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Organic cotton production may alleviate the environmental impacts of intensive conventional cotton production

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Abstract

Conventional cotton production has been associated with the extensive use of agricultural chemicals, leading to environmental and health problems, decreased effectiveness of pesticides and higher costs of production. Organic bans the use of most pesticides while providing premiums for growers, and therefore may be a beneficial alternative for growers. Unfortunately, there has been a paucity of research examining the specific practices used by organic cotton growers and the environmental aspects of those practices. This study surveyed organic cotton producers and processors to document specific approaches and techniques used in organic cotton production and processing, the environmental impacts of those techniques and challenges facing organic cotton growers. We discuss the environmental impacts of organic management techniques and methods for conserving water and reducing dependence on irrigation. We also highlight the challenges to organic production identified in the survey, including management for weeds, insects and diseases, genetic contamination of organic crops from genetically modified cotton, organic seed availability, climate change, chemical drift and marketing of organic cotton. Finally, we suggest that investing in research to produce higher-yielding organic varieties, improved methods for organic weed management, and supporting carbon-sequestering practices will improve conversion to organic production.

Introduction

When compared to other commodity crops, cotton ranks as the third greatest user of pesticides in the USA (Swezey *et al.*, 1999; USDA, 2020a) and fourth greatest user of pesticides worldwide (Ferrigno *et al.*, 2017). According to the United States Department of Agriculture (2018), conventional cotton in the USA used $4.2 billion worth of pesticides in 2017, accounting for 6.35% by value of all the plant protection chemicals sold that year. In the USA alone, approximately 48 million pounds of pesticides were used on 12.6 million acres of cotton planted in nine states in 2017 (USDA, 2018), amounting to an approximate average of 3.8 pounds of pesticides per acre of cotton grown. Many of the insecticides, nematicides, fungicides, herbicides, desiccants and defoliants used in producing a conventional cotton crop have been associated with environmental and health problems (Maumbe and Swinton, 2003; Blackburn, 2009; Settle *et al.*, 2014; Agbohessi *et al.*, 2015; Soil Association, 2019).

Decreased effectiveness of pesticides due to pesticide resistance has led to increased pesticide usage and higher costs of production in conventional cotton (Wossink and Denaux, 2006; Benbrook, 2012). For example, the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Agricultural Chemical Use Program (2020a) shows that the pounds of glyphosate used nationally growing conventional cotton doubled between 2011 and 2019, and conventional cotton acres treated with pesticides increased by 38.2% (Fig. 1) (USDA, 2020b).

Initiatives to reduce highly toxic synthetic chemical inputs used in conventional cotton production such as the Better Cotton Initiative (BCI) are attempts to address the negative environmental and health impacts of cotton production by developing standards for water stewardship, soil health, and biodiversity, among others (Shah *et al.*, 2018). These initiatives have gained traction with 360 licensed BCI farms in the 2017–18 cotton season accounting for approximately 5% of the US cotton production or about 1.1 million bales (BCI, 2019). However, some environmental standards, including BCI, still allow the use of glyphosate, which continues to foster the development of herbicide resistance across many weed species when used on genetically-modified (GM) crops such as herbicide-tolerant cotton (NAS, 2016). In addition, use of *Bt* (*Bacillus thuringiensis*) cotton, genetically modified to kill budworm/bollworm pests, and often cited as a 'softer' pest management approach, has resulted

