



## Sustainable intensification of transgenic cotton in India - A review

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### ABSTRACT

World population is projected to reach over nine billion by the year 2050, and ensuring fiber security while mitigating environmental impacts represent a major agricultural challenge. Conventional cotton (*Gossypium* sp) production technologies had significant effects on the environment and farm profitability in the past. New era transgenic or *Bt* cotton production technology can be used to simultaneously reduce the environmental footprint and enhance the profitability of cotton production. Information on these two sustainability aspects of transgenic cotton is missing in the scientific literature. Here, we review the potential advantages of insect tolerance *Bt* insect resistant technology used in hybrid cotton by comparing with the major cereal based rotations in India. Our results suggested that by using this technology, there was significant reduction in pesticide use roughly by 40%, and yield advantages of 30-40%. These resulted in saving on fossil fuels and decreasing CO<sub>2</sub> emissions– which are major bonus for climate change mitigation. During the last decade, significant increase in cotton area and production in India is attributed to better returns realized by the farmers, which were largely due to better management practices followed to grow transgenic cotton. Most of the studies conducted in India, concluded that *Bt*-cotton is more efficient in input use and had a lower environmental impact quotient, which indicates less damage to the environment than non-*Bt*-cotton. However, *Bt*-cotton based cropping systems have less profitability and energy efficiency in comparison to the major cereal based rotations in India due to lesser productivity potential of cotton crop particularly in rain-fed ecosystems. This was mainly attributed to the lesser dissemination of proven energy-efficient research technologies to the farmer's fields. Although, *Bt*-cotton can contribute to a “sustainable intensification” strategy favoured by many science academies worldwide, which allows productivity/production to be increased in the current crop land, thereby saving forests and biodiversity.

**Key words:** Cotton, Cropping systems, Economics, Environment, Sustainability, Transgenic

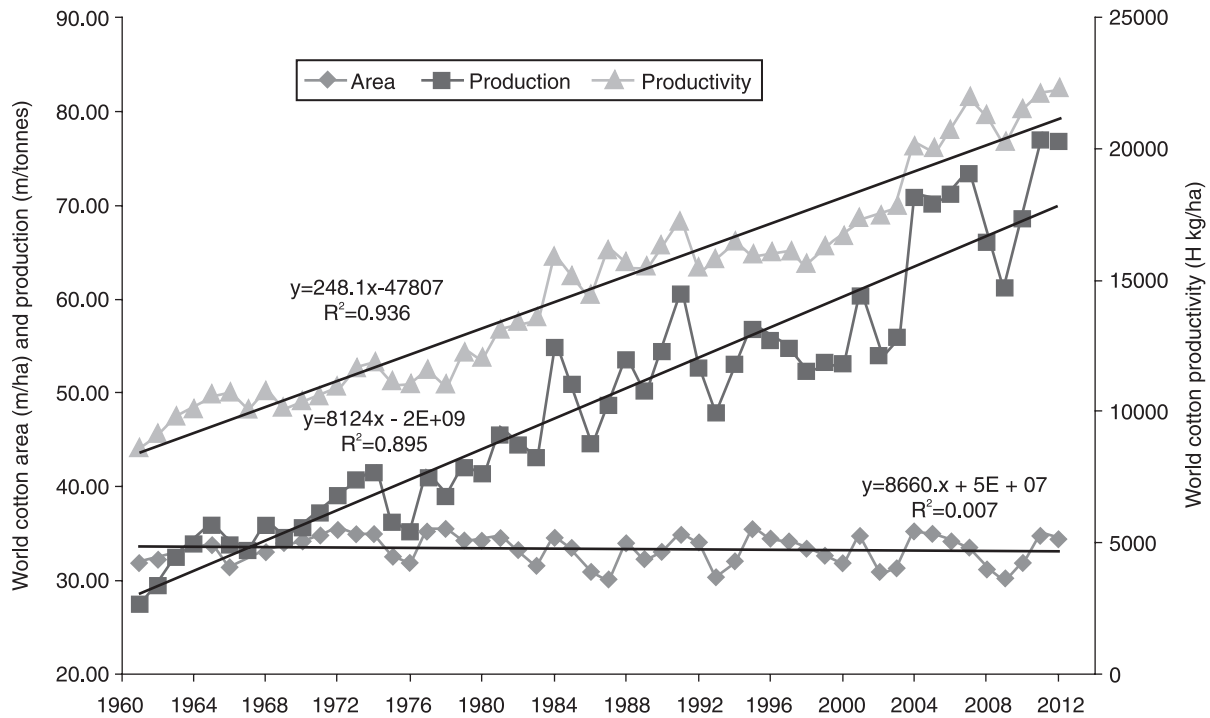
According to the Food and Agriculture Organization of the United Nations (FAO), sustainable crop production intensification is defined as producing the more outputs from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to the natural capital and flow of the environmental services (The Montpellier Panel 2013). In this concept, land is used to produce better yields in a manner which maintains soil health and farmer's profit without deteriorating the environmental health. Cotton (*Gossypium* sp.) is one of the most important textile fibers in the world, accounting for around 35% of the total world fiber use (Barwale *et al.* 2004). It is a major cash crop in the world and is grown commercially in about 75 countries (Fig 1). World cotton area remained stagnant for the last five decades (only 8% increase from 1961-2012) but production has been markedly increased (179%) because of the steep rise in productivity (158%) due to the introduction of insect resistant transgenic technology particularly in Asian

