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The yield potential of cotton (*Gossypium hirsutum* L.)

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ABSTRACT

Yield potential studies can assist in identifying the production constraints in any cropping system and economics at the farm level dictate a continual need to increase yield and profit for most crops. Cotton is a tropical indeterminate perennial grown as an annual crop for fibre (lint), oil and meal for animal feed. Its growth habit means a production season can have a long duration up to 180 days. Here we define yield potential as yields that can be obtained with current cultivars and systems under ideal conditions in the absence of poor weather, disease, soil or nutritional constraints with management and genetics optimised. This paper aims to review yield potential in cotton and particularly identify factors, such as climate, soil health, nutrition, water, weeds, pests and diseases which affect yield. Worldwide, average cotton lint yield is about 800 kg/ha and is increasing at rates of 10–20 kg/ha/year, especially where irrigation is available. Under irrigated conditions, lint yield of 3500 kg/ha is now being obtained and we use this value for yield potential under full season irrigated conditions. Yield potential for raingrown cotton production systems depends on soil water storage and rainfall but is about 800 kg lint/ha. Thus, yield potential is not a fixed value but it is increasing through time as crop management and genetics are improved—but it is also strongly affected by local conditions. We derived the theoretical yield of cotton from potential growth or photosynthesis and respiration rates by growth analysis, from radiation use efficiency or by simulation modelling. All three methods indicated theoretical yield to be about 5000 kg lint/ha. To achieve this yield, a long season is required, possibly with slower initial fruit set so canopy size is not restricted by high fruit load. Estimates of resource requirements for lint yields of 5000 kg/ha indicated that nutrient uptake of 384 kg/ha N and K and 83 kg P/ha would be a more challenging constraint than the 10.7 Ml/ha of total evapotranspiration required. Future research opportunities were identified in crop agronomy (nutrient uptake and use efficiency), plant physiology (modelling fruiting dynamics), breeding (longer season plant types with slower initial fruit setting) and biotechnology (increased photosynthesis).

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1. Introduction

As with all crops, cotton producers are dealing with a cost price squeeze. Furthermore, cotton fibre has strong competition with man-made fibres. Cotton has had a declining share of the textile market for some decades, with the share being around 30% in 2014 (ICAC, 2013). Thus, producers need to improve yield with less year to year variability or increase product value or reduce input costs to maintain economic viability. In order to achieve the aim of higher yield, there are roles for both breeding and crop management research to identify solutions in terms of yield, and cost of production. A good understanding of yield potential is important to evaluate whether a production system's constraints can reasonably be alleviated, and how the system can be improved.

Cotton differs markedly from many broad area cereal and pulse crops because of its perennial, indeterminate nature and low fibre harvest index around 15–20% (Constable and Hearn, 1981; Halevy et al., 1987; Bange and Milroy, 2004; Yeates et al., 2010a). However, cotton is also an oilseed used for crushing and/or livestock feed and this component provides about 10% of the crop gross margin, depending on relative prices of lint and fuzzy seed. Adding cotton seed yield to the lint raises its harvest index to about 60%. Determinate grain crops also have harvest indices of around 60% (Hay, 1995; Unkovich et al., 2010). Lint fraction (lint as a fraction of seed + lint) is therefore a component of harvest index and a yield component (Coyle and Smith, 1997; Clement et al., 2013).

In this paper, we will define yield potential as the yield obtained in the absence of poor weather, disease, soil or nutritional constraints, using the most suitable available cultivar and with management optimised. This definition will mean a different yield in the same environment for irrigation or raingrown crops and even a different yield potential each year depending on rainfall. To avoid the confusion with the use of the terms "potential yield" and "yield potential" (Evans and Fischer, 1999), we will use theoretical yield as the term for the yield capacity calculated from maximum growth or photosynthesis rates. In this study we will derive theoretical yield by three methods: using maximum crop growth rates, using maximum radiation use efficiency and finally by simulation modelling.