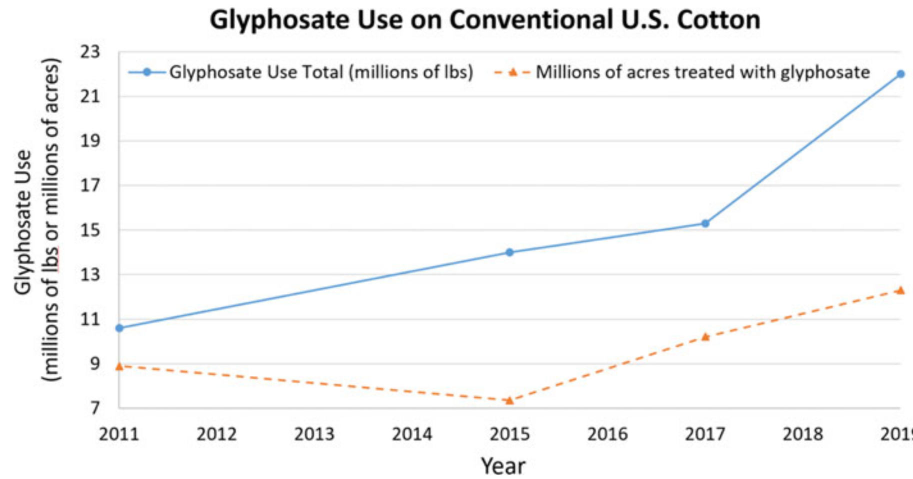

Fig. 1. Glyphosate use on conventional cotton grown in the USA. Both total glyphosate use and the number of acres treated with glyphosate have increased since 2011. Data from USDA-NASS, 2020: http://quickstats.nass.usda.gov.

in a break-down of its insecticidal properties, evidenced by insect resistance identified in two of the three *Bt* toxin families (Cry1A and Cry2A) (Reisig, 2018).

In contrast, organic cotton production offers economically viable solutions to most of the environmental and health consequences associated with pesticide-intensive cotton production. Demand for organic cotton is growing and several studies have found that consumers are willing to pay price premiums for organic cotton (Hustvedt and Bernard, 2008; Casadesus-Masanell *et al.*, 2009; Ellis *et al.*, 2012). Global production of organic cotton has increased in the last few years, with a 56% growth between 2016/17 and in 2017/18, reaching 831,193 bales (Textile Exchange, 2019). In 2019, the number of Global Organic Textile Standard (GOTS)-certified facilities grew globally by 35% across 70 countries (OTA, 2020). In the USA, organic production increased by 12% over the previous year's production in 2017, totaling about 23,341 bales of organic cotton fiber harvested over 26,302 acres (10,644 hectares) (Textile Exchange, 2019). Organic fiber is also the largest and fastest-growing sector in the organic non-food industry (including organic textiles, household products, personal care products, supplements, pet food and flowers) in the USA, with sales increasing 12.1% over 2019 to over $2 billion in 2019 (OTA, 2020). The consumer demand for domestic organic textile production has led to a rapid increase in GOTS-certified facilities in the USA. In 2019 alone, there was a 73% increase in US GOTS-certified facilities (OTA, 2020).

Despite this growth, organic adoption in cotton remains low in the USA. In 2011, for example, adoption of organic in cotton systems was lower than organic transition for any other domestic crop (USDA, 2013). Farmers considering transitioning to organic cite challenges to transition including cost, complex recordkeeping, on-farm production problems, lack of infrastructure and difficulties accessing to profitable markets (Stephenson *et al.*, 2017). However, data on the agronomic challenges that organic cotton producers, in specific, are faced with is scant. While a study by Hanson *et al.* in 2004 found that cotton growers were especially concerned about risk from yield loss and price variability when considering transitioning to organic, a better understanding of current pre- and post-farm gate challenges for those in organic cotton production is needed (Hanson *et al.*, 2004).

Because organic systems do not allow the use of genetic modification, synthetic fertilizers and most synthetic pesticides, organic cotton can be a more sustainable alternative to conventional cotton production. However, little research has examined the specific practices used by US organic cotton growers and the environmental aspects of those practices. Additionally, to more effectively encourage farmers to transition to organic, data is needed on current organic cotton production challenges. This study surveyed organic cotton producers and processors to better understand the specific approaches and techniques used in organic cotton production and processing and the environmental impacts of those techniques. We also highlight the challenges posed by organic cotton production and look at the future of how organic sustainable cotton can best be supported.

Methods

In spring 2019, a survey assessing the state of organic cotton production and handling in the USA was developed by researchers at Iowa State University (ISU) and mailed with a stamped, self-addressed return envelope to 113 organic cotton producers and handlers such as cotton gins. Those contacted were listed in the USDA-National Organic Program (NOP) Integrity Database (USDA-AMS-NOP, 2019) (Table 1). The USDA list included 119 organic cotton producers from ten states, with Texas predominating with 105 growers and 28 handlers. Organic cotton handlers were listed in six states, though the majority (21) were in Texas. Textile Exchange reported that the Texas Organic Cotton Marketing Coop (TOCMC) has approximately 35 producer members who plant approximately18–20,000 acres of organic cotton. The TOMC was established in 1993 and serves as an organic cotton production hub in the favorable cotton growing zone around Lubbock, Texas (TOMC, 2020). While the USDA database lists 105 organic cotton producers in Texas, it does not provide acreage totals. Textile Exchange also lists Procot Cooperative, managed by Allenberg Cotton Company with additional farmer members (Textile Exchange, 2019).

