December 2018
Volume XXXVI, No. 4
ISSN 1022-6303

The ICAC Recorder

International Cotton Advisory Committee

Special issue (Volume 2):

Cotton High Yields - This Time for Africa

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Editorial

'This time for Africa' is a powerful slogan. Africa has all of the natural resources that should have made it big for cotton. The continent is waiting for its time to come.

Three volumes of the special issues of the ICAC RECORDER have been dedicated to discussions on 'cotton high yields' in Africa. In the first two volumes, researchers agree that the challenges in Africa are tough, but all researchers have been unanimous that small steps can bring in a big change. Lessons from across the globe point out that cotton in Africa can win if the crop season, plant architecture and planting geometry are condensed to make the crop more efficient in using water, light and nutrients. I attempted to drive home these points in my article 'A change in plant architecture can break yield barriers in Africa' in the previous issue of the ICAC RECORDER, which has insightful articles by cotton researchers from Asia and Africa who described a wide spectrum of ideas to enhance yields and improve the cotton economy.

This sequel in the special series on 'cotton-high yields — this time for Africa' has four articles that continue to explore options for high yields and policies that can effect positive changes in the African cotton sector. Dr. Sabesh and Dr. Prakash are on a roll, at their insightful best. They examine the cotton-sectoral changes in Africa spanning 60 years since 1965. They look at Africa through a holistic prism while reviewing the technical and socio-economic dimensions to conclude that farmers deserve better prices and technologies for high yields while drawing attention towards the need for new investment enabling policies. Dr. Dong describes new 'light and simplified cultivation (LSC)' Chinese techniques that are applicable for the small-scale cotton farms in Africa. The LSC methods enable high yields of 1500 to 2000 kg per hectare at low production costs in China. Even at half their efficiency, the LSC techniques have the potential to double cotton yields in Africa. Dr. Blaise shares his expertise on conservation agriculture. He describes the technologies in a lucid manner to connect them with the farming systems in Africa. My article on 'the relevance of biotech cotton in Africa' deals with a brief description of the spectrum of biotech products and the current status and prospects for Africa.

Those who have been working for the betterment of cotton sector in Africa are familiar with the small-scale resource poor farmers, many of whom do not have access to fertilizers, pesticides, improved seeds and even the simplest of technologies due to poor purchasing power or weak logistics. Several researchers argue that without access to any of the technological inputs, yields in Africa cannot increase. In this context, it would be interesting to draw a parallel between Africa and India. India also has small scale resource poor farmers, but they have access to all the modern agri-technologies and inputs. However, yields in rainfed regions of India are as low as in Africa. For example, the Indian state of Maharashtra has an area of 4.2 million hectares which is equivalent to the cotton acreage in the whole of Africa, but the average lint yields at 350 kg/ha with a production of 1.5 million tonnes are strikingly similar. Cotton in Maharashtra is rainfed, very much like Africa. Further, Maharashtra has access not only to all agricultural inputs but has been growing the dual-gene Bt-cotton hybrids (not open pollinated varieties) in almost 95-98% of the area in the state. Therefore, it would be pertinent to ponder if the introduction of Bt-cotton, especially in the form of hybrids or emphasis on increased application of fertilisers and pesticide, would be great solutions to increase yields in Africa.

Researchers who have been batting for hybrids for high yields in Africa, must know that though hybrid cotton looks lucrative with big bolls and a promise of better quality and high yields over a longer duration, there are issues that need to be considered before taking the plunge. Cotton hybrid seeds are expensive; farmers cannot plant farm saved seeds; a hybrid cotton crop needs higher levels of water and chemical inputs; the plants have low harvest index due to higher biomass; due to the longer duration, the crop experiences severe moisture and nutrient stress in the post-monsoon phase during the critical boll formation window which causes yields and quality to plummet. Further the cotton season extends to such an extent that a second crop is rarely possible. It is interesting that except India and a few African countries which are characterized with low yields, major industrialized nations have rejected the hybrid technology, but have been getting 3 to 4-fold higher yields using open pollinated varieties, compared to India which has >95% of its cotton area under hybrid Bt-cotton and 38% under irrigation.

The discussions on Africa will continue in the future issues of the ICAC RECORDER. The ICAC will continue its technical efforts to explore tangible solutions to the intractable challenges in Africa and looks forward to collaborating with interested agencies for breaking the yield barriers and for the betterment of cotton farming systems and the entire cotton sector in Africa.

The ICAC RECORDER (ISSN 1022-6303) is published four times a year by the Secretariat of the International Cotton Advisory Committee, 1629 K Street, NW, Suite 702, Washington, DC 20006-1636, USA. Editor: Keshav Kranthi <keshav@icac.org>. Subscription rate: $220.00 hard copy.

The ICAC Recorder

Higher Cotton Productivity in Africa – A Socio Economic Analysis

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Agricultural systems are shaped primarily by technical and human interactions with natural and man-made resources. The technical factors are physical (soil, water, agrochemicals, etc.) and biological (seed varieties, insects, pathogens, etc.). These factors reflect availability in the natural environment and adoptions developed through technological interventions represented by irrigation, fertiliser and plant protection (Valerie *et al.,* 2011). Human interaction could be related to the socio-economic indicators including household size, income, land holding, poverty, health etc. Agriculture systems could be successful provided that both technical as well as human interactions and interventions are balanced appropriately for farm activities.

African agriculture is dominated by a variety of food crops and a few traditional cash crops including cotton. Cotton is a major source of foreign exchange earnings in more than 15 African countries and a source of cash income for poverty alleviation in these countries. African cotton farmers predominantly face three main constraints: very low cotton yield; very less price and forced reduction of cotton area due to production of food crops to support increasing populations. These factors make cotton cultivation less profitable in Africa. Main constraints in Africa are influenced by political, socio-economic and ecological conditions. The cotton production systems are subjected to vulnerability often due to policy decisions and changes enforced by the parastatal and internal authorities.

There was a significant shift in the cotton cultivation scenario in Africa during the past six decades. The cotton area shifted from eastern and southern African regions towards the western and central African region. Despite the fact that there is no dearth of cotton production technologies developed locally or adoptable from other countries in Africa, cotton yields have been low and stagnant for more than three decades. There is a need for an extensive socio-economic research and technical analysis to understand the reasons for the yield gaps to find solutions. Biotech cotton was introduced into Africa in Burkina-Faso, South Africa and Sudan. However, there has been no evidence of any significant yield enhancement in any of these countries, despite 6-18 years of adoption. This study attempts to analyse the key factors that influence yields and profitability in Africa.

Cotton Scenario in Africa

Cotton in Africa is predominantly a smallholder crop, mainly grown on small family farms of less than 3 to 4 hectares in size (Gouse *et al.,* 2003). Next to cocoa, cotton is a main source of cash income for millions of farmers and their families (Badiane *et al.,* 2002; Mosely and Gray, 2008) in more than 15 countries in Africa. Cotton in Africa is mostly rainfed, with exceptions of -South Africa where cotton is completely irrigated and countries such as Ethiopia, Nigeria, Kenya and Sudan, which provide irrigation in some farms. The rainfed conditions are coupled with vagaries of biotic and abiotic stresses and fluctuations in input costs and global cotton market prices. All these factors enhance risks and threaten the sustainability of cotton production in Africa.

During the period 1960 to 1980, Uganda, Egypt, Sudan, Mozambique, Tanzania and Chad were the major cotton growing countries. Though the area under cotton had been huge in these countries, the decadal growth rate was negative all through the period, in contrast to the positive growth rate in countries such as Burkina Faso, Mali, Benin, Ivory coast, and Zambia. During the 1990s cotton cultivation shifted towards Burkina Faso, Mali, Zimbabwe, Benin, Ivory Coast and to some extent in Chad (Figure 1). Thereafter, there was a significant shift in cotton cultivation domains from northern and eastern regions of Africa to the western region. Incidentally, many African countries implemented various reforms in cotton in the 1990s proposed by the Government and private investors. Intriguingly, all reforms failed to show any significant impact in the African countries. A critical analysis made by the authors indicates that reforms in agriculture should take stakeholders into confidence and more importantly should consider socio-economic and agro-ecological conditions of the implementation domains.

Until the late 1980s, countries such as Egypt, Sudan, Tanzania, Uganda and Zimbabwe were the major cotton producers. However during the past 17-18 years after 2000, Burkina Faso, Benin, Mali, Cote d'Ivoire, Cameroon and Zimbabwe emerged as top cotton producers due to adoption of new technologies and implementation of reforms in the agricultural sector. Remarkably, the annual average production in Burkina Faso was just about 42,000 Mt of cotton during the period 1965 to 2000, but between 2001 and 2017 the annual average production was 215,000 Mt, which made it the leading producer in Africa since 2013 (table 1). Likewise, Mali, Benin and Cote d'Ivoire also made notable progress in cotton production since the year 2000.

Cotton in Egypt is irrigated and productivity (yield) has been generally high. The productivity in Egypt was about 800 kg/ha for decades. Egypt cultivates only *G. barbadense* varieties under fully irrigated condition. In South Africa, the average cotton productivity was 360 kg/ha between 1965 and 1998 and the annual cotton acreage was about 110,000 hectares. *Bt*-cotton was introduced in the country in 1998 when the area was 137,000 hectares. Cotton area declined rapidly ever since to 23,000 hectares in 2004 when yields increased to 1,181 Kg/ha. By 2015, the area declined to 8,000 hectares, as yields increased to 1,208 kg/ha. Cotton area is increasing slightly in South Africa in recent years and was reported to reach 36,000 hectares in 2017. It is estimated that the area in Egypt, Sudan and South Africa declined by 60 to 75% in 17 years after 2000.

During the two decades between 1960s and 1980s, Egypt, Sudan, Uganda, and Tanzania were the leading exporters of cotton in Africa. However, subsequent to 1990, the western African countries gradually emerged as leading producers and major exporters. During the period 1965 to 2000, the annual exports by the west African countries (Burkina, Mali, Benin, Cote d'Ivoire and Cameroon) ranged from 34,000 to 71,000 tonnes. However the annual exports by the five countries increased to a range of 85,000 to 205,000 tonnes during 2000 to 2017, with Burkina and Mali in the lead. The annual average production in the five countries was 39,000 to 76,000 tonnes during 1965 to 2000, but increased significantly to 89,000 to 215,000 tonnes during 2000 to 2017, with highest production of 181,000 and 215,000 tonnes in Mali and Burkina Faso respectively.

During 1960s and 1970s cotton exports from the C4 countries (Mali, Burkina Faso, Chad and Benin) were 8% to 12%, which increased to 45% during the past three decades. Traditionally Egypt has been the highest cotton consuming country in the African continent, with an annual average consumption of 264,000 tonnes during 1970 to 2000 and 161,000 tonnes during 2000 to 2017. Countries such as South Africa, Nigeria, Ethiopia, and Tanzania have been utilising 30 to 40 tonnes of cotton annually over the 17 year period since 2000. South Africa imports cotton either from within Africa or from outside Africa for their domestic requirement. In recent years Egypt has also been importing cotton for their domestic consumption.

The high GDP rate in South Africa and Egypt combined with concomitant investment for cotton processing industries ensured the development of the textile sector to sustain the cotton economy in these countries. Except in Nigeria, cotton consumption in the west African countries has been low. Development of textile enabling policies and reforms for the development of textile industries will not only boost economy in the region but can also generate enormous employment opportunities.

