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QUANTITATIVE ASSESSMENT OF SUSTAINABILITY PILLARS IN THE INDIAN TEXTILE SECTOR REAFFIRMS COTTON'S PRIMACY

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Abstract

Textile industry plays a pivotal role in India, accounting for 3% of GDP, 14% of industrial production and 5 % of total exports. Cotton remains a cornerstone of India's textile sector. Commercialization of the Bt technology in 2002 has revolutionized cotton production in India providing leverage to textile industry making it predominantly cotton based, despite sustained growth in the synthetic fibre sector. Over the past two decades-spanning the IX to XII Five Year Plans and beyond-India has witnessed a dramatic transformation in cotton. Once a crop of subsistence, cotton has evolved into a preferred commercial crop, significantly enhancing farmers' income and strengthening national economy. This transformation set the stage for a comparative analysis of sustainability parameters between cotton and synthetic fibres in the Indian context.

On the economic dimension, sectoral data dispels the narrative that polyester is replacing cotton. While man-made fibres dominate globally, cotton in India has retained its supremacy in lint production, yarn and fibre consumption, fabric output and per capita cloth availability, underscoring cotton's centrality. During the IX Five-Year Plan, cotton-based textiles accounted for 62.7% of total exports, though this share declined in subsequent years relative to man-made textiles. Nevertheless, for most parameters, the ratio tilted in favour of cotton, except for exports.

On the environmental front, studies carried out world over project cotton in clear advantage over polyester in water footprints, carbon footprints and energy usage. Indian cotton often painted as water guzzler and highest pesticide consumer is largely a myth. Cotton has the distinction of being the sole fibre which conserves more energy than it consumes in its production with Indian cotton estimated to consume 120.374 M GJ and conserve 191.773 M GJ energy. It also has the distinction of being sole fibre which sequesters more carbon than it emits in its production with Indian cotton estimated to sequester 12.982 M t CO² against emission of 10.6216 M t CO².



Beyond economics and ecology, socially, cotton profoundly influences the lives of millions of Indians, both on-farm and off-farm. These unique properties of cotton have no match by any man-made or natural fibre.

In an era defined by sustainability imperatives, cotton reaffirms its centrality in economic resilience, ecological advantages and social relevance to India's textile sector.

Key words: *India cotton, synthetic fibre, sustainability pillars, economic, environmental and social dimensions.*

Introduction

Textile industry plays a pivotal role in Indian economy accounting for 3% of the GDP, 14% of industrial production and 5% of the country's export earnings. Cotton, the most important natural fibre since time immemorial, is the pre-dominant raw material for the Indian textile industry. Success of Green Revolution and hybridization technology in field crops made India self-sufficient in most agricultural commodities despite the growing demand of burgeoning population. Cotton also got a boost after introduction of first commercially successful hybrid in 1971 and genetically engineered Bt cotton in 2002. Of late, cotton inspite of attaining a comfortable supply position is facing challenges on multiple fronts- declining/stagnating yield and reduced profitability of cotton, mounting competition from the man-made textile industry on the cost and sustainability front and the myth about cotton production technology being

propagated by many crusaders of organic farming/ ZBNF and NGOs. Despite these odds, cotton continues to occupy a place of pride in the textile sector of India.

Discovery of Nylon and Polyester changed the world of textiles. Chemical advances in 1940s in man-made fibre, it's cheaper and faster industrial production, longer life, durable press property etc. made the shift possible towards polyester. Much changed in decades post industrialization and now near 70% share of global textile is dominated by man-made fibres. Cotton is often claimed/ blamed to be water guzzler, a highly polluting and an expensive commodity vis-a-vis polyester. The MMF industry in India and elsewhere proclaim higher environmental footprints of cotton, its low and expensive cost of production, superiority of polyester and other such reasons. It is therefore imperative to examine the three basic pillars of sustainability, economic, environmental



and social dimensions of cotton versus man-made fibre in Indian perspective.

Data source and computation

The data on production, consumption and availability of fibre/yarn and cloth/fabric of cotton and man-made textile goods starting 1997 spread over the four Five Year Plans (IX, X, XI, XII FYP) and beyond upto 2025 was sourced from the websites of Textile Commissioner, Mumbai; production, import and export of raw cotton from ICAR-Central Institute for Cotton Research, Nagpur and export of cotton and MMF based goods from Foreign Trade Statistics of India (Principal Commodities & Countries) DGCI&S, Kolkata and TEXPROCIL Mumbai. The data was averaged on five years basis starting 1997. Source of other technical data including ICAC is quoted at relevant places.

Findings and discussion

Sustainability has lately emerged as an important criterion while assessing any new technology or product which makes us understand its environmental, economic and social implications and finally the acceptability by stake holders (Park *et al.*, 2011). Data based analysis of the three basic pillars of sustainability of cotton and man-made fibre/ textile has been done hereunder.

Trends in cotton cultivation and production: Cotton cultivation in India between 1997 and 2025 presented a complex picture of expansion, intensification and eventually stagnation (Table-1). The area under cotton has grown steadily from 8.84 million hectares per year in the IX FYP (1997-02) to near 12 million hectares in XII FYP (2012-17) and beyond. Fertilizer use more than doubled during this period, rising from 89 kg to over 200 kg/ha/yr in 2022-25. Pesticide use which initially declined with the adoption of Bt cotton (0.611 kg/ha in 2007-12- XI FYP) is constantly on rise and has rebounded to levels above 1 kg/ha in recent years, suggesting renewed pest pressure and resistance.

Production rose sharply from 14.55 million bales per year during 1997-02 to a peak at 36.62 million bales in the 2012–17 commensurate with Bt cotton but has since been on decline and reduced by 4 million to 32.66 million bales, despite larger area and higher input use. Productivity trends highlight the paradox more clearly, the yields increased from 280 kg in IX FYP to 522 kg/ha/yr in XI FYP, driven largely by massive Bt cotton adoption and hybrid expansion but have since been on decline and fallen to 449 kg/ha in 2022-25.



The data suggest that while technological breakthroughs initially delivered substantial gains, cotton production has lately entered a decline phase in India. Rising fertilizer and pesticide use with higher cost without proportional yield improvement signal inefficiency of inputs,

soil fatigue and ecological imbalance. Declining returns not only concerns the farmers, the trade and the industry but also opens up plethora of criticism by MMF industry on economic and environment sustainability of cotton in India.

