Chapter 16
Cotton Relay Intercropping Under Continuous Cotton-Wheat Cropping System

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Abstract Cotton-wheat is an important cropping system of the world in which cotton is sown after harvest of wheat in the start of summer season. In the recent decades, Bt cotton cultivars have been introduced to better combat the bollworms. However, the Bt cotton cultivars have a growth period longer than the conventional cotton cultivars. This situation pressured the farmers to opt to grow either wheat or cotton in a single year. This not only could result in economic loss to farmers but also could threaten the food security of the cropping region. Relay cropping of cotton in wheat was suggested by an innovative solution for maintaining the productivity and sustainability of cotton-wheat cropping system. Relay cropping of cotton in wheat could be done either by inter-seeding the seeds of cotton in free space between the wheat strips (while wheat is at reproductive phase) or by transplanting the 5–7-week-old cotton seedlings between the wheat strips. Subsequent research work indicated that relay cropping could improve the resource use efficiency and overall productivity of the cotton-wheat cropping system. In a 2-year study in Punjab, Pakistan, conducted at two locations, intercropping cotton in bed−/ridge-sown wheat in early March improved the overall system productivity and cotton fiber quality as

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compared with conventionally tilled cotton sown after harvest of flat-sown wheat in late April. Future research may investigate the weed control and incorporation of conservation agricultural practices in the cotton-wheat relay intercropping systems.

Keywords Cotton · Wheat · Cropping system · Relay cropping

Abbreviations

BSW	Bed-sown wheat
Bt	*Bacillus thuringiensis*
BtCWCS	Bt cotton-wheat cropping system
CTC	Conventionally tilled cotton
RSW	Ridge-sown wheat

16.1 Introduction

Cotton (*Gossypium hirsutum* L.) is a cash crop in many countries of world, plays a role to provide livelihood to poor farming, and is a source for raw material for textile industry (Ahmad et al. 2014, 2017, 2018; Abbas and Ahmad 2018; Ahmad and Raza 2014; Ali et al. 2011, 2013a, b, 2014a, b). The leading cotton growers in the world are China, India, USA, Pakistan, and Turkey (Jabran and Chauhan 2019; Jabran et al. 2019). Cotton has unlimited uses and products and also possesses an inevitable role in the global economy (Jabran et al. 2019).

Globally cotton is grown as cotton-fallow as well as in-rotation with winter crops such as wheat (*Triticum aestivum* L.), etc. (Hulugalle et al. 2010; Ali et al. 2019). Major biotic stresses to cotton include insect pests, weeds, fungal pathogens, and viruses (Dogan et al. 2014; Jabran 2016; Saeed et al. 2016; Perge and Tolessa 2019; Razaq et al. 2019). Cotton-wheat is a popular cropping system and followed in several areas of world (Amin et al. 2017, 2018; Khan et al. 2004; Rahman et al. 2018; Tariq et al. 2017, 2018; Usman et al. 2009). In the recent decades, Bt cotton has been introduced in many parts of world (including the areas wherever cotton-wheat system is followed) in order to control bollworms. Although resistant or tolerant to bollworms, the Bt cotton has a crop duration longer than the conventional cotton cultivars. Usually Bt cotton cultivars are required to be sown at the time wheat is witnessing its reproductive phase. There is option to sow the Bt cotton after harvest of wheat; however, this results in a decreased growth and productivity of Bt cotton cultivars. Relay intercropping cotton in the wheat (while it is at its reproductive stage) is another option to sustain optimal production of together the wheat besides Bt cotton in the cotton-wheat cropping system. Intercropping has multiple benefits including the timely sowing of crops grown in rotation; management of weeds, insect pests, and diseases; efficient utilization of water/nutrient resources; improvement in soil quality; and system productivity (Willey 1985; Paltridge et al. 2014; Wu and Wu 2014;

Shahzad et al. 2016; Shah et al. 2016). Sometimes, intercropping may result in crop competition between both crops due to increased competition for water and nutrients. In this chapter we have discussed relay intercropping of Bt cotton for purpose of maintaining productivity of cotton-wheat system.