countries (Fig 2). During the last decade (2001-2012), world cotton production has been increased by 44% over the previous four decades (-2, 31, 16 and 29%, respectively). China, India, USA, Pakistan and Uzbekistan are the five major cotton growing countries, with China holding the highest productivity (FAO 2014). The United States, which



Fig 1 Cotton or ‘white gold’ is a major cash crop of the world.

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Source: FAO (2014)

Fig 2 World cotton area, production and productivity from 1961-2012

ranks third in production behind China and India, is the leading exporter, accounting for over one-third of global trade in raw cotton.

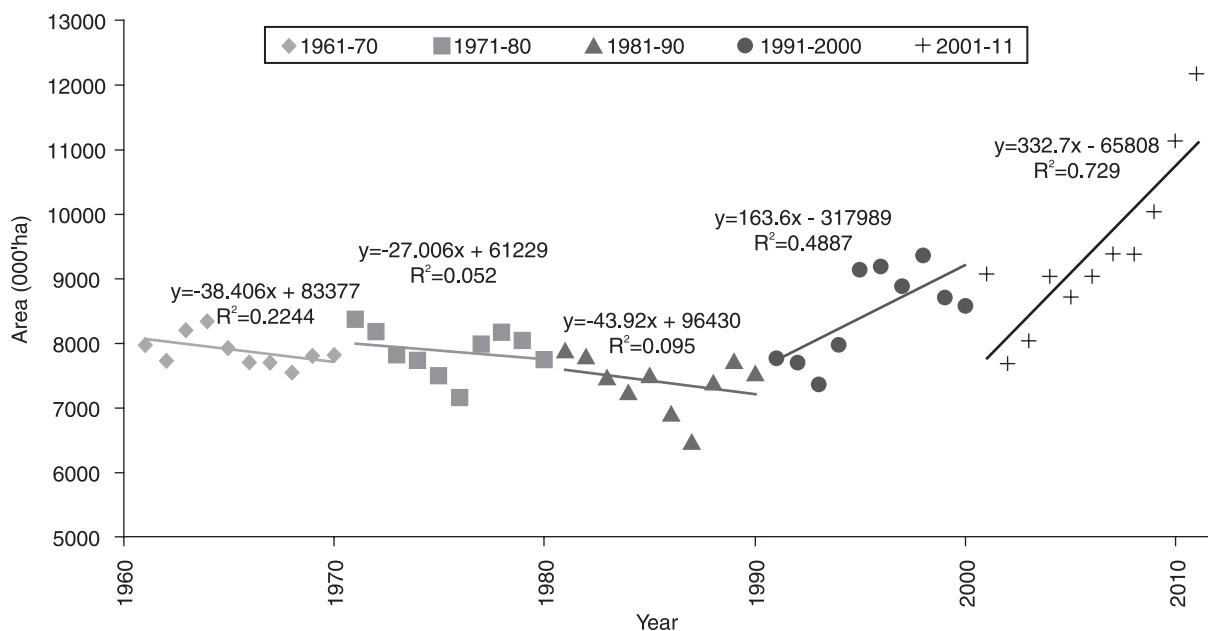
A global overview of the adoption of biotech cotton indicates that an accumulated total of 23.9 mha of biotech cotton was planted by eleven countries, nine developing and two industrial, during the first 16 years (1996–2012) of the commercialization. Top four countries were India (11.0 mha), China (4.2 mha), USA (3.7 mha), and Pakistan (2.8 mha) (<http://www.gmo-compass.org>; assessed on 04/03/2015 at 3 pm). The global hectareage of biotech cotton has climbed consistently every single year since its first commercialization in 1996 to reach 16.2 million ha in 2009, equivalent to 70% of the global cotton area of 32 mha (Brookes and Barfoot 2016). Apart from India, increases of cultivation areas were also recorded in Australia, Mexico, Columbia, Republic of South Africa; whereas in countries like Brazil and Argentina cotton area decreased during this time period. In China, on the other hand, there were no changes in the areas of cotton cultivation. In the years 2010 and 2011, India for the first time matched up with the cotton production level of China; however, productivity level of cotton in India is still very low compared with Australia and China (Fig 3). National productivity of cotton in India is about 32% lower than the global cotton productivity (779 kg/ha) (Subbiah and Jeyakumar 2009). Due to burgeoning population as well as shrinking land resources in India, it is now very difficult to increase cotton acreage in the country.

