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Pulses are companion crop for soil fertility improvement and pest control in cotton (*Gossypium* species)

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ABSTRACT

In India, area under cotton (*Gossypium* spp.) increased from 7.8 million ha in 2002 to 12.8 million ha in 2014. The increased acreage of 4 million ha under cotton was at the expense of pulses, oilseeds and coarse cereals that are vital for our food security and crop diversity. Cotton becomes competitive crop for pulses. However, production of both the crops could be encouraged by making suitable intercropping of pulses in cotton. Pulses can act as companion crop for cotton, and introduction of nutrient-efficient pulse as an intercrop into the cotton production system is a sustainable way to improve soil health, reduce fertilizer use and also achieve eco-friendly pest management. Short-duration pulses as intercrop yielded 5–6 q of additional grain/ha. Intercropping of pulses was beneficial both in yield and economics as reported from many parts of the country. Biological nitrogen fixation, abundance and diversity of soil microorganism, improved soil structure, water-holding capacity, humus content, and organic carbon content were significantly improved by intercropping and subsequent incorporation of pulses in cotton. Phosphorus availability of soil is enhanced by intercropping of pulses. Roots of many pulses release carboxylic acids that solubilize phosphate ions from bound forms such as calcium and iron phosphates that are otherwise unavailable to plants and immobile in the soil. In mixed cropping system, out of total insect-pests, 53% showed lower abundance, 18% were more abundant, 9% showed no difference, and 20% were variable in the response as compared to sole cropping system. Pulse crops like urdbean [*Vigna mungo* (L.) Hepper], cowpea [*Vigna unguiculata* (L.) Walp.], soybean [*Glycine max* (L.) Merr.] and mungbean [*Vigna radiata* (L.) R. Wilczek] can be grown as intercrops in cotton for effecting integrated pest management (IPM). The intercrops mostly reduce the population of sucking pests of cotton, viz. aphid (*Aphis gossypii* Glover) and leaf hopper and to some extent of bollworm [*Pectinophora gossypiella* (Saunders)] as well. Moreover, these enable higher activity of spider and predatory ladybird beetles. In terms of productivity, profitability, maintenance of soil health and fertility, and act as component of IPM, pulses are suitable companion crop for cotton.

Key words : Pulses, Cotton, Companion crop, Soil fertility, Pest control

INTRODUCTION

In India, area under cotton (*Gossypium* spp.) increased from 7.8 million ha in 2002 to 12.8 million ha in 2014. The increased acreage of 4.0 million ha under cotton was at the expense of pulses, oilseeds and coarse cereals that are vital for our food security and crop diversity (Venugopalan *et al.*, 2016). With the widespread adoption of Bt cotton (*Gossypium hirsutum* L.), the area under hybrid cotton increased from 40% in 2001 to 93% in 2015. As a result, the area under *G. barbadense* L., *G. arboreum* L. and *G. herbaceum* L. which was 6.6, 25 and 13% during 1995, has now declined to less than 2.0% for all the three species together. Pesticide usage significantly reduced soon after the introduction of Bt hybrids. However, there is an increasing trend after 2006. Recent reports have confirmed the resistance for pink bollworms in Bollgard II at Gujarat, warranting insecticide usage against this pest. There has been a reduction in partial factor productivity of fertilizers and increase in the cost of production (Suresh *et al.*, 2013). The investment on fertilizers in cotton almost doubled in some states and there was a significant reduction in seed-cotton yield per kg of fertilizer applied in the states of Andhra Pradesh, Haryana, Punjab, Tamil Nadu and Maharashtra between 2001 and 2011. This decline in partial factor productivity for fertilizers could be an indicator of a decline in soil health or a nutrient imbalance which might be a reason for yield stagnation (Venugopalan *et al.*, 2016). Introduction of nutrient-efficient pulse crop as an intercrop into the cotton production system is a sustainable way to improve soil health, reduce fertilizer use and also achieve eco-friendly pest management (Kranthi, 2014).