The trends in C4 countries indicate significant changes in African cotton production. During 1960s and 1970s the average cotton area harvested in C4 countries was below 11% to 13% of the total cotton area harvested in Africa (Table 2). Prior to 1981, the production share of C4 countries

Table 1: Average Cotton Production, Export and Domestic Consumption in African Countries

	Production		Export		Domestic Consumption	
	1965-2000	2000-2017	1965-2000	2000-2017	1965-2000	2000-2017
Production appreciation countries (000 Metric Tons)						
Burkina	42	215	39	205	1	4
Mali	76	181	71	176	3	3
Benin	44	118	41	113	2	4
Cote d'Ivoire	69	120	54	114	14	6
Cameroon	39	89	34	85	5	3
Zimbabwe	67	87	47	77	19	14
Tanzania	59	80	47	48	12	29
Nigeria	43	64	7	30	51	42
Zambia	11	52	4	45	7	6
Togo	23	39	21	39	1	0
Ethiopia	19	33	2	4	20	31
Production sustainable countries (000 Metric Tons)						
Chad	50	50	48	47	2	1
Mozambique	23	27	19	27	4	0
Senegal	11	13	9	12	3	1
Production depreciation countries (000 Metric Tons)						
Egypt	401	169	156	75	252	162
Sudan	150	46	138	39	14	7
Uganda	27	24	23	21	4	2
South Africa	38	15	2	6	63	40

Compiled by the authors. Data Source: ICAC, 2018

Table 2: Percent Trends in Cotton Area, Production and Export in C4 Countries to Whole African countries

	1965-70	1971-80	1981-90	1991-2000	2001-10	2010-17
Area harvested						
C4	11.08	12.67	14.46	28.99	33.62	39.32
Benin	0.48	1	2.05	7.13	6.51	7.23
Burkina Faso	1.62	1.92	3.37	5.84	11.63	14.17
Mali	1.56	2.38	4.16	9.16	9.74	12.34
Chad	7.42	7.38	4.89	6.86	5.74	5.59
Production						
C4	6.25	9.75	14.89	30.2	36.51	41.84
Benin	0.5	1.01	2.23	7.98	8.26	7.9
Burkina Faso	0.69	1.42	3.59	6.1	13.6	16.98
Mali	1.14	3.14	5.5	11.35	11.18	13.86
Chad	3.93	4.18	3.57	4.78	3.48	3.1
Export						
C4	8.39	14.47	23.17	44.33	44.66	45.9
Benin	0.65	1.36	3.18	11.61	10.22	8.64
Burkina Faso	0.9	2.12	5.77	8.7	16.12	18.83
Mali	1.38	4.41	8.53	16.81	14.04	15.04
Chad	5.46	6.58	5.68	7.21	4.28	3.39

Compiled by authors; Data Source: ICAC, 2018.

Note: African Countries include Benin, Burkina Faso, Mali, Chad, Cameroon, Cote d'Ivoire, Egypt, Ethiopia, Kenya, Malawi, Mozambique, Nigeria, Senegal, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

in Africa was less than 10.0% and the export share was less than 15%. However during 2010 to 2017 there was rapid all round growth in area, production and exports under cotton to reach an annual average of 39.3% of the area, 41.8% of production and 45.9% of the export share in Africa. The C4 countries grow cotton mainly under rainfed conditions in rotation with coarse grains predominantly in small holdings. Increase in the cotton acreage over the past two decades coupled with policy changes has resulted in increased production and exports thereby generating additional foreign exchange and fiscal revenues. At the farm level in Africa, earnings from cotton have been supporting financial investment in agricultural inputs, such as high-yielding seeds and fertilisers thereby generating increased cereal production, higher incomes, and farm asset accumulation among cotton-farming households (Tefft, 2010)

Nutrient and Irrigation management

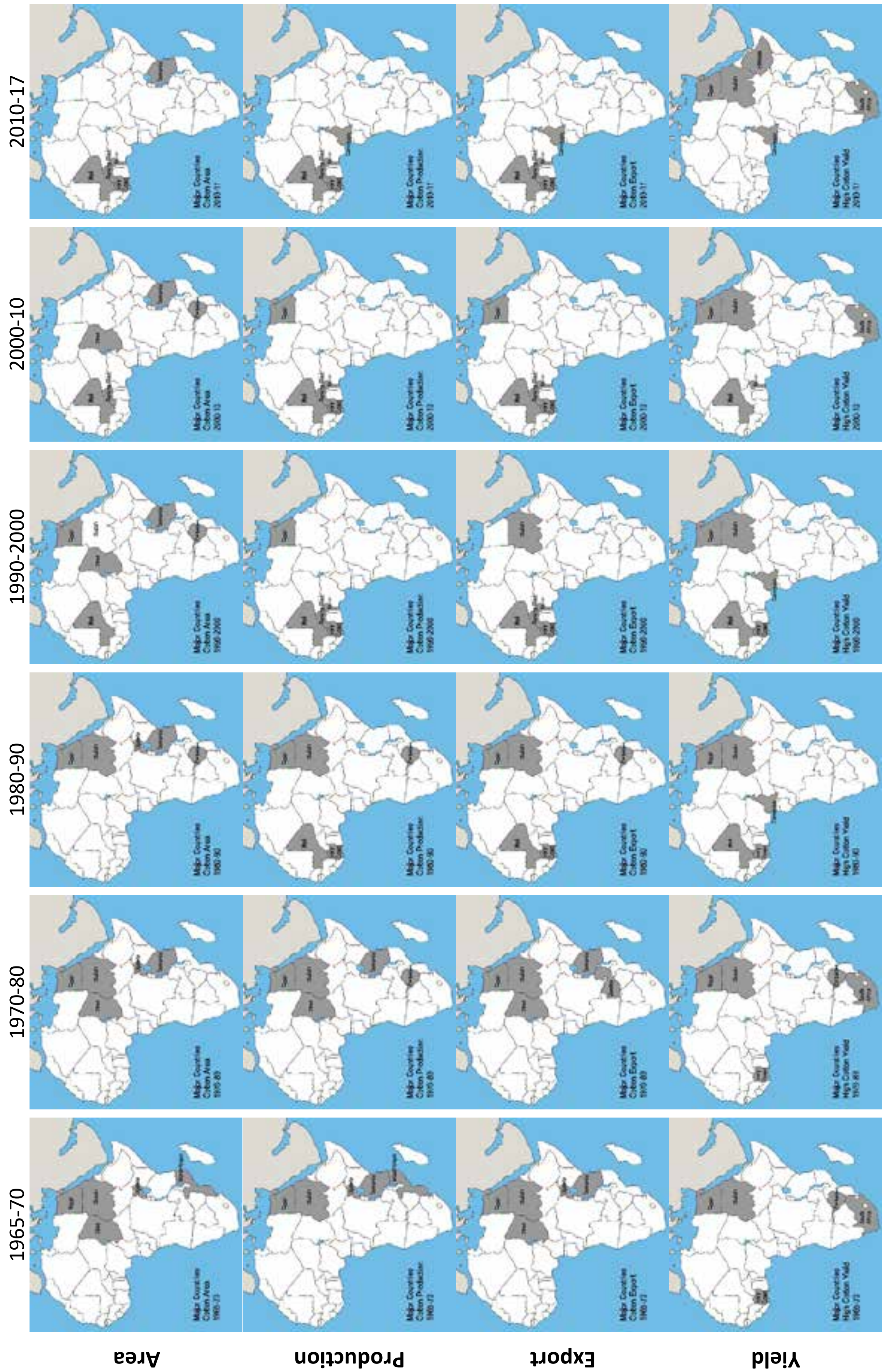
The current average fertiliser input in sub-Saharan Africa is just about 9.0 kg per hectare, compared to 100 kg to 135 kg in Asia, 73 kg in Latin America and 206 kg in the industrialised countries during 2016. Burkina Faso, which is the major cotton growing country of Africa, consumed on an average less than one kg/ha of fertiliser in 2001. It was only recently that fertiliser usage increased to reach 14.3 kg/ha in 2013 (Table 4C). In many African countries such as Benin, Uganda, Cameroon and Mozambique, the fertiliser input was below 10 kg/ha in 2013. Despite the low input of fertilisers and majority of the area under rainfed condition, the Crop Production Index (CPI) increased between 2001 and 2015 to the tune of 67%, 68%, 94%, and 106% in Benin, Burkina Faso, Mozambique and Cameroon, respectively (Table 4C).

Production and productivity barriers

The average yields in African countries vary significantly due to agro-ecological, technological advancement and socioeconomic factors. During 2001-02, in Benin, the northern region cotton yields out-performed the southern region by about 62% primarily due to the introduction of improved varieties and optimum input supply in the north. In Cameroon, agro-ecological factors linked to climatic and soil conditions contributed to the higher yield performance in northern region by about 125% than the southern region (Poulton et al. 2009). In Mali the difference in yield is about 15% higher in farms equipped with animal traction than manual cultivation, which lacked infrastructure. The general infrastructural development In Eastern and Southern African countries has been significantly less compared to the Western and Central African countries, especially in the late 1990s and early 2000s (Poulton *et al.,* 2009).

Studies were conducted in 2005-06 to assess the performance of different categories of farmers in seven African countries (Poulton et al. 2009). In the west African countries such as Burkina Faso, Mali and Cameroon, large farmers realised 25% and 65% more yield and gross revenue compared to medium and small farmers (Table 3). In southern and eastern African such as Mozambique, Tanzania, Uganda, Zambia and Zimbabwe, large farmers realised 65% and 184% more yield than medium and small farmers, respectively. The gross revenue earned by large farmers was 73% and 210% more than medium and small farmers, respectively in the southern and east African countries. The minimum difference in yields and gross revenue between large, medium and small farmers in west

Figure 1: Decadal Trend in Cotton Area, Production Export and Yield in African Countries



Prapared by authors from the data source ICAC, 2018

Table 3: Economics of cotton cultivation in Africa

Budget element	Burkina Faso	Cameroon	Mali	Mozambique	Tanzania	Uganda	Zambia	Zimbabwe
Large farmers								
Yield (kg/ha)	1,350	1,259	1,429	1,519	1,125	2,188	1,200	1,750
Seed cotton price (US$/kg)	0.33	0.32	0.32	0.21	0.28	0.25	0.25	0.31
Gross revenue (US$/kg)	441.45	399.1	452.99	322.03	314.06	547	300	542.5
Cost of input (US$/ha)	172.89	141.44	168.61	36.5	35.83	111.11	31.07	236.85
Cost of hired labour (US$/ha)	0	0	0	136.7	122.9	116.3	150.7	65.1
Net margin (US$/ha)	140.34	–1.86	156.24	91.93	71.16	137.55	56.16	173.82
Input cost/gross revenue	0.39	0.35	0.37	0.11	0.11	0.2	0.1	0.44
Medium Farmers								
Yield (kg/ha)	1,100	1,120	1,011	935	750	1,125	1,050	800
Seed cotton price (US$/kg)	0.33	0.32	0.32	0.21	0.26	0.25	0.25	0.29
Gross revenue (US$/kg)	359.7	355.04	320.49	198.22	196.88	281.25	262.5	232
Cost of input (US$/ha)	164.89	132.76	159.58	36	18	8.33	31.07	90.08
Cost of hired labour (US$/ha)	0	0	0	116.8	42.7	62.5	109.5	35.9
Net margin (US$/ha)	70.95	–4.32	51.29	–59.44	15.335	44.67	45.41	19.33
Input cost/gross revenue	0.46	0.37	0.5	0.18	0.09	0.03	0.12	0.39
Small Farmers								
Yield (kg/ha)	750	1,090	711	438	600	600	563	565
Seed cotton price (US$/kg)	0.33	0.32	0.32	0.24	0.24	0.25	0.25	0.21
Gross revenue (US$/kg)	245.25	345.53	225.39	103.91	144	150	140.75	119.78
Cost of input (US$/ha)	156.89	141.44	146.04	5.5	48.55	20.41	8.33	13.5
Cost of hired labour (US$/ha)	0	0	0	0	0	28.6	5.2	6.7
Net margin (US$/ha)	–62.06	–18.21	–0.19	2.37	–10.80	–58.91	–72.34	–41.78
Input cost/gross revenue	0.64	0.41	0.65	0.05	0.34	0.14	0.06	0.11

Source: Poulton *et al*. (2009)

Africa may be attributed to overall growth and uniformity in cultivation practices amongst all group of farmers.

There was not much variation in the cost of inputs in west African countries and on an average 46% of the gross revenue was spent on cost of inputs in all groups. On the contrary, the east and southern African countries spent just 16% of the gross revenue earned, except in Zimbabwe wherein the large farmers and medium farmers spent 44% and 39% of the gross revenue earnings respectively on inputs (Table 3). The average spending on inputs in west African countries was 153 US $/ha whereas it was 48 US $/ha in east and southern African countries. The cost of hired labour for cotton cultivation makes a lot of difference among African countries. In west African countries among all groups, the cost of hired labour is almost nil, which could be attributed to large adoption of farm equipped with animal traction for land preparation and inter-cultural operations (Kabwe & Tchirley, 2007). Poor adoption of farm equipment in east and southern countries, also reveals that the large and medium farmers spend almost 33% of their gross income on hired labour (Table 3). Small scale farm mechanisation in east and southern Africa can enable the countries to divert the investment on hired labour towards inputs as in the west African countries.

According to the ICAC, the average yield in west African countries between 2000 and 2017 was 379 kg/ha, while it was only 218 kg/ha in east and southern African countries. The yield differences in west African and east and southern African countries have been attributed to the better willingness and ability of the west African monopoly systems to invest in varietal development, input supply and credit, quality extension services, and logistical support. The major investments made in west African countries before 2000 are most likely to have been responsible for the yield differences amongst regions (Kabwe & Tchirley, 2007, Valerie *et al.,* 2011).

