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WEED SCIENCE | ORIGINAL ARTICLE

Assessing the trends of soil weed seed bank in conservation agriculture systems

Mohammad Mobarak Hossain [1*], Mahfuza Begum [2], Md Moshiur Rahman [2], Abul Hashem [3], Richard W Bell [4], Md Enamul Haque [4]

[1]Rice Breeding Platform, International Rice Research Institute, Pili Drive, Los Banos, Laguna 4031, Philippines
[2]Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[3]Department of Primary Industries and Regional Development, Industry and Economic Development, 75 York Road, Northam 6401 WA, Australia
[4]Agricultural Sciences, Murdoch University, South St, Murdoch WA 6150, Australia

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Md Moshiul Islam
moshiul@bsmrau.edu.bd

*Corresponding Author
Mohammad Mobarak Hossain
dr.mobarakphd@gmail.com

ABSTRACT

This net-house experiment was conducted at the Department of Agronomy, Bangladesh Agricultural University, Mymensingh, Bangladesh, during January-December 2016. Soil samplings were done at 0-15 cm soil depth from four locations *viz*., Mymensingh, Durgapur, Godagari, and Baliakandi areas of Bangladesh after the end of conservation agriculture (CA) trials in each site. At Mymensingh, CA trials were conducted at the soil science field laboratory during 2012-2015. Here, T. aman (summer) rice, wheat, and mungbean were grown using conventional tillage (CT), and strip tillage (ST) retained with 20 and 40% residues of the previous crop. At Durgapur and Godagari, on-farm CT and ST were practiced keeping 20 and 50% residues of the earlier crop during 2010-2015. At Durgapur, the cropping pattern was T. aman rice-mustard-boro (winter) rice and jute-lentil-mungbean while at Godagari, the cropping pattern was T. aman rice-wheat-mungbean and jute-chickpea-mungbean. At Baliakandi, T. aman rice, wheat, and jute were grown on-farm during 2012-2015 following CT, ST, bed planting (BP), and Zero tillage (ZT) retained 20 and 50% residues. Collected five soil samples from each plot of each site that is a total of 290 soil samples from four trial sites were placed in individual trays following a completely randomized design with four replications. The headcount of weed was continued during the entire time of experimentation. The experimental data revealed that, in terms of weed species composition and weed density, the smallest size weed seed bank was found in ST, followed by CT, BP, and ZT. On the other hand, smaller sized weed seed bank composition was found in 40 or 50% crop residues than 20% residues. The higher number of perennials weeds than annual weeds was recorded in ST, BP, and ZT, but the reverse was in CT. Based on the results, it could be concluded that ST with the retention of 40-50% residues of previous crops facilitate lesser weeds but favors perennial weeds compared to conventional tillage. Weed reduction in strip tillage is even higher than BP and ZT.

Keywords: Weed seed bank, conservation agriculture, strip tillage, bed planting, zero tillage, crop residues

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1 Introduction

Conservation agriculture (CA) has been identified as a useful tool for sustainably increasing crop yields, but weed control is perceived as one of the most challenging issues. Due to a reduction in tillage operations, the composition and dynamics in CA will change compared to conventional tillage (CT) (Pittelkow et al., 2014). Soil weed seed bank is the reservoir of weed seeds in the soil, determining the species composition. It is the most crucial source of weeds, and the weed population is directly related to their seed bank. Knowledge of the seed bank size and its composition can be used to predict the future weed infestation and control strategies, weed seed production after the cropping season, estimation of crop-weed competition and crop yield loss, and the crop economics (Begum et al., 2006).