Cotton as a cash crop contributes around 30% to the GDP of the nation's agriculture sector (CIBRC 2008). In the year 1990-91, cotton acreage as well as production

started increasing up to the year 2001-02. In the next year, both the area and productivity, decreased due to bollworms infestation (Fig 4 and 5). For cotton area in India, no significant decadal trend for the first three decades (1961-70, 71-80, 81-90) has been observed as the regression slope for these three decades came out to be non-significant at 5% level of significance. A significant increase ( $P=0.02$ ) in the cotton growing area of 163 600 ha/year has been observed during 1991-2000 which again increased to 332 760 ha/year during the last decade ( $P<0.01$ ). During 1981-90, significant increase ( $P<0.05$ ) in cotton productivity was observed at the rate of 8.42 kg/ha which was non-significant during the years from 1991-2000. During last decade (2001 onwards) a significant increase ( $P<0.01$ ) of 36 kg/ha was observed in cotton productivity in India. Annual losses caused by bollworms alone were estimated at about US\$ 290-350 million, despite repeated sprayings of insecticides (Qaim 2003). It was the effect of introduction of transgenic cotton in India, which increased both area and production of cotton after 2003-04 (Singh 2009).

#### Impact on cotton sector of India

In 2012, 7.2 million cultivators (93% of total cotton growers) raised transgenic cotton on 11 mha in India. Now India grows about 46% of the world's transgenic cotton, which turned into the first country in the terms of transgenic cotton acreage. *Bt* technology revolutionized the cotton sector in India because of more production with less use of toxic chemicals which ultimately improved the lives of cotton growers. The application of cotton insecticides as a percentage of total insecticides to control insect-pest



Source: FAO (2014)

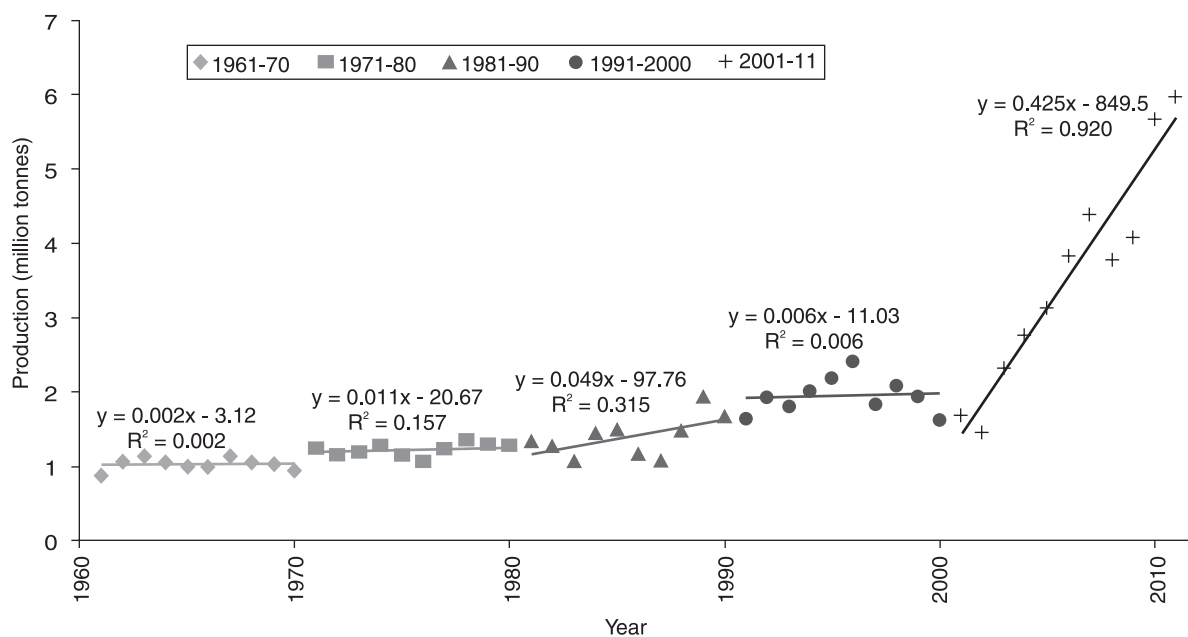
Fig 3 Decadal trends in cotton area in India during 1961-2011

halved from 46% in 2001 to 20% in 2011 (Yadav *et al.* 2015). In addition, India has become the largest exporter of lint in the world (Fig 6). In about 10 years, the area under *Bt*-cotton has increased by more than 212 times to record 10.8 million hectares and the number of *Bt*-farmers by 190 times to reach 7.2 million in 2011.