Cotton Pests and Diseases

Cotton yields and fibre quality are damaged by a wide range of insect pests and diseases. Since the 1980s, insecticide use on cotton crops in west African countries reduced considerably, largely due to the development of control methods based on pest monitoring. In most of the African countries, chemical control of pests depends on two methods: treatments applied according to a predetermined calendar, or insecticide applications triggered by the degree of infestation or extent of damage (CIRAD, 2012).

Numerous plant protection techniques have been tried in African countries. In Mali, hairy leaf cotton varieties were introduced to reduce jassid infestation. However, the hairy varieties provide cover to whitefly larvae to escape from predators (Ouola, 2008). Cotton bollworms *H. armigera*, *Earias spp.*, and *D. watersi* cause serious economic damage in west Africa. In Mali and other west African countries, de-topping of cotton plant at the peak flowering period was introduced to reduce bollworm infestation. De-topping in China restricts plant growth, induces earliness and enables proper partitioning of photosynthates to increase yields (Dai and Dong, 2014). However, de-topping did not enhance yields, but only contributed to the reduction in bollworm damage in Mali (Renou *et al.,* 2011). In Africa, pest management can become efficient with short-season compact-architecture varieties that are planted in high densities (Kranthi, 2016, 2018).

Integrated Pest Management (IPM) is a multidisciplinary decision support system in coordination with pest observation and degree of infestation for the selection and use of pest control strategies, based on economic threshold levels that consider the interests and impacts on producers and the environment (Josian Edson et, al., 2013, Bajwa and Kogan, 2002). According to a World Bank report (Credit 610-IN, Report No. 7863), under the ICDP project in India, pest scouting system helped in reducing the number of sprays undertaken by the farmers and yield increased from 469 kg per ha in 1976-77 to 651 kg in 1981-82. IPM practices have also been successful in Sudan and Egypt. In Sudan, IPM practices in cotton resulted in more than 50 percent reduction of insecticide use (Pretty, 1995) and 70% reduction in pesticide applications (Russell, 1997).

In Africa, *Bt*-cotton was introduced for commercial cultivation in 1998 in South Africa (Gouse *et al.,* 2004), in 2009 in Burkina Faso and in 2012 in Sudan (James, 2014). Nigeria, Ethiopia and Swaziland approved Bt-cotton for commercial cultivation in 2018. The cotton bollworm *Helicoverpa armigera* is a major pest in west Africa that can cause up to 90% damage if neglected (Vitale and Greenplate, 2014). In the year 2013, the yield of *Bt*-cotton was 14% higher than that of conventional cotton in Burkina Faso but production costs were equivalent to that of conventional cotton (Pertry et al. 2016). *Bt*-cotton hybrids in India are input intensive and well suited for irrigated condition, and not all *Bt*-cotton varieties are equally suitable for all climatic conditions (Sabesh[a] *et al.,* 2014 and Narayanamoorthy, 2006). Mayee and Bhagirath (2013) found in their survey that just 24% of the Maharashtra (India) farmers considered *Bt*-cotton yield as major benefit from adoption of Bt cotton - where 96% of cotton grown under rainfed conditions. However, the *Bt*-cotton growers gained additional net income of 65% more than the conventional cotton growers due to yield gain. The benefits of *Bt*-cotton, in Burkina Faso, are viewed based on the reduction in insecticide applications caused due to the efficacy of the *Bt*-gene in controlling bollworms. The significant reduction of insecticide use from six sprays during the 3-4 months of growth phase in conventional cotton to two sprays applied at the end of the growth phase has proved to be the main incentive for adoption of *Bt*-cotton by many cotton growers (Karembu *et al.,* 2014).

The Burkina Faso government announced a ban on *Bt*-cotton from 2018 citing quality deterioration as the main reason. Cotton producers estimated their losses between 2011 and 2016 at around $82 million (Deutsche Welle, 2016). The report also mentioned that Burkina Faso's decision to abandon genetically modified cotton is unlikely to have much impact in South Africa, Egypt and Sudan. Biotech-cotton trials are underway in Malawi, Kenya, Uganda, Nigeria and Ghana. Agricultural technologies undergo rigorous evaluation for specific agro-ecological conditions, but erroneous adoption and compromise on cultivation practices can diminish their value (Sabesh[b] *et al.,* 2014).

Social Aspects in African Cotton Sector

There are many diseases plaguing human health in African countries. Diseases such as malaria, HIV and more recently Ebola infections threaten the livelihood and economy of millions of Africans. According to the World Health Organisation (WHO), African countries carry 25% of the world's disease burden but their share of global health expenditure is less than 1%. In 2001, African countries agreed to allocate at least 15% of their budgets to health care, but until 2016-17 only six countries (Botswana, Burkina Faso, Malawi, Niger, Rwanda and Zambia) met this commitment. Malaria and HIV levy a heavy economic burden on many African economies. It is estimated that over one million people die from malaria each year, mostly children under five years of age, with 90 per cent of malaria cases occurring in Sub-Saharan Africa (UNICEF). An estimated 300-600 million people suffer from malaria each year. Malaria infections were huge in all the cotton growing countries of Africa. The infection ranged from 158 to 516 out of 1000 people in the year 2000 (Table 4A). But, due to the serious attention paid by the Governments to eradicate of the infection, the numbers were reduced to less than 300 out of 1000 people in the year 2016. Nevertheless, the problem is still serious in Mali where the infection rates are high. In addition, out of more than 30 million HIV patients in the world about 70% are in sub-Saharan Africa. According to a WHO report among HIV infected people in the world, six out of ten men, eight out of ten women, and nine out of ten children are in Africa. The number of HIV infections per 1,000 uninfected population from all sex and age groups, ranged from 0.55 to 11.71 out of 1000 people in the year 2000. Due to the intervention of international agencies, HIV infections were significantly reduced to less than five per 1000 people in the year 2016.

According to the World Health Organisation, one out of 12 children in Africa dies before the age of five, and about 430 women die each day from avertible causes related to pregnancy and childbirth. Pneumonia, the major disease among children remains prevalent in some of the poorest

Table 4A: Socio economic indicators of African countries

	Maternal mortality ratio per 100,000 live births	Under-five mortality rate per 1,000	Under Nourishment (%)	Below Poverty (%)	HIV infections per 1,000	Malaria incidence per 1,000	Access to electricity (%)
Burkina Faso							
2000	341	75.9	15	25.95	0.55	158.11	77.62
2010	246	51.7	12.1	13.5	0.33	118.74	83.52
2016	216	42.5	10.8	8.99	0.3	93.95	85.34
Benin							
2000	572	144.7	23.9	47.48	1.05	388.77	20.58
2010	446	111.6	12.1	40.18	0.48	331.63	34.2
2016	405	99.5	7.5	28.2	0.4	293.68	34.1
Chad							
2000	1,370	190.2	40.1	67.87	2.64	241.5	2.94
2010	1,040	160.1	41	27.5	0.97	193.87	6.4
2016	856	138.7	34.4	18.03	0.63	163.16	8.02
Mali							
2000	834	219.6	13.9	74.78	0.79	476.81	10.37
2010	630	136.6	5	47.08	0.67	364.72	22.34
2016	587	114.7	5	45.13	0.62	448.61	27.29
Zimbabwe							
2000	590	105.8	43.7	53.77	11.71	143.17	33.05
2010	446	89.5	34.7	64.59	7.15	129.61	35.6
2016	443	70.7	33.4	62.74	4.95	114.19	32.3
Uganda							
2000	620	148.4	28.4	57.53	3.51	516.78	8.38
2010	420	75.2	25.1	30.32	4.38	429.05	13.18
2016	343	54.6	25.5	18.73	2.45	218.26	20.4
Cameroon							
2000	750	150.4	32.3	25.5	3.59	461.06	41
2010	676	104.8	13.4	23.41	2.31	321.85	52.91
2016	596	87.9	9.9	15.46	1.98	264.2	56.8
Mozambique							
2000	915	171.1	42	81.83	7.76	515.63	6.95
2010	619	102.8	31.8	66.14	6.4	383.3	17.03
2016	489	78.5	25.3	52.97	3.58	297.72	21.22

Source: SDG Indicators, Global Database, United Nations Statistics Division

Note: Below poverty: Proportion of employed population above 25 years age and below the international poverty line of US$1.90 per day (the working poor) ; HIV infection: Number of HIV infections per 1,000 uninfected population from all sex and age group; Under nourishment: Prevalence of undernourishment all age group both sex (%); Access to electricity: Proportion of population with access to electricity all age group both sex (%); Malaria incidence: Malaria incidence all age group both sex per 1,000 population; Maternal mortality: Maternal mortality ratio both sex per 100,000 live births.

regions in Africa because of unaffordable expensive vaccines necessary to prevent it. According to World Health Organisation, in 2015 pneumonia killed nearly one million children under the age of five, accounting for 15% of global deaths of children of that age group in Africa. The mortality rate of children in African countries below the age of five ranged from 75 to 219 per 1000 in the year 2000. However, due to policy interventions and Government support, mortality reduced from 42 to 138 per 1000 in the year 2016 (Table 4A). The other health concerns in Africa are maternal mortality ratio and undernourishment. Adequate attention enabled significant reduction in maternal mortality and undernourishment during the past one and half decades

Basic amenities such as access to electricity, safe drinking water services and safely managed sanitation services are still lacking in many parts of Africa. Other issues such as, food insecurity, unemployed population above 25 years age and population below the international poverty line of US$1.90 per day are major concerns that need attention. Poverty (below the international poverty line) ranged from 25 to 81% in the year 2000, which declined to 8 to 62 % in the year 2016 (Table 4A). A critical analysis points out that countries such as Zimbabwe, Mozambique and Mali need to pay more attention for poverty eradication. According to Clarence and Quentin (2007), in 2003, poverty among cotton producers in Benin, Burkina Faso, Chad and Mali, was 53.3, 47.2. 72.7 and 77.8% respectively which was high compared to the poverty among general population of these countries at 39.0, 46.4, 55.0, and 47.4% respectively. The data indicate that cotton producers in Africa are, on an average more likely to be poor than the general population as a whole. However in Burkina Faso, the difference in poverty among cotton producers and general population was minimum. The differences in estimates of the share of the population in poverty between cotton producers and the population as a whole are very large in Benin, Chad, and more prominently in Mali.

According to the World Bank data, the average life expectancy at birth was 48 years in African countries from 1990 to 2000, which increased to 60 years in 2016. Over the past decade, investment on health care was more compared to investment on measures that support household income. Population growth in Africa was at 46% from 2000 to 2015, whereas it was 1.9% in Europe, 18% in Asia and 20% globally. Population growth rate was more than 50% in cotton growing countries of sub-Saharan Africa except Zimbabwe (Table 4C). However 5.5% increase in agricultural labour with a concomitant reduction in the country's rural population was recorded in Mali (Table 4C). The growth in population affects cotton production as land is diverted towards cultivation of food crops.

Table 4B: Socio economic indicator of African countries

	Average Household size	Average children	Female Headship (%)	Share of Household below 15 years children (%)
Burkina Faso	5.7	3.4	10	83
Benin	5	3.1	23	78
Chad	5.8	3.7	22	84
Mali	5.7	3.4	9	87
Zimbabwe	4.1	2.4	41	73
Uganda	4.7	3.3	30	79
Cameroon	5.2	3.2	23	71
Mozambique	4.4	2.7	36	77
Ivory Coast	5.4	3	18	73
Ethiopia	4.6	2.7	26	79
Kenya	3.9	2.6	32	66
Swaziland	4.7	3	48	66

Source: United Nation Data (2017)

Table 4C: Socio economic indicator of African countries

	Rural Population (%)	Value Added	Crop Production Index	Fertiliser consumption	Agriculture labour (%)@	Population
Burkina Faso						
2001	81.5	388.9	84.2	*0.4	^84.7	11945
2010	74.3	422.9	120.7	9.4	80.8	15605
2015	70.1	388.7	**141.6	**14.3	^^80.0	18111
Benin						
2001	61.4	827.7	89	*16.4	^46.1	7077
2010	58.1	989.9	116.2	9	45.3	9199
2015	56.1	1150.8	**149.1	**5.5	^^43.2	10576
Chad						
2001	78.3	NA	91.5	NA	^76.7	8663
2010	78	1869.1	100.8	NA	78	11887
2015	77.6	2096.6	**116.0	NA	^^76.6	14009
Mali						
2001	70.9	671	91	NA	^51.2	11293
2010	64	1156.4	137.8	19.6	58.9	15075
2015	60.9	1731.3	**138.6	**27.9	^^56.7	17468
Zimbabwe						
2001	65.8	894.9	141	*35.7	^70.1	12366
2010	66.8	371.1	99.6	34.1	68.4	14086
2015	67.6	422.2	**108.2	**36.8	^^67.5	15777
Uganda						
2001	87.8	499.7	98.9	*1.3	^73.7	24855
2010	85.5	480.2	109.4	1.7	73.7	33915
2015	83.9	473	**107.9	**2.2	^^72.1	40145
Cameroon						
2001	53.9	1012.9	78.3	*9.8	^64.1	15672
2010	48.5	1434.1	144.6	9.2	63.7	19970
2015	45.6	1786.8	**161.2	**6.7	^^61.8	22835
Mozambique						
2001	70.7	205.1	84.5	*6.0	^76.4	18589
2010	69	320.1	157.8	8.2	75.5	24221
2015	67.8	339.5	**163.7	**9.3	^^75.0	28011
Ivory Coast						
2001	55.8		93.8	*31.0	^60.9	17040
2010	49.4	2169.2	106.5	32.1	60.3	20401
2015	45.8	2795.9	**123.6	**36.1	^^56.0	23108

Source: World Bank – World Development Indicators (2017); @: United Nation Data (2017)

Note: Value addition: Agriculture value added per worker (constant 2010 US $); Crop Production Index: Crop Production Index (2004-2006=1000); Fertiliser consumption: Fertiliser consumption kg/ha of arable land; *: pertains to 2002; **: pertains to 2013; ^: pertains to 2005; ^^: pertains to 2017.