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ENHANCED NUTRIENT USE

Hybrids are known for vigorous growth owing to the heterotic effect making them more responsive to fertilizers input. As a result, the recommended dose of nutrients are higher than that of *desi* and *hirsutum* cotton varieties. Compared to *desi*, nutrient removal per kg of seed cotton is greater with hybrids (Venugopalan *et al.*, 2007). Hybrids with high-yielding genetic make-up require higher nutrient inputs to realize their yield potential. Application of N alone was sufficient to realize high yields in the initial years, but yield declined in subsequent years. Soils, especially Vertisols and Vertic-intergrades, where cotton is dominantly cropped, have a very low P status and high P-fixing capacity. Response to N cannot be expected if P is not supplied and P application soon became an integral practice (Mannikar and Venugopalan, 1999). With advancing time, fatigue was noticed even with fertilizer N, P and K at the recommended doses. Under irrigated conditions, Bt cotton response was substantial even at 125–150% of the fertilizer dose (Venugopalan *et al.*, 2009)

SOIL ORGANIC CARBON STOCKS

Vertisols and associated soils in the semi-arid tropics of Southern India have higher total soil carbon stock than Inceptisols and Alfisols (Venkanna *et al.*, 2014). Despite this, major cotton-growing area in India is poor in organic carbon, low in available nitrogen, poor in available P and medium to high in available K. In some soils, despite application of recommended dose of fertilizers, yields reduced in the absence of organic manure (Chittapur and Shenoy, 1998). The fertility of the cotton soils (alluvial soils of North India and Alfisols and Vertisols of Western and Southern India) is depleting day by day due to exhaustive nature of hybrid based-cropping systems in comparison to conventional varieties. Fertility of these soils needs to be maintained through supplementation of organic manures and intercropping with pulses for biological nitrogen fixation along with application of chemical fertilizers (Singh *et al.*, 2013). Several studies in the black soil regions of India clearly indicate that cotton–legume systems perform well in terms of soil organic carbon (SOC) sequestration throughout the sub-humid, semi-arid and arid bioclimatic zones in comparison to other cropping systems and hence cotton–legume combination (intercrop or rotation) with proper management interventions appears to be a good management protocol, for improving SOC stocks (Chaudhury *et al.*, 2016).

INTERCROPPING OF PULSES IN COTTON–HOW AND WHY?

Amongst different available approaches to improve soil fertility, intercropping with legumes is one of the options followed in many countries, mainly by small-land holders and resource-poor farmers. Traditional sources of organic manure like farmyard manure (FYM) have become scarce and costly because of higher cost involved. Under these situations, suitable agronomic practices have to be followed within the farm to improve soil health. Intercropping of cotton with pulses has long been recognized as a cultural practice for enriching soil fertility. Inclusion of pulses like urdbean, mungbean, clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] and soybean [*Glycine max* (L.) Merr.] as intercrop in cotton traditionally played a multi-beneficiary role by providing enhanced yield, improving soil fertility and insuring rainfed farmers against risk of total crop failure (Singh *et al.*, 2011) and improve stability of the cropping system. Intercropping in cotton can be remunerative with additional returns, from point of view of soil-restorer grain legume with low water requirements besides better utilizing the stored soil moisture which otherwise is subjected to evaporative loss or removal by weeds. It is reported that intercropping is spread over 12 million ha in South Asia (Woodhead *et al.*, 1994). The scope for increasing the area under short-duration pulses like mungbean, urdbean and cowpea as a sole crop is limited only as a catch crop, as other-wise farmers find them less remunerative. However, pulses can be grown as an intercrop in cotton which has a slow initial growth and a wide row spacing is adopted (Kairon and Venugopalan, 2000).

Integrating pulses into cropping systems with cotton has the potential for enhancing production of pulses to reduce imports substantially. Further, establishment of a nutrient-efficient and sustainable cotton–pulses-based cropping systems has a potential to reduce urea application in cotton at least by 50% (1.5 million tonnes) worth ₹600 billion at current price (Kranthi, 2015). Many cotton based copping systems were developed, comprising cotton with nitrogen-fixing pulses, viz. urdbean, peas (*Pisum sativum* L.), lentils (*Lens culinaris* Medikus), clusterbean, mungbean, French bean (*Phaseolus vulgaris* L.), pigeonpea [*Cajanus cajan* (L.) Millsp.], gram or chickpea (*Cicer arietinum* L.) etc. that could reduce dependence of chemical fertilizers significantly.

The agro-ecology approach in understanding insect population dynamics and pest management was proposed by Altieri (1983). In mixed-cropping system, out of total insect-pests, 53% showed lower abundance, 18% more abundance, 9% showed no difference, and 20% were found variable in the response as compared to sole cropping system (Risch *et al.*, 1983). Sometimes, multiple cropping systems are favoured, as insects were less prevalent than in sole crops (Altieri and Liebman, 1986). Mechanical barriers may be present in the form of non-host plants, insects may leave the field more quickly if it is not a pure crop stand, or there may be differences in either the microclimate or the natural enemy population in the intercrop compared to a sole crop environment. There existed a complex interaction of biological, physical and climatic conditions of the intercrop system to provide an 'associational resistance' to insects, compared to sole crops of component species (Tahvanainen and Root, 1972).

