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Tailoring the Cotton Agronomy holds the Potential to Minimize the Damage due to Pink Bollworm

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Abstract

Cotton (*Gossypium* sp.), is an important commercial crop which provides essential raw material for the global textile industry. Globally, the cotton is grown on an area of 32.88 million ha with production of 73.74 million tonnes (FAO STAT, 2021). In India, it is cultivated on an area of 13.28 million ha with production of 35.25 million bales (of 170 kg/ha) and lint productivity of 491.0 kg per ha as against the world average of 712.0 kg lint per ha (CCI STAT, 2022). In India, cotton cultivation takes place across a wide spectrum of agro-climatic conditions, encompassing both rain-fed and irrigated environments. This remarkable diversity extends to various factors, including climatic conditions ranging from arid to sub-humid to per-humid; an array of soil types such as alluviums, vertisols, vertic intergrades, red soils, and laterite soils; the presence of four cultivated species (*G. hirsutum, G. arboreum, G. barbadense* and *G. herbacium*) and inter and intra-specific hybrids; continuous cropping throughout the year; a diverse range of seed rates and plant populations varying from 10,000 to 100,000 plants per hectare; and a harvesting period spanning from September to May. This intricate amalgamation of elements significantly complicates the task of pest management. The cotton crop often faces the relentless threat of pest infestations, with the pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) standing out as one of the most damaging adversaries. This tiny, yet destructive insect, has the potential to reduce cotton yields and quality, thus posing significant challenges to cotton production, worldwide. In this article, we probe into effective cotton agronomic practices that aim to minimize the damage caused by the pink bollworm.

KEY WORDS: Agronomic methods, cultural control, early maturing cultivars, cotton, pink bollworm, timely sowing.

FEATURES MAKING PINK BOLLWORM A SERIOUS PEST OF COTTON IN INDIA

The pink bollworm is considered a serious pest of cotton due to its destructive feeding habit and ability to cause significant economic losses to cotton crop. Certain characteristics making pink bollworm a serious pest of cotton are given below:

i. ***Introduction of long duration American cotton hybrids***

Basically, pink bollworm is of Asiatic origin, and was first described by Saunders in 1843 as *Platyedra (=Depressaria)gossypiella* from specimens that were found to damage cotton in India (Saunders, 1843; Naranjo et al., 2001). The trade between India and the Indonesian Archipelago possibly during the era of Hindu expansion, introduced the pink bollworm into India. Before it became a pest of cultivated cotton, the pink bollworm remained at insignificant levels for a longer period on alternate wild host plants, like *Abutilon indicum*, *Hibiscus* spp., *Thespesia populnea* and *Thespesia lampas.*

In India, the pink bollworm had assumed a serious pest status on cotton only after the introduction of long duration American cotton hybrids. These hybrids, while offering improved yield and fiber quality, inadvertently create a more favourable environment for pink bollworm infestations mainly due to their prolonged flowering and fruiting periods. This extended availability of cotton bolls provides a greater window of opportunity for pink bollworm to lay eggs and infest the cotton crop. The resulting larger population of pink bollworm can lead to more extensive damage to the cotton crop, thereby intensifying the pest problem.

Hybrid seeds are generally costly and hence wider spacing is adopted for their sowing to reduce the seed rate (Venugopalan and Prasad, 2023). This leads to low plant density per unit area. Under such circumstances, the farmers need to realize more bolls per plant to ensure optimum economic yield from their cotton crop. Retaining more bolls per plant necessitates for keeping the cotton crop standing in the fields for longer durations leading to availability of longer fruiting window. This allows multiple generations of pink bollworm to complete in a season, posing a serious challenge to its effective management. Presently, sevral cotton hybrids of variable duration of flowering and maturity are being grown throughout the North, Central and South cotton growing zones of India. Many of these hybrids belong to late maturity group, creating the conditions favourable for multiplication and population built up of pink bollworm.

ii. ***Stenophagous nature with a narrow host range***

Traditionally, the pink bollworm is categorized as a specialized pest that has evolved mainly with Malvaceous plants (Table 1) (CABI, 2023). Nevertheless, instances of this pest infesting other host plants apart from cotton are rare or at least in negligible proportions (less than 5% infestation). As a result, cotton is considered as the primary host for the colonization and perpetuation of the pink bollworm making it a serious of the cotton crop. Despite this, the knowledge about the alternate hosts of pink bollworm is important from the point of its agronomic/ cultural management. Removal or destruction of alternate host plants from the vicinity of cotton fields is of paramount significance to reduce the chances for off season survival of pink bollworm.

Table 1. List of host plants of pink bollworm

S.N.	Common name of the host plant	Botanical name	Family
1.	American cotton	*Gossypium hirsutum*	Malvaceae
2.	Desi cotton	*Gossypium arboreum*	Malvaceae
3.	Egyptian cotton	*Gossypiumbarbadense*	Malvaceae
4.	Levant cotton	*Gossypium herbaceum*	Malvaceae
5.	Okra	*Abelmoschus esculentus*	Malvaceae
6.	Country mallow, kanghi	*Abutilon indicum*	Malvaceae
7.	Hollyhocks, gulkhera	*Althaea rosea*	Malvaceae
8.	Jungli ambadi (yellow hibiscus)	*Hibiscus pandureformis*	Malvaceae
9.	Cottonwood	*Hibiscus tiliaceus*	Malvaceae
10.	Kenaf, Deccan hemp	Hibiscus cannabinus	Malvaceae
11.	Musk mallow	*Hibiscus abelmoschos*	Malvaceae
12.	Indian tulip tree	*Thespesia populnea*	Malvaceae
13.	Janglibhindi	*Thespesia lampas*	
14.	Jamaica sorrel	Hibiscus sabdariffa	Malvaceae
15.	Lucerne	Medicagosativa (	Fabaceae
16.	Dev kapas	-	Malvaceae
17.	Tree cotton	-	Malvaceae
18.	Wild cotton	-	Malvaceae

*iii. **Poor insecticidal control due to cryptic feeding habit***

The larvae of pink bollworm feed on developing flower buds and seeds of green bolls of cotton plant, which causes rosetted flowers, premature opening and shedding of infested bolls, reduction in fibre length and poor quality of lint due to staining (Singh et al., 1988; Fand et al., 2019; Fand et al., 2020; Fand, 2021). Within < 4 h of hatching, the larvae enter the bolls by boring through the rind. The larvae of pink bollworm live concealed inside the damaged flowers and bolls of cotton, hence, remain well protected from exogenous insecticide applications. Thus, once larvae enter the bolls the use of insecticides for pink bollworm management often becomes futile because of its cryptic habit (Naranjo et al., 2001;

Fand et al., 2020; Busnoor et al., 2023).This warrants repeated insecticide applications by the farmers to achieve desired level of pest control which ultimately escalate the other adverse side effects like development of insect resistance, environmental contamination and increased cost of protection.

iv. *Insecticide induced plant growth stimulation*

In many cases, the staggered flowering and or fruiting window in cotton crop is also observed due to the faulty application of certain chemical insecticides like monocroptophos, acephate and those belonging to the neonicotinoid group during early vegetative growth phase of crop to manage the sucking pests. These insecticides trigger growth-promoting effects on plants (the phenomenon akin to hormesis in insects), by modifying or affecting the plant physiological processes such as photosynthesis, transpiration, and nutrient uptake, leading to shifts in plant growth patterns, especially the flowering and fruiting periods.