16.2 Cotton Plants and Environment

Cotton takes place among the sensitive crop plants and responds strongly to the climatic fluctuations. Being a tropical or subtropical crop, it requires a reasonably warm soil for seed germination and healthy stand establishment. On the other hand, a chilling stress during or immediately after sowing may not only result in poor crop but may also cause some disease development (Zhao et al. 2012). Low temperature also decreases the biomass production in cotton in addition to causing a poor crop stand (Reddy et al. 1999). Additionally, the optimum temperature also facilitates the proper morphological development, boll setting, and boll development (Reddy et al. 1999). However, a high rise in temperature (particularly in the wake of climate change) may damage the cotton plants through heat stress (DeRidder and Salvucci 2007; Jabran and Dogan 2018). Hence, the sensitivity of cotton crop plants is considered while selecting a sowing date. Selection of an optimum sowing date will give sufficient time for optimum germination, crop stand establishment, development of canopy and leaf area, and boll formation and boll development.

16.3 Relay Cropping of Cotton in Wheat (Inter-Seeding or Transplanting)

As described in the “Introduction” section, the introduction of Bt cotton in the cotton-wheat system compromised wheat cultivation. This is because the crop cultivation of Bt cotton expands to a part of the wheat crop growth cycle. The process of intercropping of seeds and transplanting of seedlings of Bt cotton is initiated when the wheat has completed its vegetative cycle and is continuing its reproductive phase. This intercropping of cotton seeds or transplanting of cotton seedlings in the wheat crop provides an opportunity to evade land preparation process and hence improve economic efficiency of cotton-wheat system. Upon maturity of wheat crop, the cotton plants gain a height of 30–50 cm and do not restrict the harvesting of wheat either manually or through a combine harvester. Combine harvester machine can easily harvest the wheat leaving lower 45–55 cm part, and in this way the cotton plants also remain safe from any damage (Fig. 16.1). Intercropping of cotton seeds or transplanting of seedlings also does restrict the process of interculture if required for weed control or fertilizer mixing, etc. (Fig. 16.2). Intercropping of cotton and wheat had higher light interception than

Fig. 16.1 Description of mechanical wheat harvesting with combined harvester with relay intercropped cotton (Source: CCRI, Multan)

Fig. 16.2 Description of mechanical interculturing to incorporate wheat stubbles in relay intercropped cotton

the individually sown cotton and wheat (Zhang et al. 2008). Similar research work was conducted in China where cotton was intercropped in the standing wheat (Zhang et al. 2007). In addition to sole wheat and cotton, the other treatments were one or two rows of cotton intercropped in three rows of wheat and two rows of cotton intercropped in three, four, or six rows of cotton. In general, although the yields of intercrops were decreased compared to sole crops, system productivity and land equivalent ratio were increased for most of the intercrops (Zhang et al. 2007).

Another research from Pakistan evaluated relay cropping of cotton in wheat (Nasrullah et al. 2017). Cotton relay cropping in wheat had higher income and benefit-cost ratio than the conventional cotton-wheat system. The research showed that wheat could be sown within the ridges that were spaced 150 cm apart, while later in the growing season (mid-March), cotton could be seeded on top of the ridges (Nasrullah et al. 2017).

One option is to sow the wheat on raised beds or ridges and, later in the season, transplant or sow the seeds of cotton on the free space between the wheat beds or ridges. Sowing (intercropping) of cotton may be a difficult task than transplanting of the 4–6-week-old seedlings. Either way will let the cotton to has full of its growing period in the field while also allowing the cultivation of wheat. Transplanting of cotton seedlings in the wheat may be advantageous over the sowing (intercropping) of seeds. For example, a better cotton crop establishment can be witnessed in case of transplanting because direct sowing may result in poor germination and may require a replanting. Also, transplanting can evade some of the laborious steps such as thinning (Jahromi and Mahboubi 2012). Another advantage of transplanting over seeding comprises the higher tolerance of 5–7-week-old seedlings against the harshness than the seedlings emerging from seeds. Ultimately the transplanting of 5–7-week-old seedlings provides an adequate and uniform crop stand, optimum crop growth, boll formation, and boll development. A higher yield in case of transplanting compared to direct seed sowing has also been reported (Salama et al. 1995).

