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SIXTY YEARS OF BREEDING IN CAMEROON IMPROVED FIBRE BUT NOT SEED COTTON YIELD

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SUMMARY

Seed cotton yield in Northern Cameroon has been declining since the 80s despite breeding efforts. In order to evaluate the impact of genetic improvement on this decline, we conducted field experiments in two locations with 10 widely grown cotton cultivars released in Cameroon between 1950 and 2009. The rate of genetic gain (GG) was estimated with a linear regression of the cultivar mean on its year of release (YR). Contrasts between rates of GG observed with different planting dates were estimated and tested. Our results revealed a rate of GG on fibre yield of 3.3 kg ha^{-1} year^{-1} due to increased ginning out-turn (3.9% and 6.2% in 60 years in Garoua and Maroua, respectively). There was no GG on leaf area index (LAI), radiation use efficiency (RUE), aerial biomass, harvest index and on seed cotton yield. We concluded that cotton breeding efforts in Cameroon have successfully improved cotton fibre yield but there is still some room for seed cotton yield improvement.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is a source of income for more than 10 million people in West and Central Africa (Baffes and Bank, 2004) where the cotton sector is or was supervised by development companies such as Sodecoton in Cameroon. There, cotton is grown under rainfed conditions (Sultan *et al.*, 2010), hence the tremendous importance of water availability during crop cycle on final production (M'Biandoun and Olina, 2006). Sodecoton supplies seeds, fertilisers and pesticides to farmers, holds a monopoly in buying seed cotton from farmers, ginning it and selling fibre mainly on the international market. Whereas farmers aim at producing a lot of seed cotton per unit land area to increase their incomes, Sodecoton is interested in maximising the production of high-quality fibre for securing outlets on the international market. In this context, the IRCT (Institut de Recherches du Coton et des Textiles Exotiques)

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initiated a breeding program in Cameroon in 1950 with the objectives of improving fibre yield, resistance to pests and diseases and fibre quality (Levrat, 2010). For 60 years, this breeding program has been carried out considering the specifications of Sodecoton, and then breeding several cultivars among which the Sodecoton picked the ones to be released to farmers. By 2009, more than 20 cultivars were released. Despite the breeding efforts, Naudin *et al.* (2010) showed that on-farm seed cotton yield has been decreasing steadily since the 80s in Cameroon. This could be explained either by agronomic factors (soil fertility, rainfall pattern, cultural practices) or by the performance of genetic material.

Past studies have evaluated genetic improvement of yield on cotton (Campbell *et al.*, 2011; Schwartz and Smith, 2008). In most of them widely grown cultivars were compared in field experiments and linear or break-linear regressions on the year of release (YR) of each cultivar were estimated. In other studies, the interactions between genetic improvement and several aspects of the environment were studied. Significant interactions between genetic improvement and environment were observed on seed cotton yield in the USA (Campbell *et al.*, 2012) and Australia (Liu *et al.*, 2013). In Cameroon where cotton is grown in a wide range of environmental and crop management conditions, resulting mainly from various onsets of rains and planting dates, genetic improvement should be assessed under a diverse set of production situations.

To our knowledge, genetic improvement and its interaction with planting date have never been evaluated on seed cotton and fibre yields in Africa. Therefore, this paper aims at:

i. estimating the rate of genetic gain (GG) in yield and its components on a set of cotton cultivars released between 1950 and 2009 in Cameroon;
ii. determining whether or not the rate of GG is affected by the planting date, main source of environmental variation of cotton crop in Africa.

MATERIALS AND METHODS

Plant material

We chose 10 cotton cultivars widely cultivated and released in Cameroon between 1950 and 2009. Most cultivars grown in Cameroon are derived from Allen Commun and bulk with N'Kourala and foreign cultivars as shown in Table 1.

