Climate Disruptions to Fibre Yield Growth

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Abstract

The accelerating rise in atmospheric carbon dioxide (CO_2), now at 390 ppm and 2 ppm per year, both benefits and restricts cotton fiber yield growth. Benefit derives from the fertilization effect of elevated CO_2 while detriments derive from the climate disruption of elevated temperature, intensity of rain events, duration of droughts, and depletion of fresh water sources. Decadal graphs of atmospheric CO_2 and textile fiber demand are similar and represent a challenge for the cotton industry to meet the growing global demand during a disrupted climate. Adaptation to elevated CO_2 will be critical as the time to create and extend agricultural innovations are well within the time scale of climate disruption from elevated CO_2. Current examples of beneficial adaptation include: supplemental irrigation; field drainage; no-till and conservation tillage; cropping systems diversification; community pest management; planting date flexibility; risk management policies; planting seed infrastructure; cotton co-products utilization; and farmer expertise. Examples of research to further enhance adaptation include: stress tolerance traits and germplasm; fiber yield enhancement; nitrogen use efficiency; site specific monitoring and input management;phenotypic breeding for elevated CO_2 environments; and fiber quality innovations. Research and implementation will be discussed in the context of both mechanized and traditional cotton production systems.

Introduction

The issue of crop yield growth in the face of climate disruptions will be the critical topic for agriculturalist over the next 10 years as the world struggles to meet demand from the expanding middle class and world population. Applying the decadal growth in textile fiber demand of 3% (0.5% less than global GDP growth) to the year 2050 indicates a 3 fold increase in demand. If cotton's share of textile fibre (currently 37%) holds then cotton consumption in 2050 could be 90 million metric tonnes. A staggering productioneven before climate disruption is considered. This topic, growing agricultural demand in the face of expanding challenge, is intensely discussed in the scientific and agricultural, literature. Several recent reviews (Banwart, 2011; Barnes, 2011 & Bloom *et al.*, 2010) and numerous timely articles in Nature, Science and PNAS provide useful data and concepts that combine with physiological and agronomic features of the cotton plant, *Gossypium hirsutum* and *G. barbadense*. The 130 year trends in global temperature and CO_2 show the basis for anticipated discussions. Even the global financial crisis of 2008 and 2009 did not alter the carbon emission trajectory with 2010 emissions surpassing 9 Pg of carbon, for the first time (Bollasina *et al.*, 2011). As CO_2 levels increase the global temperature is increasing, with numerous impacts on plants besides the direct temperature effect (Bhanwat, 2011).

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Annual deviations in global temperature are portrayed as either below the mean in blue or above in red. Annual average CO_2concentration are portrayed as

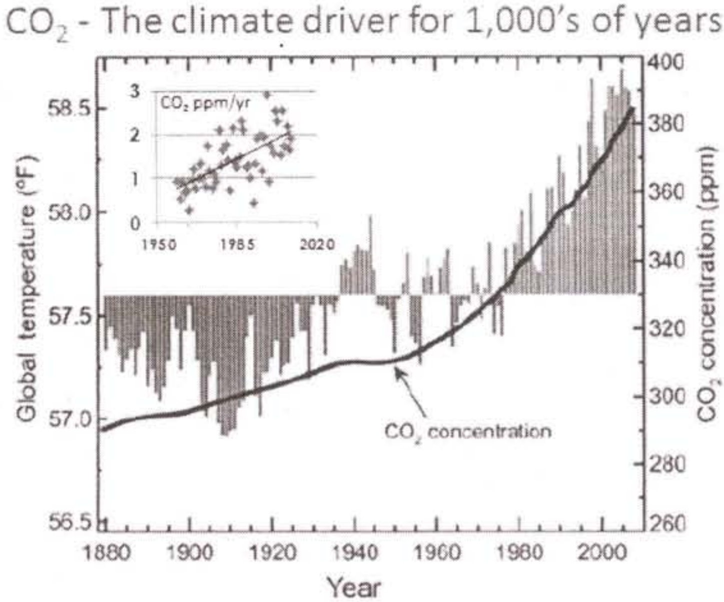

Fig. 1. Annual deviations in global temperature from the mean 100 year temperature (1901 to 2000) and annual average CO_2 concentration. Adapted from CAST 2011.

a solid line. When the rate of CO_2 increase at Mona Kea is included (Bugbee, 2011), which in 50 years has increased from 1 ppm per year to 2 ppm per year, scientist gain an even greater awareness of the challenge facing agriculture to supply crops in the disrupted environment of the future.

The temperature gain predicted for different regions is not uniform, with less temperature rise in the ocean rich southern hemisphere and more in specific regions of the northern hemisphere where land forms predominate. Notably for attendees of the World Cotton Research Conference in Mumbai are the anticipated year when India and the USA will reach 2°C, ~ 2040 and 2030, respectively (Burney *et al.*, 2010). Forecast of reaching 3°C come shortly afterwards in USA, ~2045, and delayed in India, ~2070. Both countries are vulnerable to slight disruptions in climate due to the heavy reliance on rainfed agriculture where approximately 70% of cotton area is grown without irrigation.