2. Cotton plant development and yield

An indeterminate growth habit means all mainstem, vegetative and fruiting branches end in a vegetative bud, so a cotton plant has remarkable ability to fill space and time. There can be a long crop cycle, even perennial in historical times (Lee, 1984), if climate and resources allow. Further, there can be mature bolls on a plant at the same time as new vegetative growth is being produced. Even in modern commercial production systems where the crop is managed for determinacy, there is a stage where cotton fruit and vegetative growth are occurring simultaneously (Constable and Gleeson, 1977; Fig. 1), which challenges crop management in terms of optimising nutrient and water supply to balance vegetative and reproductive growth (Hearn, 1975). Fig. 1 shows bolls at the lower layer of a cotton canopy growing at 5 g DW/m^2/day at the same time as leaves at the upper layer are growing at 2 g DW/m^2/day. Growth regulators such as Mepiquat Chloride are commonly used to manage vegetative growth within desirable boundaries (Kerby, 1985; Constable, 1994).

Descriptions of cotton crop development are published in McClelland (1916), Eaton (1955), Hearn (1976), Hearn and Constable (1984a) and Mauney (1986) and will not be covered here. Importantly, in the time it takes for the first fruiting branch to develop from branch initiation to the flowering of the first branch node, there have been about eight mainstem nodes develop above it. Once boll development begins, the increasing assimilate demands by fruit slow down the rate of mainstem node development, so a point in time is reached where new vegetative development ceases (Bange and Milroy, 2004), also evident as reduced leaf and stem growth in Fig. 1. This point is called 'cutout' and from that time the crop is <u>source</u> limited as opposed to being <u>sink</u> limited in early vegetative development (Hearn, 1976). A mature high yielding plant may have about 25 mainstem nodes, 18 of which will have a fruiting branch. After cutout it is common for young fruit to be shed through competition with older fruit for assimilates (Mason, 1922), so a typical pattern of fruit retention would be over 90% for the first fruiting branches, to less than 20% for upper branches (Turner et al., 1986).

The specifics of growth habit are fundamental for understanding and analysing cotton yield potential. Under some climatic or management combinations, cotton plants will shed a large proportion of fruit and revert to mainly vegetative growth (Hearn, 1975), despite thousands of years of domestication (Brubaker et al., 1999) and hundreds of years of breeding (Moore, 1956; Brubaker et al., 1999). At the other extreme, setting large numbers of fruit early in the growth cycle will cause the plant to cut out early, reducing yield through reduced leaf area and total fruiting sites. The yield components usually identified in studies have been the number of bolls per unit area and the mass of lint in each boll (Worley et al., 1974) although the relative importance of each yield component varies, in particular since the yield components tend to be negatively correlated with each other (Worley et al., 1976). Other important yield components identified have been mass of lint per seed and boll retention (Kilby et al., 2012) and, at a more basic level, number of seeds per unit area, number of fibres per seed and weight per fibre (Worley et al., 1976; Coyle and Smith 1997).

3. Yield potential

National average yields of cotton vary widely, but the trend for some countries has been for increasing yield over the past three decades (Fig. 2), although many countries still have average yields less than 1000 kg lint/ha. Those countries with higher yield have been increasing at rates between 10 and 30 kg lint/ha/year (Campbell et al., 2014 for US; Fig. 2 for Australia, Brazil and Turkey) but there are a number of countries and regions such as Uzbekistan and French West Africa where yields have stagnated in their production systems, likely due to combinations of water availability, soil constraints and crop nutrition.

There are varying reports of high yield in cotton, although many are not in scientific journals. Table 1 summarises some reports to indicate yield potential, showing values well in excess of 3000 kg lint/ha, some of which have been obtained at a commercial level, albeit on a relatively small scale. Three of those yields since 2010 average more than 3500 kg lint/ha and we will use that number as a working value for a commercially achievable yield potential under ideal conditions. In one case with limited details from China, a yield of 5000 kg lint/ha was reported.