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Productivity and economics of *Bt* cotton based cropping system under different nutrient levels to *rabi* crops to enhance resource utilization: A review

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Abstract

The *Bt* cotton (*Gossypium hirsutum* L.) technology is highly suited for all conditions including rainfed and irrigated. However, the unsuitability and the low productivity of cotton in rainfed regions is only especially related to the long duration hybrids that suffer moisture stress at boll formation stage, due to poor water retention of shallow soils. Cotton varieties available now a days are mid-late duration and are mostly grown by the farmers, which do not permit to cultivate second crop immediately. Small and marginal cotton growers of the country face different constraints mainly due to climatic aberrations and increase in inputs costs results in decreased profits. Due to advancement of technology, the early or short duration *Bt* cotton hybrids are now available in the market. By cultivating the early *Bt* cotton hybrid, it becomes possible to harvest cotton early and permits for timely sowing of sequence crops in *rabi* season. Studies from different areas in India showed that diversified cotton production systems can surpass cotton monocropping systems in profitability and diversify the risks. Under such circumstances, sequential cropping provides additional returns, improve soil quality, enhances bio-diversity and ensures greater use of resources. Cotton is considered as exhaustive crops demanding heavy nutrition when grown as individual crop. Use of general recommended dose of fertilizer to *kharif* cotton crop and to succeeding crop in next season may prove a viable option for sustaining the productivity of cotton based cropping sequence. This consolidated review integrates evidence from a diverse array of cropping system, its influence on sequence crop and effect of *rabi* crops in next season and highlights the advantages of cotton based cropping system based on previous research findings. It can be concluded that under cotton-based cropping system there is efficient use of resources resulting in not only high productivity from unit area but also high profitability provided with recommended dose of fertilizer, beneficial for better monetary returns.

Keywords: Cropping system, nutrient management, *rabi* crops, system productivity, system profitability, production efficiency

1. Introduction

Cotton belongs to the genus *Gossypium*, family Malvaceae. India is the only country in the world where all the four cultivated species of cotton are grown on a commercial scale besides hybrids (both inter and intra specific). Cotton (*Gossypium hirsutum* L.) is known as 'King of Fibre Crops' due to its global and industrial importance, commonly known as 'White Gold' in farming community. The area planted with *Bt* cotton hybrids increased from a meager 50,000 ha in 2003 where as at present it occupies more than 97% of the total cotton acreage. Maharashtra occupies one-third of the area under cotton in the country but less than 10% of the area is irrigated. Vertisol and associated soils are the major soil types in the region (Blaise, 2017) [3]. About two-third of cotton area in the country is rainfed and faces different abiotic stresses during the growing season. Production in India is projected to grow by around 2% p.a. over the next decade, mainly on account of yield improvements rather than area expansion since cotton already competes for land with other crops such as soybean and pulses. Cotton is traditionally grown on small farms, which limits the adoption of intensive farming technologies. Again farmers in India allocate more row space between plants to accommodate the passage of bullock and cultivator for weed control purposes, reducing plant density and overall yield potential. The outlook assumes a high yields growth potential at 1.7% p.a. over the next decade, enabling India to surpass China as the world's largest

cotton producer by 2034 (OECD/FAO, 2025) [23]. The Indian textile industry contributes around 5% to country's gross domestic product, 14% to industrial production and 11% to total exports earnings. Cotton industry provides employment to over 51 million people directly and 68 million people indirectly, including unskilled women (Berwal, 2020) [2]. Population predicts that India's population will increase from 1.5 billion in 2030 and 1.67 billion in 2050 (United Nations, 2019) [33]. Accordingly, India will need to produce 311 million tonnes of foodgrains by 2030 and 350 MT by 2050 to meet the need of population (Kumar and Sharma, 2020) [17]. Out of the of the total geographical area (328.7 m ha), nearly half is arable (159.7 m ha) and only 42.6% (about 140 m ha) is actually cultivated, that has remained static over decades, therefore no scope for horizontal expansion. Hence, in order to feed India's growing population from limited resources, an increase in crop productivity is imperative (Gulati *et al.*, 2023) [14]. As horizontal expansion to augment the food production is limited, the alternative way is to move on vertical growth by enhancing the productivity of the area. Hence, sequential cropping for increasing the cropping intensity as well as production per unit area per unit time is now gaining ground for improved production (Kanwar and Sekhon, 1998) [16]. Hence, efforts are needed to include, promote and diversify the cotton-based cropping system in the country with high-value crops for sustaining the productivity and meet out demand for pulses, oilseeds and vegetables. Hence, selection of component crops needs to be suitably planned to harvest the synergism among them towards efficient utilization of resource base and to increase overall productivity (Singh *et al.*, 2017) [8]. Therefore, the present review is taken to discuss most productive, resource-use efficient and remunerative cotton based cropping system that may help to boost the economic condition of small and marginal farmer.