Table 1: Area, production, input use and productivity of cotton in India

Year	Area M ha	Fertilizer kg/ha	Pesticide kg/ha	Production M bales	Productivity kg/ha
1997-02 IX FYP	8.84	89.0	1.328	14.55	280
2002-07 X FYP	8.36	116.4	0.878	21.64	440
2007-12 XI FYP	10.49	174.2	0.611	32.22	522
2012-17 XII FYP	11.99	174.6	0.756	36.62	519
2017-22	12.75	196.8	0.895	34.71	463
2022-25	12.35	205.4	1.067	32.66	449

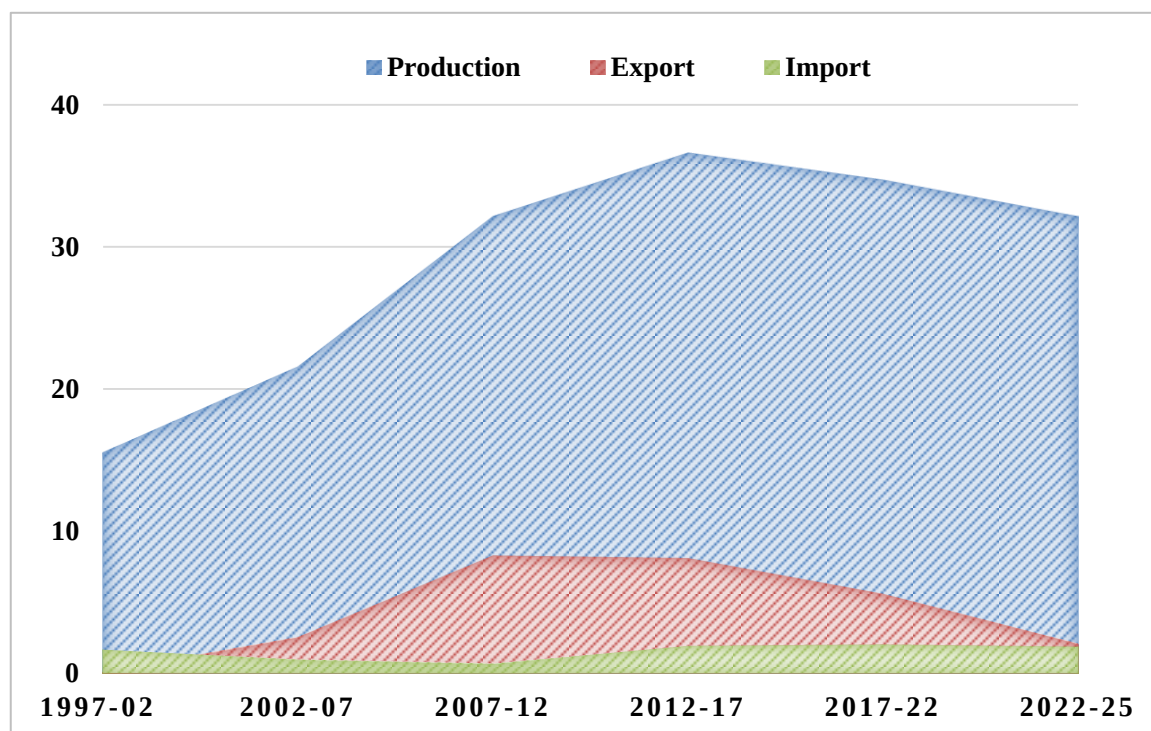


Fig 1. Export and import scenario of raw cotton (M bales/year)



Economic dimension of sustainability

Production, export and import of raw cotton:

India's cotton sector has undergone significant shifts over the past three decades (Fig-1). Production rose steadily from 15.5 million bales in IX FYP to a peak of 36.6 million bales in XI FYP before moderating to 32.1 million bales in 2022–25. Exports followed a similar trajectory, climbing sharply to over 8 million bales during 2007–17 from 0.125 million bales in 1997-02 but then declined to less than 2 million bales in the most recent period. Imports, by contrast, remained relatively modest, declined to 0.665 million in 2007-12 from 1.628 million bales during pre-Bt period (1997-02) but bounced back to pre-Bt period in the last decade.

This pattern highlights India's transition from a net importer in the late 1990s to a major exporter in the 2000s, unseating many global players in the sector. However, the situation did not last long. Decreased production and high cost of Indian cotton besides competitiveness in international market lead to rising import dependence and reducing export.

Production of major spun yarn: The cotton-based textile industry in India witnessed a structural transformation following the introduction of Bt cotton in

2002 (Table-2). Prior to this, during the IX FYP, total spun yarn production stood at 3018 million kg per year, comprising 2184 million kg of cotton yarn (SCY) and 223 million kg of non-cotton yarn (NCY). Cotton accounted for 72.4% of total production, while NCY contributed 7.4%. During the X FYP, the share of cotton yarn showed a marginal decline, whereas NCY increased to 10% of total spun yarn production. In the XI FYP, production of both SCY and NCY rose, but the balance tilted once again in favour of cotton. By the end of the XII FYP, average SCY production had reached 3950 million kg per year, compared to 516 million kg of NCY.

During subsequent five years (2017–22), spun cotton yarn production peaked at 4070 million kg per year, while non-cotton yarn rose to 585 million kg. This phase marked the highest production of SCY, reaffirming its dominance. In the most recent period 2022–25, both SCY and NCY yarn registered a decline to 3650 Million kg and 495 million kg per year, while blended yarns continued to grow, reaching 1248 million kg. This shift suggests a diversification trend, with blended yarns gaining ground, possibly reflecting changing fibre preferences, market dynamics, or sustainability considerations.



Consumption of Major Yarn/Fibre:

India's textile sector has shown dynamic shifts in fibre consumption across successive Five-Year Plans and subsequent years (Table-3). In the IX FYP, total fibre consumption was 4479 million kg per year, with cotton fibre (CF) contributing 59.4% and man-made fibres (MMF) 37.8%. Cotton maintained a clear lead with a CF to MMF ratio of 1:0.637

even before introduction of Bt cotton. During the X FYP, both CF and MMF consumption increased, reaching 3008 million kg and 2126 million kg per year, respectively. The ratio of Cf to MMF slightly improved to 1: 0.707 in favour of MMF. In the XI FYP, cotton consumption rose further to 3886 million kg and also expanded to 2401 million kg per year.

Table 2. Fibre wise production of spun yarn (M kg/yr)

Period	Cotton CY	100% Non-Cotton NCY	Blended	Total production	Ratio of CY to NCY
IX FYP	2184	223	611	3018	1: 0.102
X FYP	2363	346	596	3325	1: 0.146
XI FYP	3108	406	725	4239	1: 0.131
XII FYP	3953	516	930	5399	1: 0.131
2017-22	4070	585	1087	5742	1: 0.144
2022-25	3650	495	1248	5392	1: 0.136

A significant change occurred in the XII FYP, when CF consumption reached at 4907 million kg, while MMF declined to 1894 million kg contributing 70.8% and 27.3 %, respectively, to the total fibre consumption, resulting in a slump in CF to MMF ratio from 1:0.618 to 1:0.386. This indicated strengthening of cotton's dominance in fibre consumption in India.