The yield of intercrops is often low intercropping/relay cropping system against the sole stands of crops owing to competition for growth factors such as nutrients and water. However the yield gains in case of intercropping/relay cropping are frequently credited to complementation amid intercrops in mixture, leading to overall better use efficiency of available resources and higher system productivity (Shah et al. 2016).

16.4 Case Study on Relay Intercropping of Cotton in Wheat

Shah et al. (2016) conducted a 2-year study at two locations (Vehari and Multan) in Punjab, Pakistan, to examine production besides profitability of relay intercropping of cotton in wheat in Bt cotton-wheat system (BtCWS). The BtCWS included in research were (1) conventionally tilled cotton in fallow soil (sown in early/late March), (2) conventionally tilled cotton sown in late April after flat-sown wheat, (3) intercropping cotton on bed-sown wheat in early and late March, and (4) intercropping of cotton in ridge-sown wheat in early and late March. In bed sowing treatment, the Bt cotton was relay-intercropped on both sides of beds in bed-sown wheat or in the furrows amid 75 cm ridges in ridge-sown wheat. The layout of all the experimental treatment used in this study is given in Fig. 16.3. The results of the study indicated that the sowing of cotton in fallow soil in early March had the highest cotton yield, while the conventionally tilled cotton sown after

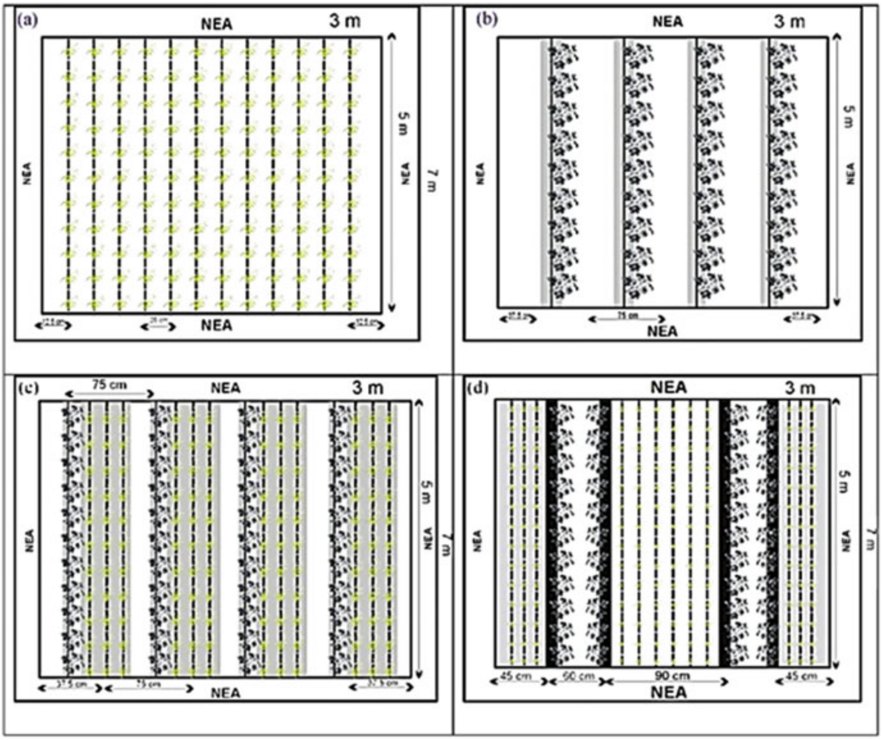

Fig. 16.3 Explanation of flat-sown wheat (**a**), conventionally tilled cotton (**b**), ridge-sown wheat with cotton intercropped (**c**), bed-sown wheat with cotton intercropped (**d**). *NEA* nonexperimental area. Net plot size = 3 m × 5 m (12 wheat rows besides 4 Bt cotton rows), gross plot size = 3 m × 7 m. (Adopted from Shah et al. (2016))

