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Use of the beta growth function to quantitatively characterize the effects of plant density and a growth regulator on growth and biomass partitioning in cotton

Lili Mao[a,b], Lizhen Zhang[c,*], Xuezhen Sun[a], Wopke van der Werf[d], Jochem B. Evers[d], Xinhua Zhao[e], Siping Zhang[e], Xianliang Song[a], Zhaohu Li[b,*]

[a] Shandong Agricultural University, Agronomy College, Taian, Shandong 271018, China
[b] China Agricultural University, Agronomy College, Beijing 100193, China
[c] China Agricultural University, College of Resources and Environmental Sciences, Beijing 100193, China
[d] Wageningen University, Centre for Crop Systems Analysis, Crop & Weed Ecology Group, 6708 PB Wageningen, The Netherlands
[e] Institute of Cotton Research of Chinese Academy of Agricultural Sciences, Key Laboratory of Cotton Genetic Improvement, Anyang, Henan 455004, China

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ABSTRACT

Allocation of newly formed biomass towards plant organs is a key determinant of plant performance that is affected by agronomic practices such as plant population density and use of growth regulators. Here we quantified biomass allocation of intercropped cotton (*Gossypium hirsutum*) growing at two population densities (3.0 and 7.5 plants m^{-2}) and with or without application of the growth regulator mepiquat chloride (MC) in three consecutive years. The beta growth function was used to quantitatively characterize the dynamics of biomass partitioning. Compared to low density, high density increased daily growth rate and final above-ground dry matter, but decreased allocation to fruits. Application of MC did not affect dry matter accumulation but increased allocation to fruits by 22%. The parameters of the beta growth function have a clear biological interpretation, providing a useful quantitative characterization of the effect of management on dry matter allocation in cotton. The function may also be used to model organ-specific daily assimilate partitioning as a component in models of plant growth and crop production with the consideration of discussed caveats.

1. Introduction

Daily partitioning of biomass growth to leaves and stems is an important determinant of yield formation. During early growth, partitioning to leaves determines access to light, affecting early growth and competitiveness, and laying the basis for yield formation later in the season. During later growth, the partitioning to vegetative and reproductive organs drives yield formation.

Cotton grows indeterminately and easily overinvests in vegetative growth if not managed appropriately. An unbalanced assimilate allocation pattern in plants may lead to leaf senescence or undesirable abscission of flowers and fruits (Marcelis et al., 2004; Wingler et al., 2006). In cotton, the measured total aboveground dry matter at harvest is often less than the maximum, mainly due to shedding of old leaves and young fruits which are then very difficult to sample. The biomass of stems and leaves may furthermore be decreased due to re-translocation of biomass to reproductive organs. Analyzing the biomass dynamics in cotton should take into account that there may be a decline phase towards the end of the season due to loss of senescent leaves and redundant fruits, and reallocation between different compartments.

Daily growth of an organ results from the allocation of growth substrates as affected by environmental and physiological factors (Yin et al., 2003; Trinder et al., 2012; Zhang et al., 2015). However, dry matter of different organs is often measured only at a few moments during the growth season, at certain phenological phases. It is not possible to measure organ biomass partitioning index (here defined as the fraction of daily organ growth rate over daily plant growth rate), by direct measurements in field experiments. However, the beta growth function (Yin et al., 2003) has a proven ability to describe daily dry matter accumulation in a wide range of systems, and this function could be used to derive functions for assimilate allocation (Bai et al., 2016; Dong et al., 2017). The three parameters of the beta growth function have clear biological meanings: the maximum dry matter (W_{max}), the time when W_{max} is reached (t_e), and the time at which maximum growth rate is reached (t_m). If this function is fitted to periodically obtained biomass data, the rate of growth can be obtained by taking its

* Corresponding authors.
E-mail addresses: Zhanglizhen@cau.edu.cn (L. Zhang), lizhaohu@cau.edu.cn (Z. Li).

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first derivative. In this way, the partitioning index can be determined by comparing the growth rates of different organs under various agronomic practices and environments. Such an approach is useful for modelling allocation of dry matter as long as attrition of previously accumulated biomass is negligible. The advantage of using the beta growth function is that it explicitly allows for a decline in biomass (i.e. a negative growth rate) beyond W_{max}. Other sigmoid functions such as the classic logistic (Verhulst, 1838) and Richards (1959) functions do not support such a decline phase.

Plant density affects dry matter partitioning through its effect on competition for space and resources (Dauzat et al., 2008; Zhu et al., 2014). Mepiquat chloride (MC) is an exogenous growth regulator that affects vegetative and reproductive growth in cotton by interfering with the biosynthesis of gibberellins (Wang et al., 2014a). MC is used in cotton to optimize plant growth for productivity and to avoid excessive vegetative growth (Ren et al., 2013). Together, plant density and application of MC have dramatic effects on cotton growth (Mao et al., 2014, 2016).

Cotton is mostly grown as a sole crop but in some regions cotton is intercropped with wheat (Dai and Dong, 2014). In intercrops, interspecific competition affects organ growth in cotton (Zhang et al., 2008). There is little knowledge on how plant density and MC interactively affect cotton growth and assimilate partitioning when intercropped. Hence, it is necessary to explore the effects of plant density and MC application and quantify biomass partitioning to aboveground organs in cotton/wheat intercropping.

The objective of this study was to quantify assimilate partitioning in cotton intercropped with wheat in response to plant density and MC, by analyzing biomass data and fitting the beta growth function and deriving partitioning functions from the fitted beta functions. To verify the applicability of the beta growth function for cotton growth, a comparison with both the logistic and Richards functions was made. Cotton growth data from three years field experiments with plant density and growth regulator treatments were analyzed to capture effects of management and environment on assimilate partitioning in an intercropped cotton system.