*Environmental sustainability*

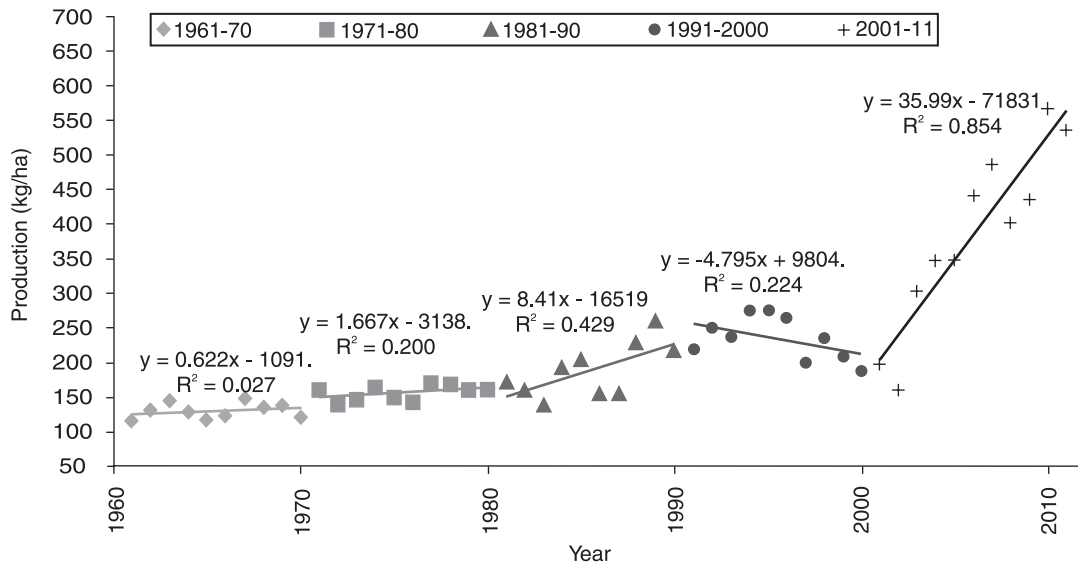
Some research findings (Blackwood and Buyer 2004, Dunfield and Germida 2004, Motavalli *et al.* 2004, O’Callaghan *et al.* 2005, Dong and Li 2007, Sarkar *et al.*

2008) concluded that genetically modified crops release *Bt*-toxins into the rhizosphere which affects soil properties of the crops in the rotation. Singh *et al.* (2013<sup>C</sup>) provided solution by growing legume like groundnut in between two rows of transgenic cotton, which significantly enhanced dehydrogenase enzyme activity, microbial population, and KMnO<sub>4</sub>-N content of transgenic cotton growing soil at all the crop growth stages. Before the introduction of transgenic cotton in India, cotton consumed 30% of the total pesticides in India which is now reduced to 18% only (Yadav *et al.* 2015) and this is equivalent to a saving of US\$82 million.



Source: FAO (2014)

Fig 4 Decadal trends in cotton production in India during 1961-2011



Source: FAO (2014)

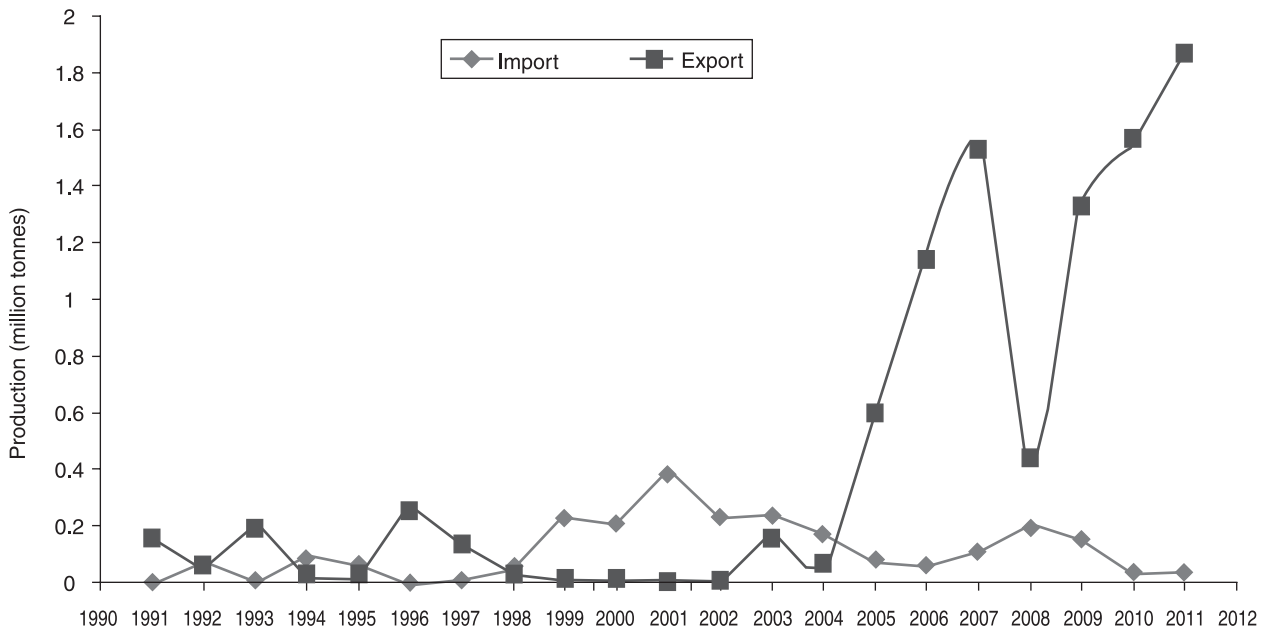
Fig 5 Decadal trends in cotton productivity in India during 1961-2011