Elevated CO_2 has direct and indirect impacts on cotton. CO_2 provides all of the carbon and most of the oxygen in plants. The direct effect of CO_2fertilization on cotton is increased fiber yield. The enzyme responsible for the first step of carbon fixation enzyme in leaves of C3 photosynthetic plants such as cotton, Rubis CO, has a low affinity for CO_2. Thus a doubling of CO_2in open field plots and growth chambers has resulted in a substantial fiber yield increase (52% and 56% under limited and ample water supply) (Campbell *et al.*, 2010) exceeding that of most other C3 crops and all C4 crops. In addition to the C3 carbon fixation machinery, cotton has an indeterminate growth pattern which allows the plant to utilize the elevated CO_2 during an extended period of boll retention and maturation. Since ,water exits leaves through the same pores, stomata, where CO_2 enters the water use efficiency (yield per transpired water) is also increased with

elevated CO_2 (Campbell *et al.*, 2010). CO_2 fertilization is a source of optimism regarding future impacts of climate change that needs to be tempered since temperature rise will cancel out much of this gain and nitrate utilization is anticipated to be restricted (Canfield *et al.*, 2010 ; Chen *et al.*, 2011 & C A S T, 2011) the dominate N form absorbed by cotton roots. Nitrogen fertilizer contributes to over 50% of cotton production's energy cost and environmental burden based on Life Cycle Analysis (Evan *et al.*, 2011)and is a global concern for its requirement to feed a growing world (Goswami, 2006) and its impact on global reactive nitrogen (Gowda, *et al.*, 2008). Another cause to temper optimism is based on the calculated impact on previous cotton yield gainsfrom the previous CO_2 fertilization effect. From the 18% increase in CO_2 fertilization over the previous 30 years a predicted 10% yield gain would be expected, leaving little yield gain from improvements in genetics and management. Whether small or large the yield fertilization from CO_2 is already impacting yield gain and no additional boost in the rate of yield gain should be anticipated.

The most concerning secondary impact of CO_2 gain on cotton yield is the impact from temperature. Although we consider cotton a "heat loving" crop analysis of cotton physiology shows that this reputation should not be a source of optimism that global warming will boost cotton yields in existing cotton growing regions. Cotton plant tissue requires a warmer temperature for growth than other crops, especially in the seedling phase (Gwarino & Lobell, 2011) when cool air temperatures are detrimental, but has a temperature optimum and failure point for yield similar to other major crops (Gutierrex *et al.*, 2008). The misperception of cotton being "heat loving" derives from well irrigated cotton's ability to cool itself when humidity is low. Cotton leaf stomates stay open during the day (Haix *et al.*, 2007) allowing the plant to evaporatively cool when the air is dry. Cotton leaf tissue can be 11°C below air temperature during hot dry daytimes (Hake & Grimes, 2010). When the humidity is high, cotton tissue temperature can be above air temperature during the day and will equilibrate with air temperature at night. The yield failure temperature of 35°C occurs at the cotton plant tissue, a level easily reached when grown in hot humid environments or under water deficit stress.

Under the humid conditions of the Mississippi delta, an increase in plant tissue temperature of 1°C during the bloom period, achieved by installing heat pads in between the plants, resulted in a 6% reduction in yield and 7% reduction in seeds per boll (Hancock *et al.*, 2011). This temperature rise did not impact any other growth or quality parameter. Pollen viability is especially vulnerable to high temper-atures approximately 14 to 17 days prior to anthesis (Halfield *et al.*, 2008) as evidenced by anthers that fail to dehisce and to shed pollen on the day of anthesis. Fertilization of cotton ovules, and subsequent seed set, are critical components of yield that are negatively impacted by high day and night temperatures. Since cotton stomates close at night, evaporative cooling in well watered plants ceases thus elevated night

Table 1. Predicted Response to Temperature and CO_2 Fertilization for Various Crops over the Next 30 Years

	Percent Yield Improvement		
	Temperature Alone	CO_2 Alone	Combined Temp. & CO_2
Corn	+4	+1	-3
Soybeans	-3.5	+7.4	+3.9
Rice	-12	+6.4	-5.6
Sorghum	-9.4	+1	-8.4
Cotton	-5.7	+9.2	+3.5
Peanuts	-5.4	+6.7	+1.3

temperatures (Hancock *et al.*, 2011)can be more detrimental to cotton yields than day light temperatures. Singh *et al.* provide a through summary of high temperature effects on cotton yield, fibre quality and underlying physiology mechanisms (Joshi *et al.*, 2011).

When the anticipated temperature rise over the next 30 years is combined with the anticipated CO_2 fertilization any benefit to cotton yield is slight (Guarino and Hobell, 2011).