During 2017–22, both CF and MMF consumption further increased with CF touching 5202 million kg and MMF 2556 million kg per year lifting total fibre use to 7916 million kg. The ratio of CF to MMF marginally improved to 1:0.491. Most recently in 2022–24, CF consumption declined to 4825 million kg, while MMF rose to 2760 million kg, narrowing the gap yielding a ratio 1:0.572 tilted in favour of



MMF. Decline in production of cotton in the country during this period probably

limited its availability for fibre/ yarn production.

Table.3: Fibre wise consumption in the textile sector (M kg/ yr)

Period	Cotton CF	Man-made Filament, fibre MMF	Others (Wool, Silk, Flax etc)	Total Consumption	Ratio of CF to MMF
IX FYP	2659	1693	127	4479	1: 0.637
X FYP	3008	2126	152	5286	1: 0.707
XI FYP	3886	2401	160	6447	1: 0.618
XII FYP	4907	1894	134	6935	1: 0.386
2017-22	5202	2556	160	7916	1: 0.491
2022-24	4825	2760	170	7760	1: 0.572

Production of fabric: The fibre-wise production of fabric presented in Table-4 reveals a clear trajectory of growth accompanied by changes in fibre consumption. Beginning with the IX FYP, total fabric production was 39,007 million m² per year, of which cotton (C) accounted for nearly half (49.0%), amounting to 19,283 million m², non-cotton fabrics (NC) 33.7% (13,143 million m²), while blended and other fabrics added 6,581 million m². The C to NC ratio at this stage stood at 1:0.566. During the X FYP, cotton fabric share declined slightly to 46.5% while non-cotton fabrics surged to 38.6%, narrowing the gap with cotton and the C to NC ratio shifted to 1:0.832, reflecting the growing competitiveness of man-made

fibres. This trend continued into the XI FYP recording total production of 58,903 million m² per year wherein cotton regained ground, contributing 49.3% while non-cotton contributing 36.3%.

The XII FYP (2012–2017) marked a turning point, with total production climbing to 64,299 million m². Cotton surged to 36,724 million m² (57.1%), its highest share in two decades, while non-cotton contracted sharply to 16,334 million m² (25.4%). Blended fabrics rose to 11,241 million m², consolidating their role in the sector. During this period, the C to NC ratio improved to 1:0.445 in favour of cotton fabric. In the subsequent period (2017–2022), of the total production of 68,816 million m², cotton stood at 39,809



million m², while non-cotton remained subdued at 16,887 million m². Blends advanced to 12,120 million m². The C to NC ratio further strengthened to 1:0.424, reflecting cotton's continued dominance. In the most recent period (2022–2025), total production peaked at 79,083 million m² per year, nearly doubling the IX FYP baseline. Cotton moderated to 37,267 million m² (47.1%), losing share despite

absolute growth. Non-cotton rebounded strongly to 23,483 million m² (29.7%), regaining competitiveness, while blended fabrics recorded their highest output at 18,333 million m², reflecting diversification and consumer preference. The C to NC ratio widened to 1:0.630, signalling synthetics' resurgence and narrowing of cotton's relative advantage.

Table.4: Fibre wise production of fabric (M m²/ yr)

<i>Period</i>	<i>Cotton</i>	<i>100 % Non-cotton</i>	<i>Blended, silk wool, khadi etc</i>	<i>Total production</i>	<i>Ratio of cotton to non-cotton</i>
1997-02	19283	13143	6581	39007	1:0.566
2002-07	21621	17986	933	46540	1: 0.832
2007-12	25059	21376	8468	58903	1: 0.735
2012-17	36724	16334	11241	64299	1: 0.445
2017-22	39809	16887	12120	68816	1: 0.424
2022-25	37267	23483	18333	79083	1: 0.630

Per capita cloth availability: Per capita cloth availability serves as an important indicator of societal development. India recorded a steady rise in cloth availability from 30.46 m² during the IX FYP to 49.63 m² during 2022-25, except a dip in the XII FYP (Fig. 2). This decline was largely driven by a sharp reduction in non-cotton (NC) cloth, which fell to 10.34 m² from 17.0 m² in the previous FYP. Cotton cloth availability consistently increased: from 14.44 m² in the IX FYP to 15.23, 19.54, and 22.72 m² in the X, XI, and XII FYPs,

respectively. By the XII FYP (2012–17), cotton's share rose to 57.6%, up from 47.4% in the IX FYP. The following five years (2017–22) witnessed steady growth in both cotton and NC cloth, with NC showing a sharp rebound. The cotton to NC ratio improved to 1:0.706, compared to 0.455 in the previous plan. However, blended cloth availability almost collapsed, dropping to 2.49 m². In the subsequent three years (2022–25), the growth slowed. Of the total 49.63 m² cloth availability, cotton maintained a dominant



share of 55% (27.43 m²), while NC accounted for 39% (19.67 m²), with only marginal shifts in the cotton-to-NC ratio.

Interestingly, the ratio of cotton to NC cloth was nearly equal (0.964) in the X FYP, reflecting parity in availability. But with the expansion of Bt cotton cultivation, yarn production, and fabric output, the ratio dropped to 0.455, indicating that cotton cloth availability more than doubled that of NC cloth. In later periods, however, the balance tilted back toward NC. Despite these fluctuations, cotton continues to hold a dominant position in India's textile sector, in sharp contrast to its dwindling share in the global textile industry.

Food and other products of cotton: Other than fibre for textile, cottonseed is used as nutrient rich animal feed and edible oil. Near 1.6 million tonnes cottonseed oil produced in India is an integral part of India culinary. The stalks and other components are used as biofuel, soil amendments, Biochar making and particle board manufacturing in India. Cotton is thus a unique crop providing holistic solution for fibre, feed and food needs of millions of Indians. Synthetic fibre or any agri-commodity is no match for these distinctive features of cotton.

Export of cotton, MMF and other textile goods:

Despite the rising share of cotton in domestic production and consumption, exports of cotton-based textile goods have not kept pace after XI FYP (Fig. 3). Average annual exports of cotton yarn, fabric, made-ups, ready-made garments (RMGs), waste, and raw goods stood at US\$ 6603.75 million during the IX FYP, accounting for 62.7% of India's total textile exports (US\$ 10536.22 million). Subsequent plans registered impressive growth, with cotton exports reaching US\$ 20583.7 million per.