In Bangladesh, the practice of CA began in 2005 (Hossain et al., 2015) to validate its' principles for small farm hold. But soil puddling for transplanting rice seedling is the crucial obstacle of CA for the intensive rice-based system. The direct-seeded rice (DSR) production system was started to overcome this problem (Johansen et al., 2012). Due to some demerits of DSR (like yield reduction occurred by uneven crop stand, rice seeds exposed to birds and rats, sudden rains immediately after seeding, heavy weed pressure with the emergence of weedy rice, increase in soil-borne pathogens such as nematodes, nutrient disorders especially nitrogen and micronutrients and higher emissions of nitrous oxides), a novel solution - strip planted non-puddled rice seedling transplanting, seeding of wheat, oilseeds, and pulses begun promoted in the form of minimum tillage (MT) in 2010 through the innovation of versatile multi-crop planter (VMP) machine driven by a two-wheeler tractor in the way of strip tillage (ST) (Johansen et al., 2012). Since then, in Bangladesh, farmers are practicing CA in the Northern part of the country for wheat cultivation. It was found that VMP operated ST could resolve inefficient use of broadcast seeding and fertigation, late planting, and high cost of land preparation of wheat under CA practiced intensive rice-based cropping system in Bangladesh (Hossain et al., 2015).

Research reports are saying that CA offers scope to reduce production costs and raise the profitability of the country. It was found similar or sometimes better yield in ST compared to conventional tillage (CT) through reducing the production costs, the betterment of soil fertility, and increasing the intensity of cropping (Gathala et al., 2011). Therefore, to feed a growing population of Bangladesh with reduced natural resources and to minimize the detrimental effect of conventional cultivation practice, CA could be a profitable alternative to the existing traditional system of agriculture of the country. During 2015-16, in Bangladesh, about 1500 hectares mustard and lentil, 21850 hectares wheat, and 5764 hectares of non-puddled transplanted rice were planted by VMP in the form of ST at Durgapur Upazila following the CA principles (Haque et al., 2016). Despite a lot of benefits, the adoption of CA in Bangladesh can't be widely popularized because the improvement of crop production under CA is highly dependent on effective weed management. In ST, when intense tillage operations are minimized, many weed species flourish in the soil weed seed bank, and farmers lose weed control offered from seed burial and pre-sowing germination of weeds. Thus, ST is characterized by heavy weed infestation. Since plowing helps to reduce weed seed banks in the soil profile in a conventional system, but in ST of CA, a massive number of weeds emerge from the weed seed bank, which makes weed control critical in this practice.

Moreover, the dynamics of a weed population in weed seed bank under CA is entirely different from the conventional system, and the eco-physical responses of weeds and their interactions with crops tend to be more involved (Price and Kelto, 2011). Further, under CA, minimum soil disturbance favors the dynamics of weed species in the seed bank, which was found to be infested with perennial weed species dominating over the annual species (Taa et al., 2004). Minimum tillage is reported to encourage perennial weeds like *Cyperus rotundus* L., *Saccharum spontaneum* L., *Sorghum halepense* (L.) Pers. in the soil weed seed bank, which are generally reproduced from tubers and rhizomes present underground in soil and by not burying them to depths or failing to uproot and kill them (Aweto, 2013). Hence, effective techniques are needed to manage perennial weeds in soil weed seed banks successfully in CA, demanding to learn the trend of weed seed bank within the soil under the Bangladesh context.

There are very few short-term studies examining the effects of CA principles on the soil weed seed bank in Bangladesh context. Hence, in this first-time study of soil weed seed bank was assessed from previously practiced long-term CA trials conducted at four locations of the country to learn the trend of weed response to CA principles. By necessity, it was hoped that knowledge gained about weed seed banks could be used to fill the gaps in weed seed bank information and the best managing of weeds to trigger the widespread adoption of CA.

2 Materials and Methods

2.1 Experimental site

This experiment was conducted at the net-house of the Department of Agronomy, Bangladesh Agricultural University (BAU), located geographically at 24°75′ N latitude and 90°50′ E longitudes at an average altitude of 18 m above the mean sea level under the Old Brahmaputra Floodplain Agro-Ecological Zone (AEZ-9) of the country (Brammer, 1996). Weather information regarding temperature, relative humidity, rainfall, and sunshine hours prevailed at the experimental site during the study period (January - December 2016) is presented in Fig. 1.