Field conditions

Field trials were conducted in 2012 in two locations in Cameroon: Maroua (Far North Region, GPS: 10.652, 14.410, and altitude: 380 m) and Garoua (North Region, GPS: 9.246, 13.471, and altitude: 250 m). In Maroua, a randomised complete block design was used with one factor (cultivar) and three replicates; in Garoua a split-plot design was used with two factors (main plot: planting date, subplot: cultivar) and three replicates. In total, there were four environments defined by the location, a planting date and its corresponding level of fertilisation according to the recommendations of Sodecoton. In Maroua, there was one late planting date. In Garoua, the earliest

Table 1. Description of cotton cultivars used in field experiments in Cameroon 2012.

Cultivars	Year of release	Geographic origin	Main genetic origin
Allen Commun	1950	Nigeria	Allen Nigeria
N'Kourala	1950	Mali	Mass selection
Allen 333–57	1959	Nigeria	Allen Nigeria
IRCO 5028	1974	Chad	Bulk with Allen commun, N'Kourala, and Triomph (USA)
IRMA 96+97	1981	Cameroon	IRCO 5028
IRMA 1243	1985	Cameroon	IRCO 5028
IRMA A1239	1996	Cameroon	IRMA BLT
IRMA D742	1999	Cameroon	IRMA 2319 and IRMA 772
IRMA L484	2008	Cameroon	NTA 88-6 (Mali) and IRMA D160
IRMA L457	2009	Cameroon	ISA 784 (Ivory Coast) and IRMA B192

Table 2. Description of field experiments conditions in Maroua and Garoua, Cameroon, 2012.

Environment	Planting date	Complex fertiliser at thinning (kg ha^{-1})	Urea at ridging (kg N ha^{-1})
Maroua	06-Jul	N:44 P:20 K:30	0
Garoua G0	14-Jun	N:44 P:20 K:30	23
Garoua G1	27-Jun	N:33 P:15 K:23	23
Garoua G2	11-Jul	N:22 P:10 K:15	0

planting date was G0, delayed planting date G1 and the latest planting date G2 (Table 2). For all sites, plots were 32 m², spacing 0.8 × 0.4 m (31250 plants ha^{-1}). Weed and pest control was maximised. Weather including solar radiation was recorded daily with a synoptic weather station within 10 km from each site, while rainfall was recorded on each site (Figure 1). In Maroua, the rainy season accumulated 671 mm of rainfall from planting to harvest with 84 days available to the crop from planting to last rain > 10 mm. In Garoua, it was 1116 mm with 121 days in G0, 1063 mm with 108 days in G1, 921 mm with 94 days in G2. In Maroua and in G2, the crop met the end of the rainy season before the 94 days after emergence necessary to achieve its physiological maturity (Gérardeaux *et al.*, 2013).

Plant measurements

Each growth stage was scored as soon as 50% of the plants in the observed row reached emergence, anthesis or first open boll stage. Cycle duration was measured in growing degree days with a base temperature of 13 °C (GDD). In each plot, three plants were randomly chosen for destructive samplings at 35, 65 and 120 days after planting (DAP). Aerial dry biomass per m² was assessed from dry biomass per plant and actual plant density. Seed cotton yield was measured on two central rows on an area of 12.8 m² per experimental plot. Fibre yield was determined by multiplying cotton yield with the ginning out-turn. Harvest index was determined as seed cotton yield divided by total aerial dry biomass at 120 DAP. In all plots, LAI dynamics was assessed with