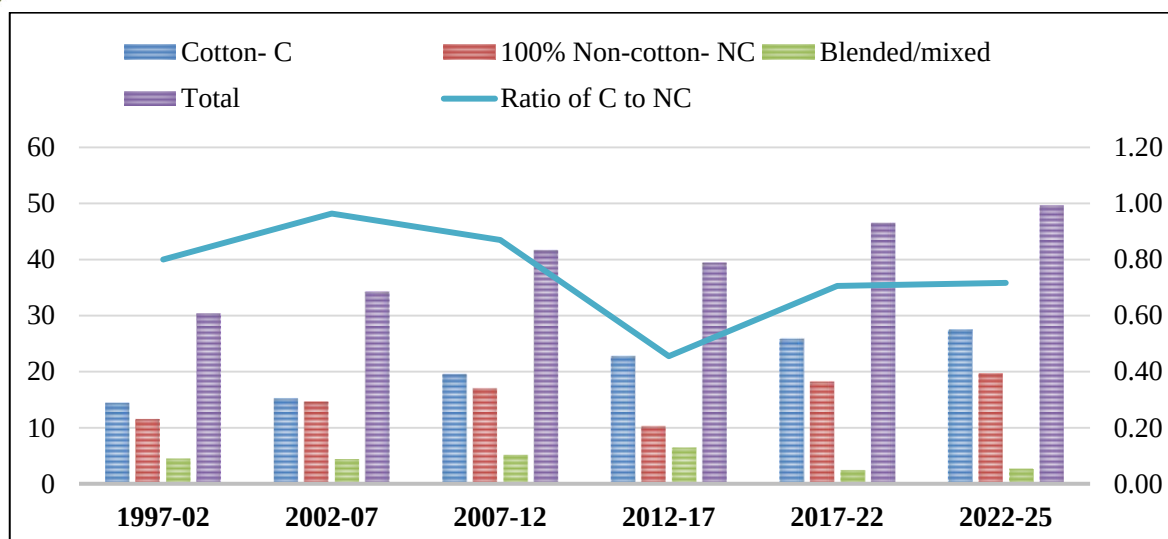


Fig 2: Per capita availability of cloth (m^2/yr)

Year in the XII FYP, out of total textile exports of US\$ 38515.16 million. However, cotton's share declined to 53.4%, down from the preceding three plans. In the subsequent periods (2017–22 and 2022–25), cotton textile exports showed only marginal growth. In contrast, man-made fibre (MMF) textile exports consistently increased, rising from 17.4% in the IX FYP to 30.2% during 2022–25. The cotton to MMF export ratio, which was 0.272 in the IX FYP, climbed to 0.547 during 2022–25, signalling a clear tilt toward MMF goods. This growth was driven by innovations, value addition, fashion industry demand and policy support through TUF and PLI schemes, coupled with aggressive international marketing. Cotton-based textiles, by contrast, struggled to keep pace.

Overall, India's textile exports as a share of total national exports have declined. While textiles accounted for 27.43% of total exports in the IX FYP, the share fell to 11.91% in the XI FYP, recovered marginally to 15.02% in the XII FYP, and continued to decline thereafter. In absolute terms, textile exports grew exponentially from US\$ 10536.22 million in the IX FYP to US\$ 39024 million during 2022–25, a 270% increase, yet their share in India's total exports dropped below 5% in 2022–25. This decline reflects both intensifying competition from countries such as China, Bangladesh, Vietnam, Philippines and Sri Lanka and the rapid expansion of India's export in service, chemical, machinery, electrical, and electronics sector.

Thus from an economic perspective, while cotton has maintained and even



strengthened its role in domestic production and consumption of yarn, fibre, fabric, and cloth availability, its relative position in export markets has weakened compared to MMF textiles.

Environmental Dimension of sustainability

Water footprints in production and processing: Cotton is often labelled a “water-thirsty” crop, although it accounts for only 2.6% of global water use from 3% of arable land (Hoekstra and Chapagain, 2008). Comparative studies show cotton’s water footprint is lower than many crops like wheat (15%), paddy (13%), maize (10%), forage (8%), and soybean (5%). Producing one kilogram of cotton fabric requires about 10,000 litres of water (Mekonnen and Hoekstra, 2010, 2011). In India, estimates range between 9788–9958 litres/kg (Water Footprints Network,

2017). Stephen Leahy (2015, *The Guardian*) cited Water Footprint Network data suggesting 22,500 litres/kg cotton in India, exceeding paddy, wheat, and corn. Earlier studies (1997-2001) reported consumptive water use of 5380 m³/tonne (including 1340 m³ blue water) and virtual water use of 8662 m³/tonne (2153 m³ blue). Safaya *et al* (2016) studying Gujarat, Maharashtra and Madhya Pradesh found wide variation: Gujarat averaged 4184 m³/tonne, while M.P. and Maharashtra recorded 338,039 and 26974 m³, respectively. Blue water contributions were relatively small- 159,252 and 42 m³ indication that grey water (pollution from agrochemicals) dominates cotton’s footprint. Given that 62% of India’s cotton area is rain-fed, projections of blue and grey water footprints may be overstated.

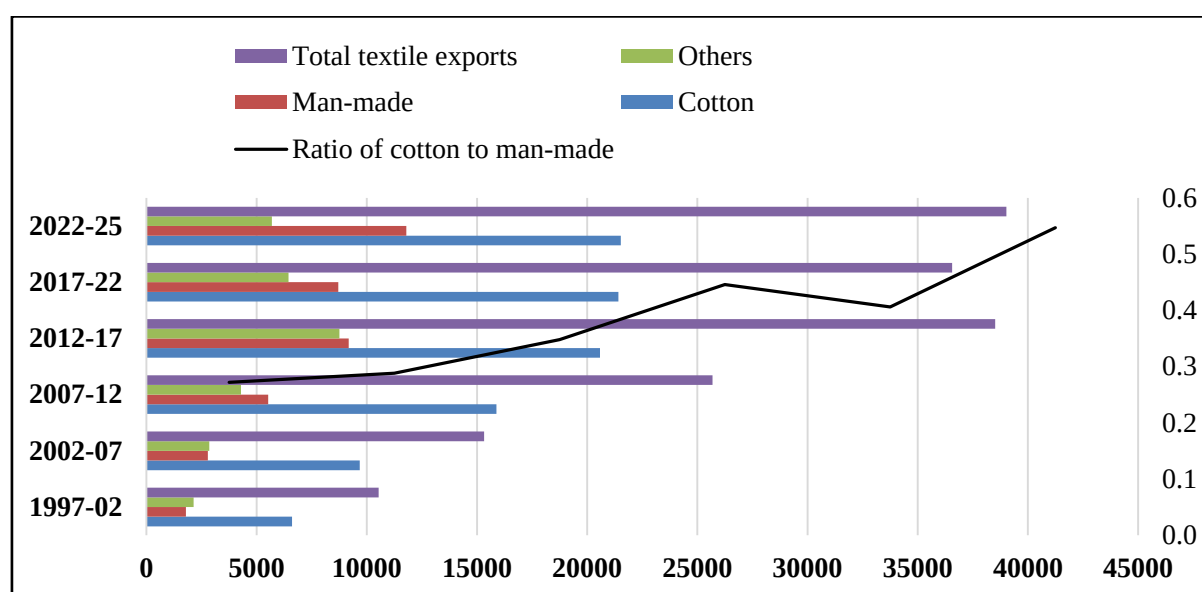


Fig 3: Export of major textile goods (M US \$ /yr)



Cotton Incorporated (2009) estimated 1811 m³/tonne for irrigated U.S. cotton. ICAC Cotton Data Book (2022) reported global averages of 2347 litres blue water/kg lint, with India at 1547 litres, compared to Pakistan (9095), Egypt (10,651), Australia (1232), and the USA (932). Studies conducted at Surat (2008-11) found 1363 litres water use per kg lint.

