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Original research paper

Designing cotton ideotypes for the future: Reducing risk of crop failure for low input rainfed conditions in Northern Cameroon

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ABSTRACT

Climate change is threatening the ability to grow cotton (*Gossypium hirsutum* L.) under low input rainfed production areas in Sub-Saharan Africa. In Northern Cameroon, yield has been declining due to unsuitable cropping practices such as sub-optimal planting dates, along with an absence in genetic gain. The aim of this study was to use a cropping system model (DSSAT CSM-CROPGRO-Cotton) to identify the best cultivars (ideotypes) for Northern Cameroon that are adapted to low input rainfed productions systems for 2050 under RCP4.5 and RCP8.5. Calibration and evaluation of the CSM-CROPGRO-Cotton were performed with field observations for two cultivars (Allen Commun and L484). For RCP4.5 and RCP8.5, 50 replications for 2050 were generated based on an ensemble of 17 Global Circulating Models. In total, 3125 virtual cultivars representing existing genetic variability for phenology, morphology and photosynthesis were simulated. Thereafter, they were evaluated for performance under the projected future climate based on potential yield and the resilience of yield to sub-optimal planting date. The widely cultivated cultivar L484 will be unsuitable under projected future climate, due to boll opening during the middle of the rainy season (median: 10/09 under RCP4.5 and 12/09 under RCP8.5). None of the ideotypes tested could optimize both yield and resilience (*Pearson* correlation < -0.82). However, compared to the current cultivar L484, two virtual ideotypes were identified: (a) “Ideo_sub” had a wide planting window, especially in the 10 worst replications of 2050, up to +5 days in RCP8.5; (b) “Ideo_Pot” had a high potential yield trait with low resilience to sub-optimal planting date, in the 10 worst replications of 2050, $+530$ kg ha^{-1} in RCP4.5 and $+591$ kg ha^{-1} in RCP8.5. Both ideotypes had an earlier anthesis date, a longer reproductive duration, and increase in the maximum photosynthetic rate. Therefore, breeding programs should consider these traits suggested by this system analysis using a crop simulation model for the identification of suitable cultivars under the projected future climate.

1. Introduction

Cotton (*Gossypium hirsutum* L.) is the major fiber crop grown in the world (ICAC, 2017). In West and Central Africa, more than 3 million metric tons of cotton were produced in 2014 (Fig 1). Cotton is an important source of cash income which contributes to the food security of millions of smallholder farmers (Tschirley et al., 2009). In addition, the residual effect of fertilizer applied on cotton improves the yield of succeeding staple crops (Ripoche et al., 2015).

However, climate change in tropical regions is expected to decrease yield and increase yield variability at the same time (Challinor et al., 2014). The use of optimal cultivars has been identified as the most efficient way to adapt to climate change (Challinor et al., 2014; Ramirez-Villegas et al., 2015). Optimal cultivars bred for a target environment are usually called ideotypes. They are described as “a combination of morphological and/or physiological traits, or their genetic bases, optimizing crop performance to a particular biophysical environment, crop management, and end-use” (Martre et al., 2015a).

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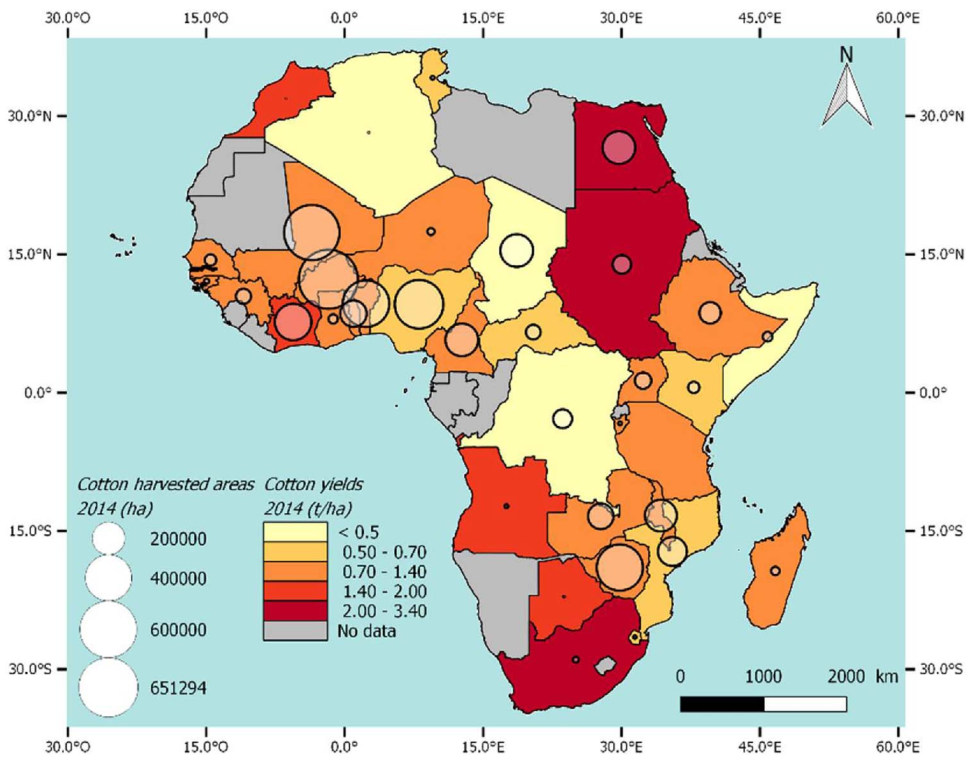

Fig. 1. Cotton harvested area and yield in Africa for 2014.
Source: FAOSTATS, September 2016.