Organic cotton producers and handlers were asked about the growth of organic and conventional cotton and their respective acreage, rank pest issues they encounter and the prevalence of GMO contamination. Finally, they were asked about production techniques and other challenges to growing and/or marketing organic cotton.

Due to time limitations during the 2019 field season, only one survey was sent to each individual. Twelve producer and five processor surveys were returned, representing 15%, a return rate

Table 1. Number of US certified organic cotton producers and cotton handlers by state (USDA-AMS-NOP, 2019)

State	No. of producers	No. of handlers
Texas	105	21
New Mexico	5	2
North Carolina	1	2
California	1	1
South Carolina	1	0
Arkansas	1	0
Oklahoma	2	0
Oregon	0	1
Florida	1	0
Georgia	1	0
Tennessee	1	0
Mississippi	0	1

experienced with a previous ISU survey on organic production (Delate *et al.*, 2016). Survey responses were followed up with telephone conversations to further explore grower and handler experiences.

Results

Survey results showed a strong recognition of production practices by farmers that attest to the knowledge of the environmental benefits of organic cotton production, as described in Table 2. The results also identified key pest management concerns as well as concerns with GM contamination, pesticide drift, weather, organic seed sourcing among other concerns.

The range of organic practices cited in survey results included the use of cover crops, rotational crops, trap crops, entomopathogens, insect and disease-resistant or tolerant varieties and planting later to take advantage of warmer soils.

Sixty percent of the respondents noted weeds as the most critical pest management issue and 90% cited weed management within the three highest-ranked constraints. Among the weeds cited within organic cotton fields were (in order of abundance): bindweed, pigweed, lakeweed, Johnson grass, morning glory, nut grass and crabgrass.

While insect pests were not cited as challenging as weed management in organic cotton, the results showed the importance of bollworm, aphid and thrips management (Table 3).

Twenty percent of producer respondents reported issues with GM contamination in their organic cotton crop, with levels between 2 and 10%. Eighty percent of organic cotton producers reported that they were able to source organic seed stock. Other challenges to organic production cited respondents included climatic conditions such as extreme weather events, inadvertent pesticide contamination and market access.

Discussion

Environmental impacts of organic management techniques

Unlike conventional cotton, which relies heavily on GM *Bt*-cotton for managing the main budworm/bollworm complex, organic management of insect pests uses a multi-pronged approach, including crop rotations, use of resistant or tolerant varieties, releases of beneficial insects and microorganisms targeting specific pests.

Since adopting organic practices, 40% of respondents reported increases in beneficial organisms on their farms, including lacewings, lady beetles and 'microbes' (presumably relating to their perception of greater soil quality). This trend corresponds with observations from other cropping systems where toxic pesticides have been eliminated or reduced, and specifically, in cotton, where organic fields hosted more generalist insect predators than conventional fields (Swezey *et al.*, 2007).

Additionally, frequently cited practices of organic cotton farmers responding to our survey are associated with multiple environmental benefits (Table 2). For example, organic cotton farmers, as for all organic farmers, are required by USDA-NOP rules to practice crop rotations to help maintain soil quality on their farms (USDA-AMS-NOP, 2019). There was a keen awareness among organic cotton producers relating to the need to rotate crops to help augment soil fertility, increase soil quality and assist with insect pest mitigation. For example, using cover crops and crop rotations helps build soil quality (Fageria *et al.*, 2005; DuPont *et al.*, 2009; Haruna and Nkongolo, 2015; Tully and McAskill, 2019).