2. Effect on Cotton

2.1. Effect of cropping system on growth and growth attributes of cotton.

Cotton being a crop of indeterminate growth habit continued to grow till its final uprooting. It is revealed that total dry matter per plant increases gradually at every stage of crop growth up to maturity. Sequence cropping promotes vegetative growth and increases plant height, number of leaves and fruiting branches. The cotton crop sown after legume produced tall plant, higher production of monopodia, sympodia in sequences i.e. cotton (before legume)- cotton (after legume) and among the tested fertilizers RDF recorded maximum value for above parameters (Kumbhar *et al.*, 2008) [18]. Application of 100% RDF through inorganic fertilizer recorded significantly higher plant height, sympodial branches plant⁻¹, dry matter plant⁻¹ in sequence cropping of cotton+soybean -safflower. (Turkhede *et al.*, 2017) [20].

2.2 Effect of cropping system on yield components and yield of cotton

Sequence cropping promotes reproductive growth and increases number of square and bolls and boll weight. The cotton cultivar with relatively shorter or early growth duration is strongly recommended for wheat-cotton double cropping systems in China (Dua *et al.*, 2016) [8] to get yield advantage. In cotton belt of Maharashtra (Latkar *et al.*, 2024) [19], revealed that mid-late sole in *Bt* cotton-summer groundnut cropping system noticed the highest number of bolls plant⁻¹ (23.5 and 23.1 bolls plant⁻¹) and comparatively more days to bloom 50 per cent flowering than rest of cropping systems. Also recorded significantly highest seed cotton yield in *kharif* cotton-summer groundnut system (2005 kg

ha⁻¹) over rest of the cropping sequences. In different cotton based rotations, the highest total cotton yield (cotton yield+CEY) was obtained in cotton-wheat followed by cotton-chickpea, cotton-barley, cotton-field pea, cotton-mustard and cotton-fallow, also recorded significantly higher seed cotton yield due to RDF applied in cotton+chickpea cropping sequence (Singh *et al.*, 2003; Gudadhe *et al.*, 2015; Charjan and Gaikwad, 2001) [29,12,4]. Inclusion of leguminous crop at least once in a two year cropping sequence is necessary for maintenance of soil fertility and enhancement of crop productivity. The cotton crop sown after legume produced more bolls, heavier seed index, maximum GOT, better staple length, higher oil content, superior seed cotton yield. Among tested fertilizers, RDF recorded above parameters at maximum (Kumbhar *et al.*, 2008) [18]. The residual effect of 100% RDF applied to chickpea had also significant influence on the green fodder yield and dry fodder yield of succeeding fodder sorghum (Chaudhari *et al.*, 2022) [5].

2.3 Effect of cropping system on quality parameters of cotton

It is observed that the cotton quality parameters viz., ginning%, micronaire value (mg inch⁻¹), UHML (mm), bundle strength (g tex⁻¹), uniformity index (%), elongation (%) were not much affected due to different organic and inorganic nutrient sources except the lint index. The cotton crop sown after legume produced higher yield attributes, yield and higher oil content (Kumbhar *et al.*, 2018) [18].

2.4 Effect of cropping system on nutrient uptake by cotton

The cotton crop sown after legume measured increased N- uptake in cotton-onion cropping system (Kumbhar *et al.*, 2008) [18]. The application of 100% RDF recorded significantly higher nutrient uptake in wheat sown after cotton over 75% RDF. This might be due to addition of more NPK into the soil through fertilizer reported in cotton - wheat sequence on Vertisol (Charjan and Gaikwad, 2001) [4].