v. *Prolonged standing of crop in the field*

In view of harvesting additional yields, the cotton farmers of rainfed areas are generally inclined towards extending the duration of cotton crop, sometimes even up to late winters (March–April) through supplementary irrigation and fertilizer applications. Being a late season pest of cotton, the intensity of damage due to pink bollworm increases progressively with the advancement of the length of the crop season (Fand et al., 2019). At the later part of the season, majority of the fruiting structures like flowers and bolls on cotton plants are found infested heavily with the pink bollworm. Late uprooting and stacking of infested cotton stalks harbours the inoculum load of hibernating larvae and pupae of pink bollworm (Mallah et al., 2000; Kranthi, 2015).Infested crop residues allows carry-over of the pink bollworm population to the next crop season, wherein the survivors can spread through damaged seeds and trash.

vi. *Development of resistance to transgenic cotton*

The pink bollworm, once a serious pest problem for cotton before introduction of Bt cotton for commercial cultivation, especially in later part of the crop season, was effectively controlled by Bt cotton during initial period of about a decade since the Bt technology was approved. Later, the pink bollworm has re-emerged as a major pest problem in Indian cotton production, mainly due to development of resistance against transgenic cotton carrying Cry1AC and Cry2Ab2 genes from entomopathogenic bacterium *Bacillus thuringiensis* Kurstaki (Dhurua and Gujar, 2011; Kranthi, 2015; Naik et al., 2018).The segregating seeds in bolls of F-1 hybrid plants and hemizygous nature accelerate the resistance development in pink bollworm. The widespread infestation of pink bollworm was reported in central and southern cotton growing belts of India during 2017-18 (Fand et al., 2019). Subsequently, heavy outbreak of pink bollworm causing huge losses to the Bt cotton crop has been reported in northern cotton belts of India during cropping season of 2021-22 (Kumar et al., 2020; Prasad and Kumar, 2022).

AGRONOMIC/ CULTURAL PRACTICES TO MINIMISE THE PINK BOLLWORM DAMAGE

The cultural practices are generally prophylactic in nature and are considered as the first line of defense against pest damage. Adoption of following agronomic measures will help in minimising the damage due to pink bollworm in cotton:

i. Create host free period

Cotton is considered as the principal host plant for the survival of pink bollworm under natural conditions. Therefore, keeping at least 6-7 months cotton free period each year will create difficult situations for the season to season survival of pink bollworm in absence of its food source. When cotton crop is not available as its primary host, the pink bollworm population enters an overwintering phase in either the infested bolls of cotton stalks or contaminated cotton lint seeds (Mallah et al., 2000; Kranthi, 2015). Diapause cycle of pink bollworm is poorly adapted to rainfed cotton in many areas. Thus, adhering to the region-specific recommended cropping window for timely termination of the cotton crop becomes crucial to mitigate pink bollworm damage (Kranthi, 2015; ICAR-CICR, 2019). The timely crop termination can effectively prevent at least two generations of pink bollworm in a season (Fand et al., 2021). Adoption of early maturing and short to medium duration cultivars can help in timely termination of the cotton crop season (Venugopalan and Prasad, 2022). With the adoption of short duration cotton cultivars supporting limited generations, the pink bollworm is manageable much more easily. In Northern cotton-growing states of India, viz, Punjab, Haryana, and North-Western parts of Rajasthan, the introduction of short-duration cultivars of cotton made it possible to shift from cotton-based mono-cropping to multiple cropping with cotton-wheat as the most dominant one followed by cotton-mustard, cotton-chickpea, and cotton-barley (Singh et al., 2003; Venugopalan et al. 2021; Waghmare et al. 2021).

ii. Destruction of infested crop residues

Cotton stalks and bolls infested with pink bollworm larvae and pupae serve as overwintering sites (Mallah et al., 2000; Kranthi, 2015). Often, farmers place the uprooted cotton stalks along the field boundaries, inadvertently creating a source of pink bollworm infestations for the next crop cycle (Figure 1). Therefore, it is crucial to refrain from stacking crop residues on field boundaries and to eliminate infested residues to prevent the carryover of pink bollworm to the upcoming crop season.In the past, these stalks were used as fuel for cooking by local villagers. Presently, there are tractor-drawn implements such as the cotton stalk uprooter-cum-shredder, which can effectively shred cotton stalks right after harvesting (Figure 2). Shredding these stalks directly eradicates larvae and pupae, while also hastening the drying of unharvested bolls that may carry pest infestations. When the shredded material is incorporated into the soil through deep ploughing, it contributes significant organic carbon upon decomposition (Venugopalan and Prasad, 2022).

Figure 1. Stacking of cotton stalks along the field bunds serves as a source of pest inoculum for the next season's cotton crop. (Photo credits: Babasaheb B. Fand, ICAR-CICR, Nagpur)

a **b**

Figure 2. Destruction of crop residues for pink bollworm management. Shredding of cotton stalks with the help of tractor drawn 'Shredder-cum-uprooter' (a), and chopped material after shredding (b) (Photo credits: Babasaheb B. Fand, ICAR-CICR, Nagpur)

iii. Follow crop rotation

When cotton is cultivated on the same field for extended periods, it facilitates the establishment and strengthening of the pest's life cycle in an ecosystem. The pink bollworm, characterized by its narrow food preferences, can be successfully controlled by implementing a well-designed crop rotation plan. By interrupting the pest's life cycle through crop rotation, the absence of suitable sustenance impedes its survival.

Consequently, this practice leads to a decline in the pest population during subsequent planting seasons. Besides inclusion of nitrogen fixing legumes in crop rotation helps in improving soil fertility. The following crops can be included in rotation plans for cotton based cropping system are:

- Cereal based crop rotations: Maize, Sorghum, Pearl millet
- Legume based crop rotations: Soybeans, Groundnut, Green gram, Black gram, Cowpea
- Vegetables based crop rotations: Onions, tomato, Ginger, Brinjal

iv. Deep summer ploughing

Deep ploughing of fields during the summer following the cotton harvest plays a vital role in destroying the dormant stages of pest (such as larvae and pupae) by exposing them to intense sunlight. It is a common scene in the fields being ploughed to witness the predatory birds like herons and crows strolling through the area, seizing the vulnerable insect stages that have been brought to light (Figure 3).Thus deep summer ploughing and other soil tillage operations are adding to the enhancement of natural biological control besides reducing the pest inoculum.

Figure 3. Birds following soil tillage picks up the soil dwelling stages of insect pests (Photo credits: Babasaheb B. Fand, ICAR-CICR, Nagpur).

v. *Destruction of alternate hosts in the off season*

While cotton serves as a primary host for harbouring the natural infestations of pink bollworm, the alternate host plants (refer to Table 1) have been reported to provide limited support to the off season survival of the pest (≤5 % infestation). Therefore, destruction of alternate or collateral hosts in the vicinity of cotton fields is warranted to prevent the off season carryover of the pink bollworm populations.

vi. *Adopt timely sowing*

An early sown cotton crop (April-May) supports the initial establishment and perpetuation of progeny of pink bollworm moths emerged from hibernating residual population, which further spreads onto the rainfed cotton crop planted during June–July. If early planting of the cotton crop is avoided, the pink bollworm moths from hibernating populations emerge only to die for the need for appropriate host stage to survive. This is called '*suicidal emergence*' which substantially reduces the pest inoculum load on coming season's cotton crop. Therefore the management strategy for pink bollworm should focus on non-practicing of early season cotton planting (Fand et al., 2019; 2021).

vii. *Adoption of early maturing, short duration cultivators*

Being a late season pest of cotton, high pink bollworm damage occurs late in the season. Therefore, planting early maturing, short duration, compact and determinate cultivars will ensure early crop harvest and thus can help to escape late-season pink bollworm damage (ICAR-CICR, 2021; Prasad, 2021).This can be the best agronomic/cultural practice to manage the late season infestation of pink boll worm by timely termination of the cotton crop.

viii. *De-topping in indeterminate cultivars*

De-topping is a technique of mechanical removal of growing points to prevent apical dominance and further vegetative growth of plants (Venugopalan and Prasad, 2023). As majority of the cotton hybrids grown presently are of inderminate type, de-topping is a recommended practice which helps in promoting lateral branching, increasing the length of sympodial branches and number of bolls (Figure 3). This results in preventing staggered flush of squares, flowers and bolls, and ensures uniform boll development and synchronised boll bursting in cotton crop (Figure 4). De-topping can prove to be useful manage the late season infestation of pink bollworm by timely termination of the cotton crop. Preliminary experimental trial conducted at ICAR-Central Institute for Cotton Research, Nagpur (India) have shown that de-topping has resulted in the reduced damage due to pink bollworm (Fand et al., Unpublished data, Table 2). This may be due to uniform development and bursting of bolls, thereby providing a narrow window for pest attack leading to the escape of the pest damage. However, detailed field studies focused on this issue are essential.