Urbanisation has been taking place rapidly in many key zones of Africa. The highest rate of 58% urbanisation was found in Congo -the major exporter of oil in Africa. Urbanisation was about 50% to 52% in the Iron and mineral ore exporter zone of Mauritania and in the gold and diamond exporter, South Africa. In oil exporting countries such as Gabon and Cameroon, urbanisation was 49% and 44% respectively till 1994 (Porter, 1995). Rural Africa had 70% of its population in 2001, which reduced to 63% in 2017. Rural populations in Africa depend completely on agriculture for livelihood. During the period 2001 to 2015, there was 10% decrease in the rural populations in Burkina Faso, Mali and Ivory Coast (Table 4C). It is speculated that the migration could be due to migration to towns in search of livelihood, because the small-holdings were inadequate to support their minimum standard of living.

Most of the African countries have a household size of an average of 5 children with more than 75% of the households having children of less than 15 years of age (table 4B). The percentage of females heading a family was more (32%) in southern and eastern African countries as compared to the west African countries (16%). To state that this could be a reason for slow and/or non adoption of improved technologies in cotton cultivation is only a speculation. By 2025, African countries would be filled with a huge working population in the world. An increase in working population seems good as long as there is adequate planning, with appropriate policy decisions to channel energies or else it could induce more poverty in Africa. It is important that the large working population in Africa is utilised properly, especially in agriculture and more so in the cotton sector, where cotton is one of the main crops that has immense potential to provide employment, livelihood and cash-flow to sustain the economy of most African countries.

The Numbers Game

Table 5 has been reproduced from Vitale et al (2011) who compared cotton production of Burkina Faso with Oklahoma in the united States. The survey concluded that on an average, the US cotton farmers incur significantly higher production costs - both variable and fixed costs than Burkina Faso farmers. The US cotton producers realised higher returns as price of cotton per kg was US$ 0.55, whereas it was US$ 0.35 in Burkina Faso (Table 5). Data were examined for remunerative returns for Burkina Faso farmers by either price or by yield escalation. Three scenarios were explored for price escalation (price escalation by 0.01, 0.02, and 0.03 US$ per kg) and three scenarios for yield escalation (yield escalation by 20%, 40%, 60% over and above the survey yield). Under yield escalation scenario, If the Burkina Faso farmers increased the yield by 10% with associated cost escalation for variable costs they would obtain additional income of US$ 42 per farm; with 40% and 60% yield escalation they would obtain an additional revenue of US $ 84 and UD$ 123 per farm, respectively. With a price escalation scenario, an increase of US$ 0.01 per Kg farmers would fetch an additional UD$39 per farm; and for an escalation of US$ 0.02 US and US$ 0.03 per kg farmers would obtain additional revenues of US$ 77 and US $ 116 per farm respectively.

The study points out that a small increase in cotton prices can more than compensate yield enhancement. It is for the Governments to decide whether to focus on increasing the cotton prices or on measures to increase the yields. The returns for cotton farmers are identical with every cent increased in the cotton price which is equivalent to 20% yield increase (figure 2). In order to increase yields, farmers may be required to increase inputs such as fertilisers, insecticides, herbicides, fungicides and associated labour costs. In this process of moving towards higher productivity, the Burkina Faso farmers may incur additional variable costs apart from contributing to increased pollution, soil degradation and resource wastage. While the importance of yield enhancement cannot be undermined, the study points out that in the current socio-economic situation of cotton cultivation in Africa, a small increase in cotton prices of one or two cents per kg can offset the efforts to produce more. Therefore, sustainable cotton production and poverty alleviation in Africa could be achieved by a small increase in cotton prices for remunerative returns while focus continues to increase yields and reduce input costs.

Discussion

- The present study summarises the status thus far and suggests the way forward for sustainable cotton cultivation in Africa
- There is a significant shift in the intensity of cotton cultivation from eastern and southern African region to western and central African countries in the recent past. This may be attributed to conducive social, economic reforms in west African countries that caused significant changes in the cotton cultivation patterns in Africa.
- There is a need to reassess and bring about adequate structural changes by means of reforms for soil nutrient management programmes in African countries.
- There is a need to encourage and empower the small holders in east and southern African countries to provide optimal input supplies for cotton cultivation.
- There is a need for adoption of farm equipment, depending on the scarcity of the labours in different zones to ensure enhanced remuneration for small holders. Community farm equipment sharing programmes may be created at an affordable cost for small holders.
- There is a need for varietal improvement programmes embracing local varieties which are environmentally suitable for different agro-ecological conditions of different parts of Africa.

Figure 2: Relationship of Price Escalation (US$ per Kg) with Yield Enhancement

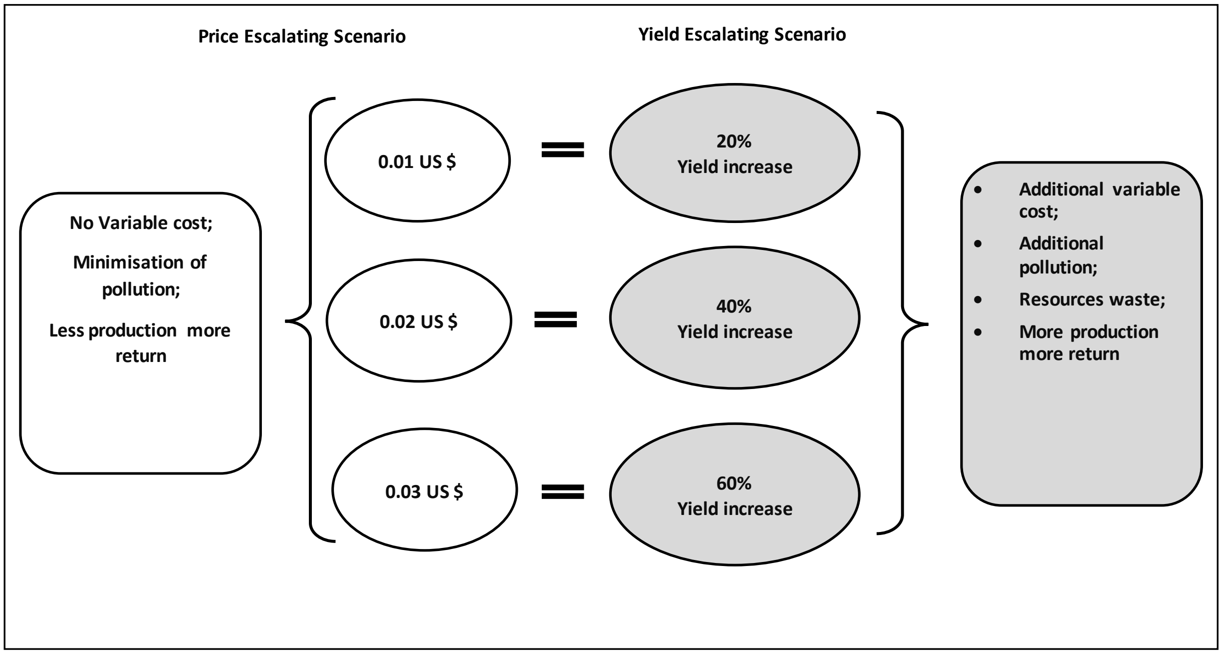


Table 5: Comparison of cotton production costs in Oklahoma (US) and Burkina Faso (West Africa)

	Actual as per survey		**Scenario for Price Escalation** US$/kg in Burkina Faso			**Scenario for yield Escalation in Burkina Faso**		
	Oklahoma	Burkina	0.01	0.02	0.03	20%	40%	60%
Price US$/kg	0.55	0.35	**0.36**	**0.37**	**0.38**	0.35	0.35	0.35
Yield kg/ha	2437	1050	1050	1050	1050	**1260**	**1470**	**1680**
Gross Revenue US$/ha	1340	367	378	388.5	399	441	514.5	588
Variable cost	1131	311	311	311	311	373	435	498
Implements	151	32	32	32	32	32	32	32
Total	1282	343	343	343	343	405	467	530
Net Revenue US$/ha	58.35	24.5	35	45.5	56	36	47.5	58
Farm size (ha)	504	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Total farm revenue US$	29408	**91**	**130**	**168**	**207**	**133.2**	**175.75**	**214.6**
Production Cost US $/kg	0.46	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Source: Vitale *et al.* 2011

- Biotech cotton for insect resistant traits could play an important role in African countries that are plagued by bollworm damage.
- There is a need to inculcate the use of efficient plant protection strategies and input supply management, especially through trainings on need based plant production and protection interventions.
- Investment on education, employment opportunities and healthcare with focus on eradicating malaria and HIV, must receive high priority.
- Population growth rate needs to be curbed, if economy has to be stabilised.
- There is a need for intensive planning so as to formulate policy decisions for proper utilisation of the huge working population that would be available by 2025.
- Increase in cotton prices can effectively enhance remuneration and net returns.
- There is a need to develop strategies that can enhance yields through low input usage

Acknowledgement

The authors thank the Director, CICR and ICAR for approving the article to be presented at 14th SEACF network meeting at Harara, Zimbabwe.

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The ICAC Recorder

Light and Simplified Cultivation (LSC) Techniques and Their Relevance for Africa

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Abstract

During the last two decades of 20th century, the application of intensive cultivation technologies has helped China to enhance yields and emerge as the world's largest cotton producer. But this approach is being debated now because of the increasing labour costs, that are linked to the rapid ECONOMIC development and urbanisation of the country. A new approach called 'light and simplified cultivation' (LSC) has been initiated to respond to the new context. This approach become more relevant to the small-scale farming systems of China as opposed to the complete mechanisation observed in developed countries. The approach of light and simplified cultivation (LSC) aims to reduce labour intensiveness. It simplifies cultivation management, diminishes the frequency of field operations, and adjusts techniques that blend with their implementation by machines. Promising techniques have been already obtained, such as single-seed precision sowing, control of vegetative branches without pruning, one-time fertilisation, fertigation, and maturity grouping for unique harvest. LSC technology is believed to provide a solid support for sustainable production of cotton in China and holds tremendous promise for yield-enhancement in the small-scale farming systems in Africa.

Keywords: cotton; light and simplified cultivation; cost-saving

Introduction

Cotton has been of vital importance to the Chinese economy. It is the main agricultural product associated with the textile industry that has contributed substantially to the economic development since the early 1980s and in which China has ranked first for three decades.

China's achievements in cotton production have resulted from the application of intensive farming technologies, in terms of input use and of labour investment (Dai and Dong, 2015). The intensive farming technologies are highly labour-intensive. Labour is required to implement seedling thinning, plant pruning to eliminate vegetative branches and growth terminals of main-stems, split fertilisation and multiple-pickings (Dai and Dong, 2014).

The continuation of these labour intensive practices for productive and profitable cotton cropping is at stake because of several socio-economic factors. The rising urbanisation has decreased the availability of rural labour workforce, due to which, wages of rural labour have greatly increased. Increased labour costs hinder the application of some labour-intensive techniques. The availability of family labour has also been reduced due to farmers' aging, and the additional burden of the elderly having to look after the offspring of their children who have migrated for city jobs (Wang et Fok, 2017). The increased costs of agricultural inputs such as quality seeds and fertilisers exacerbated the crisis.

Chinese scientists have responded to the new socio-economic challenges by developing new simpler technologies that could reduce drudgery. Their approach to adjust the techniques of intensive cropping, is called Light and Simplified Cultivation (LSC) (Dai *et al.,* 2017).