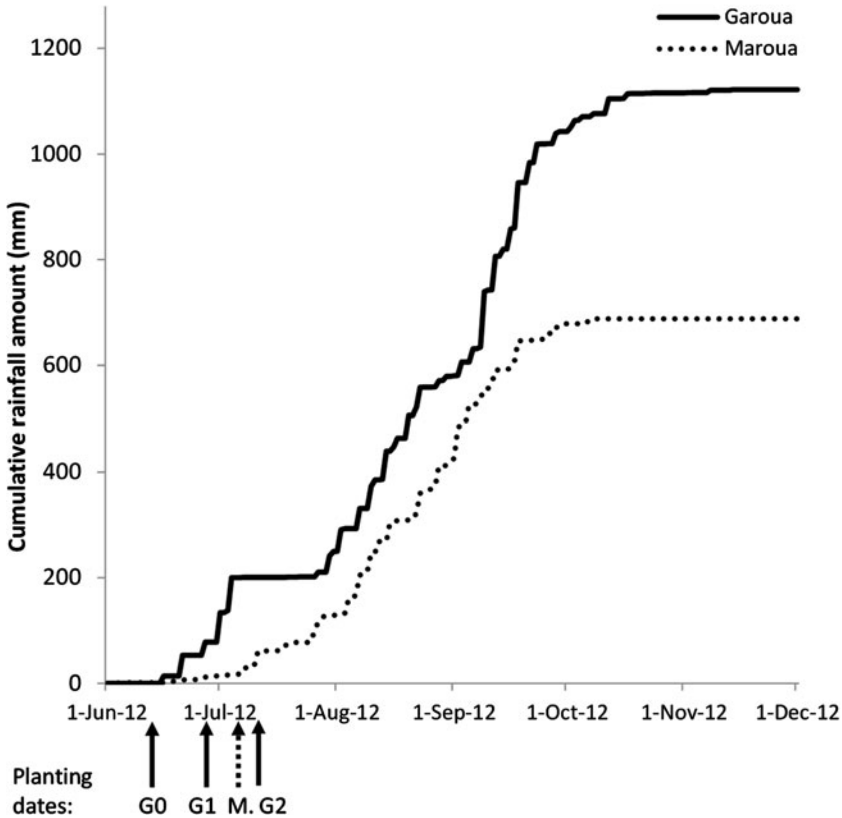

Figure 1. Cumulative rainfall amount in field experiments in Maroua (M.) and Garoua (G0,G1, G2), Cameroon, 2012.

a LICOR LAI-2200 (LI-COR, USA) during crop cycle. LAI at maximum vegetative stage was measured for Maroua, G0 and G1.

Determination of global radiation use efficiency

The global RUE was defined as the ratio of accumulated aerial dry biomass to intercepted photosynthetically active radiation over the same period (Monteith and Moss, 1977). The coefficient of light extinction was set at 0.69 (Brodrick *et al.*, 2013) and the maximum percentage of light interception at 95%. Global RUE was calculated between 35 and 95 DAP.

Statistical analyses

Analyses were carried out with SAS 9.3 proc MIXED [SAS Institute Inc., Cary, NC, USA]. For each variable, a first step analysis suitable for split plot and randomised complete block designs was performed in order to estimate adjusted means; then, a second step aimed at estimating the rate of GG, i.e. the slope of a linear regression of the adjusted mean on the YR of the cultivars. Where several planting dates were compared, contrast estimation was also used to test for any difference in rate of GG observed under these different planting dates. Maroua was the least favourable condition, as the late onset and unusually early stop of the rainy season left only 84 days of rainy season for the crop cycle. However, to test the effect of planting date, Maroua was considered separately from Garoua, as conditions other than planting date differed between the two locations (e.g. rainfall pattern, temperatures, global radiation, soil type). The YR was centered at 1980, so that the intercept of the regression is the predicted performance of any cultivar released in 1980.

RESULTS

For all variables, no significant difference in the rate of GG was found between planting dates in Garoua (results not shown). Consequently, the rate of GG in Garoua was considered to be the same irrespective of the planting date. In Maroua and Garoua, there was no significant GG on the duration from emergence to anthesis (Table 3). In Maroua, the duration from emergence to first open boll significantly increased (1.05 GDD year^{-1}) but not in Garoua. In Maroua and Garoua, there were neither significant GG on LAI at any time measured nor on RUE. Similarly, there was neither a significant genetic improvement of the maximum biomass measured at 120 DAP, nor of the harvest index at maturity. However, the fibre yield was significantly increased in Garoua with a yearly rate of 3.3 kg ha^{-1}, but not in Maroua ($p = 0.070$). The ginning out-turn was significantly increased in Maroua (6.2% in 60 years), and Garoua (3.9% in 60 years). On the contrary, there was no significant GG on boll number per square meter, average boll weight and seed cotton yield in all field conditions.

