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ARTICLE

Selection of upland cotton for the Brazilian semi-arid region under supplementary irrigation

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Abstract: *This study aimed to select cotton genotypes adapted to semi-arid conditions grown with supplementary irrigation. Two experiments were carried out between March and July 2016 in Serra Talhada- Pernambuco and Apodi-Rio Grande do Norte, Brazil. Eighteen elite genotypes bred by Embrapa Cotton and two controls (BRS 286 and BRS 336) were evaluated under drip and sprinkler irrigation. The experiment consisted of a randomized complete block design with four replications. Agronomic and fiber quality traits were evaluated. The data were subjected to individual and combined analysis of variance, and genotypes were selected by the Mulamba and Mock selection index (1978). The genetic parameters evidenced the possibility of significant gains in the selection process of cotton plants. The four genotypes (CNPA 2006-3052, CNPA 2004-266, CNPA 2006-1073, and CNPA 2005-125) with highest total genetic gains for the studied traits were considered the most promising.*

Keywords: *Gossypium hirsutum L., yield, selection index, fiber quality.*

INTRODUCTION

Cotton is an oil and fiber crop, grown in more than 70 countries around the world, which plays an essential role in the global economy. India is the largest producer, with an output of 5.9 million tons, followed by China, USA, Pakistan, and Brazil (Abrapa 2018). In the 2017 growing season, Brazil produced cotton on an area of 939.1 thousand hectares, with a mean yield of 4056.00 kg ha^{-1}. The Central-West and Northeast regions are the primary cotton producers, accounting for more than 97.6% of the national production (Conab 2018).

Although cotton is an essential national commodity, its management in Brazil is very expensive owing to the required cultural practices, not only in relation to mechanization but also to chemical pesticides. Moreover, adverse environmental conditions are quite unpredictable and can damage the crop depending on the plant development stage, especially in the case of drought and heat (Loka and Oosterhuis 2012). Elevated temperatures associated with scarce and irregular rainfall have been some of the major problems for crop sustainability in any part of the world (Dabbert and Gore 2014).

The plasticity of cotton plants is high, conferring the ability to survive under high temperatures and moderate water stress; however, the species is

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vulnerable to these stresses if they occur at the reproductive stage, affecting the crop development from the beginning of flowering to boll development (Oosterhuis and Snider 2011, Loka and Oosterhuis 2012). The suitable temperature range for plant development is between 20 °C and 32 °C. Temperatures above 35 °C reduce pollen fertility by more than 40% and, consequently, decrease the number of seeds per boll (Song et al. 2014).

The lack of rainfall during critical stages affects the photosynthetic complex by inducing a reduction in leaf area. This condition limits plant transpiration and gas exchange and reduces the yield capacity and fiber quality (Pettigrew 2004, Loka et al. 2012). In a study with cotton cultivars subjected to different water regimes (40, 70, and 100% of evaporation) as of the beginning of flowering, Ghaderi-Far et al. (2012) reported fiber yield losses of 14% in cotton subjected to supplementary irrigation (40% ETc).

Cotton plants have an indeterminate growth habit, with 140- to 160-day cycles. A minimum water supply of 300 mm during the cycle is enough to provide reasonable fiber yield and quality (Freire 2015). In Brazil drought occurs in several regions, directly impacting crop production, and breeding has substantially contributed to providing producers with more stable cultivars, adapted to the regional rainfall pattern. The species *Gossypium hirsutum* L. has a wide genetic variability for abiotic factors, such as water stress, salinity, and high temperatures. For example, the response of the varieties *G.latifolium* and *Marie galant* to the cited stresses differs in that the latter is generally more stress-tolerant (Rodrigues et al. 2016, Vasconcelos et al. 2018).

According to Lubbers et al. (2007), the existence of drought-tolerant cotton germplasm is possibly due to the contribution of perennial species adapted to semi-arid and subtropical environments, which are tolerant to the long drought periods and high temperatures of their natural habitats. As most drought tolerance mechanisms have a biochemical and molecular basis, breeding is still a valuable strategy to develop cultivars more tolerant to several types of environmental stresses (Ullah et al. 2017).