Table 2. Effect of de-topping on pink bollworm infestation recorded in cotton (Cultivar: Suraj N-Bt) during cotton growing season 2022-23 at experimental farm of ICAR-CICR, Nagpur

S.N.	Treatment	Green boll infestation (%)		Open boll damage (%)	
		155 DAS	170 DAS	At 1st picking	At 2nd picking
1.	Removal of monopodia at 50-55 DAS	30 ±4.47	48±3.74	29.52±2.19	32.43±1.14
2.	De-topping at 90-95 DAS	26±2.45	44±5.10	37.05±0.95	30.00±1.29
3.	Removal of monopodia at 50-55 DAS + de-topping at 90-95 DAS	22±2.00	40±0.00	34.29±2.83	26.77±2.03
4.	Control	36±2.45	56±2.45	47.83±1.68	36.86±1.60

a

b

Figure 4: Effect of canopy management in cotton on boll development. Staggered flowering and boll development due to indeterminate growth habit (a) and lateral branching and uniform boll development in upper canopy of cotton crop after de-topping (b) (Photo credits: Babasaheb B. Fand, ICAR-CICR, Nagpur).

a

b

Figure 5: Asynchronous boll development due to non-removal of growing tips (a), and synchronous boll development and bursting due to de-topping of cotton plants at 90 DAS (b) (Photo credits: Babasaheb B. Fand, ICAR-CICR, Nagpur).

ix. Irrigation management

Excess irrigation during boll development phase and top dressing with high doses of nitrogen during later part of the season extends the cop season leading to increased infestation and damage by pink bollworm. Therefore, it is recommended to cut off the irrigation at first boll opening stage, except in light soils. The purpose is to eliminate the food supply for pink bollworm by cutting off irrigation early enough to stop continuous production of green bolls. Application of flood irrigation to the previous season's cotton fields trigger the moth emergence from hibernating populations, thus leading to suicidal emergence in absence of the suitable host stage for colonization (Beasley and Adams, 1996).

x. Nutrient management

Timely application of fertilizers at recommended doses ensures rapid and early setting and maturity of bolls. Creation of a mismatch between boll maturation and seasonal peak of bollworm is an effective strategy to escape the pest damage. The Bt toxin expression in transgenic cotton decreases with the increase in the age of plant, leading to enhanced susceptibility of the cotton to bollworms (Kaiser 1996; Hilder and Boulter 1999; Kranthi et al. 2005; Kranthi; 2015). Pink bollworm which attacks the cotton crop in the later part of the season might be getting exposed to sub-lethal dose of Bt toxins leading to development of resistance to Bt cotton relatively earlier than the other two species of bollworms. Foliar application of 2% KNO_3 at peak flowering and early boll opening increases cry toxin expression in Bt cotton, thus providing enhanced protection from bollworm damage.

xi. Avoid ratooning/ second flowering cycle

The rainfed cotton farmers with an aim to harvest additional yields frequently adopt the practice of extending the crop growth period, occasionally even until late winters (March-April), by employing supplementary irrigation and fertilizer techniques (Kranthi, 2015; Fand et al., 2019). Discouraging re-growth and a second flowering cycle of cotton is crucial step in managing the pink bollworm menace in cotton. Therefore, timely crop termination by cutting off additional inputs like irrigation water and nutrients on time is advocated.

CONCLUSION

The cultural practices mentioned above can be easily integrated with other management practices and reduce the dependence on insecticides. Thus they have a tremendous potential for the management of cotton pink boll worm. By combining these practices into an integrated approach, cotton farmers can effectively manage pink bollworm populations while minimizing environmental impact and ensuring the sustainability of cotton production.

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Mitigating Pink Bollworm Damage in Cotton through Harnessing Short Duration Cotton Cultivars

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Abstract

Cotton (*Gossypium* sp.), often referred to as 'white gold', is one of the world's most important cash crops, providing essential raw material for the textile industry. However, cotton cultivation faces numerous challenges, including pest infestations that can significantly impact its yield and quality. Among various insect pests attacking cotton crop, pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) is the most economically damaging insect pest of global importance. It has recently emerged as a serious menace on transgenic cotton on account of resistance development to Bt toxins in major cotton-growing countries of the world *viz*., India, China, Pakistan and Southern USA). The pink bollworm infestation not only reduces cotton yield but also impairs the quality of the fiber, leading to substantial economic losses to cotton growers. Being a late-season pest of cotton, the adoption of short-duration cotton cultivars can offer a promising solution to escape pink bollworm damage. This article delves into the potential benefits of this strategy and examines its implications for sustainable cotton production.

KEY WORDS: Early maturing cultivars, escape of pink bollworm damage, short duration varieties.

UNDERSTANDING THE PINK BOLLWORM CHALLENGE

Generally, pink bollworm is a late-season pest, the infestation of which coincides with the beginning of reproductive structures like squaring, flowering, and boll development in cotton crop; thus, causing significant yield losses. The larvae of pink bollworm feed on developing flower buds and seeds of green bolls of the cotton plant, leading to the formation of rosette flowers, premature opening and shedding of infested bolls, reduction in fibre length, and poor quality of lint due to staining with larval excreta (Singh et al., 1988; Fand et al., 2019; Fand, 2021). The squares, flower buds, and developing green bolls of cotton plants are considered the preferred feeding sites for pink bollworm. Normally, the first in-field generation of pink bollworm is completed on squares and flowers, whereas the second generation onwards are completed on green bolls (Ellsworth et al., 2006). Thus, a cotton plant approximately 40-45 days after sowing (DAS) bearing ample numbers of squares and flower buds, becomes a favourable host for the onset of pink bollworm infestation (Fand et al., 2021; Fand, 2021; Kranthi, 2021).

The pink bollworm moths emerging from the previous season's overwintering population lay eggs on young floral buds *i.e.* squares. The larvae feed and develop within squares and leading to the formation of rosette flowers. The full-grown larvae pupate either in rosette flowers or in soil debris near the base of the cotton plant. This chain of events is repeated in the same manner for succeeding generations that usually develop on green bolls instead of squares and flower buds (Sevacherian and El-Zik, 1983; Ellsworth et al., 2006). The generation developing on squares and flower buds generally takes 35-37 days to complete, by the time the cotton crop reaches about 75-80 DAS. With the ample availability of bolls from 80 to 100 DAS, the second generation of pink bollworms develops on green bolls. Likewise, a third generation of pink bollworm is expected to occur only after the cotton crop reaches ≥120 DAS. Considering the low survival rate of pink bollworm larvae on squares than on green bolls, a large population is seldom expected to build up during the early periods of the cotton season. The data on pink bollworm moth trap catches recorded at different locations in India revealed that the pink bollworm population usually reaches its peak in the third generation or later (Figure 1) (Fand et al., 2021; Fand, 2021). A progressive increase in field infestation of pink bollworm with the advancement of the crop season is observed. This was indicated by a steep increase towards the end of the season in the number of moths captured in pheromone traps (Fand et al., 2021) and the severity of damage to the green bolls and open bolls (Figure 2) (Fand et al., 2019). The information on key bio-ecological aspects of pink bollworm described above is highly crucial to devise an effective management strategy for this notorious pest of cotton.