The LSC techniques have been developed to reduce drudgery and simplify canopy management for high yields, which may suit the small-scale farming conditions of African countries.

Concept and Characteristics of Light and Simplified Cotton Cultivation

The approach of LSC is based on two dimensions of adaptation to reduce or replace manual operations (Dong *et al.,* 2016; Dai *et al.,* 2017). The first dimension is to focus on new techniques to simplify cultivation practices, reduce the frequency of field operations, and adjust the implementation of techniques in view of their mechanisation. The second dimension takes the variation of local farming characteristics into account. It is pertinent to mention that the local farming practices can differ a lot, not only between the Northwestern region and the valleys of Yellow and Yangtze rivers, but also between different locations within the same valley.

The meaning of LSC in cotton cropping needs elaboration. "Light" refers to the small-scale agricultural machinery, materials, and equipment designed to reduce or replace manual operations. "Simplified" deals with the implementation of field operations whose frequency is reduced and which are less inter-linked, so that the overall management of cultivation is made easier. Hence, "Light and simplified" pertains to a systemic connotation through the integration of small-scale agricultural machinery and agronomic practices, and of new techniques with inputs of quality seeds or fertilisers. Although illustrative examples are few, the LSC approach considers the combination of fibre quality with quantity, as well as the concern for ecology and environment (Dong *et al.,* 2016; Dai *et al.,* 2017).

In cotton cropping, several characteristics of LSC are worth emphasising. First, LSC is not relevant only in a specific period or for a specific operation, it applies over the whole cropping cycle. Second, the modalities of its implementation could vary according to periods, regions and notably farming characteristics (Dong *et al.,* 2016). Finally, LSC is inherently dynamic and evolving. Techniques, management methods, machine types, and other necessary measures could be continuously upgraded, improved and made more adapted to local conditions. Thus, LSC implies moving forward with constant upgradation.

LSC in cotton cropping complies with the objectives of productivity and mechanisation under variable farming characteristics. The intensive cultivation techniques are not discarded but are adjusted to make them compatible with the new farming challenges. The objective of 'productivity-enhancement' is constrained by the large population and limited arable land. Though the basic principles and methods that have worked for the last three decades are still valid, the former techniques need contextual adaptation. For example, the use of film-mulching or the operation of plant pruning to remove unproductive vegetative branches still make sense, but the implementation practices differ.

Key Technologies of LSC in Cotton Cropping

Precision mono-seeding technology

Cluster seeding (up to 10 seeds per hill) used to be a popular technique for cotton production in China. The seeding rate of cotton was usually 35 to 45 kg per hectare, and the resulting number of seedlings was always much larger than the targeted plant density. The cluster seed method required one or two times of manual thinning to remove the extra seedlings after emergence (Dai and Dong, 2015). Such a technique is difficult to follow now due to labour scarcity, high labour wages and increased cost of seeds.

A new technique called 'Precision mono-seeding' is based on using high-quality seeds sown as single-seed per hill on finely prepared soil-beds, at row spacing defined for mechanical sowing (Kong *et al.,* 2018). This technique is applied through diverse modalities depending on regions.

The mono-seeding technique has been established and was applied first in the mono-culture cotton area of the Yellow River valley, wherein, sowing is done before spreading the mulching film.

In the north-western region, the precision mono-seeding technique is implemented by a machine which spreads the mulching film, punches holes, and drops down a single seed in each hole at the desired depth. This technique eliminates the need for seedling thinning and freeing seedlings from the underside of the plastic film.

Precision mono-seeding is applied also in areas where cotton is grown following a double cropping system and where cotton is transplanted. In the valleys of Yellow and the Yangtze rivers, cotton used to be relay-cropped with a winter crop such as garlic, wheat or rapeseed. The release of new varieties of shorter cycle, shorter by 30 days than the varieties commonly used, enables the establishment of a desired plant population by sowing a single seed, with machines thereby harvesting good yields before the onset of winter. The reduction of labour requirement with the 'precision mono-seeding' technique is particularly substantial (Lu *et al.,* 2017).

Light and simplified seedling nursery technology

Raising seedlings and transplanting of cotton has been widely adopted since the 1980s, especially in the valleys of Yangtze and Yellow rivers (Dai and Dong, 2014). These techniques were used for many years, despite being labour intensive in preparing seedlings, raising them in nursery and in transplanting them in field. Seedlings were obtained by sowing in small column-shaped blocks of soil, which had to be prepared in a nursery constituted of a tunnel made with a plastic film stretched over arches of bamboo sticks. The preparation of soil blocks is labour intensive and physically harsh particularly to women.

The seedling nursery and transplanting technique has been made light and simplified while following the same principles. Seeds are sown in small plastic pots containing a commercial matrix (mixtures of peat, vermiculite, and river sand) instead of handmade soil blocks. The growth of seedlings is enhanced by the use of root growth promoter, leaf preservation agents and other plant growth regulators. More importantly, seedlings can be produced at industrial scale (Dong *et al.,* 2016) because the number of seedlings per unit area is increased significantly due to the shift from soil-blocks to small pots containing a specific substrate. The industrial production of seedlings is enhanced by the technique of bare-root seedlings growing on a very light sand-based substrate. Consequently, cotton producers do not have to produce seedlings by themselves; they can buy seedlings exactly like the way they do for seeds.

The transplanting technique is enhanced through the LSC approach due to the availability of machines that enable transplanting in a semi-mechanical or fully mechanical mode. In a semi-mechanical mode, the machine digs the holes and workers fill the holes manually with seedlings.

Fig.1 Precision monoseeding and seedling transplanting. (a) precision monoseeding by a machine which spreads the mulching film, punches holes, and let down a single seed in each at the desired depth in monoculture; (b) a cotton field from mono-seeding at seedling stage; (c) traditional seedling raising with soil blocks; (d) and (e) Seeds are sown in sand or on small plastic pots containing a commercial matrix to raise seedlings; (f) mechanic transplanting; (g, h) directly seeded short-season cotton after garlic or wheat.

In the fully mechanical transplanting mode, labour is used to feed the machine with seedlings.

Non-pruning technology

Plant pruning is also a widely adopted intensive cultivation technique in China; it involves the removal of vegetative branches and the apical bud (plant topping) at distinct times. Plant pruning is implemented because it can optimally coordinate vegetative and reproductive growths by adjusting the distribution of nutrients in cotton plant tissues, thereby reducing the nutrient consumption by unproductive parts of the plant (Dai and Dong, 2016). In addition, plant pruning also improves the microclimate of the cotton field so that boll abscission and boll rot are reduced thereby enhancing yield and fibre quality (Dai and Dong, 2014; Dai *et al.,* 2014).

The need to remove vegetative branches is eliminated in the LSC approach simply by preventing the vegetative branches from developing. The development of vegetative branches can be greatly inhibited by increased plant population density as various studies have demonstrated. A non-pruning technology is now launched; it consists of setting up a large population of small individual plants whose growth is properly regulated. In the Yellow river valley, plant density has been increased to 90,000 plants/ha from the common density of 30-40,000 plants/ha. In the North-Western region, plant density has been increased to about 200,000 plants/ha (Feng *et al.,* 2017).

Growth of the apical bud is now restricted using chemical growth regulators instead of the manual de-topping methods that were used earlier. In the North-western region where production is fully irrigated, mepiquat chloride is applied with irrigation to inhibit the growth of the apical bud. In the Yellow River valley, chemical topping is achieved by adjusting the growth regulation program by increasing the number of applications and augmenting the dosage of the last application substantially.

One-time fertilisation technique

Under the earlier techniques of intensive cultivation, cotton used to be grown with relatively large amounts of up to 225-270 kg/ha of nutrients of conventional fast-release chemical fertilisers, in the Yellow and Yangtze River valleys and 300-330 kg/ha in the Northwestern region (Dai and Dong, 2014). The LSC approach has led to a reduction in the number of fertiliser applications and the amounts of fertilisers under various conditions depending on regions and yield targets.

- In the Yangtze River valley, seed cotton yield is expected at 3,600–4,500 kg/ha for N application of 225 kg/ha. Nitrogen, Phosphorous and potassium are applied following the ratio of 1.0-0.6-0.8 for N-P_2O_5-K_2O.
- In the Yellow River valley, application of N at 195 kg/ha results in seed cotton yield at 3,000–3,750 kg/ha. When expected yields are higher than 3,750 kg/ha, the amount of N is increased to 210 kg/ha, and phosphorous and potassium are applied following the ratio of 1.0-0.6- 0.8.
- In the North-western region, the yield of seed cotton could reach 4,500–5,250 kg/ha and the required amount of N is 280 kg/ha. The ratio of N-P_2O_5- K_2O is approximately 1.0-0.5-0.2. The amount of fertilisers can be reduced by approximately 15% when fertigation is implemented (Lin *et al.,* 2013; Dai *et al.,* 2017b).

The adoption of special slow-release fertilisers can help to reduce the frequency of fertiliser application. In Yangtze River valley as well as in Yellow River valley, a single basal application of controlled or slow-release fertiliser is ade-

(a) (b)

Fig. 2 In crop tillage: traditional way (a) and current mechanic way (b)

(a) (b)

Fig. 3 Non-pruning cotton field under high plant density and chemical topping

(a) (b)

Fig. 4 Fertigation in drip irrigation under plastic mulching: (a) tank containing fertiliser for fertigation; (b) drip irrigation belt

quate for the season. In addition, the quantity is reduced by 10% compared to using standard fertilisers (Geng *et al.,* 2016).

Fertigation technology

The efficiency of water-use in irrigation is improved when effective technology of water-saving is applied. The extent of the improvement achieved varies depending on regions.

In the fully irrigated cotton production systems in the north-western region, drip irrigation under the plastic mulching is most commonly deployed. It is implemented through a low-pressure pipeline system for water supply; pressurised water is filtered and injected with the water-soluble fertiliser. The aqueous fertiliser solution uniformly infiltrates by drip in area concentration around the root to maintain the desired moisture level as prescribed for water and fertiliser. On an average, water consumption is reduced by 12% compared to traditional furrow irrigation and by 50% compared to sprinkler irrigation. The amount of fertiliser required is also reduced by 15 to 20% (Luo *et al.,* 2018).

In the Yellow River valley where irrigation is only provided before land preparation, the water use efficiency can be greatly improved by border or furrow irrigation as compared to flood irrigation. The shift from long plots to short plots, from wide plots to narrow ones, and from large to small plots have increased water use efficiency. The reduction of the amount of water used in irrigation operations has led to conservation of irrigation water.

(a) (b)

(c) (d)

Fig. 5 Technology for holistic control of plant population in Yellow River (a, b) and North-west inland (c, d)

Technology for plant population management

In China, synchronous boll bursting can lead to one or two pickings as compared to the current systems of multiple pickings. In the intensive cotton production system, cotton is picked 4-5 times, which is time-consuming, labour-intensive and less acceptable due to scarce availability of labour.

The impact of regulating and optimising cotton plant population in realising higher yields is very significant. It is an effective way to improve the micro-ecological environment of a cotton field and to coordinate the nutrient distribution between roots and shoot and photosynthate partitioning between sink and source. Optimum plant population and canopy management also improve the light use efficiency, to increase the yield and fibre quality, and to achieve a synchronous boll opening for easier harvest.

The techniques to achieve desired plant population structures are different in different cotton growing areas. These techniques are generally adapted to local conditions.

In the North-western region, five factors are managed to reach the desired population structure for mechanical harvest:

- The first factor is the selection of suitable cotton varieties combining the characteristics of early maturity, high yield, fibre quality, stress-resistance, and appropriate plant architecture.
- The second factor is the use of high-quality seeds to be sown in time and properly on finely prepared soil-beds. A sowing depth of about 2.5 cm ensures full and strong stand establishment under precision mono-seeding.
- The third factor is to adjust density with plant height. For mechanical harvesting, the plant height has to be relatively augmented by reducing the plant density commonly set up. In the northern part of Xinjiang, the number of harvested plants is adjusted to 180,000–210,000 plants/ha to obtain 70–80 cm height. In the southern part of Xinjiang area, plant population is reduced to 150,000–195,000 plants/ha to achieve a plant height of 75–85 cm.
- The fourth factor pertains to the management of plant canopy and nutrition in irrigation under plastic mulching. Water, fertiliser, and plant growth regulators are fine-tuned to regulate the canopy and nurture the root system of cotton plants.
- The fifth factor is to maximise the photosynthetic ca-

pacity of the non-leaf green organs. This capacity can be increased through the breeding of cotton varieties with sturdy stems and large bracts. The expression of this capacity is controlled by a reasonably high planting density, proper row spacing, and appropriate provision of water and fertiliser.