This study selected cotton genotypes adapted to semi-arid climate conditions cultivated under irrigation for high yields and the standards of the fiber quality traits required by the textile industry.

MATERIAL AND METHODS

Experimental procedure

Eighteen cotton lines were tested in the semi-arid region of the Northeast of Brazil, in Serra Talhada (lat 8° 18’ 5.8” S, long 38° 30’ 37.2’’ W, alt 438 m asl), PE and Apodi (lat 7º 18’ 18’’ S, long 39º 18’ 7’’ W, alt 59 m asl), RN, from March to July 2016. The climate of the region is BSwh, according to Köppen’s classification, with less than 800 mm rainfall.

The soils of Serra Talhada-PE and Apodi-RN are classified as Bruno Não Cálcico and Cambissolo Eutrófico, respectively. Fertilization was performed with NPK (urea, super simple phosphate and potassium chloride, 6:24:12) and FTE, and two topdressings, one at 25 days after planting, and the other at 45 days after planting, with nitrogen and potassium. The plots consisted of four 5-m rows, spaced 1 m apart, with a density of 7 plants m^{-1}. The two central rows were selected as the area for experimental data collection.

The experiment consisted of a randomized block design with 20 treatments and four replications. The treatments consisted of 18 elite lines (F8 generation, obtained by the genealogical method) and the controls BRS 286 and BRS 336 (adapted to the semi-arid and Cerrado regions, respectively) (Morello et al. 2012, Zonta et al. 2015). Crop management followed the recommendations of Carvalho et al. (2015).

In Serra Talhada-PE, a drip irrigation system distributed artesian well water, following a weekly irrigation schedule; the supplementary irrigation provided 246 mm and rainfall 165.2 mm, totaling 411.2 mm distributed during the crop cycle. In Apodi, a sprinkler system provided irrigation with artesian well water, according to a weekly irrigation schedule. The supplementary irrigation provided 266 mm and rainfall 135.2 mm, i.e., a total of 401.2 mm distributed during the cycle

The following agronomic variables were analyzed: boll weight (mean weight of one boll, BW, g), cotton boll yield (Y, kg ha^{-1}), lint yield (LY, kg ha^{-1}), and fiber percentage (FP, %). The following fiber quality traits were estimated based on a 20-boll standard sample: fiber upper-half mean length (UHM, mm), strength (STR, gf tex^{-1}), elongation (ELG), micronaire

(MIC) and count strength product (CSP). A HVI equipment (Uster HVI 1000) was used for fiber analysis.

Statistical analysis

Individual analyses of variance were performed for each environment, considering the treatment effects fixed and the others random, followed by the combined analysis of variance of the experiments. The ratio between the highest and lowest mean square of the residue was lower than seven, indicating homogeneity of residual variances. The following statistical model was used in the combined analysis (Cruz et al. 2012):

$$Y_{ijk} = m + g_i + b/a_{jk} + a_j + ga_{ij} + e_{ijk}$$

where Y_{ijk} is the phenotypic value of genotype i in environment j; *m* is the overall mean; b/a_{jk} the block effect (k = 1, 2 .... r) within environments (j = 1, 2 .... q); g_i the effect of genotypes (i = 1, 2 .... p); a_j the effect of environments (j = 1, 2.... q); ga_{ij} the effect of the genotype × environment (G x E) interaction; e_{ijk} the random error, *m*; b/a_{jk}; a_j; ga_{ij}; e_{ijk} are the random effects; and g_i is the fixed effect. Means were classified by the Scott and Knott test (1974), at 5% probability.

The following genetic parameters were estimated: genotypic determination coefficient (GDC), coefficient of genetic variation (CVg), and coefficient of relative variation (CVg/CVe). The selection index proposed by Mulamba and Mock (1978) was used to select the genotypes and estimate selection gains. This index consists in classifying the genotypes according to each trait in decreasing order of performance (Cruz et al. 2012). The selection index was estimated based on multicollinearity analysis; the variables that contributed to collinearity were excluded from the analysis. All genetic-statistical procedures were performed using software GENES (Cruz 2013).