Effect on productivity and profitability

Intercropping of mungbean (mung) in cotton in 1:1, 1:2 or 2:1 row ratios was beneficial both in yield and economics as reported under irrigated conditions of Punjab, Haryana, Andhra Pradesh, Karnataka and Tamil Nadu (Chittapur, 2004). Short-duration legumes like mungbean and urdbean as intercrop yielded 5–6 q of additional grain/ha with minimal impact on seed-cotton yield (Mudholkar and Basu, 1995). At Nanded (Maharashtra), pigeonpea as an intercrop in *desi* cotton gave similar seed-cotton yields to that obtained in sole cotton. Although no beneficial interaction was realized in Punjab, Haryana and Delhi, intercropping trials at Guntur, Andhra Pradesh recorded consistently higher monetary returns with reduced pest incidence and weed menace.

In few cases also, intercropping decreased the yield in cotton significantly. Yet these not only covered the loss accrued due to yield decrease in main cotton crop, but also raised overall productivity (Khan and Khaliq, 2004). Higher net field benefit was obtained from cotton + mungbean over sole cropping of cotton. Similarly, cotton + urdbean raised in paired-row system (2:1) resulted in highest mean seed-cotton-yield equivalent (1,815 kg/ha). In another trial, although cowpea suppressed the cotton yield, the reduction in yield was compensated by cowpea grain yield (Rusinamhodzi *et al.*, 2006).

In a rainfed system, growing of urdbean as an intercrop at 1:1 ratio had additional yield of 311 kg/ha of pulses (Sankaranarayanan *et al.*, 2011). Additional grain yield and higher market price associated with urdbean, cumulatively resulted in maximum seed-cotton equivalent yield. Intercropping of urdbean in cotton was remunerative with higher net monetary returns at many locations in Tamil Nadu, Karnataka, Andhra Pradesh and Madhya Pradesh (Tomar *et al.*, 1994; Wankhede *et al.*, 2000) over cotton + soybean [*Glycine max* (L.) Merr.] and sole cotton (Giri *et al.*, 2006). At Lam (Andra Pradesh), cotton planted in paired rows and intercropped with 3 rows of urdbean was most suitable for realizing higher monetary returns. At Dharwad (Karnataka), Lam and Nandyal (Andhra Pradesh), soybean intercropping proved remunerative. In field trial conducted at Banswara in Rajasthan, intercropping of urdbean, mungbean or cowpea in rainfed crop increased the net profit compared with sole cotton (Singh and Chauhan, 1981). Cotton intercropped with soybean, urdbean and mungbean also gave an additional profit of ₹1,057, ₹748 and ₹708/ha respectively (Patel *et al.*, 1995). A compilation on intercropping system reveals that all these systems recorded higher net returns/ha than sole crop of cotton and groundnut (*Arachis hypogaea* L.) (Koraddi *et al.*, 1991).

Effect on microbial population

Microbes play an important role in the availability and recycling of soil nutrients and also in-nutrient-storage capability of soils (Arancon *et al.*, 2006). Microorganisms play a vital role in soil fertility; thus help improve soil structure and texture, gas exchange, infiltration and soil-water retention and soil chemical and nutritional properties. The abundance and diversity of soil arthropods were significantly higher (79%) in legume-mulched plot. Restricted land preparation with direct seeding on mulch-based systems, favoured the establishment of diverse macro faunal communities in cotton cropping system (Brevault *et al.*, 2007). *In-situ* incorporation of intercropped residues of clusterbean registered significantly higher bacterial population (210 and 227 × 10^6 CFU/g), fungi (23.43 and 25.30 × 10^6 CFU/g) and actinomycetes (26.7 and 28.2 × 10^3 CFU/g) in dry soil during summer and winter season respectively. This was closely followed by *in-situ* incorporation of urdbean residue. The microbial population was low in the rhizosphere soil of sole cotton. The clusterbean intercropping added higher amount of organic matter, hence the highest population of microorganism was observed (Jayakumar *et al.*, 2009).

Effect on soil structure and organic carbon

Intercropping and subsequent incorporation of residue pulses could improve soil structure, water-holding capacity, humus content, and organic carbon content of soils (Leithold *et al.*, 1997; Jensen *et al.*, 2011), and reduce soil compaction by providing a continuous network of residual root channels and macrospores in the subsoil, penetrating soil hardpans (Jensen and Hauggaard-Nielsen, 2003; Peoples *et al.*, 2009). Gidnavar *et al.* (1992) reported an increase in soil organic carbon from 0.54% in sole cotton to 0.61–0.63% in intercropping systems of cotton with cowpea, soybean or horsegram [*Macrotyloma uniflorum* (Lam.) Verdc.], and this increase was equivalent to that obtained with the application of 10 tonnes of FYM/ha.