There were 35 other crops listed on organic cotton farms in the USDA-NOP database, which can be assumed to be planted in rotation with cotton, since organic regulations prohibit growing the same crop on the same land each year (Table 4). Our survey found that cover crops such as cereal rye and crimson clover were the primary rotational cover crops used by organic cotton growers in the USA. Additionally, there is extensive research demonstrating the benefits of cover crops and rotating crops. In contrast, cotton monocropping may lead to a build-up of disease and depletion of soil fertility which, in turn, can lead to greater use of pesticides and fertilizers to compensate (Kurtz *et al.*, 1984; Bullock, 1992; Helmers *et al.*, 2001; Peters *et al.*, 2003; Smith *et al.*, 2008). By using organic principles and practices, organic farmers' methods have led to research showing organic soils tend to have higher levels of soil health metrics than conventional soils. For example, organic soils tend to have more aggregate stability, have higher water holding capacity and are more porous than conventionally managed soils (Lotter *et al.*, 2003; Gomiero *et al.*, 2011). Organic practices can also lead to greater soil organic carbon sequestration (Mondelaers *et al.*, 2009; Gomiero *et al.*, 2011; Gattinger *et al.*, 2012; Tuomisto *et al.*, 2012; Ghabbour *et al.*, 2017), which may aid in mitigating climate change.

Enhancing water quality and quantity through moisture-conserving practices

According to the Textile Exchange (2014), cotton production accounts for 69% of textile fiber's water footprint. Organic cotton production practices can reduce water consumption by as much as 91% (Textile Exchange, 2017). Water management is a critical component of organic cotton production and processing. Boll and fiber properties, such as lint to seed ratio, and length, strength and micronaire (fineness of lint), are primarily determined by the cotton variety, as well as, to a lesser extent, irrigation and fertilization practices. An adequate water amount is necessary for vigorous growth, good budding and fruiting, and the formation of healthy bolls during cotton production, and ranges from 700 to 1300 mm,

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Table 2. Organic practices cited in survey results and their benefits, compared with typical conventional cotton practices

Nutrient and pest management practice in organic cotton production	Environmental effects of practice	Nutrient and pest management practice in conventional cotton production	Environmental effects of practice
Cover crops (e.g., cereal rye, crimson clover)	Carbon and nitrogen fertility added to soil (Carr *et al*., 2019)	Synthetic nitrogen fertilizer	Acidification of soils; detrimental effect on beneficial soil biota (Bouman *et al*., 1995; Bunemann *et al*., 2006; Alves *et al*., 2013)
Rotational crops (e.g., chickpea, lentil, sunflower, soybean)	Soil fertility enhanced; insect and disease pests mitigated by varying host crops; weed management assistance (Delate and Nair, 2016)	No rotational crops; herbicides and herbicide-tolerant cotton	Monoculture system supporting build-up of insect and disease pests; resistance development in GM crops (Wetzel *et al*., 2016; Kranthi and Stone, 2020)
Trap crops (e.g., okra, sunflowers)	Trap insect pests to isolate cotton crop and/or trap for organic-compliant treatments (Flint and Dreistadt, 1998)	Synthetic insecticides; *Bt* cotton	Some insecticides with toxicity to bees; potential harmful effect on beneficial insects who help keep pest populations in check; resistance development in GM crops (Gill *et al*., 2012; Kranthi and Stone, 2020)
Entomopathogens: *Bacillus thuringiensis*; *Steinernema* spp.	Natural treatments of beneficial bacteria and nematodes that can manage bollworms and armyworms (Gassmann *et al*., 2008; Cranshaw and Zimmerman, 2013; Howell *et al*., 2000)	Synthetic insecticides; *Bt* cotton	Some insecticides with toxicity to bees; potential harmful effect on beneficial insects who help keep pest populations in check; resistance development in GM crops (Gill *et al*., 2012; Kranthi and Stone, 2020)
Insect and disease-resistant or tolerant varieties	Enhancement of beneficial organisms unharmed by pesticides (Hassan *et al*., 1987; Flint and Dreistadt, 1998)	Synthetic insecticides; *Bt* cotton	Some insecticides with toxicity to bees; potential harmful effect on beneficial insects who help keep pest populations in check; resistance development in GM crops (Gill *et al*., 2012; Kranthi and Stone, 2020)
Planting later and in warm soils	Avoiding soil-borne fungal attack of seedlings; enhancement of beneficial organisms unharmed by pesticides (Schrem and Yang, 1996)	Synthetic seed treatments	Detrimental effect on beneficial soil biota (Bunemann *et al*., 2006; Alves *et al*., 2013)

depending on climate and length of the total growing period (UN-FAO, 2019).