RESULTS AND DISCUSSION

Table 1 shows the combined analysis of variance for agronomic and industrial fiber traits of cotton lines. The F test ($p<0.01$) revealed high significance of the genotypes for all traits, indicating high variability among lines originated from crosses between the germplasms Upland and Mocó, with different levels of adaptation to Cerrado and semi-arid environments. The environmental effects were not significant for most traits, indicating similarity between environments, except for Y, LY, and STR.

For the effects of G x E interaction, most traits differed significantly from each other, indicating the different behavior of the genotypes in the two environments evaluated, except for FP, UHM, ELG, and CSP. Lines from diallel crosses of commercial Upland and Mocó cultivars were evaluated by Vasconcelos et al. (2018) under rainfed and irrigated management in the region of Cariri in the state of Ceará, for two years. The authors detected a strong effect between genotype x water treatment interaction for Y and FP, demonstrating the sensitivity of the genotypes to environmental changes.

In both environments, the mean cotton boll yield of the genotypes was higher than 3,800 kg ha^{-1} and the lint yield higher than 1,500 kg ha^{-1}, indicating that the water supply provided in each environment was satisfactory. This fact

Table 1. Summary of the combined analysis of variance and means of agronomic and fiber traits of cotton lines evaluated in Serra Talhada (PE) and Apodi (RN)

Trait	Genotype (G)	Environment (E)	G x E	Error	CV (%)	Mean
Y	1073099.93**	39263422.5**	1138903.55**	174671.26	10.65	3922.75
LY	306268.04**	5230728.43**	184400.33**	29875.12	11.30	1529.49
FP	60.99**	7.39	1.52	1.72	3.36	38.93
BW	1.17**	1.07	0.45**	0.17	6.94	6.06
UHM	29.97**	1.78	0.82	1.28	3.67	30.85
STR	20.05**	84.97**	3.23*	1.83	4.23	31.95
ELG	3.24**	0.01	0.31	0.22	9.14	5.12
MIC	0.89**	0.31	0.12*	0.07	5.41	4.73
CSP	505056.09**	376942.2	51407.48	36757.18	6.39	3001.14

**, * significant at $p < 0.01$ and $p <0.05$, respectively, by the F test; CV: coefficient of variation. Y: cotton boll yield, LY: lint yield, FP: fiber percentage, BW: boll weight, UHM: fiber length, STR: strength, ELG: Elongation, MIC: micronaire, CSP: count strength product.

was even more evident at bud and flower emission, the most water-demanding stages that directly contribute to yield. Figure 1 shows the average temperature and rainfall during the cotton cycle. At both sites, total rainfall from the beginning of the reproductive stage was lower than 60 mm, indicating that without additional water supply, crop management would have been unsustainable. The total water supply (rain + irrigation) in Serra Talhada-PE and Apodi-RN was approximately 400 mm.

In Apodi-RN, Zonta et al. (2016) tested cotton cultivars adapted to the Cerrado under different irrigation levels of between 311 mm and 1297 mm. Their results indicated a linear trend between cotton yield and plant water supply.

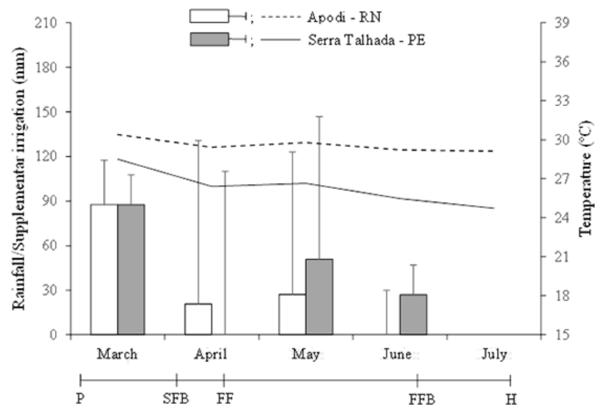

Figure 1. Rainfall, supplementary irrigation and average temperature in Serra Talhada (PE) and Apodi (RN), during the cotton cycle. P: Planting; FFB: First flower bud; FF: First flower; FB: First boll; H: Harvest. The trace above the bars indicates the irrigated water volume.