DISCUSSION

Genetic improvement

There are two possible explanations for the absence of significant GG on seed cotton yield. First, with little or no change at all in cycle duration, no significant GG on LAI and on RUE, no GG on the biomass production was observed in any location. This absence of GG on biomass production was coupled with no significant GG on harvest index. Secondly, no significant GG on the number of bolls produced and on the average weight of each boll were observed. Our results confirmed that breeders aimed at increasing fibre yield, while Sodecoton aimed at increasing fibre yield and the ginning out-turn in their choice of cultivar to release. However, breeding for increased ginning out-turns may lead to higher seed-coat fragments content in lint due to increased brittleness of the seed coat (Bowman, 1996).

The seed cotton yields obtained in this study in Garoua under favourable conditions (G0, G1, Table 3) were higher than 1460 kg ha^{-1} obtained by Naudin *et al.*, (2010) on average in farmers' fields. However, the results in late planting conditions (G2 and Maroua) were similar to theirs.

We found an increase of 3.3 kg ha^{-1} year^{-1} (0.38 % year^{-1}) in fibre yield (Table 3). In the USA, Schwartz and Smith (2008) observed a rate of GG on fibre yield of 8.7 kg ha^{-1} year^{-1} (0.93 % year^{-1}). In Australia, Liu *et al.* (2013) observed a rate of

Table 3. Yearly rate of genetic gain (GG) and prediction at year 1980 in field experiments conducted in Cameroon in 2012.

	Garoua				Maroua	
		‡Prediction for 1980				Prediction
Variables	†Slopes	G0	G1	G2	Slope	for 1980
Development & growth						
Duration from emergence to	0.38 ns	914	841	831	− 0.36 ns	1043
anthesis [GDD]¶	§ ± 0.24	± 7	± 7	± 7	± 0.32	± 7
Duration from emergence to	0.29 ns	1627	1536	1475	1.05*	1684
1st open boll [GDD]	± 0.27	± 9	± 9	± 9	± 0.42	± 9
Radiation use						
Leaf area index at 65 DAP	− 0.003 ns	1.47	1.74	1.11	− 0.005 ns	2.15
	± 0.003	± 0.08	± 0.08	± 0.08	± 0.004	± 0.08
Leaf area index maximum	− 0.001 ns	2.93	3.07	–	− 0.004 ns	2.95
	± 0.005	± 0.14	± 0.14	–	± 0.006	± 0.14
Radiation use efficiency	0.001 ns	1.26	1.89	1.06	− 0.003 ns	1.28
[g MJ^{-1} m^{-2}]	± 0.002	± 0.08	± 0.08	± 0.08	± 0.004	± 0.08
Biomass and allocation						
Aerial dry biomass at 120 DAP	− 9.2 ns	7805	6184	4433	− 10.0 ns	5199
[kg ha^{-1}]	± 9.8	± 325	± 325	± 325	± 15.3	± 325
Harvest index [%]	0.028 ns	38.9	41.2	31.5	0.053 ns	24.0
	± 0.056	± 2.0	± 2.0	± 2.0	± 0.095	± 2.0
Yield and components						
Ginning out-turn [%]	0.065*	39.7	40.0	38.6	0.104**	37.7
	± 0.030	±0.7	±0.7	±0.7	± 0.031	± 0.7
Boll number [# m^{-2}]	−0.022 ns	54.1	49.9	32.7	0.039 ns	23.3
	± 0.060	± 1.8	± 1.8	± 1.8	± 0.083	± 1.8
Average boll weight [g]	0.001 ns	5.3	5.2	4.0	–	–
	± 0.004	± 0.1	± 0.1	± 0.1	–	–
Seed cotton yield [kg ha^{-1}]	−0.10 ns	2770	2408	1357	1.70 ns	1138
	± 1.66	± 60	± 60	± 60	± 2.79	± 60
Fibre yield [kg ha^{-1}]	3.3***	1101	962	539	2.3 ns	455
	± 0.8	± 27	± 27	± 27	± 1.2	± 27