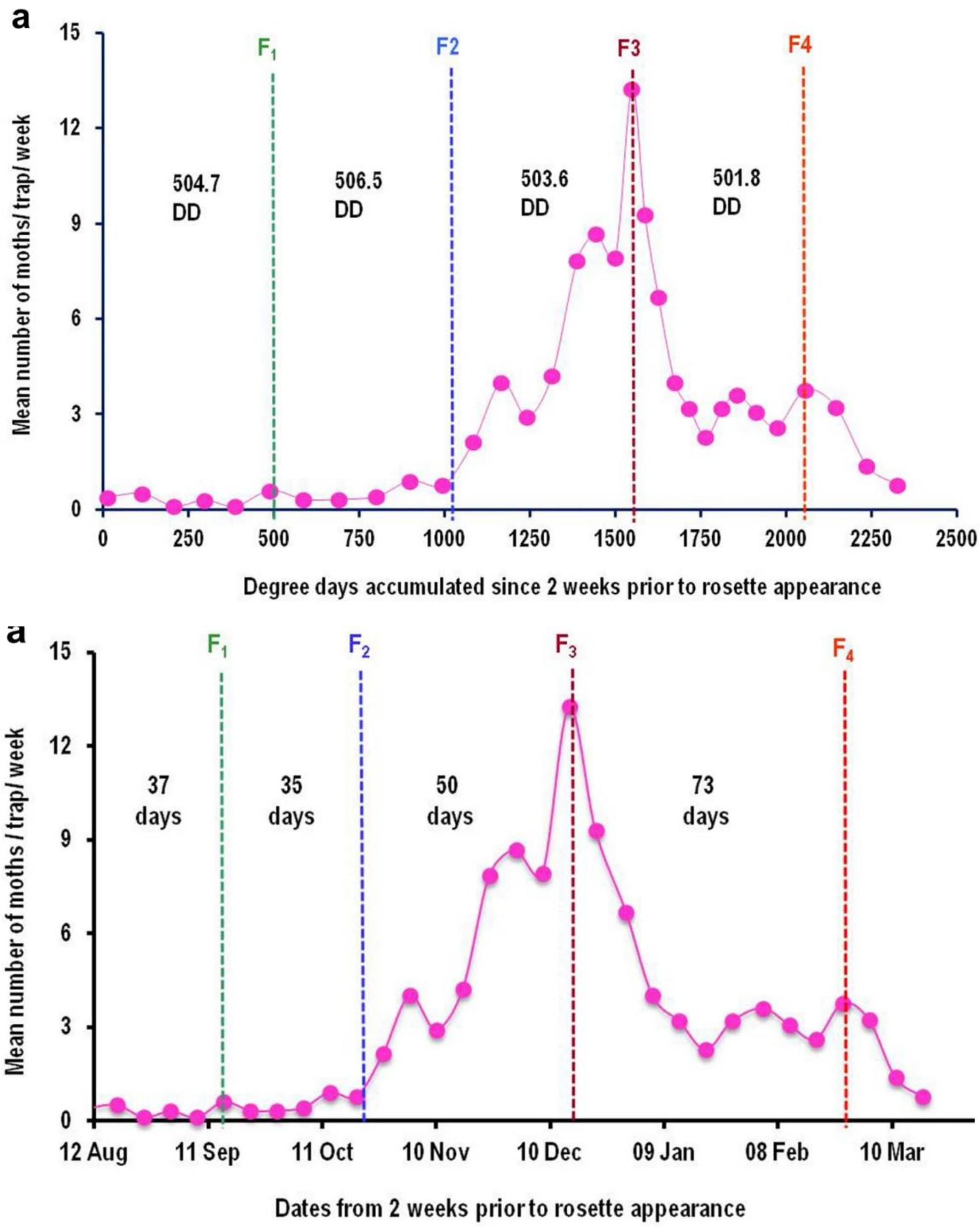

Figure 1. Generation events estimated for pink bollworm based on degree days (a) and number of days (b) lapsed between successive moth catch peaks recorded in sex pheromone traps at Nagpur (India). (Adopted from Fand et al., 2021).

Figure 2. Typical pattern of progressive increase in loculi damage by pink bollworm with advancement of cotton crop season. Boll with single locule damaged (a), boll with two loculi damaged (b), boll with three loculi damaged (c) and boll with all the four loculi damaged (d) (Adopted from Fand et al., 2019).

EARLY MATURING AND SHORT TO MEDIUM DURATION CULTIVARS: A SOLUTION IN THE MAKING

The pink bollworm is generally considered a stenophagous pest that has co-evolved with Malvaceous food plants like cotton, okra, Deccan hemp, and Roselle (CABI, 2023). However, natural infestations of this pest could seldom establish on host plants other than cotton. Thus, cotton is considered the principal host for pink bollworm establishment, survival, and perpetuation. Growing of long duration cotton cultivars that usually take ≥180 days to mature, and extending the length of the cotton crop season beyond the normally recommended cropping window, have been found as the key factors leading to an upsurge of pink bollworm damage in cotton (Kranthi, 2015; Naik et al., 2017; Fand et al., 2019). The conventional cotton varieties cultivated in many regions of India have a longer growing cycle (>180 days), providing a prolonged window for pink bollworm infestations to occur (Naik et al., 2017; Fand et al., 2019).

In contrast, short-duration cotton cultivars (130-150 days) exhibit a faster growth rate, reaching key developmental stages sooner leading to escape from pink bollworm damage. Adoption of early maturing cotton cultivars (variety or hybrid) requiring ~150 days to mature has been advocated as one of the key integrated pest management (IPM) strategies for escaping the pink bollworm damage (Kranthi, 2015; Fand et al., 2019; Prasad, 2021). In the absence of cotton as its principal host, the pink bollworm population enters into overwintering either in the infested bolls of cotton stalks or infested seeds of cotton lint (Mallah et al., 2000; Kranthi, 2015). Therefore, timely termination of the cotton crop as per the region-specific recommended cropping window is highly crucial in minimizing pink bollworm damage. The results of the temperature-dependent population dynamics modeling have shown that adopting timely crop termination helps to reduce at least two in-field generations of pink bollworm and thus helps to minimize the probable damage due to pink bollworm (Fand et al., 2021).

The timely crop termination will be best possible with the availability of early maturing cotton cultivars. Therefore, cotton breeding programs that are focused on the development of early maturing cotton cultivars are highly imperative in this context. The studies carried out at ICAR-CICR, Nagpur revealed that the early crop maturity (measured as percentage of boll bursting) had profound influence on the damage by pink bollworm measured as percentage of open boll damage. The highest population of pink bollworm (number of moths caught in pheromone traps) was observed in the third week of November (170 DAS) and an early maturing variety (140-150 days duration) sown in mid-June can potentially escape pink bollworm damage (ICAR-CICR, 2021). Cultivating genotypes that mature early and can be harvested in a single picking holds promise in addressing the significant threat of pink bollworm infestation, which becomes most destructive in the later part of crop season. Ensuring that susceptible crop stages do not coincide with the pest's arrival is essential for gradually reducing its resistant populations. Both public and private sector research are actively preparing to evaluate this approach. The All India Coordinated Cotton Improvement Project (AICCIP) has initiated an extensive assessment of early maturing cotton varieties or hybrids, laying the groundwork for their testing and eventual commercial release (Prasad, 2021).