Table 2 shows the genetic parameters estimated from the combined analysis of variance. The estimates of the genotypic quadratic component (GQC), which expresses the variability of the set of fixed genotypes, represented the major part of the phenotypic variability for all traits except BW. This result suggests the possibility of significant genetic gains with selection.

The genotypic determination coefficient (GDC) was higher than 80% for all traits, which shows that the variations in fiber yield and quality are mostly of genetic nature, allowing a more effective selection of superior lines, with a higher probability of success and selection gain. These findings were also reported by Resende et al. (2014), who evaluated 240 cotton genotypes for three years in the semi-arid region of the state of Minas Gerais. The authors found high GDCs for FP (88%), UHM (87%), and MIC (81%).

In a tropical environment, Bonifácio et al. (2015) evaluated 22 cotton lines from biparental crosses and detected GDCs higher than 80% for most fiber traits, with maximum values for UHM (92.90%) and STR (98.65%). These results indicate that the heritability of most fiber traits tends to be high, which facilitates the selection process and allows the capitalization of desirable and significant genetic gains. This fact was confirmed by the coefficient of relative variation (CVg/CVe), estimated at ≥ 1, indicating successful selection (Vencovsky 1992). In this study, the CVg/CVe ratios were ≥ 1 for most of the traits, except Y and BW.

Table 3 shows the clustering of the trait means evaluated in cotton lines, considering the general mean of the two environments. Although some traits were significantly influenced by the G x E interaction, the objective was to indicate environment-specific genotypes. Of the 18 lines evaluated, nine had excellent cotton boll and fiber yield (> 3,800 kg ha^{-1} and >1,600 kg ha^{-1}, respectively) and boll weight (BW) (> 5.8 g), and their agronomic performance was considered

Table 2. Estimates of genetic parameters of agronomic and fiber traits of the genotypes. Serra Talhada (PE) and Apodi (RN)

	GQC	**RV**	**GDC** (%)	**CVg** (%)	**CVg/CVe**
Y	112303.58	174671.26	83.72	8.54	0.80
LY	34549.11	29875.12	90.25	12.15	1.07
FP	7.40	1.71	97.19	6.99	2.07
BW	0.12	0.17	84.95	5.83	0.83
UHM	3.58	1.28	95.71	6.13	1.67
STR	2.28	1.82	90.88	4.72	1.12
ELG	0.38	0.21	93.23	11.99	1.31
MIC	0.10	0.06	92.68	6.79	1.26
CSP	58537.36	36757.17	92.72	8.06	1.26

GQC: genotypic quadratic component; RV: residual variance; GDC: genotypic determination coefficient; CVg - coefficient of genotypic variation; CVg/CVe: coefficient of relative variation. Y: cotton boll yield, LY: lint yield, FP: fiber percentage, BW: boll weight, UHM: fiber length, STR: strength, ELG: Elongation, MIC: micronaire, CSP: count strength product.

excellent. The fiber strength of all evaluated lines exceeded 30 gf tex^{-1}, except for CNPA 2006-160 (strength of 26.59 gf tex^{-1}).

All these nine lines also had good performance for length, elongation and count strength product. The textile industry requires fibers with a length of 28.5 mm, strength > 28, elongation > 7, and count strength product of > 2200 (Vidal Neto and Freire 2013). The environment strongly influenced only the parameter micronaire. Textile industry requires fibers within a MNC range of 3.5 to 4.5. The only genotype that met all these requirements was CNPA 2006-1073.

Micronaire is a crucial parameter for cotton fiber quality and processing. Differences or deviations in micronaire can lead to variations and reductions in fiber quality, yield and processing efficiency, fabric quality, and yarn consistency (Marth et al. 1952, Kennamer et al. 1956). Micronaire is a measure and function of fiber maturity and fineness, which in turn is a measure of fiber density (Zumba et al. 2017). Temperature has great influence on fiber fineness. According to Roberts et al. (1992), high and low temperatures can inhibit the cellulose synthesis rate and fiber maturity and elongation, resulting in poor fiber quality. Based on data from 32 experiments performed over 10 years with 17 cotton cultivars by Bange et al. (2010), high temperatures have a positive correlation with MIC. The authors found that MIC increased by 0.16 and 0.19 for each additional degree Celsius of the minimum and maximum temperatures, respectively.