A delicate water balance is required for optimum production, with excess water early in the growing period restricting root and crop development and lack of sufficient water during bud formation depressing yields. Excessive vegetative growth can also result if too much water is present during flower opening and boll formation, leading to decreased yields. A moderate water deficit after peak flowering to restrict vegetative growth will lead to good boll-set and higher yields, despite a reduction in the number of flowers. Consistency in water supply will help ensure adequate growth and avoid yield depressing flower and boll shedding.

While the majority of cotton producers in the survey respondents rely on furrow or sprinkler irrigation, many are using or examining the potential for drip irrigation to reduce water quantities and energy costs. Dry land production, where cotton is grown without the aid of irrigation, has also been gaining popularity (Mauget *et al*., 2020). Biologically-based soil-building practices, such as crop rotation, cover crops and compost applications, have also been shown to increase the water-holding capacity of soils (Cambardella *et al*., 2015) and can lead to lessen applications of water over the growing season. Additionally, cover crops help conserve water in cotton production in the southeastern USA (Vann *et al*., 2018).

In lieu of toxic synthetic defoliants used in conventional cotton, organic cotton boll maturation and defoliation is accomplished by water and nutrient management and defoliants permitted in organic production. Depending on climate and depth of stored soil water, irrigation can be terminated 4–5 weeks before final picking to facilitate defoliation. The absence of green leaf material is imperative at harvest since it increases moisture content, leaf trash and other impurities, and lowers fiber grade (Hutmacher *et al*., 2003).

Any discussion of the environmental footprint of organic cotton must include the extensive use of water in cotton processing and contamination of water resulting from the toxic chemicals used in cotton processing (Choudhury, 2017). The use of regulated processing aids in organic cotton processing, in accordance with the GOTS, helps protect water supplies from harsh chemical pollutants (GOTS, 2019).

Challenges to organic production: weeds, insects and diseases

Weeds were the top concern for most organic cotton growers. In addressing this concern, organic cotton growers use a variety of methods to manage weeds, including crop rotations (described below), tillage, hand-weeding and some organic herbicides, if not cost-prohibitive. These results mirror what Swezey *et al*. (2007) found that costs of production averaged 37% higher for organic when compared to conventional cotton production, primarily due to costs associated with hand-weeding.

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Table 3. List of insect pests cited in 2019 survey of organic cotton producers

Pest	Respondents citing as problem (%)
Bollworm	89
Aphids	89
Thrips	89
Boll weevil	56
Stink bug	11
Armyworm	11
Root-knot nematode	11

Insect pests listed as a concern for organic cotton growers included Western Lygus plant bugs, spider mites, whiteflies, aphids, stink bugs and moths, though it was assumed 'moths' referred to lepidopteran larvae, which is usually controlled with *Bt* sprays.

Diseases were generally not cited as a problem in most cotton-growing regions likely due to resistant or tolerant varieties and crop rotations mitigating pathogen inoculum carry-over. Only one survey respondent in Texas reported problems with *Fusarium* and *Rhizoctonia*, which are common soilborne fungi that can attack cotton seedlings during cool, damp weather. Delaying planting until warmer soil conditions can mitigate these diseases, and they are not commonly reported on older plants, since cotton plants demonstrate more resistance to them with age (UC-ANR, 2019). Rotating to other crops, particularly non-hosts, is important to prevent *Verticillium* wilt, bacterial blight, damping off diseases and root-knot nematode management, and is a required organic practice.

Challenges to organic production: GM contamination and GM-free seed availability

In the USA, there has been a proliferation of 'stacked' GM traits conferring both herbicide tolerance (HT) and insect resistance from the soil bacterium, *Bt*. Since the introduction of GM cotton in 1996, the percent of cotton acreage grown with both HT-only and stacked-gene varieties increased from 2 to 91% by 2017 (USDA ERS, 2018).