In the Yellow River and Yangtze River valleys, the desired plant population structure is achieved by controlling various factors.

- Crop density is increased, and plant height is reduced. In Yangtze River valley where hybrids are also grown, the density is increased from 15,000–18,000 to 22,500–37,500 plants/ha. In Yellow River valley, plant density is increased by 20,000–30,000 to reach about 90,000 plants/ha but with reduced plant height to 90-100 cm so as to ensure timely and appropriate canopy closure.
- Traditional wide and narrow row spacing is replaced by equal row spacing suitable for mechanical harvesting. The row scheme of single rows every 76 cm is being retained. It differs substantially from the scheme alternating double narrow lines (50-60 cm) separated by large inter-row of 90-120 cm. Plant growth regulation is adjusted in a timely manner to ensure desired row closure.
- The plant population structure is managed along the promoted development of the root system. Such a development is achieved by deep ploughing (up to 30 cm) or deep loosening of the soil for every 2-3 years, with incorporation of crushed straws into the soil. The root system is also developed by the early underground application of controlled-release fertiliser, at 10 cm below the surface of the soil. It is also favoured by the timely removal or breakage of the plastic film, at full squaring stage, associated with tillage.
- Full maturity of bolls is obtained through delayed senescence. It is achieved by using suitable cotton varieties with desired plant shape and size. The period of cotton boll opening can be compressed from more than 70 days to 40 days, hence enabling grouped harvesting and more suitable for mechanical picking.

In summary, the development and application of LSC are indispensable for the sustainable cotton production in China to comply with the scarcity and higher cost of labour. For the techniques already operational, the shift from the intensive cultivation system to LSC are significant.

In spite of the achievements presented above, there is a need for the development of new machines and equipment that are suited for the new LSC techniques in small-scale farming systems. The need for new machinery extends from sowing adaptation in the double cropping systems, fixed row spacing in ridges and furrows to mechanised harvesting.

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The following table summarises the changes in the shift from the intensive system to LSC.

Operations	Intensive System	LSC System
Seeding and thinning	Conventional seeding, 30-45 kg seed per hectare, and 2-3 times of manual thinning	Precision seeding, 15-20 kg seed per hectare, no-thinning.
In-crop tillage	5-6 times during the whole growth season.	2 times at the full post emergence and full squaring or flowering stage.
Fertiliser application	3-4 times with conventional fertilisers of rapid release, at planting, squaring or flowering stage and after topping. High labour input and low fertiliser use efficiency	Single time at planting with slow- or controlled-release fertiliser. Labour saving and high fertiliser use efficiency
Plant pruning	Manual removal of vegetative branches, old leaves and redundant buds as well as apical bud of the main stem.	Pruning is avoided due to increased plant density and application of plant growth regulators
Plastic mulching	Film thickness of 0.004-0.006 mm, no recycling of film is possible	Film thickness ≥0.01mm, film removal is easier and recycling is possible
Planting pattern	Relay intercropping through transplanting before harvest of winter crop	Direct seeding of short-season cotton after the harvest of winter crop
Cotton picking	Multiple manual pickings adapted to scattered distribution of bolls	One or two pickings of synchronous maturing bolls
Mechanisation	40% covering land preparation, straw incorporation, sowing, fertiliser application and in-crop tillage	≥90%, covering land preparation, straw incorporation, sowing, fertiliser application, in-crop tillage and harvesting

Conservation Agriculture for Sustainable Cotton Production in Africa

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Cotton is a commercial crop sustaining the livelihoods of millions of farmers on the African continent (FAOSTAT, 2017). However, there is a concern among cotton growers due to stagnating yields over the past few years. What ails the cotton grower in this part of the world? Low yields in the region reflect that the African cotton-based systems are far from the best management practices (BMPs) (Tripp, 2009).

Soil is the foundation upon which rests the sustainability of crop production. However, land degradation is now a serious threat and a cause for declining productivity in most of the cotton-growing countries in Africa. This stems from intensive tillage operations and limited crop residue recycling as manure, due to its competing uses – fuel and animal feed. Such practices result in a decline in the soil organic carbon (SOC) and also loss of topsoil ultimately leading to loss of soil fertility (Bolliger *et al*., 2006). Loss of topsoil has been established in Africa in the 1980's (Elwell and Stocking, 1988; Lal, 1985). Further, the topsoil on removal gets transported to streams and lakes polluting the surface waters (Heathcote *et al*., 2013). The CO_2 released to the atmosphere, by way of excessive cultivation of crops including cotton, has implications on global climate change (IPCC, 2013).

Can we arrest the degradation and improve cotton productivity in the cotton growing countries of Africa? Yes, surely, we can arrest land degradation by adopting the 'BMPs'. Lessons can be learnt from the rest of the world as to how cotton is grown successfully with high fibre quality at high productivity levels. The BMPs, for improving soil health, are discussed here specifically for the cotton growing countries in Africa, where farmers own small land holdings and cotton cultivation is mostly rainfed. Thus, moisture is a major limiting

Soil erosion after heavy rain shower – main cause of soil degradation in the tropics

factor affecting crop yields apart from the poor soil fertility. In addition, because of the small land holdings, most of the farmers are resource-poor with limited capacity for investments. Thus, conservation agriculture (CA) is a BMP that holds the key to not only improving but also sustaining cotton production in Africa.

Conservation Agriculture (CA)

CA is an integration of ecological management with scientific and modern techniques tempered with traditional knowledge gained from generations of successful farmers (Dumanski and Peiretti, 2013). CA revolves around three basic principles: (i) minimising tillage, (ii) including a permanent cover and (iii) rotation crops. This system is more sustainable and has a wider adaptation because it improves soil quality (Thierfelder *et al*., 2009, 2010) and crop productivity. These three technologies in combination result in synergism. Thus, CA becomes more than the sum of an individual practice. These systems are best suited to the African countries since soil and water is conserved and contributes to improvement in the livelihoods of the farmers (Kassam *et al*., 2016).

Tillage

Presently, farmers practice intensive tillage operations with two main objectives (i) prepare a good seed bed and (ii) provide effective weed control. However, such practices lead to oxidation of the organic matter and a decline in soil organic carbon content. To mitigate C loss, conservation tillage practices are recommended. Conservation tillage denotes soil management systems that result in at least 30% of the soil surface being covered with crop residues after seeding of the subsequent crop. To achieve this level of ground cover, conservation tillage normally involves some degree of tillage reduction and the use of non-inversion tillage methods such as no-till, minimum till or reduced till. A substantial reduction in total soil loss and soil quality improvement was reported following the adoption of modern agricultural technologies such as conservation tillage (Montgomery, 2007). According to a study done by the Cotton Incorporated, USA, two-thirds of the cotton growers adopt some form of conservation tillage in the USA (Nyakatawa *et al*., 2001; Boquet *et al*., 2004; Reed *et al*., 2009). Similarly, conservation tillage practices are followed by cotton growers in Australia (Hulugalle *et al*., 1997), Brazil (Casao *et al*., 2012) and Turkey (Mert *et al*., 2006). Conservation tillage practices have been found to produce cotton yields greater than the conventional tillage treatments in West Africa (Baudron, 2007), Cameroon (Naudin *et al*., 2010) and Zambia (Haggblade and Tenbo, 2003).

Under the sustainable land management programmes, conservation tillage practices are promoted in Africa to a greater extent in food crops. A summary of the results of experiments conducted on cotton with different forms of conservation tillage are presented in Table 1. In Sub-Saharan Africa, the principal factor limiting the area of cropped fields is weeding. Where herbicides have been adopted in reduced tillage, farmers have increased their crop area by over 140% from 1.1 to 2.7 hectares (Haggblade and Plerhoples, 2010). Giller *et al.* (2009) compared two case studies of Africa - West Africa and Central Africa and observed differences in the response of cotton to the CA practices and also the mindset of the people in the region. In southern Zambia, conservation tillage did not perform well because the coarse textured soils are prone to crusting (Baudron *et al*., 2012). Under such situations, CA was perceived as a water shedding technology and not a water harvesting one (Thierfelder and Wall, 2009). Thus, ploughing was considered a better option on such soils to improve water infiltration. Mavukidnadze *et al*. (2017), reported similar seed cotton yields under the conservation and conventional till systems in Zimbabwe. On the other hand, in Cameroon, conservation till systems were better

Table 1. Effect of conservation tillage vs. conventional till systems across the different countries

S. No.	Location	Soil Type	Yield (kg/ha)		% Yield Change	Reference
			Conventional till	Conservation till		
1	Alabama, USA	Silt loam	2660	3130	17.7	Schwab *et al*. (2002)
2	Alabama, USA	Coastal loamy sand	1176	1415	20.3	Watts *et al*. (2017)
3	Dera Ismail Khan, Pakistan	Silty clay soil	*2289	*2124	-	Usman *et al.* (2013)
4	Ladhowal, India	Sandy loam	*2555	*2640	3.3	Chaudhary *et al*. (2016)
5	Kadoma, Zimbabwe	Ustopept	*1715	*1717	--	Mavunganidze *et al.* (2014)
6	Turkey	Vertisol	1941	2050	NS	Mert *et al*. (2006)
7	Cameroon	Fluvisols, Luvisols, Vertisols	*1220	*1390	13.9	Naudin *et al.* (2010)
8	Sikasso, Mali	Ferruginous	*1825±104	*1666±105	-8.7	Sissoko *et al*. (2013)

*Seed cotton yield (kg/ha)

than the conventional tillage systems (Naudin *et al*., 2010). In the Mediterranean region of Turkey, Mert *et al*., (2006) observed ridge till systems to yield better and promote earliness in a year that was wetter than the normal. While in the drier years, the tillage systems were not significant. On the Vertisols of semi-arid central India, conservation tillage systems were found to be either better or as good as the conventional till systems (Blaise and Ravindran, 2003; Blaise, 2006). But on the silty clay loam soil of Pakistan (Usman *et al.,* 2013) and the sandy loam of north India (Chaudhary *et al*., 2016), tillage systems had no significant effect. From the findings of the researchers mentioned above, it is evident that the conservation till system was either better than or similar to the conventional till systems. It is important to note that the conservation till systems result in significant savings in terms of fuel and labour (Raunet and Naudin, 2006). Thus, it should not be judged on the basis of yield alone. Even if the yield levels are similar, the net gains should be an incentive good enough for the management practice to be taken up, unless there is a significant decline in yields such as the one reported by Baudron *et al*. (2012) in southern Zambia. It cannot be considered that the tillage system will work in a similar manner all across soil types and climates (Giller *et al*., 2009). Moreover, limitations in knowledge and availability of farm equipment could constrain the adoption of the conservation till systems (Grabowski *et al*., 2016). Therefore, it is important to learn and adapt to the local conditions through innovative technologies. Furthermore, it is also essential to understand that the conservation tillage systems tend to show benefits over a period of time.

Soil cover

Management of crop residues is a critical part of CA systems because conservation tillage systems alone cannot improve organic C (Corbeels *et al*., 2006). Cotton is considered a low residue crop that may not provide sufficient surface residue to reduce erosion and protect the soil. There are five possible avenues for producing adequate quantities of crop residue mulch.

- Residue from the previous crop can be used as mulch through minimum/no tillage or non-inversion tillage (Blaise and Ravindran, 2003; Jalota *et al*., 2008).

***Chrysanthemum* grown as intercrop**

Sunnhemp grown as an intercrop

Sunnhemp mulched offers very good protection against the weeds and also adds nitrogen to soil

- Specific crop can be grown to produce biomass that can form mulch for succeeding cotton e.g. maize/soybean/finger millet or rapid growing legumes followed by cotton.
- Producing the mulch locally and imported to the field from surrounding areas e.g. L*eucaenea loppings* (Tarhalkar and Venugopalan, 1995).
- Intercropping or co-cultivation of short duration legumes between cotton rows and turning down is an option (Blaise, 2011). Strips of legumes can be grown as an alley after few rows of cotton and pruned regularly to be used as mulch. Intercropping and sequential relay cropping in cotton based cropping systems provide the mulch (Naudin and Balarabe, 2009).

When the soil surface is provided a cover and the crop residues are mulched, in general, it offers the following benefits (Unger, 1990); (i) moderate soil temperatures, (ii) reduce evaporation, (iii) improve biological activity and (iv) provides favourable environment for root growth.