Fiber can be coarse and immature, even when the crop is cultivated within an ideal temperature range. This foccurs because fiber MIC is a relation between variables and thus an indirect measure (Bradow and Davidons 2000). Aside from temperature, water availability seems to affect micronaire even more in the semi-arid environment. In Apodi, Zonta et al. (2015) tested four cotton cultivars for two years, at ETc levels from 40 to 130%, and obtained a micronaire value ranging from 4.88 to 5.05, higher than that demanded by the textile industry. In this study, the maximum temperatures recorded in Serra Talhada varied from 33.8 to 36.2 °C, and the minimum temperatures from 16.4 to 20 °C. In Apodi, the maximum temperatures varied from 34.23 to 35.48 °C, and the minimum temperatures from 23.51 to 25.04 °C (data not shown), with a total water supply (rain + irrigation) of about 400 mm at both locations.

Table 3. Overall mean of yield and fiber traits for the cotton lines cultivated in the semi-arid of Serra Talhada (PE) and Apodi (RN)

Genotypes	Y (kg ha^{-1})	LY (kg ha^{-1})	FP (%)	BW (g)	UHM (mm)	STR (gftex^{-1})	ELG (%)	MIC -	CSP -
CNPA 2006-1006	3385.94b	1305.90c	38.48b	5.45b	30.54c	31.54b	4.84c	4.28c	2952.13a
CNPA 2006-3075	4008.81a	1487.38b	37.14c	6.70a	31.85b	32.73a	4.40c	5.08a	3043.75a
CNPA 2004-295	4564.00a	1677.36b	36.90c	6.28a	31.84b	31.79b	4.79c	4.69b	3072.38a
BRS 286*	4515.00a	1923.37a	42.54a	5.34b	27.93d	30.06c	5.45b	4.95a	2465.75c
CNPA 2006-3065	3881.63b	1439.19c	37.09c	6.40a	32.19b	33.80a	4.38c	4.99a	3206.38a
CNPA 2006-3052	4155.25a	1575.09b	37.89b	6.35a	31.69b	33.23a	5.19b	4.71b	3174.25a
CNPA 2004-92	4007.81a	1728.08a	43.04a	6.15a	27.66d	30.51c	6.09a	5.26a	2584.25c
CNPA 2006-1601	3799.75b	1591.39b	41.94a	6.28a	29.96c	29.59c	5.41b	4.55b	2881.75b
CNPA 2006-1109	4067.81a	1642.27b	40.43a	6.13a	29.70c	31.73b	4.80c	4.79a	2837.25b
BRS 336*	4424.63a	1651.64b	37.43c	6.40a	33.61a	34.95a	3.79c	5.14a	3315.88a
CNPA 2004-60	3420.00b	1345.04c	39.25b	6.04a	29.26c	33.55a	6.18a	5.04a	3028.50a
CNPA 2004-266	3842.06b	1643.91b	42.83a	6.63a	28.66d	31.16b	5.51b	4.70b	2846.38b
CNPA 2004-618	4192.19a	1798.19a	42.91a	5.86b	28.61d	30.39c	6.01a	5.21a	2698.00c
CNPA 2006-1073	4169.38a	1535.96b	36.90c	5.88b	32.94a	31.56b	5.10b	4.21c	3212.13a
CNPA 2004-318	3784.38b	1577.75b	41.65a	6.34a	29.26c	29.41c	5.66b	4.99a	2675.00c
CNPA 2005-15	4085.94a	1507.20b	36.90c	5.90b	31.85b	33.05a	4.81c	4.58b	3170.38a
CNPA 2005-128	3813.94b	1500.59b	39.49b	5.36b	29.99c	31.93b	5.48b	4.28c	3100.13a
CNPA 2006-3047	3462.19b	1243.03c	35.86c	5.88b	33.00a	34.10a	4.61c	4.43c	3338.13a
CNPA 2005-5581	3382.31b	1153.53c	33.98d	6.10a	34.04a	33.29a	4.46c	4.48c	3283.13a
CNPA 2006-1065	3492.00b	1262.94c	36.04c	5.83b	32.41b	30.65c	5.50b	4.35c	3137.25a
Overall mean	3922.75	1529.49	38.93	6.06	30.84	31.95	5.12	4.73	3001.14