BENEFITS OF SHORT DURATION COTTON CULTIVARS IN MITIGATING PINK BOLLWORM MENACE

The accelerated growth pattern of short-duration cultivars has numerous potential benefits in the context of pink bollworm management as mentioned below:

i. *Reduced exposure period*

One of the key benefits of short-duration cultivars is their shorter growth cycle. By maturing earlier, the cotton plants will remain for less time in the field, potentially reducing the window of vulnerability to pink bollworm attack. This minimizes the chances of prolonged exposure to the pest and its damaging effects.

ii. ***Temporal asynchrony between host and pest life cycles***

Early maturing cultivars can create a temporal asynchrony between the peak emergence of pink bollworm adults and the presence of a suitable stage of its host *i.e.* squares, flowers and bolls of cotton plants (Prasad, 2021). This disruption in synchronization can reduce the severity of pest infestations, as the pests may not find suitable hosts at the optimal developmental stage for its colonization and perpetuation. By reaching maturity faster, short-duration cultivars disrupt the pink bollworm's lifecycle, reducing the number of generations that can infest a field in a single growing season (Fand et al., 2021).

iii. ***Reduced selection pressure***

Adoption of short-duration cultivars will reduce the length of the cotton growing season which may lead to a lower cumulative pest pressure, potentially reducing the selection pressure for the development of resistance to Bt toxins and/or insecticides in pink bollworm populations (Kranthi, 2015; Naik et al., 2017).

iv. ***Reduced need for insecticides***

Due to the failure of transgenic cotton to provide satisfactory protection against pink bollworms, the cotton growers have to resort back to the use of chemical insecticides for protecting their crops from pink bollworm damage (Fand et al., 2019). However, being an internal feeder, the satisfactory control of pink bollworms could not be achieved with insecticides on account of increased target site inaccessibility of the spray chemical once the larvae enter the bolls (Naranjo et al., 2001; Busnoor et al., 2023). Planting short-duration cotton cultivars may lead to a reduced reliance on insecticide applications for pink bollworm management. If the cotton plants can mature and be harvested well before the pink bollworm populations reach severely damaging levels, farmers may be able to reduce the number and volume of insecticide sprays needed, resulting in savings in cost and reduced environmental impact.

v. ***Better fibre quality due to reduced pest damage***

The pink bollworm causes damage to the seed and lint of cotton leading to the deterioration of the quality and market value of the produce. Due to rapid maturity of cultivars the bolls can be harvested before significant pest damage occurs, thereby enhancing the overall market value of the cotton crop.

CONSIDERATIONS AND CHALLENGES

While early maturing and short to medium-duration cotton cultivars show promise in mitigating pink bollworm damage, several considerations and challenges should be taken into consideration.

i. ***Adaptation of cultivar to local climate, soil, and pest pressure***

The success of this strategy may vary depending on geographical location, climate, and local pest dynamics. The deep black cotton soils having good water holding capacity may prolong the maturity duration of crop. Cultivar selection should therefore be carefully tailored to suit the local climate, soil conditions, and pest pressures. Not all regions may benefit equally from these cultivars, and some amendments might be required to optimize their performance under target agroecologies.

ii. ***Maintaining the yield potential of cultivars***

Early maturing cultivars might have lower yield potential compared to traditional varieties with longer growth cycles. Therefore, it is highly essential to strike a balance between escaping pink bollworm damage and maintaining adequate cotton production. In this regard, it is sagacious on the breeders to tailor the plant architecture to suit to high density planting while breeding short duration cultivars. With compact and early maturing cultivars, higher yields can be achieved through high density planting system (HDPS) as was done in many cotton growing countries.

iii. ***Balancing the trait penalties on fibre quality with early maturity***

The fibre quality and early maturity are genetically negatively correlated. Principally the quality of the lint is mainly determined by the accumulation of cellulose during the process of boll development. When genotypes are selected for earliness, the plant get lesser time for cellulose accumulation thus adversely affecting the fibre quality. The trait penalty is observed on fibre strength, length and micronaire when early maturing cultivars are bred through intensive selection for earliness (≤120 days duration). In this regard, it is prudent on breeders to focus their selection with target duration of 140-150 days so that trait penalty on fibre quality is taken care while breeding for short duration varieties. Another approach can be selection of the lines which are early in flowering but have sufficient boll maturation period (the timeframe between flowering to boll opening). This approach serves twin purposes, ensures lesser trait penalty on fibre quality in short duration cultivars and also provide lesser time period of early generations of pink bollworm, thus creating lesser population load in the succeeding generations.

iv. ***Genetic diversity for crop resilience***

Overreliance on a few cultivars could lead to reduced genetic diversity, making the cotton crop more susceptible to other pests and diseases in the long run. Diversification of cultivars remains important for overall crop resilience.

i. Sustainability of pest management systems

Incorporating this approach into a comprehensive integrated pest management strategy, including practices such as crop rotation, biological control, and judicious use of insecticides, is crucial for long-term sustainability.

ii. Complicated nature of earliness traits in cotton

While selecting early maturing genotypes in the breeding process it is observed that earliness traits in cotton are complicated to measure because the flowering and opening of bolls in cotton plant occurred over long periods. Further earliness is impacted through the date of flowering, period of flower development and the days necessary for the bolls to open (Mahdi et al., 2014). Among the different traits of measuring earliness in cotton crop the most practical and positively correlated with seed cotton yield is Bartlett's earliness Index. It is the measure of combined yield of first and second cotton picking expressed as percentage of total cotton harvest. The higher the value of Bartlett's earliness index earlier could be the cultivar. Hence in the development of early maturing cultivars breeders should focus on Bartlett's earliness index.

iii. Farmer acceptance and awareness

The majority of rainfed cotton farmers are inclined towards the use of long-duration cotton cultivars that ensures at least three pickings. The crop extension, sometimes even up to late winters (March–April) through supplementary irrigation and fertilizer applications because of harnessing additional yields has been observed as a common practice among cotton farmers of rainfed agro-ecologies. The two important dimensions that add to the intensification of resistance development in pink bollworm to Bt cotton are the growing of long-duration cotton hybrids and the extension of the cotton season in late winters that supports the continuous multiplication of the pest (Kranthi, 2015; Fand et al., 2019). In this context, the farmers need to be educated about the benefits and challenges of adopting these cultivars to ensure successful implementation.

CONCLUSION

The menace posed by the pink bollworm to cotton production emphasizes the need for innovative strategies that enhance crop resilience and minimize economic losses. In this context, short-duration cotton cultivars hold promise as an effective strategy to escape pink bollworm damage, contributing to more sustainable cotton production. By reducing the exposure period and integrating these cultivars into comprehensive pest management strategies, farmers can not only mitigate pink bollworm infestations but also move toward a more balanced and resilient cotton production system. However, careful consideration of local conditions, yield potential, and genetic diversity is crucial to maximize the benefits of this approach.

