



Influence of diverse crop management practices on weed suppression, crop and water productivity and nutrient dynamics in Bt-cotton (*Gossypium hirsutum*) based intercropping systems in a semi-arid Indo-Gangetic plains region

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Cotton (*Gossypium* sp.) considered as white gold, is one of the most important commercial crops in India. India has the world's largest acreage of 11.99 M ha with average yield of 512 kg/ha (DES 2011); which is far below the world average (677 kg/ha) (Choudhary *et al.* 2015). Presently, major area under cotton cultivation in northern zone comprises hybrids (both Bt and non-Bt). Cultivation of Bt-cotton hybrids has evoked a considerable enthusiasm among farming and scientific community to boost cotton productivity at reduced cost of production besides least environment pollution because of lower pesticidal load (Blaise *et al.* 2014). Second fortnight of May is the optimum sowing time of cotton in northern India. But, May sown crop requires frequent irrigations and weeding operations owing to high temperature, slow initial crop growth and wider spacing; promoting weed infestation. Thus, frequent irrigations and weeding operations lead to elevated cost of cultivation in May sown crop. Besides, declining ground water table, limited surface water resources and inadequate power supply further aggravates the production vulnerabilities of this crop, thus, it becomes impractical to supply assured irrigations under aforesaid circumstances to maintain optimum plant stand (Rana *et al.* 2014a, Choudhary *et al.* 2015). Moreover, direct seeding of Bt-cotton lead to higher cost of cultivation due to high cost of Bt-cotton seed (Rana *et al.* 2014a). Keeping in view above facts, transplanting of Bt-cotton seedlings on the onset of monsoon can be a viable option to maintain optimum plant stand under high temperature regimes, limited irrigation water availability vis-a-vis high weed infestation in the crop. In addition to this, Bt-cotton ideally offers a vast scope for cultivation of selected short duration legumes and vegetables

as intercrops in its wider spaced planting geometry, slow initial growth as well as short stature of relatively longer duration (Dass and Kumar 2013, Choudhary *et al.* 2015). Therefore, present investigation was undertaken to study the influence of crop establishment methods, planting geometry and intercrops on weed suppression, water productivity and nutrient dynamics in Bt-cotton based intercropping systems in semi-arid Indo-Gangetic Plains Region (IGPR).

A field experiment was conducted at ICAR–Indian Agricultural Research Institute, New Delhi (28°37'N longitude; 77°09'E latitude; 228.7 m altitude) during *kharif* 2012 (June–December). The soil of experimental site was sandy-loam (Inceptisol; Mahauli series) with 0.38% soil organic carbon (SOC), bulk density 1.53 Mg m⁻³, field capacity 17.5% (w/w), and permanent wilting point (4.3%). The available N, P and K in the soil were 160, 14 and 268 kg/ha, respectively. The experiment was laid-out in a split-plot design with three replications. Combination of planting methods and planting geometry were kept in main-plots while intercropping systems were allotted in sub-plots. Main-plot treatments, viz. four crop establishment methods were: M₁ – Direct sowing (90 × 60 cm spacing); M₂ – Direct sowing (120 × 45 cm spacing); M₃ – Transplanting (90 × 60 cm spacing); M₄ – Transplanting (120 × 45 cm spacing); while sub-plot treatments, viz. three intercropping systems were: S-Ct – Sole cotton; Ct+Ok – Cotton + Okra (1:2 row ratio); Ct+Cp – Cotton + Cowpea (vegetable purpose) (1:2 row ratio), respectively. For Bt-cotton nursery raising, poly-glass of 15 cm height and 10 cm diameter were filled with soil and farmyard manure (FYM) in the ratio of 3:1. Two Bt-cotton seeds were sown in each poly-glass on 5 June 2012, and were watered on alternate days till transplanting of one month old seedling (7 July 2012) in similar land configuration and spacing as followed in case of direct sowing method (M₁ and M₂). Direct sowing of Bt-