Effect on nitrogen fixation

Incorporation of pulses residue in cotton rows, favoured a higher rate of mineralization and steady release of nutrients to the soil pool. Lower demand of soil nitrogen by intercropped pulses and subsequently no loss of N from the soil leads to high legume effect (Muruganandam, 1984; Balasubramanian, 1987). Cotton + urdbean intercropping resulted in higher available nitrogen, which could be attributed to enhance N availability by atmospheric N fixation (Jayakumar *et al.*, 2009). The increased availability of N (237.9 and 163.2 kg/ha) was observed under cotton + urdbean intercropping system during summer and winter season respectively. However, it was on a par with cotton + mungbean intercropping system (Harisudan *et al.*, 2010). Satar (1983) revealed that nitrogen content of cotton plant was significantly higher in cotton + urdbean intercropping, owing to better N fixation by pulses. Similarly, Brajdar (1987) also indicated enhanced N uptake of cotton in cotton + urdbean intercropping system. The uptake of NPK was higher when cotton was intercropped with urdbean than soybean intercropping system (Giri *et al.*, 2006). Chellaiah and Gopalswamy (1996) noticed that more N was available in cotton + urdbean intercropping system than in sole cotton. Soybean added nitrogen through its root nodules up to 250 kg/ha besides releasing organic acids, enzymes and cytokinin known for increasing the cotton yield (Kesavan, 2005). Sankaranarayanan *et al.*(2012) estimated that higher available nitrogen (198.2 kg/ha) in multi-tier intercropping system involving cotton with clusterbean, vegetable cowpea and dolichos.

Effect on phosphorus availability and utilization

The major difference between legumes and non-legumes is that legumes are generally able to solubilize soil phosphates through root exudates (Nuruzzaman *et al.*, 2005) and the deep rooting of some species contributes to efficient nutrient utilization (Jensen and Hauggaard-Nielsen, 2003). Roots of many legumes release carboxylic acids that solubilize phosphate ions from bound forms such as calcium and iron phosphates that are otherwise unavailable to plants and immobile in the soil. The data on post-harvest soil available P status was significantly influenced by legumes particularly urdbean intercropping (18.65 and 16.58 kg/ha) during the summer and winter season respectively (Harisudan *et al.*, 2010). It might be due to decomposition of legume residues and increase in P solubilization. The organic materials form a cover on sesquioxides and thus reduce the phosphate-fixing capacity of the soil. This was in conformity with Kaleeswari *et al.* (2005), who reported that organic acids produced during decomposition of crop residues converted insoluble Ca, Fe and Al bound P into soluble and post-harvest soil available P through chelation and complex formation. Gidnavar *et al.* (1992) reported that *in-situ* incorporation of biomass of legumes has a potential for availability of soil-available P. However, reduction in residual phosphorus in urdbean intercropping system was due to the depletion of P by higher energy pulse crop (Solaiapppan, 1995). Satar (1983) revealed that phosphorus and potassium contents of plants were not influenced by cotton + urdbean intercropping.

Effect on potassium availability

Potassium status was not significantly altered in cotton-based cropping system (Harisudan *et al.*, 2010). This

Table 1. Increased efficacy of predators in multiple cropping systems

Cropping system	Pest regulated	Predators	References
Cotton + cowpea	*Aphis gossypii, Amrasca devastans*	*Menochilus sexmaculatus*	Natarajan and Seshadri (1988)
Cotton + mungbean/ soybean/ castor/sorghum	*Helicoverpa armigera*	Conservation of natural enemies	Jayaraj *et al.* (1990)
Cotton relayed with rape, wheat, sorghum and cotton	Aphid	Increased number of predators	Parajulee *et al.* (1997)
Cotton + safflower/ sorghum	*H. armigera*	*Chrysoperla*	Geetha (1994)
Cotton + cowpea	*H. armigera, Aphis gossypii*	*C. carnea*	Swaminathan *et al.* (1999)

Adapted from Praharaj *et al.* (2010)

Table 2. Effect of intercropping on the incidence of jassids and occurrence of coccinellids

Cropping system	Leafhopper	Coccinellids	Bollworm (%)	Parasitism on *Earias* sp.*	
				1985	1986
Cotton + cowpea	7.4 [a]	4.3 [a]	5.7	24.8 [a]	35.2 [a]
Cotton + soybean	6.5 [a]	1.6 [b]	5.1	40.6 [a]	32.9 [a]
Cotton alone	9.1 [b]	1.5 [b]	6.2	25.0 [b]	18.2 [b]