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Much Change, Little Progress: Cotton Yields Must Rise

Terry Townsend
Cotton Analytics

Paper presented to the annual conference of the International Textile Manufacturers Federation (ITMF)
Samarkand, Uzbekistan
September 2024

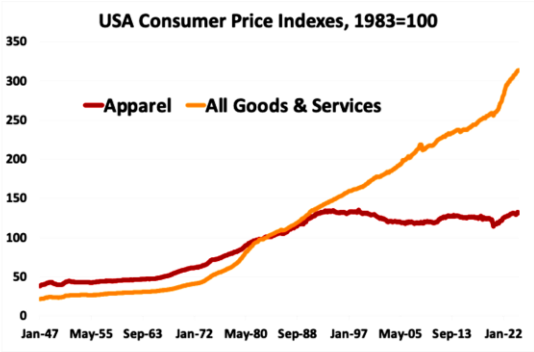
The annual meeting of the International Textile Manufacturers Federation (ITMF) was held in the beautiful city of Samarkand, Uzbekistan, along the historic Silk Road, during September 2024. The very name Silk Road reminds us of the long and important role of natural fibres in the history of the world economy.

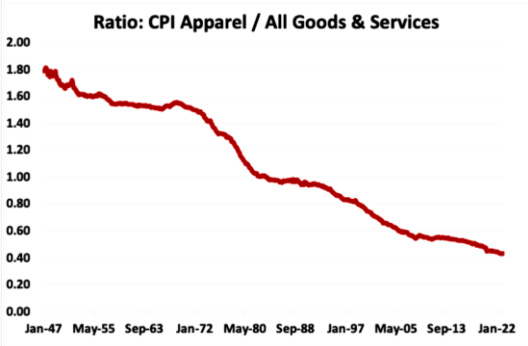
The role of natural fibres in the world economy was recognized when the United Nations General Assembly declared 2009 to be the International Year of Natural Fibres. The organizing committee for the International Year continues in the form of the Discover Natural Fibres Initiative (DNFI). Anyone with an interest in natural fibres may sign up for monthly updates on www.DNFI.org.

Real Prices Falling

Over the last seven decades since the end of World War II, there have been recessions, wars, periods of high inflation, periods of negative interest rates, and tremendous technology changes. The world GDP has climbed from US$5.3 trillion to $101 trillion. Despite all those changes, there have been certain continuing trends, including downward pressure on real prices throughout the cotton value chain, resulting in closures, bankruptcies, and consolidations.

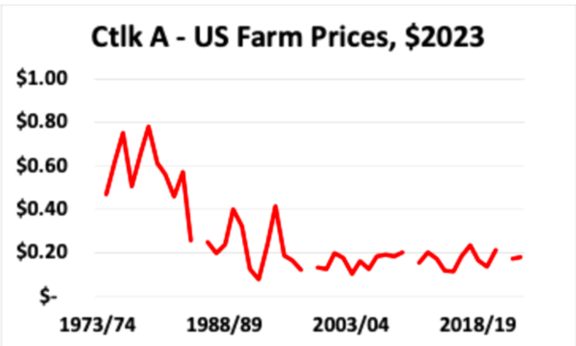
The Consumer Price Index in the United States is indicative of changes in prices adjusted for inflation in markets around the world. The CPI for all goods and services in the US economy, 1983=100, climbed from 21.5 in 1947 to 313.5 in July 2024, a change of approximately 15. In other words, if averaged over all goods and services in the United States, everything from golf balls to houses, prices have increased by a factor of 15 since 1947.

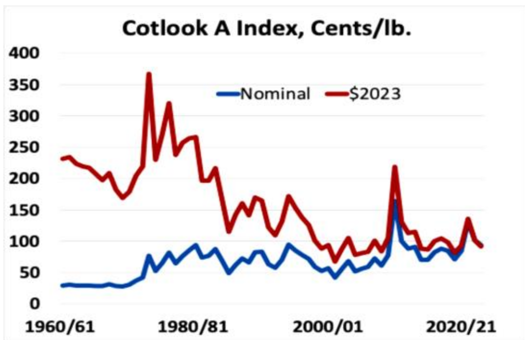




In comparison, the CPI for apparel in the United States climbed from 38.4 in 1947 to 134 in 1993, roughly keeping pace with the increase in prices of all goods and services for 45 years. However, in the three decades since, the CPI for apparel in the United States has grown no further and was still just 131 in July 2024. Over the last three decades, prices of apparel have grown not all, while prices of all goods and services continued upward. As of July 2024, the ratio of the Apparel CPI to the All Goods and Services CPI was 0.42, meaning that when adjusted for inflation, prices of apparel were just 42% of what they had been in 1983. In real terms prices of apparel have never been cheaper in the history of the world.

The same trend is occurring in the cotton industry. In the 1970s, the Cotlook A Index, an indicator of prices of cotton delivered to textile mills in Europe and East Asia, averaged around 70 cents per pound. During the same years, the average price paid to farmers in the United States was about 50 cents per pound. Therefore, the marketing margin for cotton, the difference between prices paid to farmers and the prices paid by textile mills, was about 20 cents per pound.





In recent years, the A Index has averaged 97 cents per pound, while US farm prices have averaged 76 cents, for a marketing margin of 21 cents per pound. However, if you deflate the marketing margin to put all prices on a 2023 basis, the marketing margin for cotton has fallen from more than 60 cents (2023 dollars) to 21 cents currently (2023 dollars). In other words, the marketing margin in real terms has fallen by a factor of three in five decades, reflecting greater efficiencies in the use of HVI for grading cotton, containers for shipping cotton, the web for communications, electronic trading of cotton futures, and other developments.

The pattern of falling prices in real terms is apparent for cotton also. The Cotlook A Index in 2023 dollars fell from more than $2 per pound in the early 1970s to its current level of less than $1.

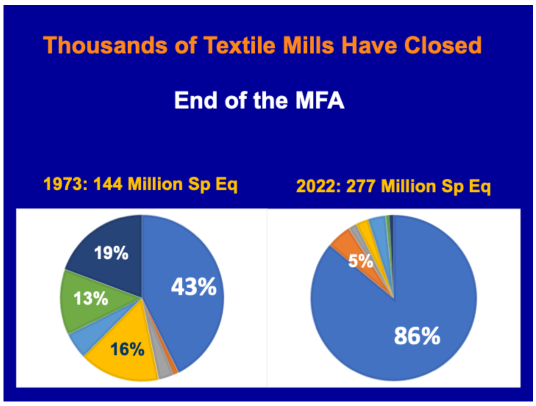
Bankruptcies and Consolidation

One manifestation of the downward trends in real prices at all stages of the cotton value chain has been waves of bankruptcies, closures and consolidations.

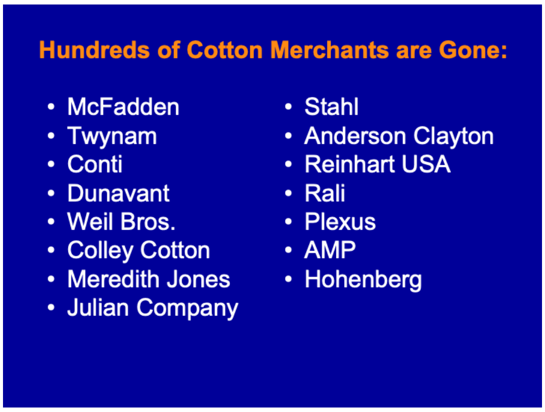
At the retail level, hundreds of formerly prominent retail brands have declared bankruptcy over the last 50 years, including Sears, once the largest retailer in the world. Other brands that have gone out of business or restructured under bankruptcy include Brooks Brothers, Lucky Brand, Lord and Taylor and more recently, J. Crew. There are thousands more brands and retailers around the world who exist no more.

Among textile mills, thousands have been closed over the past fifty years. In 1973, world short staple spinning capacity totaled 144 million spindle equivalents, with 43% in Asia, with large percentages in Japan, Korea, Taiwan and Hong Kong. In 1973, 16% of short staple spinning capacity was still in North America, 13% in Western Europe and 19% in Eastern Europe. Turkey was just 1% of the world total at that time.