harvesting flat-sown wheat in late April had the lowest yield. However, the system production regarding benefit-cost ratio, net income, and marginal rate of returns was the highest when Bt cotton was intercropped in bed-sown wheat during early March in both years at both locations (Table 16.1; Shah et al. 2016). The plant height, biomass production, and fiber quality for fiber strength, fiber length, fiber uniformity, as well as fiber firmness were also highest in the relay intercropping Bt cotton in bed-sown wheat in early March as compared with sowing of conventionally tilled cotton after wheat harvest in late April (unpublished data; Table 16.2).

16.5 Conclusions

Wheat is planted in winter and harvested at the start of summer season and a vice versa pattern is followed for the cotton. In an effort to introduce Bt cotton cultivars in cotton-wheat systems, an overlap between wheat and cotton growth cycles was

Table 16.1 Impact of relay intercropping of Bt cotton in wheat on system productivity of Bt cotton-wheat system

	Net income[a] (US$ ha^{-1})		System productivity[b]	
Experimental treatments	Multan	Vehari	Multan	Vehari
CTC on fallow soil during early-March	1057	1186	1.68	1.77
CTC on fallow soil during late-March	836	926	1.54	1.6
CTC during late April after flat-sown wheat	2655	2891	2.05	2.13
Cotton intercropping in BSW during early March	3344	3415	2.37	2.39
Cotton intercropping in BSW during late March	3132	3168	2.28	2.3
Cotton intercropping in RSW during early March	3170	3241	2.3	2.33
Cotton intercropping in RSW during late March	3102	3120	2.27	2.28

All values are mean of 2 years

[a]Net income was acquired by subtracting total expenses ($ ha^{-1}) from gross income ($ ha^{-1})

[b]System productivity was appraised as ratio of output harvested ($ ha^{-1}) to input applied ($ ha^{-1}) on yearly basis

Table 16.2 Impact of cotton relay cropping in wheat on fiber quality of Bt cotton in Bt cotton-wheat system

	Fiber length (mm)		Fiber strength (g tex^{-1})		Fiber fineness (μg $inch^{-1}$)	
Experimental treatments	Multan	Vehari	Multan	Vehari	Multan	Vehari
CTC on fallow-land during early-March	28.72	28.80	28.80	28.95	5.04	5.27
CTC on fallow-land during late -March	28.51	28.61	28.71	28.75	4.91	5.15
CTC during late April after flat-sown wheat	27.70	27.80	27.79	27.89	4.46	4.55
Cotton intercropping in BSW during early March	28.34	28.42	28.61	28.67	4.78	4.98
Cotton intercropping in BSW during late March	28.04	28.10	28.37	28.44	4.66	4.70
Cotton intercropping in RSW during early March	28.24	28.25	28.50	28.57	4.74	4.89
Cotton intercropping in RSW during late March	27.90	27.96	28.32	28.40	4.61	4.75

All values are mean of 2 years; (Shah et al. 2019)

witnessed. This was because Bt cotton cultivars had a longer growth period than the conventional cotton cultivars. Under the situation, farmers had to opt one from the two crops (cotton or wheat). Relay cropping of cotton in wheat (inter-seeding of seeds or transplanting of cotton seedlings) was investigated and suggested as an innovative solution to maintain the productivity of cotton-wheat cropping system. Recent literature indicated that cotton relay cropping in wheat results in efficient use of resources and improved system productivity. Such relay cropping may also allow the use of conservation agriculture practices (such as zero tillage, soil cover). Ridge and bed sowing of cotton and wheat may also be useful to facilitate the relay cropping of cotton in wheat. We suggest that conservation agriculture practices, ridge sowing and bed sowing, should be focused as future research for the sustainable development of cotton-wheat relay cropping system. Another important aspect is to investigate the comparative weed biology and management in the conventional and relay cotton-wheat systems.

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