In processing, cotton fabric requires 250-300 litres/kg, higher than polyester or acrylic (100-200 litres/kg) due to cotton's absorbent fibre structure (Textile Learner, 2014). Yet this very property makes cotton the preferred fibre in tropical regions

Polyester's footprint is 71,000 m³/tonne, mostly grey water from oil exploration and refining, with only 50 m³ blue water (Water Footprints Network, 2017). In Europe, cotton, polyester, and viscose account for 67%, 24%, and 9% of purchases, but contribute 28%, 68%, and 6% of water footprints, respectively (Freitas *et al.*, 2017)-a clear indication of cotton's lower footprint despite its dominant market share.

Energy usages in production and processing: Fibre productions natural or synthetic are energy intensive process but cotton has lower energy requirements compared to man-made fibres. The World

Wide Fund for Nature-Cymru/Stockholm Environment Institute estimated that U.S. polyester consumes 126.71 GJ/tonne spun fibre (1 GJ = 277.78 kWh), while Europe consumes 104.48 GJ/tonne. In contrast, U.S. cotton requires only 25.59 GJ/tonne, nearly 80% less than polyester. In Punjab, India, spun cotton consumed 16.20 GJ/tonne, about 87% less than U.S. polyester and 84.5% less than European polyester. However, Punjab's mechanized cultivation with higher pesticide, fertilizer, and water use may not reflect India's broader production conditions.

The New Zealand Merino Wool Association reported embodied energy values across fibres: cotton (55 GJ/tonne), viscose (100 GJ), polyester (125 GJ), acrylic (175 GJ), and nylon (250 GJ) (LCA New Zealand, tech.plym.ac.uk). Thus, synthetic fibres require 127-354% more energy than cotton.

Energy consumed versus conserved:

Cotton is unique in that while it consumes energy during production, it conserves more through its seeds and biomass. A Cotton Incorporated (2009) study in the U.S. found that producing one tonne of cotton fibre consumed 20.4 GJ, but conserved 32.5 GJ in seeds-59% more than consumed. No synthetic fibre offers this advantage.



By U.S. standards, cotton production in India consumes about 120.374 million GJ, while conserving 191.773 million GJ, yielding a net gain of 71.4 million GJ. This figure could even be higher because of least mechanization in India. This highlights cotton's distinctive role as a fibre that not only requires less energy than synthetics but also contributes positively to energy balance through by-products

Carbon footprints in production and processing: Studies across countries show that estimating carbon footprints of fibres—especially cotton—is complex due to variations in cultivation practices, inputs, and technology. Indian cotton cultivation is largely manual and 60% rain-fed, grown on conserved moisture, rest 40% is irrigated, partly through surface, bore well, or drip systems which limit the use of fertilizer and pesticide due to uncertainty of irrigation water and/or soil moisture.

A WWF study in Warangal, India reported emissions of 430 kg CO₂/t seed cotton in best-managed plots versus 1500 kg/t in traditional plots. Kumar *et al.* (2017) found 251 kg CO₂/t seed cotton in Bt hybrids compared to 794 kg/t in non-Bt hybrids, due to reduced pesticide use. Nigam *et al.* (2016) estimated Indian cotton's farm-stage emissions at 1.83 kg CO₂/kg fibre, close to US cotton at 1.8 kg

CO₂/kg fibre. Australian cotton was higher at 2.5 kg CO₂/kg fibre (Cotton Incorporated, 2009).

According to BioRegional Development Group and WWF-Cymru, polyester production emits 9.52 kg CO₂/t spun fibre in the US and 7.20 kg in Europe. Cotton in the US emits 4.2 kg CO₂ during cultivation and 1.7 kg during spinning, totalling 5.9 kg CO₂/t fibre. Indian cotton emits 3.1 kg during cultivation and 1.8 kg during spinning, totalling 4.9 kg CO₂/t fibre (Cherrett *et al.*, 2005). Thus, US and Indian cotton show 38% and 48.5% lower emissions than US polyester, and 18% and 32% lower than European polyester, respectively. Despite emissions from fertilizers and mechanization, polyester remains more energy-intensive.

Carbon sequestration by cotton: Cotton emits CO₂ during fibre production like other crops but sequesters more carbon than it releases, making it a net carbon sink. Globally, cotton removes CO₂ from the atmosphere equivalent to the annual emissions of 7.5 million cars. In the US, studies show cotton emits about 1.8 kg CO₂/kg fibre but conserves 2.2 kg CO₂ in seeds and soil—22% more than its emissions (Cotton Incorporated, 2009). Applying these parameters to India, cotton is estimated to sequester 12.982 million tonnes CO₂ against emissions of 10.621



million tonnes. Actual emissions may be lower due to India's lower mechanization compared to the US, further strengthening cotton's role in carbon conservation.

Thus polyester has high carbon footprint, energy-intensive with no sequestration whereas cotton has lower footprint, with significant sequestration potential, especially in less mechanized systems like India.

Pesticide usage in cotton: The belief that cotton consumes the highest amount of pesticides and is a major source of CO₂ emissions is a myth. In reality, cotton uses less than 5% of total global pesticides, lowest amongst the major crops. Without pesticides, however, over 80% of global cotton could be lost to insects, fungi, and weeds (source: Cotton Incorporated-<https://lnkd.in/d9-p-u# cotton#fact#truthaboutcotton#pesticides>).

Earlier reports exaggerated cotton's share at 24–25%, a 1995 report estimated cotton at 10% of all pesticide and 22.5% of insecticide sales, while by 2014 the figures had declined to 5.7% of pesticides and 16.1% of insecticides. More recent data from 2019 put cotton at 4.71% of pesticides and 10.24% of insecticides (Transformers Foundation, 2021). The

global average for 2018–22 was only ~4% pesticide use (Kranthi, 2024).