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cotton (M_1 and M_2) was done on the same date (5 June 2012) as that followed for nursery raising for transplanted cotton (M_3 and M_4) so as to ideally work-out the actual irrigation water requirement (IWR) and weed suppression behaviour in the current study. Bt-cotton seedlings were transplanted at the centre of ridge by making pit of desired dimension under M_3 and M_4 . Intercrops as per treatments were also sown at the time of Bt-cotton transplanting (7 July 2012) on both sides of cotton row, i.e. at the margin of respective broad-beds (M_1, M_2, M_3 and M_4). Bt-cotton crop was finally harvested on 10 December, 2012 after three pickings; while intercrops' fruit (okra)/pod (cowpea) pickings were done during mid-August to mid-September. Recommended N (180 kg/ha) as urea was applied in two equal splits i.e. first at sowing/transplanting and remaining half N was applied at appearance of first flower in Bt-cotton. Recommended P (60 kg/ha P_2O_5) as single super phosphate, and K (50 kg/ha K_2O) as muriate of potash, were applied at sowing time in direct seeding method (M_1 and M_2) and at transplanting time (M_3 and M_4). Total number of weeds present in one m^2 area selected at random in each plot, were recorded at 60 and 90 days after sowing (DAS) under both crop establishment methods. The one m^2 area in treatments comprising intercrops was so selected to cover both main and intercrop rows. All the weeds present in one m^2 were selected at random and pulled out at 60 and 90 DAS and then counted. They were air-dried and then oven-dried at $70^\circ C$ to a constant weight and the dry weight was recorded. Direct sown cotton received 5 irrigations before onset of monsoon rainfall including pre-sowing irrigation. Cotton transplanting was done on the onset of monsoon without irrigation. Irrigation to cotton was provided to supplement the rainfall if needed. Irrigation water use

efficiency (IWUE) and irrigation water productivity (IWP) was worked out using standard procedures (Choudhary *et al.* 2006). Estimation of $KMnO_4$ oxidizable N/ha, 0.5 N $NaHCO_3$ extractable P/ha, 1 N NH_4OAc exchangeable K/ha, pH, and SOC at initiation and at harvest of the experiment as well as NPK concentrations in plant samples and their respective uptake was done using standard procedures (Rana *et al.* 2014b).

Data presented in Table 1 revealed that transplanted Bt-cotton harnessed significantly highest seed cotton yield (SCY) over directed seeding method (Dong *et al.* 2005, Salakinkop 2011). However, direct and transplanted cotton recorded statistically similar system productivity in terms of SCY owing to higher yield of intercrop under direct sowing in current study over transplanted method. Planting geometry (90×60 cm) proved to be significantly superior over 120×45 cm spacing in terms of SCY and system productivity; while seed cotton equivalent yield (SCEY) was significantly highest in wider spaced planting geometry (120×45 cm). Among intercropping systems, sole cotton (S-Ct) registered significantly highest SCY (3.25 tonnes/ha.) followed by cotton + cowpea (Ct + Cp) (3.12 t/ha) and cotton + okra (Ct + Ok) cropping system (3.06 t/ha). On the other hand, Ct + Cp intercropping system registered significantly highest SCEY of intercrops, system productivity and production-efficiency followed by Ct + Ok intercropping system (Table 1). Higher productivity under Ct + Cp intercropping system may be attributed to enhanced productivity of component crops as a result of better weed suppression, moisture conservation and biological N_2 fixation vis-a-vis its *in-situ* recycling by the inclusion of cowpea (Singh and Singh 2015; Pooniya *et al.* 2015).

Weed population and weed dry weight at 60 DAS were

Table 1 Influence of crop management practices on seed cotton yield, intercrops yield, system productivity and weed suppression behaviour in Bt-cotton based intercropping systems.