2.2 Sites of long-term CA trials

CA trials were conducted at four locations (Fig. 2). At Mymensingh, long-term CA trials were conducted at the Soil Science Field Laboratory of the BAU campus, which is located at Sadar Upazila of Mymensingh district of Bangladesh under AEZ-9, as stated above. In this site, CA trials began in 2012 following T. aman rice-wheat-mungbean cropping pattern, which was ended in 2015. Here six experiments were conducted. Durgapur and Godagari Upazilas are under the Rajshahi district. Trial sites were located at Alipur and Digram village, respectively. Geographically, sites are located at 24°22′ N latitude, 88°36′ E longitude belongings to AEZ 26: High Barind Tract. CA trials began in 2010 and ended in 2015 following T. aman rice-mustard-Boro rice, T. aman rice-mungbean-lentil, and lentil-jute-T. aman rice patterns at Durgapur while T. aman rice-wheat-mungbean, T. aman rice-wheat-jute, and T. aman rice-chickpea-jute patterns at Godagari. In these two sites, 12 trials were done, respectively. Baliakandi Upazila is located at the Rajbari district. Experiments were conducted at Beluapara village. Geographically, it is situated at 23°39′45′′ N latitude, 89°29′39′′ E longitude, which belongs to the AEZ 12: Low Ganges River Floodplain. CA trials began here in 2012 and ended in 2015. The cropping pattern was T. aman rice, wheat, and jute were grown during 2012-2015. In this site, six trials were performed. The treatments used in these four locations have been presented in Table 1.

2.3 Weed control strategies

In CT, weeds were controlled by hand weeding in all crops. On the other hand, in ST, bed BP, and ZT, weeds were controlled using different herbicides for different crops, as stated in Table 2. Similar herbicides were used at all locations.

2.4 Tillage practices followed

CT did by using a two-wheel tractor (2WT) by four plowings and cross plowing followed by sun-drying for two days (in non-rice crops) followed by inundation and laddering (in rice). ST was done by a versatile multi-crop planter (VMP) in a single pass operation. Strips were prepared for four rows, each of six cm wide and five cm deep made at a time. In BP, raised beds (15 cm high and 90 cm wide with 60 cm tops and 30 cm furrows) were made with a bed planting machine. In ZT, the land remained untilled. Initially, at Mymensingh, the effect of ST was tested at limited areas university field laboratory. With the view to achieving more justified results, additionally, BP was included in the farmer's field of Durgapur and Godagari. In contrast, ZT was included along with these three tillage types at Baliakandi. That is why tillage types were not uniform across the experimental sites.

2.5 Crop residue retention levels

Two levels of crop residues (height basis) were used across the experimental sites. There were 20% residues in all locations, while 40% residue in Mymensingh and 50% residue in other areas. Here VPM machine was used for strip tillage. During the tillage operation, tines of VMP were clogged by standing 50% residues. To avoid this interruption, this was reduced to 40% at Mymensingh.

2.6 Soil sampling procedure

The soil was collected from the field of all locations from 0-15 cm soil depth. Five samples from each plot; hence 290 samples were collected using a stainless-steel pipe of five cm diameter following the "W" shape pattern described by Chancellor (1966). After sampling, pieces were tagged and appropriately bagged for transportation to net-house.

2.7 Experimental set-up

Sub-samples from each plot were combined, and approximately one-kilogram soil was placed immediately in an individual round-shaped plastic tray of 33 cm in diameter. The trays were arranged in a completely randomized design in the net-house. The study period was January 02- December 29, 2016.

2.8 Data collection in net-house

Emerged seedlings were identified, counted, and removed at 30 days intervals using the seedling keys of Chancellor (1966). Unnamed seedlings were transferred to another pot and grown until maturity to facilitate identification. After the removal of each batch of seedlings, soils were air-dried, thoroughly mixed, and re-wetted to permit further emergence. The number of seedlings emerged converted to the numbers m^{-2} using the formula as below:

$$A = \pi r^2 \tag{1}$$

where, π =3.1416, r = radius of the tray (33 cm)