3. Effect on *rabi* or sequence crops

3.1 Effect of nutrient management on growth and growth attributes of sequence crops.

Cropping system and nutrient management are the important factors which affect the growth and growth attributing characters of the plant. The residual effect of general recommended dose of fertilizer (10 t FYM ha⁻¹ + RDF) applied to cotton was recorded significantly higher values of chickpea in respect of different growth attributes of chickpea in hybrid cotton-chickpea cropping sequence (Gudadhe, 2008) [11]. In chickpea 100% RDF + FYM 5 tonne ha⁻¹ + *Rhizobium*+ PSB was ahead in recording recorded significantly higher almost all growth characters (Raut *et al.*, 2028) [28]. The effect of inorganic fertilizer, biofertilizers on chickpea growth as well as their residual effect on succeeding fodder sorghum revealed that 100% RDF (25-50 kg NP ha⁻¹) had significant influence on growth attributing characters like plant height, number of branches plant⁻¹, number of nodules plant⁻¹ of chickpea as compared to 75% RDF (Chaudhari *et al.*, 2022) [5].

3.2 Effect of nutrient management on yield components and yield of sequence crops

The earliness associated with *Bt* hybrids ensures timely sowing of the succeeding *wheat* crop and enhanced wheat yields (Mayee *et al.*, 2008) [21]. In cropping system residual effect of first crop results on succeeding crop and succeeding crop residual effect occurs on the crop sown in next season. Increased fertilizer levels increased protoplasmic constituents and accelerated the process of cell division and elongation which in turn increase the value of

yield attributes and finally the yield (Charjan and Gaikwad, 2001)^[4] in cotton - wheat sequence and stated that, application of 100% RDF to wheat recorded significantly higher wheat grain and straw yield. Significant increase in higher grain and straw yield of wheat (*Triticum aestivum* L.) due to 100% RDF (Joshi *et al.*, 2024)^[15]. The increase in chickpea grain yield due to addition of FYM to preceding cotton resulted in improvement in soil structure which reduced the soil crusting and also serve as a source of energy for soil microflora which resulted in better root nodulation and nitrogen fixation and (Gudadhe *et al.*, 2015)^[12] revealed that among subplot significantly superior chickpea grain yield was registered to 100% RDF followed by 75% RDF. The effect of inorganic fertilizers, organic manures and bio- fertilizers on growth and yield of *rabi* onion (*Allium cepa* L.) and its residual effect on succeeding crop okra was accessed concluded that application of 75% RDF of NPKS + 5 t ha⁻¹ poultry manure gave significantly better yield from onion and its succeeding crop okra by utilizing residual effect of treatment (Mahala, 2022)^[26].

3.3 Nutrient uptake by sequence crops

The better nutrient utilization by more healthy and vigorous plants under recommended level of fertilizer results into more dry matter accumulation, which ultimately increases the total uptake of NPK ha⁻¹. In wheat the total uptake of N, P and K were found significant and increased with the increase in levels of fertilizer (Auti *et al.*, 1999)^[1]. hybrid cotton-chickpea cropping sequence the residual effect of general recommended dose of fertilizer (10+1)(10 t FYM ha⁻¹ + RDF) on chickpea recorded significantly higher nutrient uptake (Gudadhe, 2008)^[11].

4. Biological studies

Application of organic manure plays a crucial role in cropping system. Organic plant nutrients reduces the soil pH due to microbial degradation and production of organic acids from applied organic manures, may be due to decomposition of added organic matter in soil which improves the physical properties of soil. About chickpea, maximum bacterial and fungal population was found in control at 32.18 x 10³ and 27.67 x 10³, respectively (Ojha *et al.*, 2014)^[24]. However maximum population of actinomycetes was recorded by application of 100% RDF as reviewed (Gudadhe *et al.*, 2015)^[12] under cotton-chickpea cropping system under rainfed cotton (Ghodpage *et al.* 2009)^[9]. The biological indicators like microbial population, DHA, MBC and MBN were found to be comparatively higher in *Bt* grown soils than their non *Bt* counter parts over a period of 10 years. When legumes are introduced in a crop rotation, macroaggregate formation increases because of deep roots, leaf drop, increased rhizosphere activity,

5. Cropping system and nutrient management

5.1 Nutrient uptake by cropping system

Pulses are an integral part of the cropping system because these crops fit well in crop rotation. It also plays an important role in sustaining soil productivity by improving its physical, chemical and biological properties and trapping atmospheric nitrogen in their root nodules. In cotton - wheat sequence, application of 100% RDF recorded significantly higher nutrient uptake and soil available NPK after cotton over 75% RDF. This might be due to addition of more NPK into the soil through fertilizer (Charjan and Gaikwad, (2001)^[4]. The cotton crop sown after legume increased N uptake (Kumbhar *et al.*, 2008)^[18].