Treatment	Seed cotton yield (SCY) (t/ha)	Seed cotton equivalent yield (SCEY) of intercrops (t/ha)	System productivity in term of SCY (t/ha)	Weed population (No./ m^2)		Weed dry weight (g/ m^2)	
				60 DAS	90 DAS	60 DAS	90 DAS
<i>Crop establishment methods</i>							
Transplanting method	3.22	0.34	3.56	7.3	19.1	11.3	16.7
Direct sowing method	3.06	0.52	3.58	25.9	17.8	34.4	20.3
SEm \pm	0.03	0.01	0.03	0.83	0.46	0.81	1.98
CD (P=0.05)	0.10	0.05	0.09	2.89	NS	2.79	NS
<i>Planting geometry</i>							
90×60 cm	3.27	0.42	3.69	16.8	18.0	22.2	16.9
120×45 cm	3.01	0.44	3.45	16.4	18.8	23.5	20.1
SEm \pm	0.03	0.01	0.03	0.84	0.46	0.81	1.98
CD (P=0.05)	0.10	0.05	0.09	NS	NS	NS	NS
<i>Bt-cotton based intercropping systems</i>							
Sole cotton	3.25		3.25	24.2	25.8	36.8	28.5
Bt-Cotton + Okra	3.06	0.41	3.47	18.7	19.3	21.1	19.8
Cotton + Cowpea	3.12	0.44	3.56	6.8	10.2	10.6	7.3
SEm \pm	0.03	0.01	0.03	0.8	0.48	1.66	1.43
CD (P=0.05)	0.10	0.03	0.09	2.4	1.44	4.99	4.28

significantly influenced by the crop establishment methods with significantly highest magnitude of both the parameters in case of direct seeded Bt-cotton probably due to more weed infestation under direct seeded cotton in first week of June supported by frequent irrigations as well as poor crop establishment over transplanted cotton; while at 90 DAS, both these parameters showed a non-significant influence of both these crop establishment methods (Table 1). In general, in case of June month sown direct seeded cotton, the soil surface temperature was very high (sometime ~50°C) as compared to ambient atmosphere temperature which resulted in poor seed germination coupled with more mortality of germinated seeds. Contrary to that, in case of transplanted cotton, mortality percentage after transplanting was extremely low (4.1%), favouring higher plant stand as

compared to direct sown cotton, thus, resulting in low chances of weed proliferation, their weed population and weed dry weight (Table 1). In case of both the planting geometries, no significant effect was observed on weed population and weed dry weight at both the observational stages (60 and 90 DAS). In case of intercropping systems, Ct + Cp intercropping system was proved as best production system followed by Ct + Ok in suppressing the weed flora both in terms of number and weed dry weigh at 60 and 90 DAS because of the smoothening nature of cowpea (Table 1). While sole cotton was the inferior most in suppressing the weeds in the present study. Irrigation water use efficiency (IWUE) and irrigation water productivity (IWP) were higher in case of transplanted cotton over direct seeded cotton (Fig 1), due to less irrigation water requirement (IWR),