* Control cultivars; Means followed by the same letter did not differ statistically from each other by the Scott-Knott test at $p < 0.05$. Y: cotton boll yield, LY: lint yield, FP: fiber percentage, BW: boll weight, UHM: fiber length, STR: strength, ELG: Elongation, MIC: micronaire, CSP: count strength product.

Table 4. Selection gain of the genotypes for the agronomic traits [boll weight (BW), cotton boll yield (Y), and fiber percentage (FP)] and industrial traits [length (UHM), strength (STR), elongation (ELG) and Micronaire (MIC), using the selection index proposed by Mulamba and Mock (1978)

Traits	**Xo**	**Xs**	**GDC** (%)	**SG**	**SG** (%)
Y	3922.75	4187.10	83.72	221.32	5.64
FP	38.93	39.20	97.19	0.26	0.68
BW	6.06	6.41	84.95	0.30	4.95
UHM	30.85	30.73	95.71	-0.11	-0.37
STR	31.95	32.06	90.88	0.09	0.31
ELG	5.12	5.16	93.23	0.04	0.73
MIC	4.73	4.70	92.68	-0.03	-0.66

Xo: means of the original population, Xs: means of the selected population, GDC: genotypic determination coefficient, SG: total selection gain.

The performance of the controls was quite satisfactory, considering that both are recommended for the Cerrado region, although BRS 286 has a double adaptation and is also cultivated in semi-arid environments. Under full irrigation, cultivar BRS 286 produced higher yields in Apodi, with mean yields of 4634.6 kg ha^{-1} cotton boll and 2014.7 kg ha^{-1} fiber (Zonta et al. 2015).

Table 4 shows the selection gains obtained for each variable, based on the Mulamba and Mock index (1978). For the selection of the best genotypes, LY and CSP were excluded for overestimating their correlations due to the high collinearity.

Although the CVg indicates the possibility of genetic gain by direct selection (Table 2), some values were not the same as those found by simultaneous selection (Table 4), and this result is mainly due to the negative correlations between traits. Desirable genetic gains were detected for Y (5.64%) and BW (4.95%) (Table 4). According to Carvalho et al. (1997), who estimated the genetic progress in the selection of cotton genotypes in the Brazilian semi-arid region, annual gains of > 1% are considered remarkable for environments under water stress.

For the fiber traits, the most satisfactory gains were obtained for elongation (0.73%) and micronaire (-0.66%), which, although negative, is desirable for the textile industry (from 3.9 to 4.2). The mean micronaire value of the studied cotton lines was 4.73.

The gains for strength and fiber length were practically zero (between 0.31% and -0.37%). This result does not indicate a failure in cotton selection since the means of these traits (Table 3) meet the standard required by the textile industry for the environment where the lines were evaluated.

According to Hoogerheide et al. (2007), fiber strength and length are negatively correlated with micronaire, which impairs gains in one of these traits when selecting for micronaire. However, due to the simultaneous selection, fiber gains were lower since the experiment prioritized traits related to yield and micronaire, which are the most important for the crop.

Carvalho et al. (2017) evaluated 22 cotton lines in two environments in the semi-arid region of the Northeast and also reported low genetic gain for fiber length (0.26%), indicating the greater difficulty in the selection of this trait, mainly due to its negative correlation with micronaire. Conversely, strength was high (1.87%), demonstrating that the population and environmental conditions (site and irrigation system) provided a better result.

This study revealed the presence of genetic variability for the studied traits among the lines, with a possibility of genetic gains in future selection cycles, confirmed by the genetic parameter estimates. The genotypes CNPA 2006-3052, CNPA 2004-266, and CNPA 2004-295 are the most promising for presenting the most expressive genetic gains for most yield and fiber quality traits under supplementary irrigation.

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