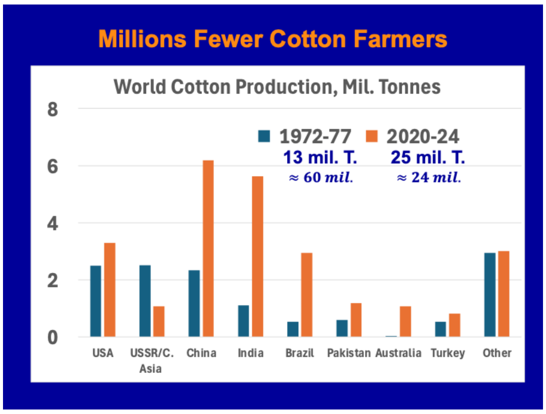
Today, with the elimination of the Multifibre Arrangement and the growth in world trade, world short staple spinning capacity has approximately doubled to 277 million spindle equivalents, and 86% of spindle equivalents are in Asia, meaning mostly China and India, along with Bangladesh, Vietnam and Indonesia, and 5% are in Turkey. Thousands of mills in Japan, Korea, Taiwan, Hong Kong, North America, Western Europe and Eastern Europe have closed and hundreds of thousands of workers have lost their jobs over the past 50 years as real prices of apparel have fallen.



In the cotton sector, there have been extraordinary disruptions to industry structure as once-major companies have closed. Dunavant was once the largest cotton merchant in the world, and today it is gone. Weil Brothers, Colley Cotton, Meredith Jones, Anderson Clayton, Rali, Plexus, AMP, and hundreds of other iconic cotton firms have closed, gone bankrupt or been merged with other firms, unable to overcome the relentless downward pressure on marketing margins as trade has become more efficient and the cotton marketing margin has shrunk.



Finally, millions of households that used to grow cotton have moved on to other pursuits over the last 50 years. In the early 1970s, world cotton production averaged 13 million tonnes, and there were an estimated 60 million households producing cotton. Today, world production is about double at 25 million tonnes, but the number of cotton households has fallen to an estimated 24 million. If you count seasonal labor, total employment in cotton production has probably fallen from around 350 million in the 1970s to around 100 million today.



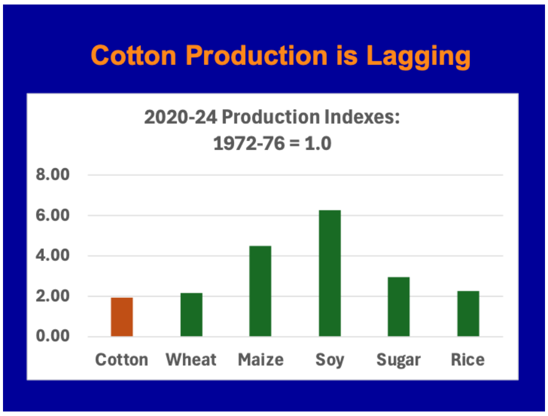
Throughout the cotton-to-fashion value chain, the pattern is the same: falling real prices have resulted in bankruptcies and closures. The competitive pressures on actors in the cotton value chain have been relentless.

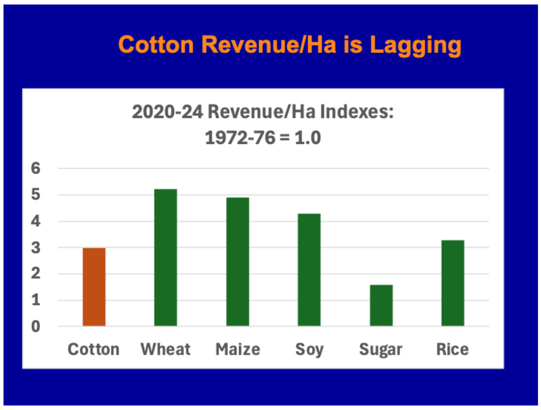
Cotton is Lagging

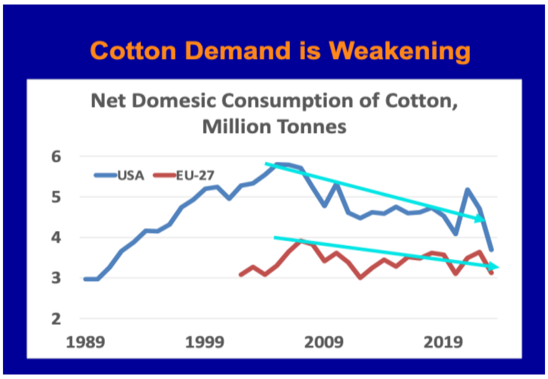
Within an environment of competitive pressures, the cotton sector is lagging its key sister commodities in terms of growth in production, revenue per hectare and demand in consumer markets. For example, world production of cotton has roughly doubled from 13 million tonnes per year in the early 1970s to 25 million tonnes on average in the 2020s. World production of wheat and rice have also roughly doubled. In contrast, world production of maize has increased by more than four times, while production of soybeans is up more than six times what it was in the 1970s.

Likewise, revenue per hectare of cotton has grown less than revenue per hectare of wheat, maize, soy and rice. Multiplying average yields per hectare by average price received by farmers, revenue per hectare of cotton in nominal terms increased by a factor of three between the 1970s and the

2020s. In comparison, revenue per hectare of wheat and maize rose about five times, and revenue per hectare of soy increased four times. Revenue per hectare of rice rose about the same as cotton, and only sugar revenue has grown less than cotton.







Demonization Contributes to Cotton's Decline

Markets are complex, and there are always many reasons for changes in industry performance. For cotton, it is tempting to blame problems on competition with polyester, but all commodities face competition. Coffee competes with orange juice. Aluminum competes with steel. Copper competes with fibre optic cables. Beef competes with chicken. Obviously, the growth of polyester since the 1960s has had a huge impact on cotton.

Nevertheless, there is another factor that is weighing on cotton, undermining the ability of the cotton industry to meet the competitive pressure posed by polyester: tropes about cotton and agriculture have become established in the common understanding. Compared with 50 years ago, there has been a major change in public perceptions of agricultural science, and cotton has been targeted.

Decades ago, famine was still a common occurrence in the world, including famines in China during the Mao era, and famine in Bengal India. In the 1970s, the world was worried about population growth and the specter of mass starvation ("The Population Bomb," by Paul Ehrlich), and the work of Norman Borlaug to create the Green Revolution was heralded with a Noble Prize.

Today, most of the world's population lives in relative urban abundance, and most are generations removed from the realities of agricultural production. Tropes about agriculture are embedded in the common understanding. Typical tropes are that:

- GMOs are dangerous (Every person on earth has eaten food containing GMO traits by now, and there is not a single reported incidence of injury);
- Fertilizers are toxic (If fertilizer was toxic, we would all be dead. 72% of our atmosphere is Nitrogen);
- Pesticides are harmful (Pesticides are supposed to be harmful. The purpose of pesticides is to kill things! Of course, pesticides represent a hazard, but with safe handling and application, exposure to hazards can be managed and risk reduced to an acceptable level.)
- Conventional agriculture is BAD, and Organic agriculture is GOOD. If all agriculture in the world returned to organic methods, as was the case prior to World War II, about 5 billion people would starve within a decade. How can that be considered GOOD?)

In all these tropes, cotton has been targeted, and the impact has been to undermine consumer demand, depress prices, prevent technology adoption, and undermine livelihoods.