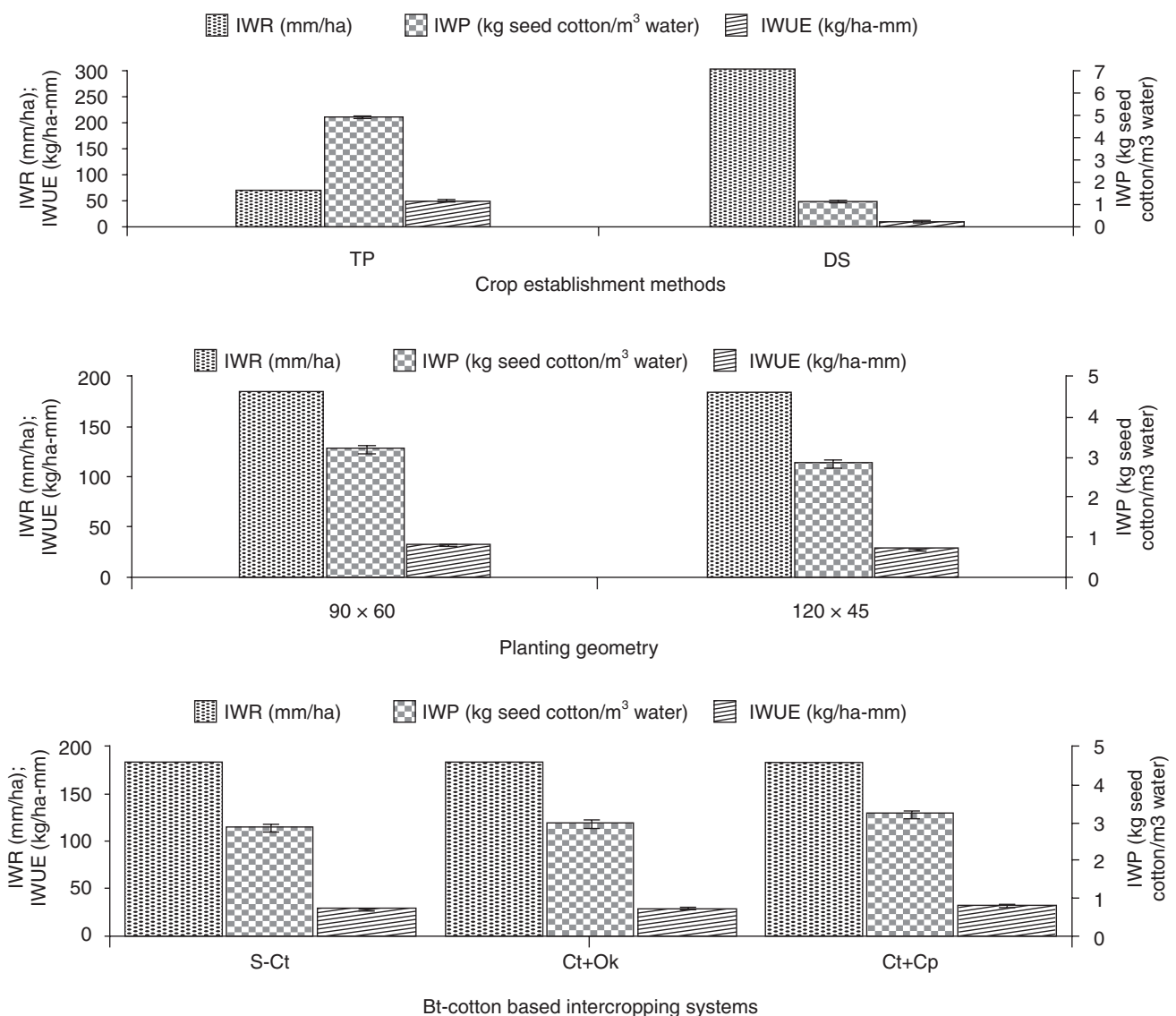


Fig 1 Influence of crop establishment methods, planting geometry and intercropping systems on irrigation water requirement (mm/ha), irrigation water productivity (kg seed cotton/m³ water), and irrigation water use efficiency (kg/ha-mm) in Bt-cotton based intercropping systems. (Note: For Bt-cotton nursery raising, about 100 m³ water/ha was used which is equivalent to water depth of 10 mm/ha; TP: Transplanting method; DS: Direct sowing method; S-Ct: Sole cotton; Ct+Ok: Cotton + Okra intercropping system; Ct+Cp: Cotton + Cowpea intercropping system; IWR: Irrigation water requirement; IWP: Irrigation water productivity; IWUE: Irrigation water use efficiency].

higher growth, yield attributes and yield. In case of planting geometries, 90 × 60 cm spacing had IWUE and IWP over 120 × 45 cm spacing (Fig 1), as a result of higher system productivity in current study (Table 1). Among intercropping systems, Ct + Cp proved as statistically superiormost in terms of IWUE and IWP, followed by Ct + Ok and S-Ct, respectively owing to higher system productivity under Ct + Cp system over other systems due to better moisture conservation and weed suppression, and biological nitrogen fixation as well by the cowpea (Rana *et al.* 2014a, Singh and Singh 2015).