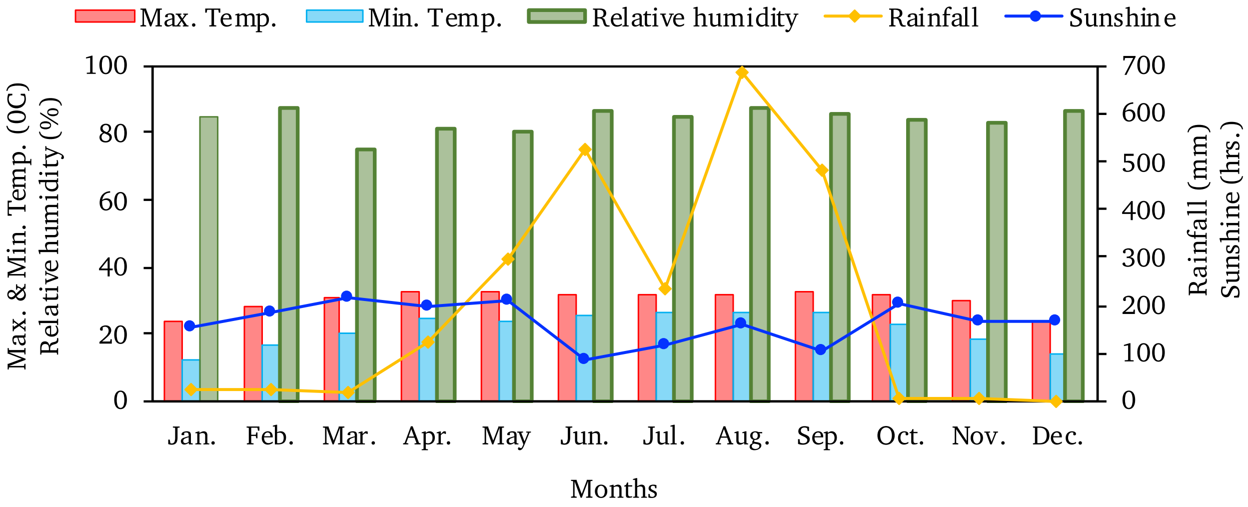

Figure 1. Monthly average weather information of the experimental site in 2016

Figure 2. Map of Bangladesh showing the sites of long-term conservation agriculture (CA) trials

Table 1. Treatments used in four locations of long-term conservation agriculture (CA) trial

Location	Tillage type	Residue levels (%)	Replication	No. of plots
Mymensingh	Conventional tillage (CT) Strip tillage (ST)	20 40	3	12
Durgapur and Godagari	Conventional tillage Strip tillage Bed planting (BP)	20 50	4	24
Baliakandi	Conventional tillage Strip tillage Bed planting Zero tillage (ZT)	20 50	4	32

Table 2. Weeding regimes of long-term conservation agriculture (CA) trial in the study

Weed control	Tillage	Dose (ha^{-1}) and time	Crops
Hand weeding	CT	3 HWs at 25, 45, and 65 DAT/DAS	Rice, wheat
		2 HWs at 25 and 45 DAS	Mustard, jute, mungbean, lentil, chickpea
Herbicides	ST, BP, ZT	Glyphosate at 3 DBT @ 3.7 L	Rice, wheat, mustard, jute, mungbean lentil, chickpea
		Pendimethalin at 3 DAT/DAS @ 2.7 L	Rice, wheat
		Pendimethalin at IAS @ 2.7 L	Mustard, jute, lentil, mungbean, chickpea
		Oxadiazon (non-foliar) at 15 DAS @ 2.5 L	Mustard
		Ethoxysulfuron-ethyl at 25 DAT @ 100 g	Rice
		Carfentrazon-ethyl at 25 DAS @ 1.25 kg	Wheat
		Fenoxaprop-p-ethyl at 25 DAS @ 650 mL	Jute, mungbean, lentil, chickpea

CT = Conventional tillage, ST = Strip tillage, BP = Bed planting, ZT = Zero tillage. DAT = Days after transplanting, DAS = Days after sowing, DBT = Days before tillage, IAS = Immediately after sowing

3 Results

3.1 Weed species composition

At Mymensingh, CT with 20% residue retention produced 28 weed species consisting of 18 broadleafs, five of grass and sedges (Table 3). Among them, 24 were annuals, and four were perennials. On the other hand, there were four fewer weeds in 40% residue compared to 20% residue. There were three less broadleaf and one less grass weed. In ST with 20% residue, 25 species were found consisting of 15 broadleaf and five grass and five sedges. Among them, 18 were annuals, and seven were perennials. But in ST with 40% residue, there were seven fewer weed species, including five broadleafs and one each of grass and sedge, compared to 20% residue. Data reveal that, compared to CT, ST produced a lower number of weed species with a higher number of perennials and a lower number of annuals. Retention of 40% residue had more tropical weeds than 20% residue.