In India, cotton is often labelled pesticide-intensive, yet actual consumption is modest at 0.895 kg/ha (2017-22), far lower than China (13.07 kg), Brazil (5.94 kg), USA (2.54 kg), Egypt (2.10 kg), and Australia (2.03 kg) (ICAC Cotton Data Book, 2022). On per kg lint basis, India fares poorly, but overall usage is not excessive. During 2017-22, India's cotton consumed just 9.26% of the total pesticides used. By contrast, wheat accounted for 35.56%, pulses 12%, oilseeds 10.86%, and vegetables 9.34% (source:

<https://www.ppqqs.gov.in>statistical-database> States/UTs zonal conference on inputs of plant protection for kharif and rabi season). This evidence clearly disproves the misinformation that cotton consumes 45–50% of India's pesticides (Table-5).



Table 5. Average consumption of chemical pesticides (tones technical grade) per year in different crops during 2017-22 in India

Value /Crop	Cereal	Vege- table	Pulse	Oil seed	Fruits	Planta- tion	Cash crops	Fibre	Others
M Tones	15840	4162	5342	4838	2025	343	4838	4126	1606
% over country	35.56	9.34	12.0	10.86	4.55	0.77	10.86	9.26	3.61

Fertilizer usages in cotton: Fertilizers are a major source of greenhouse gases such as CO₂, methane, and nitrous oxide, contributing significantly to climate change. While alternatives like organic or regenerative farming exist, they cannot meet the needs of India's 1.42 billion population. Despite high fertilizer use compared to many countries, Indian cotton reflects poor fertilizer use efficiency (FUE) and productivity.

Large rain-fed areas and injudicious application often mismatched with crop requirements in timing and dosage are key reasons for low FUE. Over the past 28 years (1997-2025), trends are frightening. During 1997-2002, it was 318 g/ kg lint, 264.5 g in 2002-07 (early phase of Bt adoption) showing improved efficiency but in subsequent period, it continued to decline to 457 g/ kg lint in 2022-25 underscoring inefficiency and need for corrective measures to make Indian cotton more competitive and profitable.

Overall, cotton's environmental footprint is complex but more balanced than often portrayed. While challenges remain in fertilizer use efficiency, pesticide usage and water management in India, cotton's actual pesticide share is modest and far below earlier exaggerated claims. Importantly, cotton has a lower carbon footprint, biodegradable/ compostable compared to polyester and uniquely contributes to carbon sequestration (ecotextiles.wordpress.com/2011/estimating-carbon-footprints-of-a-fibre/), offsetting part of its emissions. In contrast, polyester is energy-intensive, high CO₂ emitting, non-biodegradable taking 20 to 200 years to decompose and make good share of micro plastics found in water and soil and implicated as the source of pollution (Ashlee Uren, 2018).

Social dimension of sustainability

Cotton sustains the livelihoods of near 8 million farm families and millions of agricultural labourers across more than 12 million hectares in India, with 60% area



being rain-fed and offering no viable alternative crop. It is thus the backbone of subsistence for rural communities. The growth of cotton has also driven women's empowerment, supported the seed and agrochemical industries, ginneries, cottonseed oil enterprises, and thousands of small traders, while strengthening the textile sector and contributing significantly to foreign exchange earnings.

Beyond economics, cotton's comfort in semi-arid climates, skin-friendliness, sweat absorbency, and adaptability to modern weaving and knitting technologies make it a fibre of choice, with wide applications in medical and hospitality sectors. In India, cotton is not just a crop but a social and cultural pillar of sustainability, enriching lives across multiple dimensions.

Not everything is grey for synthetics. Their entry into India in the 1960s revolutionized the textile industry by enabling high-speed, efficient spinning and weaving, making fabric more affordable and accessible to the masses. Synthetic fabrics gained popularity due to their durability, resistance to shrinkage and creasing, and colour fastness, which appealed to a wide section of society. Recent innovations have further enhanced their appeal, with properties such as UV resistance, sweat absorption, anti-bacterial finishes and blending with natural fibres,

making synthetics a fabric of comfort and convenience

Conclusion: In India, cotton sustains millions of farm families while offering lower pesticide use, modest carbon emissions and unique sequestration benefits, though fertilizer efficiency and water management remain challenges. Polyester, by contrast, is energy-intensive, non-biodegradable and polluting, yet has revolutionized the textile industry since the 1960s by making durable, affordable fabrics accessible to the masses. Together, synthetics stand as technological and economic pillar, and cotton serves as a social, economic and ecological driver while India's textile future lies in balancing the both.

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PROMOTING STRIP-TILLAGE IN COTTON-BASED CROPPING SYSTEMS IN BENIN

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Abstract

This study presents the promotion and implementation of strip-tillage practices in cotton-based cropping systems in Bembèrèkè, northern Benin, during the 2025 growing season. A total of 23 plots representing 107,8 hectares were prepared using strip-tillage. The study analyse agricultural operation in these strip-tilled plots.

The results revealed variability in farmer practices regarding sowing date, sowing methods, and Single Super Phosphate (SSP) spreading date after sowing. These results highlighted the importance of following the recommended timelines, particularly regarding the application of SSP, as well as of developing appropriate recommendations for sowing, fertilizer application, and pesticide use in strip-tilled cropping systems.

Key words: strip-tillage, Benin, cotton-based cropping system, sowing date, SSP application date

Introduction

In Benin, as in several West African countries, numerous publications indicate that soil quality is deteriorating (Couédel, et al., 2025). In concrete terms, negative impacts are visible on the productivity and resilience of cropping systems. It is therefore more necessary than ever to continue efforts in soil conservation.

Research projects implemented in Benin, such as MecaWAT¹ and TAZCO², but also the activities led by the National Society of Agricultural Mechanisation (SoNaMA) of

¹Mechanization and Work in Agroecological Transitions (Benin, Ghana, Côte d'Ivoire). <https://www.cirad.fr/en/worldwide/cirad-worldwide/projects/mecawat-project>

²Agroecological Transition in Cotton Areas (Benin) <https://www.cirad.fr/en/worldwide/cirad-worldwide/projects/tazco-2-project>



Benin, promote conservation agriculture (CA) practices. CA is based on three pillars:

- 1) Minimising (or even eliminating) tillage through direct seeding or no-till techniques. The aim is to disturb the topsoil, where the most living and fertile elements are found, as little as possible.
- 2) Maintaining permanent soil cover by leaving residues from the previous crop on the ground (mulch) and by planting cover crops between harvests; these cover crops protect the soil surface, maintain moisture, feed soil microorganisms and compete with weeds.

Diversifying and extending crop rotations to take advantage of the complementary nature of the species grown on the same plot. This breaks the weed cycle and also limits the development of fungal or microbial diseases.