Transgenic cotton has lower environmental impact quotient than traditional cotton due to high nutrient use efficiency and harvest index; and less use of pesticides (Brookes and Barfoot 2013). From 2002 to 2012, *Bt* cotton contributed to food security, sustainability and climate change by increasing crop production; providing a better environment, by the saving of pesticides; reducing CO<sub>2</sub> emissions, equivalent to taking millions of cars off the road; conserving biodiversity; and helped alleviate poverty by helping millions of small farmers, and their families (Brookes and Barfoot 2013). *Bt*- cotton can contribute to a “sustainable intensification” strategy favoured by many science academies worldwide, which allows productivity/production to be increased only in

the current crop land, thereby saving forests and biodiversity.

*Cropping systems*

To know the economic and environmental performance of *Bt*-cotton based cropping systems (BCBCS), net returns, benefit:cost ratio and energy use efficiency (EUE) of major cropping systems of India tested in various studies conducted by researchers from various parts of India were compared (Table 1). In conclusion, it was found that there is still a wide gap between BCBCS and other systems in terms of profitability and EUE. BCBCS have lesser net returns or profit per hectare than rice based (83 US \$), maize based (124 US \$), groundnut based (80 US \$) and



Source: FAO (2014)

Fig 6 Trend of cotton export and import in India from 1991-2011

Table 1 Profitability and energy use efficiency of conventional/farmer's practices in different cropping systems of India

Cropping system	Location	Net returns (US \$/ha)	Return per US \$ invested	Source	Energy use efficiency*	Source
<i>Cotton based systems</i>						
Cotton-wheat	Ludhiana, Punjab	851.4	1.30	Walia <i>et al.</i> (2011)	9.5	Walia <i>et al.</i> (2014)
<i>Bt</i> cotton-wheat	New Delhi	881.1	1.55	Singh <i>et al.</i> (2009)	8.4	Singh and Ahlawat (2015)
<i>Bt</i> cotton-wheat	New Delhi	1048.9	1.06	Kumar (2012)	6.7	Kumar (2012)
<i>Bt</i> cotton-green gram	Raichur, Karnataka	1075.8	1.93	Honnali and Chittapur (2014)	1.7	Pandey and Dave (2014)
<i>Bt</i> cotton-sesame	Raichur	940.3	1.82	Honnali and Chittapur (2014)	1.6	Honnali and Chittapur (2014)
Cotton-mustard	Ludhiana, Punjab	973.3	1.70	Walia <i>et al.</i> (2011)	10.7	Walia <i>et al.</i> (2014)
Mean±SD		961.8±89.3	1.56±0.33		6.4±3.9	
<i>Rice based systems</i>						
Rice-wheat	Raipur, Chhattisgarh	1136.7	1.64	Pandey and Dave (2014)	8.4	Pandey and Dave (2014)
Rice-wheat	Ludhiana, Punjab	952.5	1.45	Walia <i>et al.</i> (2011)	8.4	Walia <i>et al.</i> (2014)
Rice-wheat	Varanasi, UP	828.3	1.35	Saha <i>et al.</i> (2012)	-	-
Rice-wheat	Dehradun, Uttarakhand	1366.1	1.51	Singh and Kumar (2014)	9.1	Singh and Kumar (2014)
Rice-linseed	Raipur, Chhattisgarh	1024.6	1.49	Pandey and Dave (2014)	8.8	Pandey and Dave (2014)
Rice-chickpea	Raipur, Chhattisgarh	1396.4	1.97	Pandey and Dave (2014)	10.7	Pandey and Dave (2014)
Rice-rice	North-24 Pargana, West Bengal	612.0	1.50	Kumar <i>et al.</i> (2014)	7.8	Kumar <i>et al.</i> (2014)
Mean±SD		1045.2±282.4	1.55±0.20		8.9±1.0	
<i>Maize based systems</i>						
Maize-wheat (R)	Palmpur, Himachal Pradesh	3941.9	2.27	Ramesh <i>et al.</i> (2014)	20.8	Ramesh <i>et al.</i> (2014)
Maize-wheat	New Delhi	898.1	1.51	Choudhary (2011)	9.77	Choudhary and Behera (2012)
Maize-wheat	New Delhi	897.6	1.6	Kiran Kumar <i>et al.</i> (2013)	10.4	Kiran Kumar <i>et al.</i> (2013)
Maize-wheat (R)	Dehradun, Uttarakhand	258.2	0.69	Ghosh <i>et al.</i> (2016)	7.3	Singh <i>et al.</i> (2016)
Maize-wheat (R)	Dehradun, Uttarakhand	229.4	1.19	Ghosh <i>et al.</i> (2016)	6.3	Singh <i>et al.</i> (2016)
Maize-wheat	Ludhiana	989.0	1.54	Walia <i>et al.</i> (2011)	12.4	Walia <i>et al.</i> (2014)
Maize-pea (R)	Basar, Arunachal Pradesh	851.6	2.34	Choudhary and Kumar (2013)	7.0	Choudhary and Kumar (2013)
Maize-mustard (R)	Basar, Arunachal Pradesh	783.7	2.11	Choudhary and Kumar (2013)	5.5	Choudhary and Kumar (2013)
Maize-French bean (R)	Basar, Arunachal Pradesh	1136.1	2.74	Choudhary and Kumar (2013)	7.3	Choudhary and Kumar (2013)
Maize-groundnut (R)	Basar, Arunachal Pradesh	873.4	2.27	Choudhary and Kumar (2013)	6.4	Choudhary and Kumar (2013)
Mean±SD		1085.9±1046.1	1.83±0.62		9.3±4.6	