*Parasites: *Rogas aligharensis* (80% parasitization), *Agathis fabiae*
Source : Natarajan and Sheshadri (1988)

might be due to high potassium status of majority of the cotton-growing soils, and native potassium was adequate to meet the demand of cotton (Mannikar and Venugopalan, 1999). Similarly, there was also poor response of pulses to potassium. Solaiappan (1998) also reported similar results on available K after harvesting cotton + urdbean intercropping system. Satar (1983) revealed that potassium content of plants were not influenced by cotton + urdbean intercropping. Nevertheless *in-situ* incorporation of legumes grown between cotton rows has a potential to enrich soil available potassium (Gidnavar *et al.*, 1992).

PULSES AS COMPONENT OF INTEGRATED PEST MANAGEMENT

Pulse crops like urdbean, cowpea, soybean and mungbean can be grown as intercrops in cotton for effecting integrated pest management (IPM) (Puri *et al.*, 1999). These intercrops mostly reduce the population of sucking pests of cotton, viz. aphid and leaf hopper and to some extent of bollworm as well. Moreover, these enable higher activity of spider and predatory ladybird beetles (TNAU, 1999). Kadam *et al.* (2014) reported that intercropping systems were superior to sole cotton in respect of sucking-pest population and population of natural enemies.

Cotton + mungbean and cotton + urdbean were more effective intercropping systems that recorded the lowest incidence of sucking pests, followed by cotton + soybean and cotton + sesame (*Sesamum indicum* L.). Cotton intercropped with mungbean, urdbean, cowpea, soybean and sorghum [*Sorghum bicolor* (L.) Moench] recorded significantly less number of leaf hoppers due to increased activity of natural enemies population (Surulivelu, 2006; Sree Rekha *et al.*, 2008). Godhani *et al.* (2009) concluded that cotton intercropped with soybean enhanced the population of various natural enemies of insect-pests attacking cotton. Rajaram (2006) observed increased common green lacewing (*Chrysoperla carnea* Stephens) population when cotton was intercropped with cowpea, urdbean and mungbean.

Intercropping with urdbean reduced the intensity of bollworms (*Pectinophora gossypiella* Saunders) infestation in cotton (Mallapur *et al.*, 2004). There are evidences to show that the nature of volatiles emanated from the canopy of intercropped systems differed from that of sole cotton system. Whether this causes differential oviposition or any other disruption is not clear. In addition to control of pests, an intercrop of cowpea helps in colonization of coccinellid predators and also increased natural parasitization of *Earias vitella* Fabricius (Rajendran and Jain, 2004).

Cowpea planted as a bund crop encourages predators such as coccinellids, syrphids etc. which will keep the sucking pests under check. Cowpea is also a good eco-feast crop encouraging multiplication of coccinellids and other predators. Cotton ecosystem is abundant with natural enemies. Chrysopid is an important example and thus, recommended against the pests of cotton. The allelochemicals released by *Helicoverpa armigera* (Hübner) infested cotton found to induce attractant behaviour in several natural enemies. The abundance of *Chrysoperla carnea* in cotton intercropping is also reported by Swaminathan *et al.* (1999).

Pigeonpea mask the odour emanated from volatile compounds of cotton and offer less preference for oviposition by *Helicoverpa* in cotton. The lowest pink bollworm incidence was observed with cotton intercropped with soybean (Vennila, 2002). Intercropping also influenced the growth, development and maturity of cotton that, in turn, affected *P. gossypiella* damage. Pigeonpea served as an attractant crop for population of *H. armigera* emerging from cotton, implying the impact of chronology of cropping system determining host availability and population dynamics of the pest.

FUTURE LINES OF WORK

- Development of short-duration, early, determinate, compact and high-yielding genotypes of pulses to make them more compatible for intercropping in cotton.
- Identification and evaluation of suitable pre- and post-emergence herbicides selective to both the crops in cotton-based cropping systems.
- Creating awareness among farmers of non-adopted areas about the manifold advantages of pulses in order to popularize pulses in the cotton-production system.
- Identification of location-specific cotton-based pulse cropping system for further fine tuning to meet the multiple needs of the farmers.
- Standardization of planting geometry and development of appropriate machinery to facilitate sowing of cotton and intercrops.

CONCLUSION

In terms of productivity, profitability, maintenance of soil health and fertility, and component of IPM, pulses are suitable companion crop for cotton. Intercropping is a knowledge-intensive system and hence offers enormous scope for research in understanding the behaviour of cotton and component crops in terms of modification in architecture, crop development phase, pestilence, physiological efficiency and in turn exploit the synergy for economic advantage of the system.

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