Cotton crop residues

After cotton harvest, approximately 1.5-2.0 t/ha of cotton crop residue is available in the form of stalks and leaves. This crop residue is considered as a waste material and disposed of by burning. The quantity though low, is a precious C source especially in situations where only a single crop of cotton is taken up in a year. However, on-farm experiences indicate that when crop residues such as cotton stalks are recycled, it improved productivity (Blaise and Ravindran, 2003). In north India, which is irrigated, cotton-wheat and cotton-gram are established cropping systems. The residue of the previous crop can be effectively utilised as a surface cover and cotton planted directly with minimum soil disturbance (Jalota *et al*., 2008). In cotton-cereal systems, the biomass produced prior to cotton planting is as great as 5 t/ha and offers considerable protection to the soil and improves soil quality. On the other hand, in the cotton-legume system, the amount of residue cover provided by legume crop is small.

Considering this, farmers need to be advised that retaining even small amount of crop residues, available at the farm, would result in increased SOC. Importantly, no potential harmful effects of retaining cotton crop residues on the field were observed. However, cotton stalks are of poor quality because of their high lignin content, high C/N ratio (Blaise and Bhaskar, 2003) and therefore, could cause problems of N immobilisation (Chen *et al*., 2014). Further, for phytosanitary reasons, cotton crop residues are not recycled in most of the countries. However, the crop residue can be composted and made safe for application. By enriching with minerals such as rock phosphate and other organic manures such as poultry manure, farmyard manure, the value of the cotton stalk compost can be further enhanced (Reddy *et al*., 2017).

Legume cover crops

Various cover crops (legume and forage crops) have been tried in the cotton growing countries in Africa. It is ideal to incorporate leguminous residues because they mineralise at faster rate and release N rapidly due to its low C/N ratio. Conservation tillage practices when combined with surface managed crop residues sets in the processes whereby slow decomposition of residues results in (i) soil structural improvement and (ii) better recycling and availability of plant nutrients (Unger, 1990). Popular cover crops for Africa are Mucuna and lablab. In general, in Africa, cover crop is not grown as an inter-row crop since it affects the cotton lint quality.

Crop rotation

Apart from enhancing nutrient-use-efficiency, crop rotations offer the benefit of providing adequate residue cover and also to break cycles of the pest and disease (Giller *et al*., 2009). Nutrient use efficiency of N, P and K was higher with the cotton-soybean rotation (C-S) compared to the cotton-cotton (C-C) monoculture on the Vertisols of central India. Therefore, crop rotations that best fit the region and the cropping system, its economic viability etc. should be considered while designing the crop rotations. In Cameroon, the two-year rotation of cereal-cotton was designed (Naudin *et al*., 2010). The two year rotation of 'sorghum + cowpea – cotton' was found to be an ideal system that not only provides sufficient crop residues, but also ensures food security. In these systems, cotton is preferentially treated with fertilisers that benefit the subsequent cereal crops which do not receive any fertiliser inputs.

Conclusions

Producing more from less land will be the major challenge in the coming decades. Using the Best Management Practices such as the Conservation Agriculture (CA) can help address this challenge. Performance of CA in cotton based systems depends on three critical elements – minimising tillage, residue generation and its retention, and crop rotation. From the above, we can see how CA practices differ from region to region. Non-availability of adequate amount of crop residues, poor efficacy of popular herbicides to manage a wide spectrum of grassy and broad leaved weeds and lack of appropriate farm implements for practicing conservation agriculture are the impediments in adopting CA in cotton based systems. Therefore, it needs to be tailormade to suit the situation by considering the local conditions. Further information is needed, specifically for the various regions of Africa, on

1) Identification of tillage requirements
2) Identification of suitable cover crops that provide adequate plant biomass
3) Identification of an appropriate crop rotation system to avoid pests and disease outbreaks
4) Change in the farmers mindset for technology adoption

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Biotech Cotton - Relevance For Africa

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Since 1996, biotech cotton has been significantly influencing cotton production systems in major cotton growing countries across the globe. In 2017, insect resistant *Bacillus thuringiensis* based *Bt*-cotton cotton comprised 74.9% of the total global biotech cotton area and herbicide tolerant (HT) cotton comprised the rest. While Asian countries adopted only *Bt*-cotton, industrialised countries such as Argentina, Australia, US, Brazil, Mexico and South Africa adopted both *Bt* and HT cotton. Until 2017, three countries in Africa (South Africa, Burkina-Faso and Sudan) grew biotech cotton. Three more African countries — Nigeria, Swaziland and Ethiopia — approved *Bt*-cotton in 2018. Further, Malawi, Kenya and Cameroon are conducting multi-location trials of *Bt*-cotton and are likely to approve *Bt*-cotton soon.

In Africa, HT cotton was approved in South Africa and trials are underway in Cameroon. As in Asia, the relevance of biotech cotton in Africa would be more for the IR trait and less for the HT trait. Biotech cotton has been grown for 10-20 years in major cotton growing countries, notably India and China, which have small-scale farming systems similar to those in Africa. Impacts of biotech cotton have been wide ranging across different countries. Africa has the advantage of learning from the experiences of the world.

This article attempts to provide a short summary of the global status of biotech cotton with reference to the relevance for African countries.

Biotech Crops — Global Status

Biotech cotton, transgenic cotton and genetically modified cotton are synonyms. China was the first country in the world to commercialise a biotech crop: 'virus-resistant tobacco'. In 2017, 24 countries grew biotech crops on 189.8 million hectares. More than 90% of the global biotech area is in just five countries (Argentina, Brazil, Canada, India and USA). More than 99.0% of the global biotech area is under just four crops — soybeans: 50.0%; maize 31.0%; cotton: 13.0% and canola: 5.0%

Biotech Cotton — Global Status

So far until October 2018, biotech cotton has been approved for commercial cultivation in 19 countries (listed below).

In 2017, biotech cotton was cultivated by 13 countries in 24.07 million hectares, which comprised 80.0% of the global cotton area. More than 94.0% of the global biotech cotton area is located only in five countries: India (47.4%), USA (19.1%), Pakistan (12.5%), China (11.5%) and Brazil (3.9%). In 2017, the share of biotech cotton was 84% to 100% in major cotton growing countries such as Australia (100%), Argentina (100%), Brazil (84%), China (96%), India (93%), Pakistan (96%) and USA (96%).

Two traits: HT cotton and *Bt*-cotton

There are only two traits available in biotech cotton: Insect resistance (mainly *Bt*-cotton) and herbicide tolerance (HT). Argentina, Australia, Brazil, Colombia, Mexico, Paraguay, South Africa and USA approved Bt-cotton and HT cotton. Developing countries such as India, Burkina Faso, China, Pakistan, Myanmar and Sudan approved only *Bt*-cotton and have not approved HT cotton as yet. In 2017, the share of *Bt*-cotton in the global biotech cotton area was 74.9%, with 3.5% under HT cotton and 21.6% under *Bt*+HT cotton.

Year	Countries	Year	Countries
1995	USA	2005	Brazil
1996	Mexico	2007	Paraguay
1997	Australia & China	2008	Costa-Rica
1998	Argentina & South Africa	2009	Burkina-Faso (Currently under ban)
2002	India	2010	Pakistan & Myanmar
2003	Colombia	2012	Sudan
2004	Japan	2018	Nigeria, Ethiopia & Swaziland

Genetically engineered HT cotton varieties were developed as follows:

S.No	HT Cotton	Transgene/protein	Source	Mode of action
1	Glufosinate resistant cotton (Bayer)	Bialaphos resistance (bar) phosphinothricin N-acetyltransferase (PAT)	*Streptomyces hygroscopicus*	Acetylates the free amino group of glufosinate to inactivate it
2	Glyphosate resistant cotton (Monsanto and Bayer)	'*epsps*' gene encoding '5-enolpyruvulshikimate-3-phosphate synthase'	*Agrobacterium tumefaciens* CP4 strain	Overexpression of the *epsps* gene in HT cotton neutralizes the toxic effects of the herbicide glyphosate
3	Dicamba resistant cotton (Monsanto)	*Demethylase* gene codes for a dicamba mono-oxygenase (DMO) protein	*Stenotrophomonas maltophilia*	Demethylates dicamba to the herbicidally inactive metabolite DCSA
4	2,4-D resistant cotton (Dow)	'Aryloxyalkanoate dioxygenase-12' (*aad-12*) gene	*Delftia acidovorans*	Alpha ketoglutarate-dependent dioxygenase activity inactivates 2,4-D herbicide
5	Isoxaflutole resistant cotton (Bayer)	p-Hydroxyphenylpyruvate dioxygenase (hppd) enzyme	*Pseudomonas fluorescens* strain A32	Reduces the specificity for the herbicide's bioactive constituent
6	Bromoxynil resistant cotton (not in use)	*Nitrilase* gene	*Klebsiella pneumoniae subsp. Ozaenae*	Inactivates bromoxynil

HT Cotton

Herbicide tolerant cotton contains genes derived from micro-organisms or maize and has the ability to survive specific herbicide applications which kill weeds. HT-cotton cultivars are now available for tolerance to six different herbicides namely, glyphosate, glufosinate, dicamba, 2,4-D, Isoxaflutole and bromoxynil (HT not in use). HT cotton is more of necessity in industrialised countries that either do not have adequate manpower for manual or mechanical weeding or these processes are uneconomical through mechanical means.

Bt-cotton

Bt-cotton is a potent technology for almost season-long control of bollworms. *Bt*-cotton provides benefits until insect resistance becomes a problem. *Bt*-cotton controls only lepidopteran larvae (caterpillars). The target insects across the world are: bollworms, *Helicoverpa armigera*, *Heliothis virescens*, and *Helicoverpa zea*; pink bollworm *Pectinophora gossypiella*; spotted bollworms, *Earias* spp., the red bollworms *Diparopsis* spp., the tobacco caterpillar *Spodoptera litura* and a few semi-loopers and hairy caterpillars.

A soil bacterium, *Bacillus thuringiensis* (*Bt*) is known to produce proteins which act as oral toxins. When consumed the proteins perforate the mid-gut membranes and cause mortality in 2-4 days after consumption. So far, insect resistance in biotech cotton has been almost completely based on seven *Bt*-toxins, Cry1Ac, Cry1Ab, Cry1C, Cry1F, Cry2Ab, Cry2Ae And Vip3a. Though cowpea trypsin inhibitor (CpTi) protein was also deployed in insect resistant biotech cotton in China, the area under cultivation appears to be negligible.

The first-generation *Bt*-cotton, Bollgard, Ingard etc., was based on a single gene *cry1Ac.* The second-generation biotech cotton was Bollgard-II (*cry1Ac+cry2Ab*); Wide-strike (*cry1Ac+cry1F*); Twin-link (*cry1Ab+cry2Ae*); *Bt*-III (*cry1+cry2+vip3A*) and *Bt*+HT (*epsps*).

Economic benefits from *Bt*-cotton can arise from higher yields due to effective protection from lepidopteran larval damage and from savings due to reduced insecticides for bollworm control.

_Bt_-cotton & HT cotton technology developers

1. Monsanto company, USA
2. Bayer crop science, Germany
3. Dow Agro Sciences LLC, USA

_Bt_-cotton technology developers

4. Syngenta, Switzerland
5. Metahelix life sciences Pvt. Limited, India
6. JK Agri genetics Pvt. Limited India
7. Cotton-Sericulture Department, Myanmar

Insect resistant cotton (_Bt_ and Protease inhibitor) technology developer

8. Chinese Academy of Agricultural Sciences (CAAS), China

Insect resistance to *Bt*-cotton and weed resistance to herbicides

Two bollworm species, namely, *Helicoverpa zea* (in the USA) and the pink bollworm *Pectinophora gossypiella* (in India) have developed resistance to Cry2Ab and Cry1Ac toxins in *Bt*-cotton.

Glyphosate resistance was recorded in 13 weed species each in USA and Australia and 8 each in Argentina and Brazil. The main glyphosate resistant weeds are: *Amaranthus palmeri, Conyza canadensis, Amaranthus tuberculatus, Ambrosia artemisiifolia, Ambrosia trifida, Kochia scoparia and Lolium perenne.* The weed species *Lolium perenne* was found to be resistant to glyphosate and glufosinate in the USA.

Relevance of Biotech Cotton for Africa

The main bollworms in Africa are: the cotton bollworm, *Helicoverpa armigera,* the Spotted bollworms *Earias insulana,* the Sudan bollworm, *Diparopsis watersi* and the red bollworm, *Diparopsis castanea* spp., The pink bollworm *Pectinophora gossypiella* is a serious pest mostly in southern and east African countries. *Bt*-cotton was reported to be highly effective in controlling bollworms, which are known to cause maximum damage to the crop. *Bt*-cotton can be a useful pest management technology for Africa wherever bollworms cause serious economic losses despite the implementation of IPM.