Cond.

Table 1 (Concluded)

Cropping system	Location	Net returns (US \$/ha)	Return per US \$ invested	Source	Energy use efficiency*	Source
<i>Pigeonpea based systems</i>						
Pigeonpea-castor (R)	Hyderabad, Telangana				6.7	Pratibha <i>et al.</i> (2015)
Pigeonpea-wheat (R)	Almora, Uttarakhand	901.6	1.14	Tuti <i>et al.</i> (2013)	1.4	Tuti <i>et al.</i> (2013)
Pigeonpea-barley (R)	Almora, Uttarakhand	733.9	1.06	Tuti <i>et al.</i> (2013)	1.3	Tuti <i>et al.</i> (2013)
Pigeonpea-lentil (R)	Almora, Uttarakhand	1026.1	1.64	Tuti <i>et al.</i> (2013)	1.9	Tuti <i>et al.</i> (2013)
Pigeonpea-field pea (R)	Almora, Uttarakhand	882.3	1.37	Tuti <i>et al.</i> (2013)	1.4	Tuti <i>et al.</i> (2013)
Pigeonpea-toria(R)	Almora, Uttarakhand	911.0	1.50	Tuti <i>et al.</i> (2013)	1.7	Tuti <i>et al.</i> (2013)
Mean±SD		890.9±104.3	1.34±0.24		2.4±2.1	
<i>Groundnut based systems</i>						
Groundnut-wheat	New Delhi	497.6	1.07	Singh <i>et al.</i> (2009)	7.3	Singh and Ahlawat (2015)
Groundnut-wheat	New Delhi	1116.9	2.0	Kiran Kumar <i>et al.</i> (2013)	11.4	Kiran Kumar <i>et al.</i> (2013)
Groundnut-mustard	Ludhiana, Punjab	1520.0	2.7	Walia <i>et al.</i> (2011)	16.3	Walia <i>et al.</i> (2014)
Mean±SD		1044.8±515.0	1.92±0.82		11.7±4.5	
<i>Soybean based systems</i>						
Soybean-wheat	New Delhi	877.4	1.62	Karunakaran and Behera (2013)	4.3	Karunakaran and Behera (2013)
Soybean-wheat	New Delhi	867.7	1.60	Kiran Kumar <i>et al.</i> (2013)	11.5	Kiran Kumar <i>et al.</i> (2013)
Mean±SD		872.5±6.9	1.61±0.01		7.9±5.1	
<i>Jute based systems</i>						
Jute-rice-wheat	North 24 Pargana, West Bengal	769.9	1.50	Kumar <i>et al.</i> (2014)	9.7	Kumar <i>et al.</i> (2014)
Jute-rice-potato	North 24 Pargana, West Bengal	2175.3	2.00	Kumar <i>et al.</i> (2014)	7.3	Kumar <i>et al.</i> (2014)
Jute-rice-lentil	North 24 Pargana, West Bengal	659.4	1.40	Kumar <i>et al.</i> (2014)	10.3	Kumar <i>et al.</i> (2014)
Jute-rice-mustard	North 24 Pargana, West Bengal	735.8	1.50	Kumar <i>et al.</i> (2014)	10.1	Kumar <i>et al.</i> (2014)
Jute-rice-rice	North 24 Pargana, West Bengal	818.0	1.50	Kumar <i>et al.</i> (2014)	9.8	Kumar <i>et al.</i> (2014)
Mean±SD		1031.7±641.9	1.58±0.24		9.4±1.2	