Temperature impacts both cotton and its pests. Life cycles of insect pests are shortened with elevated temperature building damaging populations earlier in the growing season. Temperature also impacts the geographical range of insect pests. As global temperatures have warmed terrestrial organisms have been observed to move on average 17 km poleward per decade(Ki Min *et al.*, 2011). Warm season insects such as *Pectinophora gossypiella* (pink bollworm) significantly expand their range with only slight increases in temperature, < 2°C (Kimball *et al.*, 2002). Other warm season insects are also threatening temperate cotton growing regions:*Bemisia argentifolii* (silver leaf whitefly), *Tetranychus urticae* (two spotted spider mite), *Amrasca devastans* (jassids), Phenacoccus solenopsis (mealy bug), and *Anthonomus grandis* (boll weevils).

Another secondary impact of elevated CO_2 is a disruption to the global hydrologic cycle since atmospheric water-holding capacity increases exponentially with air temperature. This negative impact of elevated CO_2 is already impacting the severity of storm events (Lobell *et al.*, 2011, 2007) and cyclones/hurricanes (Montgomery, 2007). Impacts on agriculture in India and USA have been deleterious and are anticipated to get worse with an increase in both storm and drought intensity (NOAA).

Excess rainfall leads to flooding and soil erosion loss causing both short term and long term negative impacts on yield that can be ameliorated with management and investment (Norby *et al.*, 2010 & Oosterhuis, 1999). Supplemental fertilization, surface drainage and raised beds can mitigated modest flooding induced water logging. Conservation tillage (no-till or zero-till) leaves plant residue on the soil surface to protect soil from the impact of rainfall and erosion soil loss that in bare soil often exceeds 100 fold the rate of new soil production (Oosterhuis & Snider, 2011) Non-eroded soil is a globally threatened resource for agriculture that is essential to support crop growth in between rain events (Pederson *et al.*, 2011). Soil health will be a growing challenge and opportunity in the two largest cotton producing countries, China and India, as labor costs drive adoption of mechanized weed control. Mechanical cultivation dislodges weed roots making them vulnerable to desiccation but also stirs the soil which promotes organic matter oxidation and soil surface exposure to the force of rain drops that further breaks down soil structure. Adoption of no-till not only protects the soil surface from rain but provides other adaptation benefits to climate change: cultural practices can be more timely since field entry by foot or tractor is increased, root health is improved with less pruning and stable soil moisture and temperature environment, and costs to convert and maintain mechanization are reduced since large tractors for tillage are not needed. In no-till fields the weeds are controlled with herbicides and soil organic matter is often augmented with cover crops. Although herbicide tolerant (HT) crops are not essential for no-till, they facilitate no-till by expanding the foliar applied herbicidal mechanisms of action available to control weeds. Countries considering adopting HT crops are encouraged to adopt multiple herbicidal mechanisms of action to delay and avoid the development of herbicide resistant

weeds.

Besides flooding and extreme rain events, climate change impacts water supply in several key cotton growing areas. In the USA snowpack declines and rapid snow melting threaten streamflow and water supplies (Peters *et al.*, 2011) India underwent a weakened summer monsoon during the second half of the 20[th] century mainly due to human-influenced aerosol emissions (Pettigrew, 2008). China is experiencing rapid melting of glaciers that feed rivers for irrigation in Xinjiang province (Piao *et al.*, 2010 & Rahmstorf andCoumou, 2011). Although glacier melt water builds irrigation capacity, it is a single use commodity that is not sustainable. Cotton can be successfully grown on limited rainfall if supplemental irrigation is applied. Supplemental irrigation that provides limited (less than half crop ET) moisture at the critical periods just before and after first bloom can increase the water use efficiency of available rainwater and stabilize yields and fibre quality (Savdainene, 2011 & Sawan, 2009). To properly use supplemental irrigation cotton growers need to invest in an efficient and uniform method of applying small amounts of water (<50 mm) at multiple intervals such as center pivot irrigation. Where capital for large investments is limited, farmers can utilize short irrigation runs with high on flow rates. Regardless of the irrigation system, farmers need accurate and current information about weather forecast, crop water use, and soil moisture to make precise use of supplemental irrigation (Schiermeier, 2011).

The adaptation of cotton production regions to climate disruption will be essential to meet the growing world demand for textile fiber. Besides the adaptions discussed above: soil health, conservation tillage, supplemental irrigation, field drainage, pest control vigilance, and farmer access to training and real time weather/ soil/crop data, it will be necessary to expand cotton breeding and testing for yield stability under combined moisture and temperature extremes. Sequencing the cotton genome will open the breeding tools developed for model crops (Singh *et al.*, 2007, Sriver, 2011 & T-On 2011) and facilitate access to the stress tolerance inherent in wild cottons and cultivated diploid cottons (Wang *et al.*, 2011). Fortunately, cotton growers around the world have a history of rapidly adapting to change and adopting useful technology; provided an investment is made in cotton research commensurate with the challenge that climate disruption poses so cotton growers will have the tools necessary to face these challenges.

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