Physiological breeding of ideotypes has already been demonstrated as efficient in increasing genetic gains under a wide range of environments for wheat (Reynolds and Langridge, 2016). As reviewed by Jeuffroy et al. (2014), breeding programs seeking for such ideotypes could be supported by cropping system models (CSM). The CSM dynamically estimate agricultural production (usually on a daily basis) as a function of weather, soil conditions and crop management. Hence, the CSM are theoretically able to represent Genotype x Environments x Management interactions (Jeuffroy et al., 2014). Among other applications, CSM were successfully used for optimizing planting date (Kim et al., 2013) and fertilization (García-Vila and Fereres, 2012), studying the impact of climate variability and climate change on production (Gérardeaux et al., 2013; He et al., 2015; Rötter et al., 2013; Xiao and Tao, 2014), and evaluating cultivars (Casadebaig et al., 2016; He et al., 2015; Xiao and Tao, 2014). The CSM have been used for the design of ideotype for cereals (Rötter et al., 2015; Stratonovitch and Semenov, 2015; Zheng et al., 2016; , 2012), rice (Paleari et al., 2017), peanut (Singh et al., 2014, 2012), sunflower (Casadebaig et al., 2011) and fruit trees (Quilot-Turion et al., 2012). Some CSM were successfully calibrated in African low input rainfed conditions for millet in Niger (Rezaei et al., 2014; Soler et al., 2008), peanut in West Africa (Singh et al., 2014) and cotton in Cameroon (Gérardeaux et al., 2013).

In Northern Cameroon, cotton is the main cash crop and it is exclusively grown by smallholder farmers under rainfed conditions (Sultan et al., 2010). The climate in Northern Cameroon is characterized by a very high spatial and temporal variability in rainfall (Fig. 2). There are both seasonal and intra-seasonal variabilities (M'Biandoun and Olina, 2006), which widely affect cotton yield, especially in the driest areas (Sultan et al., 2010). Spatial factors linked to climatic and soil conditions contribute to large differences in yields between the humid and the driest areas (1500 kg ha^{-1} and 670 kg ha^{-1}, respectively; Tschirley et al., 2009). National cotton yield has been decreasing steadily since the 1980s (Naudin et al., 2010). This was mainly attributed to the absence of genetic gain on yield despite a dedicated breeding program (Loison et al., 2017), together with an increasing number of farmers using unsuitable cropping practices for cotton such as late planting, sub-optimal fertilization and cultivation of infertile plots because they allocate their limited resources (time, fertilizer and labor force) giving priority to the production of staple crops for personal consumption (Cao et al., 2011; Mahop and Van Ranst, 1997). This trend in yield is likely to worsen, as lower rainfall has been predicted because of climate change (Dai, 2012). In Northern Cameroon, cotton ideotypes, should be resilient to sub-optimal planting dates, low fertility and climatic variability and should prevent crop failure under climate change. To our knowledge, the use and evaluation of CSM for the design of rainfed cotton ideotypes under low fertility conditions in order to support breeders has not been documented. Therefore, the aim of this study, was to identify the traits of rainfed cotton ideotypes for Northern Cameroon under projected climate change conditions in 2050.

2. Material and methods

2.1. Model description

The CSM-CROPGRO-Cotton model of the Decision Support System for Agrotechnology Transfer (DSSAT) includes several modules: soil, weather, soil-plant-atmosphere, management, and crop (Jones et al., 2003). The soil module includes soil water (Ritchie, 1998), soil temperature, soil carbon model CENTURY suitable for low-input systems (Gijsman et al., 2002), and nitrogen dynamics (Godwin and Singh, 1998) in a one-dimensional vertical layers profile. The weather module uses daily weather data, with at least minimum and maximum air temperatures, solar radiation, and precipitation. The crop response to atmospheric CO_2 concentrations is simulated in DSSAT CROPGRO with similar impacts compared to those reported in the literature (up to 660 ppm, Alagarswamy et al., 2006). The soil-plant-atmosphere module computes daily soil evaporation and plant transpiration. The management module determines timing and characteristics of crop management (planting, tillage, harvesting, inorganic fertilization, irrigation, and application of crop residues or organic amendments). Finally, the crop module predicts the growth, development and yield of various crops. Each crop is described with its own set of genetic parameters. There are three sets of genetic parameters (species, ecotypes and cultivars) that account for differences in development, growth, and yield