1 USD ~ 65 INR; \*Energy output/energy inputs; R, rainfed; SD, Standard deviation

jute based (70 US \$) systems. However, BCBCS is more profitable than pigeonpea based (72 US \$) and soybean based (89 US \$) systems. In terms of return per unit of money invested, BCBCS have almost similar potential to rice and jute based systems and comparatively 16% higher potential to pigeonpea based systems. However, BCBCS have a lesser potential in terms of return per unit of money invested, in comparison to maize based (17%), groundnut based (23%) and soybean based (3%) systems. EUE is an important environmental index to measure the pressure on the environment in terms of bio-energy outputs produced per unit consumption of energy inputs in terms of

non-renewable and renewable energy resources. In terms of EUE, BCBCS had less energy efficient (23-83%) than other major cropping systems evaluated except pigeonpea based system. This happened due to the fact that BCBCS produced less bio-energy outputs due to smaller energy coefficient values for cotton lint (11.8 MJ/kg) in comparison to oilseeds (25.0 MJ/kg) and cereals (14.7 MJ/kg) (Singh and Ahlawat 2015).

Among all the cotton based cropping systems in India, cotton followed by wheat is a well-developed crop rotation, which is followed in north-western plains of India (1.40 mha) and Pakistan (2.62 mha) (Mayee *et al.*

2008) and provides employment to more than 8.0 million workers. There is wide scope to increase productivity and profitability potential of *Bt* -cotton crop by utilizing the findings of several studies conducted in various parts of India on resource enhancing technologies like intercropping, integrated nutrient management, conservation agriculture practices etc. (Table 2). Singh and Ahlawat (2011) reported that groundnut as an intercrop enhanced the productivity of transgenic cotton by 0.25 tonnes/ha and succeeding wheat by 0.16 tonnes/ha. By growing groundnut in between wide rows of transgenic cotton, farmers can get the additional benefit of ₹ 13980/ha than pure cotton (Singh *et al.* 2013<sup>b</sup>). Similarly, by growing groundnut, soybean, fodder maize, french bean and green gram or moongbean in between wide rows of *Bt* cotton hybrids, net return enhanced in the range of 105-412 US \$ without sacrificing the yield of the main crop of cotton. By utilizing the concept of multi-tier cropping (*Bt* cotton+ radish+ cluster bean+ beet root), an additional net return of 1209 US \$ and more return per unit of money (1.1) invested over sole cotton crop. Fertilizer-N management is a costly and energy requiring agricultural operation in cotton cultivation, so efficient utilization of this resource through optimum synergistic combination with organic manures like farmyard manure (FYM) is essential for sustained productivity and environmental quotient of

BCBCS (Singh *et al.* 2013<sup>b</sup>).

#### *Impact of increasing Bt cotton area in other crop areas*

Generally, if planting area of one crop increases, definitely it sacrifices the areas of other less remunerative crops. So is the case of transgenic cotton in India. More profit generation potential of transgenic cotton forced farmers to grow cotton instead of less valuable crops like groundnut in major groundnut producing states of India (Gujarat, Andhra Pradesh and Tamil Nadu). Groundnut is an important oilseed crop in India to supply cooking oil to households. This situation forced the government to import cooking oil, which adversely affected the Indian economy (GOI 2015, Singh *et al.* 2015). *Bt*- cotton production technology favours sowing of intercrops in between wide rows of cotton hybrids (Singh and Ahlawat 2011, Singh *et al.* 2013<sup>b</sup>). By adopting this technology not only problem of import of cooking oil can be solved, but also problem of soil fertility depletion can be solved. Cotton hybrids are soil exhaustive in nature due to their high yield potential, albeit cotton grows on degraded soils in rain-fed ecosystem (Dunfield and Germida, 2004). Further, association of cotton and groundnut also suppresses groundnut root-knot nematodes also (Rodríguez-Ka *et al.* 1987).