Among crop establishment methods, transplanted cotton removed highest N (196 kg/ha) and P (13.6 kg/ha); but K (135 kg/ha) was highest in direct-seeded cotton. Among planting geometries, the 90 × 60 cm spacing exhibited higher positive N balance followed by spacing of 120 × 45 cm. Favourable effects of 90 × 60 cm planting geometry were observed on N, P and K content in stalk, seed and lint of cotton and also on uptake of these nutrients in different plant parts and their respective total uptake; which may be ascribed to less competition for various resources among the plants under 90 × 60 cm spacing. Similarly among intercropping systems, Ct + Cp intercropping system removed highest NPK content followed by Ct + Ok and S-Ct, respectively with highest positive NPK balance in Ct + Cp, while lowest apparently NPK balance was again observed in Ct + Cp intercropping system. As, Ct + Cp cropping system exhibited significantly higher N uptake in cotton and intercrops as well as total N uptake followed by S-Ct and Ct + Ok, respectively. In case of total K uptake, Ct + Ok exhibited highest total K uptake followed by Ct + Cp and S-Ct, respectively. In contrast to base crop, intercrops recorded higher P and K content in different plant parts and their respective uptake under wider row spacing of base crop, which again led to favourable conditions for the intercrops under wider row spacing over narrow row spacing of base crop. Inclusion of cowpea as intercrop in cotton improved the available N status in soil owing to biological N₂ fixation, thus, resulting in +ve N balance over the expected -ve N balance (Solunke *et al.* 2011). In contrast to N, available P and K at the end of experiment were more under sole cotton than intercrops, which may be ascribed to more uptake of nutrients by the intercrops along with base crop, thus, resulting in comparatively less actual +ve P balance over the larger expected +ve P balance as well as -ve K balance over the expected +ve K balance. In general, there was -ve or less +ve P actual balance over the larger expected +ve P balance owing to more P uptake by the intercrops along with base crop. On the other hand, there was -ve actual K balance over the expected +ve K balance due to higher K removal by the crops and leaching losses as well. In general, despite very high NPK uptake by the base and intercrops, available nutrient status in the soil after harvest of cotton remained around initial value of available NPK, which may be attributed to inclusion of cowpea as intercrop, robust rooting system of cotton leading to nutrient acquisition from deeper soil layers, addition of sufficient biomass in the

soil due to leaf fall of base as well as intercrops which contributed in NPK supplies through their residue recycling.

SUMMARY

Transplanted cotton (*Gossypium* sp) harnessed significantly highest seed cotton yield (3.22 tonnes/ha), system productivity, IWUE and IWP over direct-seeded cotton besides suppressing weed population. Cotton + cowpea intercropping system also suppressed the weeds and their growth at different growth stages over cotton + okra system and sole cotton. Planting geometry of 90 × 60 cm proved significantly superior over 120 × 45 cm in terms of seed cotton yield, system productivity, IWUE and IWP. Among intercropping systems, sole cotton registered significantly highest seed cotton yield. Total N and P uptake was highest under transplanted cotton while direct seeded cotton revealed higher total K uptake. Cotton + cowpea intercropping system removed highest N and P while cotton + okra exhibited highest K uptake. Transplanted cotton and cotton + cowpea intercropping system led to actual N build up of +8 and +17 kg N/ha, respectively. Similarly, cotton + cowpea and cotton + okra intercropping systems led to actual K balance of -102.1 and -105.4 kg K/ha, respectively. Overall, transplanted Bt-cotton with planting geometry of 90 × 60 cm under cotton + cowpea intercropping system led to highest seed cotton yield, system productivity, less weed infestation and high IWUE and IWP. Transplanted Bt-cotton also led to comparatively +ve N balance and less depletion of P and K as compared to direct seeding in a semi-arid IGPR.

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