In Benin, CA practices are disseminated at various levels to reinforce integration in crop systems: training areas, agricultural technical high schools, and farmers' fields. In 2025, SoNaMA began to scale up CA practices through training sessions and demonstrations for groups of farmers. One

of these experiments took place in Bembèrèkè area, north of Borgou department.

For this first year, strip-tillage was promoted. Strip-tillage consists of ploughing localised furrows in the field. These furrows are the sowing lines. The first step was to change the tool behind the tractor, to put a strip-tiller instead of disc plough. By recording the dates of agricultural operations, it was possible to understand how farmers adapt or not their crop system when they change their tool. This study focused specifically on this point.

Materials and Methods

Study area:

The promotion and monitoring of strip-tillage were conducted in 2025 in the area of Bembèrèkè, located in the Borgou department in north-central Benin (Figure 1). The region is characterized by a unimodal rainfall pattern, with a single rainy season extending from May to October. Rainfall regularity has increasingly been affected by climatic variability. Farming systems in the area are dominated by cotton, maize, and soybean production.



Figure 1. Map of Benin and location of Bembèrèkè region (Illustration provided by Encyclopaedia Universalis under CC BY-NC licence)

Plot selection

The study monitored 23 cotton plots, representing a total of 107.8 hectares, where strip-tillage was implemented following training sessions and field demonstrations organized by SoNaMA. Training sessions were focused on strip-tillage technique. They took place in three stages after the farmers had been grouped together: 1) explanations of strip-tillage

techniques, 2) presentation of the equipment used, and 3) demonstration in the field. The demonstration of strip-tillage took place in a volunteer farmer's field. The demonstration was carried out using a tractor belonging to a local service provider and with his own equipment. These factors enable farmers to consider strip tillage as an affordable and accessible technique.



After the demonstration, some farmers accept the monitoring of agricultural operation in their strip-tilled field. These selected fields were based on the farmers' voluntary participation. So, the study therefore corresponded to on-farm monitoring under real production conditions.

Data collection and statistical analysis:

Crop monitoring was conducted through regular field visits by an agricultural mechanization specialist from SoNaMA. Data were collected using the KoboCollect tool. Recorded variables included strip-tillage date, sowing date, sowing method, fertilizers and pesticides application dates, and yield. Less than one week before the harvest made by the farmer, the agricultural mechanization specialist harvested three sub-plots of 4 m² in each monitored plot to evaluate the yield.

Data processing and statistical analyses were performed using RStudio software (R software environment). Descriptive statistics were computed to characterize farmer practices. Inferential analyses were

conducted to test relationships between management practices and yield. Statistical significance was assessed at $p < 0.05$.

Results:

Using strip-tillage in fields

The average size of strip-tilled plots was 4.7 ha. This figure is high compared with the average farm sizes in northern Benin, around 2 ha, and because a farm is composed by one or more plots (MAEP, 2017). It underlines the interest of farmers for innovations and new practices. Farmers interested in these practices come from big.

Almost 85 % of farmers have carried out strip-tillage themselves. Farmers testify interest and adaptation of their equipment to this new practice. The equipment is usually a cultivator with aligned tines designed for working in strips (Figure 2). The average working depth observed was 15,2 cm. Operations were performed just before or after a rain around mid-May, with a mean intervention date of 17 May 2025.



Figure 2: Demonstration of strip-tillage with a group of farmers in Benin, April 2025

Crop management:

Cotton sowing systematically began with seed treatment. Seeding rates ranged between 10 and 20 kg.ha⁻¹ (average 13 kg.ha⁻¹). No re-sowing was reported, although thinning was conducted in 34,7% of cases. Commonly, thinning was done at 2 plants per seed hole.

Fertilizer applications generally followed national recommendations provided by IRC (Cotton Research Institute, Benin). According to information provided by farmers, the average quantities applied per hectare were 100 kg of SSP (Single Super Phosphate), 100 kg of NPKSB (Nitrogen, Phosphorus, Potassium, Sulphur, and Boron), and 50 kg of urea.

Two sowing periods:

Among the 23 monitored cotton plots, farmers sowed during two periods (Figure 3): around 6 June (day 157 of the year) and around 4 July (day 185 of the year). Although recommendations for north-central Benin suggest sowing between June 10 and June 30 (Amonmide, Fayalo, & Dagbenonbakin, 2020), farmers did not follow these recommendations.

Based on these 23 cotton plots and the corresponding dataset, we found no statistically significant correlation between sowing date and seed-cotton yield both overall for all 23 plots (p-value=0.16) and for the 14 plots sown in June (p-value=0.20) or the 9 ones sown in July (p-value=0.87).

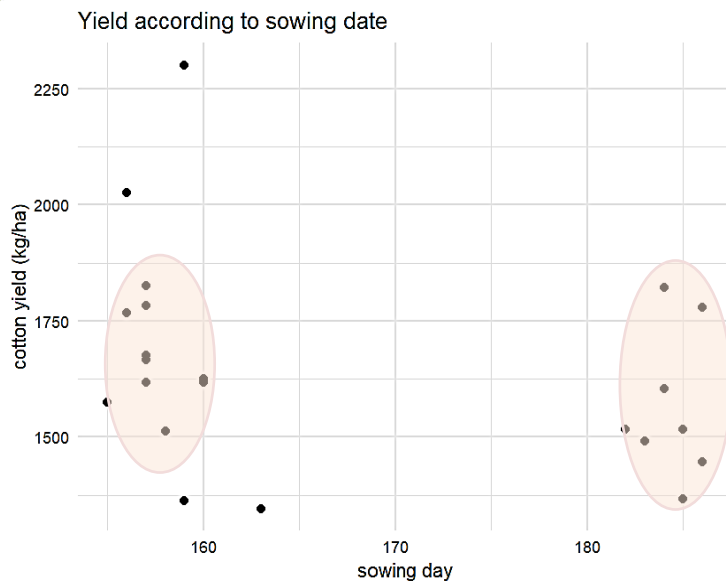


Figure 3: Link between sowing dates and seed-cotton yield for the 23 monitored cotton plots

Different sowing methods

Although farmers own tractor-mounted seeders, which are supplied as part of a kit sold with their tractor, most of them used to sow either by hand or using a hand-operated seeder wheeled seeder (**Error! Reference source not found.**). Data showed that the choice of a sowing method

was not significantly related to plot size. Manual sowing occurred on average 25 days after strip-tillage, compared to 17 days when they use a hand-operated wheeled seeder (**Error! Reference source not found.**).