Without change, cotton will follow its sister natural fibres as a niche commodity. Wool used to account for 10% of world fibre use; today wool is barely 1% and falling. In the age of sail, sisal, hemp, and linen were huge industries involving millions of tonnes of production and employing millions of people in production and processing. A single tall ship contained 60 kilometers of rigging, mostly sisal and hemp, and 4,000 square meters of sail, mostly linen. A single ship carried about 20 tonnes of natural fibre rigging and sales to produce power, and the rigging and sails had to be replaced every few years. Prior to the development of cargo containers, all freight was carried break bulk, and jute was used extensively in cargo nets and as a packaging and bagging material. Today, these natural fibre industries are shadows of their former selves, and cotton will go the same way without change.

Only Technology Can Save Cotton

Decades of data indicate that only increased supply can prevent the demise of the cotton industry, and only technology can expand supply.

The long decline in average real prices at the retail level within the cotton value chain, from farmers to retail, shows that demand growth will not save the cotton industry. Government environmental regulations, consumer preferences for natural fibers and new technologies that might expand the range of uses of cotton will not be sufficient to boost the industry if supply does not expand.

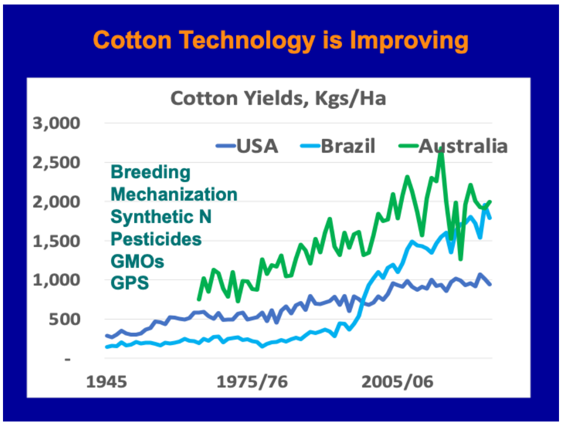
In order for supply to expand, yields must increase. Real prices are declining, while input costs are rising. The area devoted to cotton worldwide has not increased since the 1950s, and it will not increase in the future. Therefore, for cotton to survive, yields must rise, and only technology can lead to higher yields.

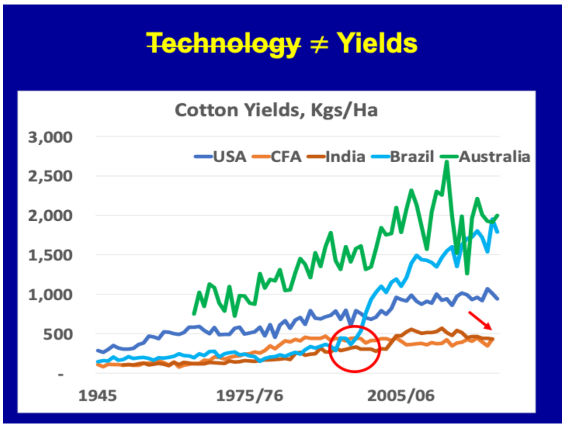
Fortunately, cotton technology is improving, and yields are rising in countries that adopt technologies.

Australia, Brazil and the United States are examples of cotton producing countries with rising trends in yields. In the 1940s, yields in the United States averaged 250 kilograms of lint per hectare, and today they are around 1,000 kilograms.

In the 1940s, yields in Brazil were just 200 kilograms per hectare, and they remained low for decades. Finally, in the early 2000's, Brazilian farmers started adopting agricultural technologies including GMOs, directed breeding of optimized varieties, expanded mechanization, extensive use of synthetic nitrogen and sophisticated application of pesticide technologies, all coordinated with precision input applications using GPS systems. Today, yields in Brazil are around 2,000 kilograms of lint per hectare.

Likewise, Australia, starting from essentially zero in the 1960s, and contending with great year-to-year variation because of drought, yields in Australia are also around two tonnes of lint per hectare because of the development and adoption of extraordinary technologies that overcome yield constraints.





Cotton has many advantages that can enable it to serve the world community for decades more. Cotton is biodegradable. It does not shed synthetic microfibres. Cotton is not made from oil. Consumers prefer cotton, and millions are employed in cotton production. As Australia, Brazil and the United States demonstrate, with technology, yields can rise, and cotton can serve.

However, not all producers have the means or the access to technologies that can ensure the survival of cotton in a relentlessly competitive environment.

Africa and India are examples of lagging adopters whose yields remain mired at low levels. During the 1940s, 1950s, 1960s, 1970s, and into the 1980s, cotton yields in Brazil, the CFA Zone of Africa (countries using the currency of Francophone Africa) and India were essentially the same, climbing from around 200 kilograms of lint per hectare to around 400 kilograms, and nearly 500 kilograms per hectare. In the 1980s and 1990s, yields in the CFA zone were ABOVE yields in Brazil and India!

Then around 2000, yields started diverging. As farmers in Brazil adopted technologies, yields began rising to their current levels.

When India introduced biotech traits to hirsutim varieties in the early 2000s, yields rose substantially until around 2010. Tragically, yields in India have trended lower during the past decade as resistance to the original biotech traits has developed among target insect populations. Whole papers have been written on factors affecting cotton yields in India, and developments in agriculture always have multiple causes. Nevertheless, clearly the failure to train farmers in proper use of biotech tools and to enforce the use of non-biotech refuges, combined with a legal system that does not encourage private sector development of new biotech traits, have contributed to the downward trend in yields.

Meanwhile yields in the CFA zone have continued at about 450 kilograms per hectare since the 1990s, and they remain there today. As with anywhere else, there are always multiple reasons for yield stagnation or decline, including climate change, political disfunction, economic dislocation and security breakdowns in some countries. The bottom line in the CFA zone is that yields are not rising because technologies are not being adopted.

The lesson is clear, technology drives yields. Yields result in production. Production leads to improved farmer welfare. In countries where robust breeding programs, input availability, and farmer training, combine with incentive structures that facilitate technology development and adoption, yields rise, and farmers are better off.

A word about organic agriculture:

There is nothing wrong with organic cotton production practices. All agriculture was organic until about 80 or so years ago, and farmers anywhere can use organic agronomic techniques if they wish to. Nevertheless, despite decades of promotion and subsidy, legitimate organic cotton production worldwide is less than 1% of world cotton production. Farmers want to use the tools of modern agriculture, and consumers want high-quality products at low prices; organic doesn't fit into that picture except as a niche product purchased by mostly-affluent, self-righteous consumers. Organic cotton is an engine of farmer poverty and industry stagnation, and there is no future for organic cotton in a competitive world economy.

Conclusion

If cotton is to remain relevant in the world economy in which competitive pressures lead inexorably to declines in real prices over the long-run, yields must rise for supply to expand. Yields can rise only if agricultural technologies are developed and adopted. Accordingly, advocates of cotton must aggressively combat the tropes about agricultural sciences that have seeped into mainstream thought and that undermine the adoption of technologies crucial to industry survival.

Just as sailing ships have given way to modern cargo carriers, cotton must evolve using new technologies in the life sciences, mechanical engineering, precision input applications, and better crop protection tools to achieve higher yields and increased production while reducing resource consumption.

Like ships, cotton must evolve. Imagine a world in which regulators in the 1850s had prevented the adoption of steam engines and internal combustion engines because they were dirty, dangerous, and contributed to global warming. Imagine a world in which sailing ships and horses remained the dominant modes of transportation because they are deemed to be “natural” and thus “Good.” Tropes about agricultural technologies, and applications in cotton in particular, are strangling the cotton industry, preventing yield gains and fibre quality improvements and leaving farmers impoverished.

Cotton must meet consumer demand for fiber performance properties at prices competitive with other fibers, and cotton must return an income to growers that justifies the devotion of land, labor and capital. Only technology can ensure a future for the world cotton industry.