Cotton bollworms are major pests of cotton, mostly dominated by the cotton bollworm *Helicoverpa armigera* and the pink bollworm *Pectinophora gossypiella*. There are anecdotal evidences coupled with a widespread belief in Asia that *H. armigera* which was an 'inconsequential pest of cotton' prior to 1981, emerged as a major pest of cotton in India and Pakistan only after the introduction of synthetic pyrethroids which were meant to control the pink bollworm and cotton leaf worm *Spodoptera litura*. Therefore, it would be important for African countries to consider conducting scientific studies with massive reduction of pyrethroid usage to examine if this would reduce *H. armigera* infestation on cotton. Bollworm problems can be reduced to a greater extent by growing short season (140-150 days) varieties to create asynchrony between a short 'reproductive phase window' and the bollworm infestation peaks. Further, recently introduced insecticides such as spinosad, emamectin benzoate, chlorantraniliprole etc., are effective in bollworm management. However, if none if these strategies work, *Bt*-cotton could be effective. Nevertheless, IPM would play a major role in the management of the wide spectrum of pests with or without *Bt*-cotton, because *Bt*-cotton controls only bollworms and not sap-sucking pests.

Current Status of Biotech Cotton in Africa

So far insect resistant biotech *Bt*-cotton has been approved in six countries in Africa, namely, South Africa, Burkina-Faso (currently banned), Sudan, Nigeria, Swaziland and Ethiopia. In addition, herbicide tolerant trait was also approved in South Africa. Malawi, Kenya and Cameroon are conducting multi-location trials of *Bt*-cotton. Cameroon is also considering herbicide tolerant traits for approval.

Following is the status of biotech cotton in Africa:

- **South Africa:** Biotech *Bt*-cotton was approved for commercial planting in 1998. South Africa approved *Bt*-cotton and HT cotton. Cotton was cultivated in 137,000 hectares in 1998. However, cotton area started declining subsequently due to drought and other factors, to a meagre 5000 hectares by 2009. Cotton was cultivated in 37,000 hectares in 2017 with almost all of it being biotech cotton.
- **Sudan:** Sudan approved *Bt*-cotton in 2012. As of now, all *Bt*-cotton is based on the single gene *cry1Ac*. Initially one variety called Seeni 1 was approved and two hybrids from India, Hindi 1 and Hindi 2 were approved in 2015. About 75.0% of the cotton area is under irrigated conditions. The private sector seeds comprise 31.0% of the cotton acreage. The Government of Sudan signed an agreement with China's Agriculture Ministry to plant 500,000 hectares of cotton in the Gezira region in the 2017/18 season. Sudan grew cotton in 194,000 hectares with 99.0% under Bt-cotton.
- **Burkina-Faso:** *Bt*-cotton was approved in 2009 and spread to about 65% of the area in 2015. Burkina Faso approved the two gene (*cry1Ac* + *cry2Ab2*) based Bollgard-II. The cotton bollworm, *Helicoverpa armigera* and the Sudan bollworm *Diparopsis watersi* were effectively controlled. However, the use of technology was suspended in 2016 following complaints of increasing short fibres and inferior fibre quality.
- **Nigeria:** Bt-cotton multilocation trials were conducted by Monsanto Agriculture Nigeria Ltd for seeking approval for commercial release. The two gene (*cry1Ac* + *cry2Ab2*) based Bollgard-II was approved for commercial cultivation in July 2018.
- **Ethiopia and Swaziland:** Multilocation trials with *Bt*-cotton were conducted by Ethiopia Institute of Agricultural Research (EIAR). The single gene *cry1Ac* based *Bt*-cotton (event-1) developed by JK Agrigenetics India was approved for commercial cultivation in June 2018.
- **Zimbabwe, Uganda and Senegal:** Reports indicate that trials were conducted but results and status of regulatory approvals for commercial cultivation are unknown.

Major insect pests in Africa

	Sucking pests						Bollworms				
	Aphids	Thrips	Mites	whitefly	Jassids	Red-bug	Red	African	Pink	Spotted	Leaf worm
Burkina Faso											
Cameroon											
Cote d'Ivoire											
Mali											
Benin											
Togo											
Nigeria											
Chad											
Egypt											
Sudan											
Ethiopia											
Kenya											
Uganda											
Tanzania											
Mozambique											
South Africa											
Zambia											
Zimbabwe											

- **Malawi:** *Bt*-cotton trials were conducted by LUANAR, DARS, Monsanto, Quton and general environmental trial approvals were granted. Variety registration trials are under consideration.
- **Kenya:** Conditional approvals for environmental release to conduct National Performance Trials (NPTs) were granted. *Kenya* Agricultural and Livestock Research Organisation (*KARLO*) and Monsanto are conducting the trials.
- **Cameroon:** Trials with insect resistant and herbicide resistant biotech cotton were conducted by Bayer Crop Science and application for environmental release is under consideration.

Impact of Biotech Cotton

Insect resistant *Bt*-cotton and herbicide tolerant HT-cotton exercised a strong influence on cotton production in more than three-fourth of the global cotton area. Both technologies are different in their own way. *Bt*-cotton effectively controlled the major bollworm insect pests in all the countries where it was introduced. Several research publications show that biotech cotton had a significant initial impact in effectively controlling bollworms thereby reducing the usage of chemical pesticides used for bollworm control at least over the first five to six years after introduction in most countries. But, subsequently, in some countries, pesticide usage increased for the control of *Bt*-resistant bollworms and new insect pests that were unaffected by *Bt*-toxins. Studies pointed out that increase in the usage of insecticides may have been due to two main factors.

1. Insect pest species that were not affected by *Bt*-toxins in biotech cotton increased progressively over the years, due to reduction in insecticide applications for bollworm control on *Bt*-cotton. Thus, minor pests, such as mirid-bugs, mealybugs, thrips etc., which would otherwise have been controlled by the bollworm-insecticides, emerged as major pests, warranting insecticide applications for their control.
2. Bollworm adaptation to *Bt*-toxins enabled them to survive on biotech Bt-cotton to various degrees in different countries, necessitating the usage of insecticides. Pink bollworm resistance to *Bt*-cotton in India is a striking example, where insecticide usage is increasing due to bollworm resistance.

Insecticide usage has been increasing constantly over the past 10 years in India, Pakistan, China, Brazil and USA for the control of thrips, whiteflies, mealybugs, pink bollworms and recently also for the cotton bollworm infestation. Insecticide use for boll weevil control is a major concern in Brazil. Enhanced use of herbicides to control resistant weeds in USA and Brazil is an emerging concern. Thus, there has been a rising trend in the usage of insecticides and herbicides in all the top five cotton growing countries over the past 10 years.

This predicament presents major concerns on the following fronts.

- Increased crop damage
- Declining yields
- Enhanced production risks
- Enhanced usage of pesticides
- Increased cost of production
- Increased ecological and environmental hazards

Beyond doubt, biotechnology has influenced cotton production systems in major cotton growing countries. But, a critical analysis of innovations in the past two decades points out that the pace of technological developments in the past ten years did not match those of the preceding ten years. The *cry1Ac* gene in *Bt*-cotton that was released in 1996, represented the first arsenal continues to be the main source of resistance to bollworms even after 20 years of continuous deployment. The other genes *cry1Ab*, *cry1C, VIP3Aa, cry1F* and *cry2Ab* played their role in bollworm management, but were not superior to *cry1Ac* in controlling bollworms. Further, there is no scientific evidence to show that the new biotech cotton events developed recently are in any way superior to the previous ones.

Recommendations for Africa Based on Global Experiences

Biotech cotton will be a useful technology provided the following diligent measures are considered

Africa needs basic yield enhancement technologies first

Cotton yields in Africa have been low and stagnant for about 30 years. What Africa needs is basic technologies that can enhance yields. For yields to be increased, the current dependence on multi-monopodial plant types and long duration low density planting needs to be changed first to be replaced with short-season compact-architecture varieties cultivated in high density planting systems. *Bt*-cotton or HT cotton are only plant protection or weed control technologies and have nothing to do with yield enhancement.

Examine the need

- Explore the options for *Bt*-cotton only where bollworms cause serious economic losses and IPM strategies are ineffective. Bollworms can also be effectively controlled by ecological methods and through Integrated Pest Management (IPM). For example, two strategies, namely, short-season cotton varieties plus avoidance of synthetic pyrethroid insecticides have the potential to significantly reduce bollworm infestations. *Bt*-cotton would be economical only if bollworms are a big menace and cannot be controlled by any other strategies.

- Explore the option for HT cotton if labour availability is a serious constraint and if selective herbicides are unavailable or target-specific herbicide application is not possible. HT cotton renders farms dependent on the usage of specific herbicides.

Preference for short-season cultivars (varieties)

Emphasis must be placed on the development and deployment of short season cultivars to reduce the 'bollworm-vulnerable window'.

Curb usage of synthetic pyrethroids

Synthetic pyrethroid usage must be reduced as much as possible to curtail any possible 'bollworm-resurgence effect'.

Choice of elite local cultivars

If *Bt*-cotton is to be deployed, locally adapted elite varieties must be used as recurrent parents for the conversion into biotech cotton.

Proper introgression of transgenes

Plant breeding techniques to introgress the biotech traits into locally adapted varieties must be carried out diligently by carrying out the whole process of introgression breeding and selection in the same agro-eco regions of cultivation. The methodology of plant breeding for proper selection of progeny from segregating populations over progressive generations to achieve homozygosity for the *Bt* genes and homogeneity for economically important traits in the cultivars is extremely important. The wisdom and role of local scientists such as plant breeders, agronomists, entomologists etc., must be respected at all times and used in the entire process of developing *Bt*-cultivars to ensure adaptability and sustainability of the biotech technologies.

Stacked genes for insect resistance management

If *Bt*-genes are to be deployed, to ensure sustainable and durable performance of *Bt*-toxins, it is always better to introduce all the available *Bt*-genes as a stack in a single simultaneous introduction. This can significantly delay insect resistance development to the toxins. For example, introduce the three gene based *Bt*-cotton (*cry1Ac+cry2Ab2+VIP3Aa*) at a go, instead of introducing cry1Ac followed by cry1Ac+cry2Ab after a few years and thereafter cry1Ac+cry2Ab2+VIP3Aa after a few more years.

Open-pollinated cultivars must be preferred over hybrid varieties

Private seed companies prefer to sell hybrid seeds because farmers would have to buy fresh hybrid seeds every season. Farm saved seeds from a hybrid-crop cannot be used for sowing in the subsequent season. High yields (1000 to 2500 Kg/ha) have been obtained by major cotton growing countries such as USA, Mexico, Brazil, Turkey, Uzbekistan, China and Australia by growing open pollinated varieties in contrast to low yields of 500 Kg/ha in India wherein >95% of the area is under hybrid *Bt*-cotton. Hybrid cotton varieties are less sustainable compared to open-pollinated cultivars. Hybrid seed production is expensive, cumbersome and labor-intensive. Majority of the cotton hybrids are designed to produce a large number (40-100) of bolls per plant which leads to longer duration and a larger crop canopy that warrants low crop densities. Hybrid seeds are expensive and are planted at low crop densities which also necessitates longer duration for high yields to be realized. A long duration crop becomes more vulnerable to insect pests, moisture stress and nutrient deficiencies, thereby leading to crop management problems, production uncertainties and yield risks. There is hardly any robust evidence to show that hybrid seeds provide higher yields in a shorter time frame as compared to open-pollinated varieties. Further the seeds harvested from a hybrid crop cannot be reused for subsequent sowing to raise a homogenous crop. Hybrid crop demands more fertilizers to maintain hybrid vigour that also leads to more foliage and higher pest infestation, thereby warranting more pesticide usage. Because of the longer duration, hybrid cotton can lead towards potential problems of pink bollworms, bacterial blight and mealybugs. In the interest of long term sustainability, hybrid cotton must be scrupulously avoided in Africa especially in rainfed regions.

Minor insect pests can become concerns

Secondary insect pests are expected to assume the status of major pests generally due to overall reduction in insecticide usage for bollworm control in *Bt*-cotton. Experience in India shows that 1.15 kg insecticide per hectare was used prior to the introduction of *Bt*-cotton. The usage decreased initially in the first five years to 0.5 kg/ha but increased again to 1.2 kg/ha by 2014, mainly due to the need for insecticides to control secondary pests.

Do not neglect IPM and IRM

Bt-cotton must be considered only as a component of overall Integrated Pest Management (IPM) and not as an independent pest management strategy all by itself. Experience shows that indiscriminate deployment of *Bt*-cotton and HT cotton with scant regard to the principles of IPM and insect resistance management (IRM) leads rapidly to severe pest problems and *Bt*-resistant target pests. Compliance with regulatory guidelines holds the key to sustainability. Resistance in target pests to *Bt*-cotton and development of resistant weeds to herbicides, are inevitable eventualities that get accelerated in the wake of poor compliance of resistance management strategies.