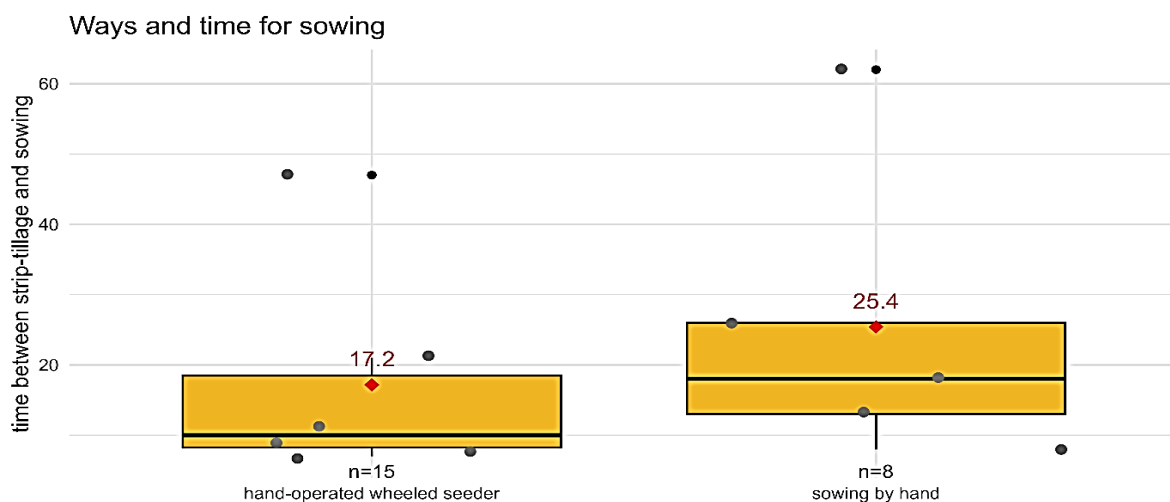


Figure 4: Link between sowing methods and time (in days) after strip-tillage for the 23 monitored cotton plots.



Figure 5: Hand-operated wheeled seeder

As the choice of sowing method does not depend on plot size, the relevant recommendations take into account the availability of hand-operated wheeled seeder from service providers, soil moisture and sowing speed.

Yield improvement with proper SSP use

SSP is a relatively new fertilizer in Benin. Its increasing use is linked to rising prices and limited access to NPKSB, the main fertilizer in Benin for a long time (Abiolos, 2024). Its recommended application date is

around the sowing time, due to its role in plant growth.

Among the 23 monitored cotton plots, SSP was applied either at sowing (recommended date) or around 30 days after sowing (Figure 6**Error! Reference source not found.**). Yield analysis showed a statistically significant difference ($p < 0.05$), with a seed-cotton yield gap of approximately 100 kg ha^{-1} in favour of the recommended date (Figure 6**Error! Reference source not found.**).

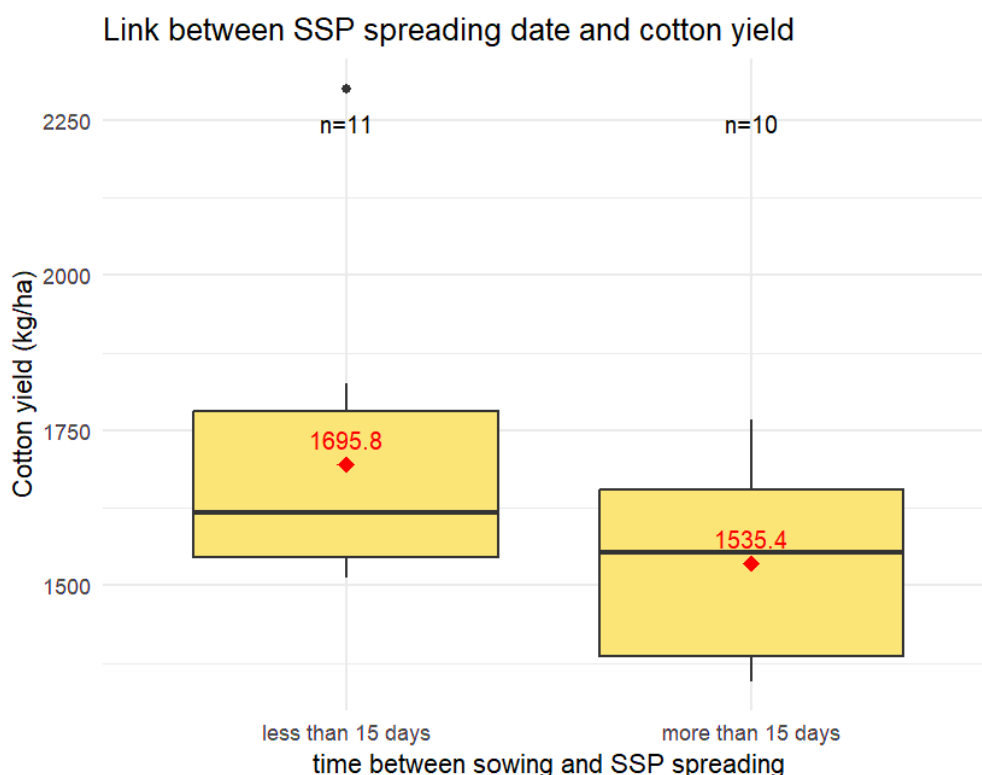


Figure 6: Average seed-cotton yield according to time between sowing and SSP spreading for the 23 monitored cotton plots

Conclusion:

Farmers are keen to try strip-tillage, seeking solutions to their many problems: soil fertility degradation, erosion, production costs. However, the implementation of strip-tillage requires adjustments to the cropping systems. They face national recommendations based on conventional tillage, whether manual or mechanized. There are no specific recommendations for strip-tilled cropping systems. Actually, farmers are not adapting their cropping system sufficiently to this new technique: soil preparation and sowing date are similar to conventional system, and herbicides and fertilizers are

used in the same way in conventional tillage.

Whilst talking to these farmers, we learnt that they lacked technical information on how to manage their cropping system in strip-tilled plots. Therefore, continued farmer support is essential to strengthen conservation agriculture-based mechanized cotton systems. Respecting recommended sowing periods, improving appropriate tools, and ensuring suitable pesticide application regimes are priority actions.

In order to improve farmers' mastery of sowing techniques, an initial set of actions would involve conducting a survey to



understand (i) why farmers do not use their mechanical seeder, (ii) why they prefer to sow by hand or with hand-operated wheeled seeder, and (iii) to what extent access to labour is difficult through service provision. Based on the results of this survey, SoNaMA could organise training sessions for farmers on the use and adjustment of mechanical seeders.

In order to preserve soil health, a second set of actions would involve (i) training farmers to understand how their cropping systems work and (ii) improving these systems by drawing on strip-tillage, based on conservation agriculture practices, through diversified farming practices (use of biomass, cover crops, biochar, compost, etc.) and a co-design approach.

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