5.2 Nutrient status of soil after system harvest

In sequence cropping there is more efficient use of resources like

nutrient and water leading to increased biological diversity, higher production stability and restoring soil fertility. For example, when legumes are introduced in a crop rotation, macroaggregate formation increases because of deep roots, leaf drop, increased rhizosphere activity, and root exudates. The treatment of inorganic, organic and Azotobacter combined sources of N on cotton that included FYM, improved or maintained the soil fertility status in terms of available N, P, K in cotton-wheat system (Das *et al.*, 2004)^[6].

5.3 Water use efficiency of cotton based system

Water use efficiency can be increased by increasing the yield. The earliness associated with *Bt* hybrid could be exploited to design more efficient cotton based cropping systems. Introduction of *Bt* cotton also gives scope for raising some short duration sequential crop wherever supplemental irrigation is available. The maximum water use efficiency was recorded in rotation with pulse crop (cotton-chickpea and cotton-field pea) followed by cotton-wheat. Higher water use efficiency of rotations with pulse crop was due to the lower water requirement and positive effect on second year cotton crops consisting of cotton (*Gossypium hirsutum*) in summer followed by wheat, chickpea (Singh *et al.*, 2003)^[29].

5.4 Influence on system productivity, profitability and production efficiency

Developing eco-efficient cropping systems in cotton fields that are productive and sustainable is key in increasing productivity and economic benefits. Cropping system is a planned sequence of multiple crop species grown in recurring succession on the same area of land. Cotton-based rotation is an important way to increase productivity in agro-ecosystems. Cotton-based rotations also increase profitability, a key factor influencing farmer decisions to adopt a crop rotation (Dhaliwal, 2015)^[7]. Legumes are a viable option for small landholders using cotton-based cropping in India. Cotton-legume rotations have been widely adopted in India because of increased profitability. Thus, productivity and economic benefits are greater with cotton-based rotations than with continuous cotton, when rotated with legumes (Turkhede *et al.*, 2032)^[32] different crops are grown in sequence, its individual outcome could have only be compared when their equivalent production is assessed. The highest cotton equivalent yield was obtained for wheat followed by chickpea, where cotton in summer followed by wheat and chickpea during winter (Singh *et al.* 2019)^[29]. Significantly higher cotton equivalent yield obtained with *Bt*. cotton-groundnut (5288 kg ha⁻¹), followed by *Bt*. cotton-okra (4459 kg ha⁻¹) cropping systems (Rathod *et al.*, 2016)^[27]. The various treatments combination of cotton+soybean - safflower with application of 100% RDF through inorganic fertilizer recorded significantly higher cotton equivalent yield, RWE (2.91 and 2.52), system productivity and profitability (8.25 and 7.43 kg ha⁻¹ day⁻¹ and 179.80 and 136.28 Rs. ha⁻¹ day⁻¹) (Turkhede *et al.*, 2017)^[32]. The application of 10 t farmyard manure ha⁻¹ + 100% recommended dose of fertilizer (100:50:50 kg NPK ha⁻¹) to cotton followed by 100% RDF or 75% RDF to chickpea produce higher cotton equivalent yield and economic returns in cotton-chickpea cropping sequence (Gudadhe *et al.*, 2015)^[12]. Medium duration *khariif* cotton cultivar (PDKV JKAL-116) - summer groundnut (TAG-24) cropping system recorded significantly the highest crop equivalent yield (4120 kg ha⁻¹) Whereas, *khariif* cotton with early duration cultivar (Ajit-5) - *rabi* chickpea cropping system recorded the highest system profitability of Rs. 449 kg day⁻¹ ha⁻¹, highest production efficiency of (1238 khha⁻¹day⁻¹ which was closely followed by medium duration *khariif* cotton-summer

groundnut system profitability (Rs. 430 kg day⁻¹ ha⁻¹) (Latkar *et al.*, 2024) ^[19]. Cotton-onion cropping system was ahead in recording significantly greater cotton equivalent yield (9.45 t/ha), production efficiency (27.0 kg ha⁻¹ day⁻¹) and economic efficiency (736.9 ha⁻¹ day⁻¹) (Paul *et al.*, 2015) ^[26] where as significantly higher production efficiency was obtained with Bt. cotton-groundnut (19.68 kg ha⁻¹ day⁻¹) cropping systems (Rathod *et al.*, 2016) ^[17].