Although organic cotton producers source and plant seed grown organically without the use of GM, episodes of GM contamination continue across the Cotton Belt (Donaldson, 2015). Some of the causes of GM contamination have been reported to include the following: accidental use of GM seed; cross-pollination from GM crops; contamination from farm equipment; and accidental mixing during storage, transport or ginning (Textile Exchange, 2019).

This study found great concern around GM contamination of their organic cotton crop. Although none of the producers had been involved in any litigation over contamination, it is an on-going concern and is particularly noted as a risk during seed, ginning, hauling and the delinting process. One respondent mentioned cross-pollination with GM cotton as a concern. Although cotton has been reported to have a low level of cross-pollination (Reisig, 2018), cross-pollination with GM cotton can occur.

Twenty percent of producers and one processor noted awareness of resistance to *Bt* developing in *Bt*-cotton conventional fields. *Bt* resistance closely associated with the proliferation of *Bt* GM corn is especially concerning to organic farmers, because many organic farmers rely on naturally derived *Bt* as a form of pest control.

Table 4. Other crops grown on organic cotton farms in the USA, USDA-NOP Integrity Database, 2019

Alfalfa	Oats
Austrian winter peas	Peanut hay
Barley	Peanuts
Bermuda grass	Pecans
Black-eyed peas	Pumpkin
Cereal rye	Runner peanuts
Chickpeas	Seed pod vegetables
Chili peppers	Sesame
Corn	Sorghum
Cow peas	Soybeans
Daikon radish	Spanish peanuts
Field forageable cotton	Spring wheat
Fruit	Squash
Garbanzo beans	Sudan grass
Millet	Triticale
Milo	Tuber/roots
Native grass	Winter wheat
Native rye	

The concern over GM contamination is linked with pesticide contamination (see *Challenges to organic production: climate, chemical drift and markets* section below), as the increased prevalence of GM crops has been associated with an uptick in pesticide use on conventional crops, especially glyphosate, which can then drift to an organic field crop (Benbrook, 2012).

There was a discrepancy between GM testing and GM presence, as reported by processors. Only one processor reported testing for GM presence in the organic cotton they processed, while the remainder rely on the veracity of the organic certificate or certification process to verify the GM-free status of the cotton. However, two out of five processors reported GM contamination in cotton they processed, ranging from 10 to 12% contamination. It was unclear if another entity determined contamination. This differs from organic food grain crops, which are routinely subjected to GM testing before purchasing and processing, and processors record the level of contamination for each load.

Contamination of organic cotton with any GM material is costly to organic growers. If GOTS-certified, a GM-positive test result would cause growers and other organic stakeholders to invest time and money to identify the cause of contamination, conduct additional tests and engage insurance companies and certifiers in order to remain compliant. In some cases, the product may be rejected and/or the organic land would need to undergo a 3-yr conversion period if the certifier determines an excessive contamination level, or revert to conventional production.

Challenges to organic production: sourcing seed

The majority (80%) of organic cotton producers reported that they were able to source organic seed stock. The 20% that had

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issues securing non-GM, organic-compliant seed did not specify the extent of their seed search, which may relate to their answers. Multiplication issues (e.g., easier access to organic seed) seem to be a worldwide concern (Textile Exchange, 2015). Oftentimes, organic producers must reach out to a number of companies before finding the specific organic variety they wish to plant. One producer reported the need for *higher-yielding* organic cotton varieties, citing lower organic yields compared to conventional counterparts. While research has shown similar yields for organic and conventional cotton (Swezey *et al.*, 2007), but, as is the case in other organic crops, weather can dramatically impact organic yields (Delate *et al.*, 2015). For example, if weed management does not proceed on in a timely fashion, due to rain and wet soils, yields can be decreased up to 20% of that harvested in normal years. More recent studies in India by Forster *et al.* (2013) reported 14% lower yields in organic *vs* conventional cotton, but stability of organic yields in the face of detrimental weather, which may become more critical with worldwide climate change.

In addition, public plant breeding for true organic varieties, i.e., bred under organic conditions, is lacking, with only one plant breeder in Texas working on developing cotton varieties for organic producers. Efforts by Dr Jane Dever (Texas A & M University) include developing a cotton variety with elongated seed packets to help prevent physical mixing and contamination with conventional and GM-cotton.

