	5.30	4.90	7.55	19.30	16.30	15.10
Mean	8.21	6.05	25.20	5.70	5.10	11.20	20.35	14.68	27.30
CV (%)	11.90		6.70	5.50		25.70	10.10		13.70
$LSD_{0.05}$ W	0.31***		-	0.11***		-	0.64***		-
$LSD_{0.05}$ G	NS		20.12*	0.34***		11.23***	2.03**		15.27**
$LSD_{0.05}$ W × G	1.37**		-	0.48***		-	2.87*		-

W1: Non-stressed water regime, W2: stressed water regime, G: genotype, W: water regime, bcp: bulk of chosen plants NS, *, **, ***Not significant, significant at P< 0.05, 0.01, 0.001, respectively.

Table 6. Coefficients of correlation among growth and morphological traits under water stress in cotton evaluated in translucent plastic screen house at Bunda College, March to June 2012.

Correlation	TRL	LRN	SFW	SDW	RDW	RFW	SL	RV	SD	NL	TBM
TRL	1										
LRN	0.44***	1									
SFW	0.31***	0.29***	1								
SDW	0.33***	0.26**	0.90***	1							
RDW	0.39***	0.30***	0.64***	0.57***	1						
RFW	0.44***	0.35***	0.54***	0.48***	0.69***	1					
SL	0.30***	0.14	0.66***	0.67***	0.48***	0.33***	1				
RV	0.16	0.14	0.35***	0.34***	0.29**	0.44***	0.25**	1			
SD	0.31***	0.30***	0.57***	0.53***	0.49***	0.41***	0.55***	0.27**	1		
LN	0.42***	0.27**	0.57***	0.64***	0.44***	0.38***	0.57***	0.16	0.38***	1	
TBM	0.36***	0.28**	0.91***	0.99***	0.68***	0.55***	0.68***	0.35***	0.55***	0.64***	1

TRL: Tap root length; LRN: lateral root number; SFW: shoot fresh weight; SDW: shoot dry weight; RDW: root dry weight; RFW : root fresh weight; SL: shoot length; RV: root volume; SD: stem diameter; NL: number of leaves per plant; TBM: total biomass. **, ***Significant at 0.01, 0.001 level of significance, respectively.

plant were positively correlated with total biomass. The association between growth parameters and total biomass had positive correlation coefficients implying that selection for taproot length, lateral root number, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, shoot length, root volume, stem diameter and number of leaves might improve total biomass under water stressed conditions. Correlation analysis further suggested that simultaneous improvement could be possible for shoot fresh weight, shoot dry weight and shoot length due to positive and highly significant correlation between these traits. These traits showed significant correlation and strongest association with total biomass, revealing their importance for selecting genotypes with drought tolerance and higher biomass. The mentioned traits are easy and more practical to use for indirect selection. This gives breeders the opportunity to combine different growth characteristics to improve dry matter production. Paytas (2009) reported that any reduction in biomass production in cotton decreases final yield. Taproot length and lateral root number correlated significantly and positively with total biomass in this study. Kohel and Lewis (1984) noted that the correlations of taproot length and vigorous laterals with dry matter production suggested that root vigor may allow superior strains to be better competitors for limited soil water. In the current study, most of the parameters were significantly and positively correlated with each other, thereby providing a chance for selection of desirable genotypes with desirable traits.