5.5 Economics of cotton based cropping system

An ideal cotton based cropping system aims at higher yield and net profits per unit area, bring stability into the production system, ensure optimal utilization of the available resources, While studying different cotton based rotations revealed that maximum net returns were obtained from cotton-wheat followed by cotton-chickpea, cotton-barley, cotton field pea, cotton mustard and cotton. In the case of benefit cost ratio during first year the maximum ratio was observed in cotton-chickpea followed by cotton-wheat while during second year due to effect of winter crop on cotton (Singh *et al.*, 2003) ^[19]. In cotton - wheat sequence at Rahuri revealed that, net monetary returns, benefit: cost ratio, were recorded highest with 100% RDF to cotton. In cotton - chickpea system 100% RDF to cotton and chickpea registered higher net monetary returns and benefit cost ratio (Charjan and Gaikwad, 2001; Gudadhe *et al.*, 2016) ^[4,13]. Application of 10 t FYM ha⁻¹ + 100% RDF (100:50:50 kg NPK ha⁻¹) to cotton and to chickpea produce higher cotton equivalent yield and economic returns in cotton-chickpea cropping sequence (Gudhadhe, 2008) ^[11]. Application of 100% RDF through inorganic fertilizer recorded significantly NMR, B:C ratio (2.01 and 1.75) in cotton+soybean – safflower system (Turkhede *et al.*, 2017) ^[32]. Since cotton is a crop of longer duration, but availability of short duration or early Bt cotton in the market, offers a vast scope for growing of other premium crops in sequence immediate after harvest of early Bt or short duration cotton indicated that, medium duration *kharif* cotton cultivar (PDKV JKAL-116) - summer groundnut (TAG-24) cropping system recorded significantly the highest crop GMR (Rs. 231394 ha⁻¹), NMR (Rs. 152134 ha⁻¹) and B:C ratio of 2.92 (Latkar *et al.*, 2024) ^[19].

5.6 Nutrient balance

After sequence the net gain of soil-available N was increased with decrease levels of fertilizer and manures to cotton and increased with increased levels of fertilizer to wheat in cotton - wheat sequence. The magnitude was increased with increased levels of fertilizer and manures with respect to net gain of soil available P. While net loss of soil-available K, the magnitude of reduction was decreased with increased levels of fertilizer and manure (Charjan and Gaikwad, 2001) ^[4]. FYM play a most important role in cropping system it is reported that Nitrogen and P balance was positive in the fertilizer-N and P applied plots whereas K balance was negative in spite of the addition of fertilizer-K. Potassium balance was positive only when FYM was applied. This study suggest the advantages of FYM in cropping system. The maximum residual status of available nitrogen and potassium, was observed due to application of 100% RDF (Blaise *et al.*, 2005) ^[3].

6. Conclusion

Cotton based cropping system offers ample scope for utilization of available resources to improve crop productivity and ecological benefits by inclusion of important crops during rabi season. Cotton based cropping system is popular in India and research evidences clearly indicated greater resource use

efficiency in term of LER and cotton equivalent yield, system productivity, system profitability and system production efficiency. Application of 100% RDF cotton and to rabi crops increases the growth and growth attributes, yield and yield attributes of cotton and rabi crops due increase in uptake and improving soil nutrient status. Cropping system can increase soil nutrient and organic matter content and change soil microbiological diversity. These benefits are also reflected into economics of cotton cultivation recording highest GMR, NMR and BC ratio. It also creates the diversity due to cultivation of crops in sequence that reduces weeds, pests and pest population. Thus adoption of cotton based cropping system may be a suitable option to cotton growers to enhance yield, yield output from unit area as well as agricultural sustainability.

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