$^{*}\alpha = 0.05$; $^{**}\alpha = 0.01$; $^{***}\alpha = 0.001$; ns = Not significant.
†Slope of the linear regression on the year of release.
‡Intercept of the linear regression on year or release centered at 1980, i.e. predicted value for an average cultivar released in 1980. Always significant at the 0.001 probability level.
§Standards errors.
¶GDD: growing degree days with a base temperature of 13 °C.

fibre yield GG of 12.3 kg ha^{-1} $year^{-1}$ (0.67 % $year^{-1}$). Also in Australia, Rochester and Constable (2015) observed a rate of GG of 28.8 kg ha^{-1} $year^{-1}$ (1.2 % $year^{-1}$) on fibre yield and of 0.14 % $year^{-1}$ on ginning out-turn. However, these authors found no change in harvest index despite a joint increase in aerial biomass and seed cotton yield. Our rate of GG is very low as compared to that obtained in the USA and in Australia. This is probably because cotton breeding in Cameroon is targeting less favourable growing conditions (poor soil fertility, harsh climate, no irrigation). From our results, we concluded to no improvement of seed cotton yield in Cameroon. However, under similar conditions, breeding has increased yield of other important crops such as corn in Nigeria (Badu-Apraku *et al.*, 2013) and in Kenya (Beyene *et al.*, 2015), and cowpea in Nigeria (Kamara *et al.*, 2011). A GG in seed cotton yield is probably attainable if targeted in priority by the cotton sector.

Non-genetic limiting factors

The decreasing seed cotton yield that has been observed from the 1980s in Cameroon's farms (Naudin *et al.*, 2010) was very likely due to agronomic factors, as we did not find a clear genetic explanation for this negative trend (Table 3). This yield decline in Cameroon could be attributed to limiting factors such as low soil fertility, low water availability during the crop cycle (M'Biandoun and Olina, 2006), lack of training for new farmers (Cao *et al.*, 2011), use of fertilisers below recommended rates, cultivation of infertile plots and to late planting dates (Cao *et al.*, 2011) explained by priority to food crops and late onset of rainy season.

Perspectives

An optimisation of examined cotton breeding strategy seems possible for seed cotton yield improvement with a major shift in the ranking of breeding criteria. For example, breeding for more boll numbers should efficiently increase seed cotton yield since the boll number and the seed cotton yield are highly positively correlated in water-limited conditions (Rahman *et al.*, 2008). In addition, some physiological variables related to crop yield in water-limited conditions were successful for yield improvement: stability of metabolic response on peanut (Singh *et al.*, 2014), greater global RUE and high leaf assimilation rate on cereals (Fischer and Edmeades, 2010), high $\Delta^{13}C$ on emmer wheat (Konvalina *et al.*, 2012), and leaf enhanced RuBisCo activity on cotton (Plaut and Federman, 1991). These additional physiological traits indirectly linked to high yields in drought conditions should be targeted as early as in generation F5 when there are still many different lines to test and already a population of plants for evaluating yield.

CONCLUSION

In conclusion, the breeding program in Cameroon has improved cotton fibre yield by 200 kg ha^{-1} in 60 years entirely due to increased ginning out-turn. Since growers are paid based on their seed cotton production, it seems that it is mainly the development company that has reaped the benefits of these breeding efforts. In order to increase seed cotton yield for the farmers, breeding efforts should target cultivars with more boll numbers or include physiological measurements such as those relative to photosynthesis capacity. For example, the highest leaf chlorophyll content and the lowest specific leaf area could easily be targeted *in campo*.

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