2. Materials and methods

2.1. Experimental design

Three years of field experiments were conducted in Anyang, Henan province, China (36°07′N, 116°22′E) in 2010–2012. The soil texture is a sandy loam, with a pH of 8.0, total N of 1.02 g kg^{-1}, available P of 23.6 mg kg^{-1}, available K of 71.3 mg kg^{-1}, organic matter content of 13.2 g kg^{-1} in the top 20 cm soil layer. Annual rainfall was 529 mm in 2010, 446 mm in 2011, 467 mm in 2012. Daily maximum and minimum air temperatures during cotton growing season in each year are presented in Fig. 1. Meteorological data were measured at the site of the experiments by GRWS100 weather station (Campbell Scientific, Inc. Logan, USA).

Bt (*Bacillus thuringiensis*) transgenic cotton (*Gossypium hirsutum*) ‘Guoxin 3’ was used in the experiments growing as a relay strip intercrop with wheat (*Triticum aestivum*) ‘Zhongyu 10’. Both cultivars and cropping system are commonly used in the Yellow River Region, China. Two plant densities (3.0 and 7.5 plants m^{-2}) with or without MC were tested, resulting in four treatments. MC treatment levels were MC-free control (M0), and MC application at seedling, squaring, flowering and boll stage (M4) at a total dose of 129 g ha^{-1} and doses of 6.0, 18.0, 45.0 and 60.0 g ha^{-1} at each stage, respectively. The experiments were laid out in a randomized complete block design with three replicates.

The relay intercrop of wheat and cotton consisted of three rows of wheat and two rows of cotton with 40 cm row space for cotton, 20 cm row space for wheat, and 30 cm between adjacent wheat and cotton rows, resulting in a total strip width (wheat + cotton) of 1.4 m. Each plot was 33.6 m^2 (4.2 m in width × 8.0 m in length). Wheat was sown on 3–5 November (2009–2011) and harvested on 15 June in the next year. Cotton was sown on 29–30 April and harvested on 25 October in 2010–2012. All vegetative branches were removed at squaring stage. Removal of vegetative branches is a common practice to control excessive vegetative growth (Dai and Dong, 2014). Fertilizer with 225 kg ha^{-1} N, 150 kg ha^{-1} P_2O_5, 225 kg ha^{-1} K_2O was applied in each plot according to farmer’s practice. The total amount of irrigation during the cotton growing season was 222 mm in 2010, 200 mm in 2011, and 180 mm in 2012. Topping of the main stem was carried out on 30 July in all years. All other management was conducted according to local agronomic practice.

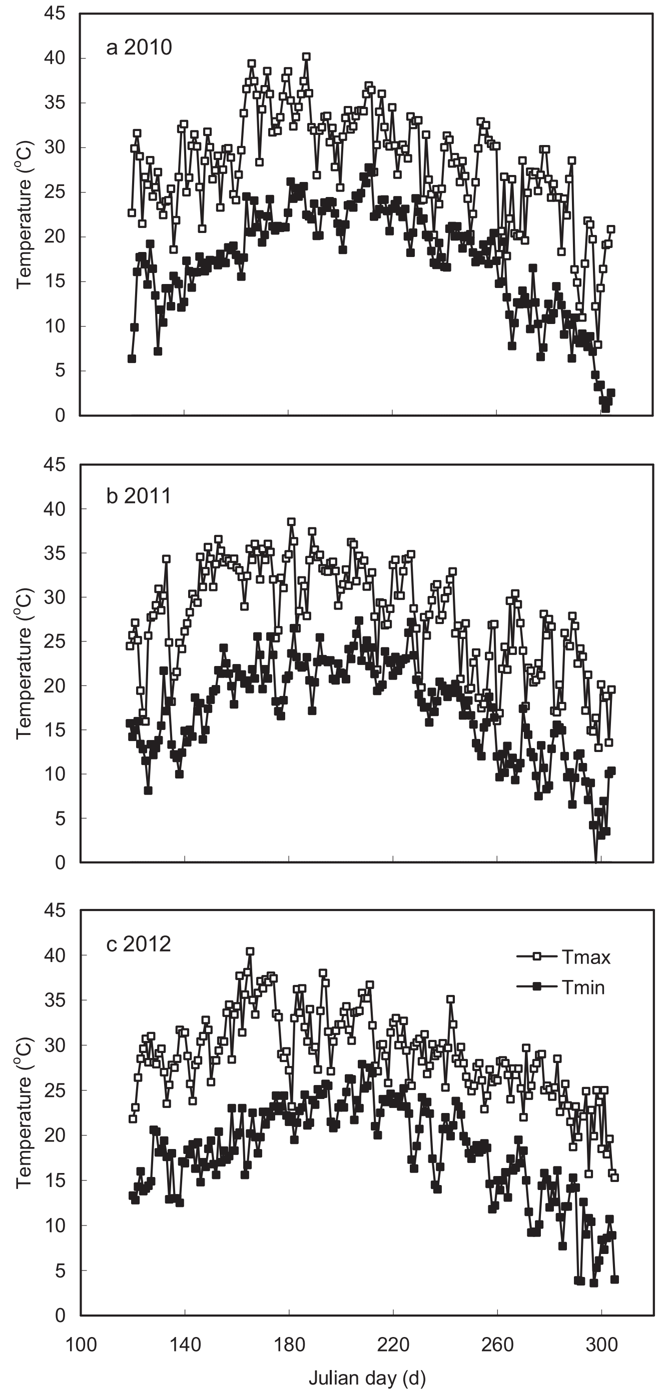

Fig. 1. Daily maximum and minimum air temperatures in intercropped cotton during the crop growing season in 2010 (a), 2011 (b) and 2012 (c) in Anyang, Henan, China.