Conclusion

Genotypic variation existed for growth and productivity traits in response to water stress under plastic translucent screen house, implying that selection for drought tolerance is possible. The significant and positive association of growth traits with total biomass implied that indirect selection for different morphological traits under water-limited conditions is possible. Overall, according to the current study, genotypes SPAN 837, 06K485, FQMA (05) 5 bcp, Chureza, 06K486, and RASAM 17 were the most tolerant to drought. In contrast, CHUMA (04) 17 bcp, Acala glandless, SZMA (04) 4 bcp, SZ9314, and IRM 81 were the most susceptible. Selecting tolerant cotton genotypes would assist to minimize the effect of drought on cotton in Malawi.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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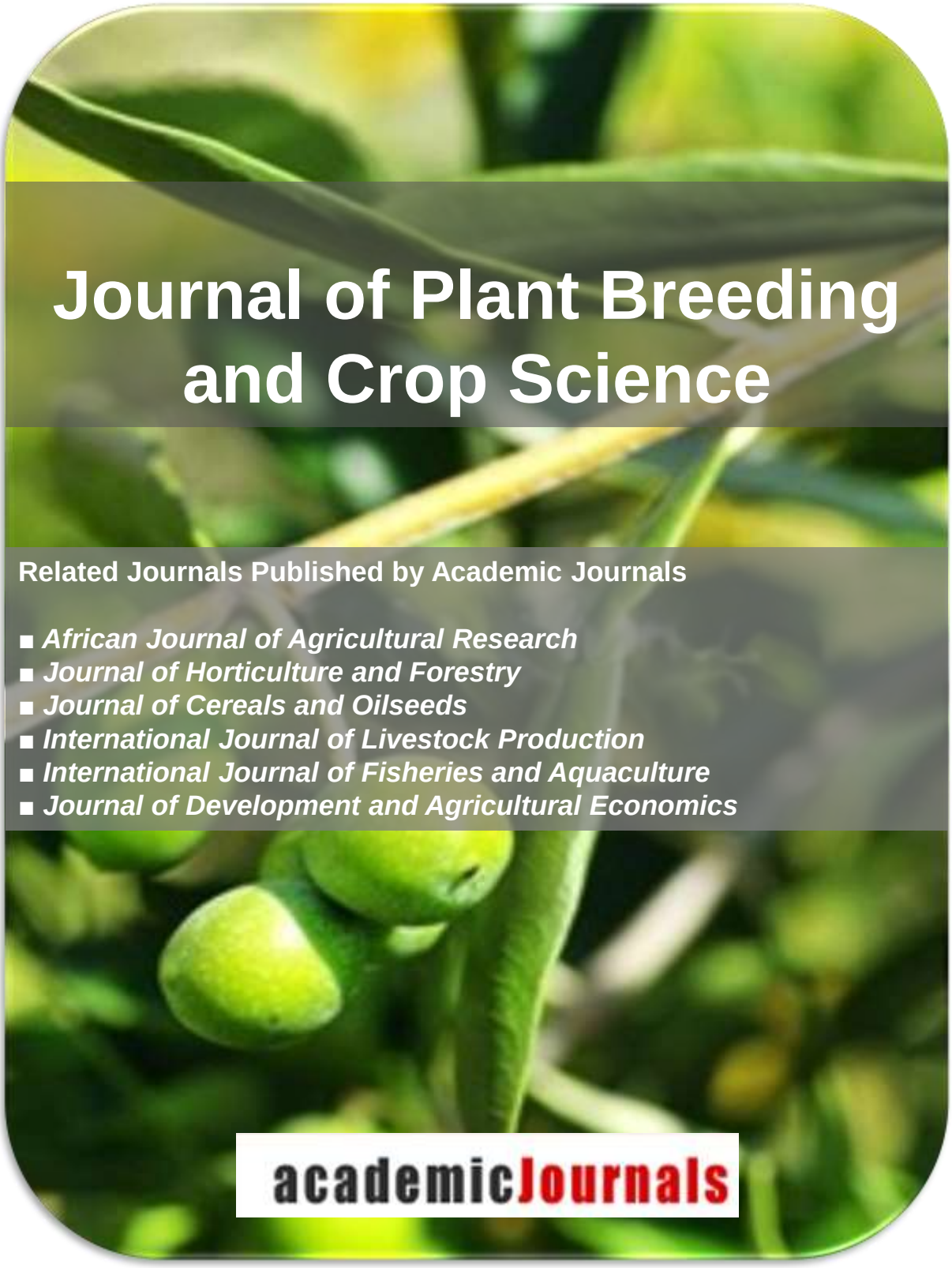

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