Table 2 Profitability of best management practice used in *Bt* cotton of India

Best management practice	Location	Increase over conventional/ farmers practice		Source
		Net return (US \$/ ha)	B:C ratio	
<i>Intercropping practice</i>				
<i>Bt</i> cotton+ groundnut (1:3)	New Delhi	232.9	0.37	Singh <i>et al.</i> (2009)
<i>Bt</i> cotton+ groundnut (1:3)	New Delhi	104.8	0.20	Sepat <i>et al.</i> (2012)
<i>Bt</i> cotton+ soybean (1:3)	New Delhi	104.7	0.11	Sepat <i>et al.</i> (2012)
<i>Bt</i> cotton+ soybean (1:2)	Dharwad	104.7	0.11	Ganajaxi <i>et al.</i> (2011)
<i>Bt</i> cotton+ fodder maize (1:1)	Ludhiana	412.4	0.52	Singh <i>et al.</i> (2014)
<i>Bt</i> cotton+ radish+ cluster bean+ beet root (multi-tier cropping)	Coimbatore	1208.9	1.1	Sankaranarayanan <i>et al.</i> (2012)
<i>Bt</i> cotton+ french bean (1:3)	Dharwad	137.0	-0.01	Ganajaxi <i>et al.</i> (2011)
<i>Bt</i> cotton (R) + greengram (1:1)	Nagpur	303.0	0.81	Singh <i>et al.</i> (2013 <sup>a</sup> )
<i>Nutrient management practice</i>				
Substitution of 25 % RDN of <i>Bt</i> cotton through FYM	New Delhi	194.8	0.63	Singh <i>et al.</i> (2009)
Application of 100 % RDN + micronutrient as Fe+ B each @ 10 kg/ha to <i>Bt</i> cotton	Nagpur	121.0	0.31	Singh <i>et al.</i> (2013a)
<i>Resource conservation technique</i>				
Permanent broad-bed with residue retention in <i>Bt</i> cotton-wheat system	New Delhi	582.4	0.34	Das <i>et al.</i> (2014)
Conventional tillage-bed for <i>Bt</i> cotton and following wheat crop on zero tillage-bed in combination with cotton residue	New Delhi	206.2	0.19	Kumar (2012)
Relay planting of wheat in standing <i>Bt</i> cotton crop using the self-propelled relay seeder	Bhatinda	351.8	0.36	Buttar <i>et al.</i> (2012)

1 USD ~ 65 INR; R, rainfed; RDN, recommended dose of nitrogen

### Cotton stalk as a potential energy and nutrient source

Residue management is an important issue in India due to lack of scientific recommendations turned into practices in farmers' fields. Due to high yield potential of transgenic cotton hybrids, residue yield is also increased. Cotton stalk is used in several ways in India like use as bio-fuel for household consumption. In India, cotton crop generates a maximum bio-residue of 53 Mt, which is 11% of total bio-residues produced in the country. According to Devasenapathy *et al.* (2009), this bio-residue has equivalent energy content of  $2.124 \times 10^8$  GJ (1 kg cotton stalk has an energy equivalent of 18 MJ). This bio-mass energy (renewable or clean energy) can be used for electricity generation, bio-fuel, industrial purposes like pulp preparation, coal making, bio-char preparation for soil fertility management, or can be used directly as well as in briquetted form for a variety of energy end uses (Heijndermans 1995, Coates 1996, White *et al.* 1996, Kumar *et al.* 2002, Stavi and Lal 2013). All of these practices have the potential of reduction of carbon emission into the atmosphere. The surplus residues, when left unattended, often disrupt land preparation, crop establishment, and early crop growth, and are typically burnt on farm causing environment and public health problems and substantial nutrient losses.

### Critical new problem of insect resistance

In 2009, pink bollworm (*Pectinophora gossypiella*), resistance was confirmed in single-protein (*Bacillus thuringiensis*) Bollgard® I cotton in India. Today, Bollgard II – a second-generation cotton seed that contains two different *Bt* proteins has replaced Bollgard I in all of the cotton seed markets. It provides additional and more robust protection against the bollworm. Among the factors that may have contributed to pink bollworm resistance are limited refuge planting and the early use of unapproved *Bt* cotton seed, planted prior to GEAC approval of Bollgard I cotton, which may have had lower protein expression levels (Monsanto 2016). ICAR-Central Institute of Cotton Research, Nagpur, India (CICR 2015) recommended refuge in a bag at 95:5 (*Bt:Nbt*) seeds, which may partly help to decelerate the rate of development of bollworm resistance to *Bt*-cotton. The non-*Bt* cotton seeds should be of the corresponding near-isogenic hybrid. Insecticides such as quinalphos or thiodicarb may be used in early stages and synthetic pyrethroids after October at economic threshold levels of damage. The simplest and most potent way to overcome the problem is to take up timely sowing and cultivate early maturing short duration varieties of about 150 days duration. All other management strategies such as avoidance of excess urea + organo-phosphorus insecticides, use of light traps, pheromone traps, bio-pesticides, biological control etc., can minimize the damage to zero levels.

In a developing country such as India, where cost of planting hybrid seeds has been already very high; higher initial investments in the new technology can make farmers more risk prone. One possibility is that, if the technology

is reasonably priced, besides returning the cost of the technology to the promoter along with a profit, the volume of sales may even reduce the prices of conventional hybrids, which have long been disproportionately and arbitrarily priced. Another option, is to have transgenic cotton varieties (in place of hybrids), which will be cheaper and robust enough to suit harsh moisture stress conditions. This option will have to be exercised and expedited mainly by the public sector. Studies of sucking pests and herbicide tolerant traits, nitrogen efficient lines for enhancing nitrogen use efficiency, integrated nutrient management for enhancing soil health, new profitable cotton based cropping systems, cotton picking machines, ultra-narrow row planting of cotton, use of cotton residues as manure, run-off and soil erosion studies etc. are urgently needed for increasing the sustainability of transgenic cotton in developing countries. Furthermore, extensive multidisciplinary field studies are needed to draw a valid conclusion about socio-economic sustainability of transgenic cotton especially in developing countries.

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