Worldwide, there appears to be an interest in participatory plant breeding, where growers are involved with the cultivar selection process on their farms. The Seed, Integrity and Community Investment (SICI) program is investing in non-GM cotton seed in participatory breeding, multiplication programs and product traceability solutions (Textile Exchange, 2019). Participatory breeding may, or may not, speed the planting of *higher-yielding varieties*, as this has not yet occurred with participatory organic corn breeding programs, for example. Rather, success in developing varieties with specific quality traits has occurred in participatory breeding programs.

Challenges to organic production: climate, chemical drift and markets

Other challenges reported by survey respondents included the changing climate, citing lack of sufficient rainfall, hail, excessive rains and early season winds, and snow on the cotton crop before harvest. Efforts to deal with climate change, particularly through carbon-sequestering practices that build soil organic matter and retain soil moisture levels, can assist with drought mitigation (Franzluebbers *et al.*, 2012).

Other concerns facing organic cotton growers who responded to the survey included chemical drift from neighboring conventional fields and uncertain markets. Strict adherence to federal rules governing drift, and litigation in the case of non-compliance, could level the playing field with conventional producers. Unfortunately, current rules governing drift place the burden of minimizing contamination on organic producers. While some research has been conducted investigating methods for reducing GM contamination, including isolation, border rows and shifted planting dates, these can be costly for organic producers to implement and are not always effective, and 71% of organic farmers believe that federal regulations overseeing GM crop approvals are not adequate for protecting organic farm products (Hubbard, 2019). For example, while the USDA has ample authority under the Plant Protection Act (USDA APHIS, 2000) to address genetic contamination of organic crops, the most recent USDA proposed rule on the 'Movement of Certain Genetically Engineered Organisms' gives a narrow interpretation of mandated authority, leaving regulatory decisions in the hands of agricultural biotechnology companies (USDA-AMS-NOP, 2019).

Market demand for cotton, in general, has been increasing, with world consumption in 2018/19 reaching 123.6 million bales, growing 0.9% from the previous year, to the highest level since 2007/08 (Dohlman *et al.*, 2019). Organic cotton production specifically has been growing, with a 56% increase in 2017–2018 to 831,193 bales, exceeding the previous year's growth rate of 10% (Textile Exchange, 2019). Organic cotton usage should increase, particularly if concerted efforts advertise the outstanding environmental, social and economic benefits of organic cotton for producers, farmworkers and consumers.

Future scenarios

Organic cotton will continue to raise the environmental bar for all cotton production. Many industry groups are aligned with this effort, under the auspices of the Organic Trade Association, Textile Exchange and GOTS. In December 2018, GOTS aligned with the Fashion Industry Charter for Climate Action, supporting the goals of the Paris Agreement, with the organic cotton industry aiming for achieving net zero emissions by 2050. Among the issues that will be addressed are a more carbon-neutral (or carbon-accumulating, if soil is involved) production phase, 'selection of climate-friendly and sustainable materials, low-carbon transport, improved consumer dialogue and awareness, working with the financing community and policymakers to catalyze scalable solutions, and exploring circular business models' (UNFCCC, 2018). If producers are supported for carbon-sequestering practices, such as crop rotations and cover crops, there is apt to be more conversion to organic production, as demonstrated for other crops (Singerman *et al.*, 2011). It is incumbent upon universities, NGOs and industry groups to work together toward the goal of creating an organic cotton sector steeped in the principles of ecology, health, fairness and care (Rahmann *et al.*, 2016). A forward-looking research agenda could include participatory breeding efforts toward higher-yielding organic cotton varieties with specific characteristics that differentiate organic from conventional cotton. In addition, improved methods of organic weed management, such as flame or electric weeding that maintain soil quality, will also contribute to a more robust organic cotton industry in the USA. Finally, an in-depth analysis of current organic cotton marketing structures is needed, including the economic and social benefits of collective *vs* individual marketing, and methods to increase the number of cotton co-operative members. As members of the 27-yr-old Texas Organic Cotton Marketing Co-op note, cooperative efforts, including pooling production to level yield variation across sites, help mitigate risks and ensure a quality product for consumers (Hanson *et al.*, 2004).

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