At Durgapur, CT, with 20% residue, produced 29 species consisting of 19 broadleaf, five grass, and sedges each, of which 25 were annuals and four perennials (Table 4). Retention of 50% residue generated 21 annuals and four perennials. ST with 20% residue produced 23 1species, including 14 broadleaf, four grass, and five sedges. Annuals were outnumbered than perennials. In ST with 50% residue, 18 species found having ten broadleaf, four grass, and sedges each, of which 13 annuals and five perennials. BP, with 20% residue, made 25 species consisting of 15 broadleaf, four grass, and six sedges where 20 were annuals and five perennials. BP, with 50% residue, had 23 species with 19 annuals and four perennials. Results reflect that the lowest number of weed species was found in ST, followed by BP and CT. In ST, perennials were higher than annuals but vice-versa in BP and CT. Retention of 50% residue produced lower weeds than 20% residue. This trend was more or less similar in Godagari ((Table 4).

At Baliakandi, CT with 20% residue produced 14 species, of which eight broadleaf, three grass, and sedges each, consisting of 10 annuals and four perennials ((Table 5). But at 50% residue, 12 species found having eight broadleaf, two grass, and sedge each, including nine annuals and three perennials. ST with 20% residue produced ten species consisting of seven broadleaf, two grass, and one sedge having four annuals and six perennials. But nine species were having an almost similar number of all types of weed except one with 50% residue. In BP with 20% residue, 17 species were found, including ten broadleaf, three grass, and four sedges. There were 16 annuals and one perennial. In 50% residue, 15 species were found with a similar amount of grass and sedge and fewer annual broadleaf. ZT, with 20% residue produced 19 weed species, belonged to 11 broadleaf and four grass and four sedges, having 15 annuals and four perennials. But in ZT with 50% residue, 16 species were found having less number annual broadleaf, annual grass. There were four sedges and four perennial weeds.

3.2 Type and density of weeds

Data presented in Table 6 reflect that, at Mymensingh, ST created 777 less number of weeds than CT, and 40% residue produced 288 less number of weed m^{-2} than 20% residue. Broadleaf weeds were most dominant over sedges and grasses in CT but dominant over grasses and sedges in ST. Annuals led over perennials in CT, but perennials led over annuals in ST.

At Durgapur and Godagari, BP generated the highest weed density, followed by CT and ST. Compared to CT (1738 at Durgapur and 2079 at Godagari), ST had 172 and 237 fewer weeds, but BP had 717 and 776 more number of weeds at two locations, respectively. Retention of 50% residue produced 442 and 610 fewer numbers of weeds than 20% residue at two locations, respectively. Broadleaf weeds were the most dominant in all types of tillage at both locations, while grasses>sedges in ST at Durgapur and BP at Godagari but sedges>grasses in BP at Durgapur and ST at Godagari. Annuals led over perennials in CT, but perennials led over annuals both in ST and BP at both locations.

At Baliakandi, the trend of weed density m^{-2} was ZT>BP>CT>ST. Compared to CT (1668), ST has 560 fewer weeds, but 386 and 2639 more weeds in BP and ZT, respectively. On the other hand, 50% of residue produced 608 fewer weeds than 20 % residue. In all types of tillage and residue levels, broadleaf led over sedges and grasses. Annuals were dominant over perennials in CT, but perennials led over annuals in ST, BP, and ZT.

4 Discussion

The higher number of weeds composting broadleaf, grass, and sedge types was found in CT than ST. This phenomenon might be attributed to the emergence of more weed species in CT over ST. The earlier research suggests that about 80% disturbed heavily pulverized soil of CT (Haque et al., 2016) bring up dormant weed seeds from the deeper soil layers to the upper, which fortunate the higher germination of weed seeds and the emergence of weeds. Nichols et al. (2015) concluded, tilled soils of CT offer better germination of weed seeds by making soils more aerated and warmer. CT also allows seedlings to emerge from deeper in the ground compared to reduced tilled soils in ST (Buhler and Mester, 1991) that may increase the weed species composition in the weed seed bank of CT than ST.

Table 3. Composition of weed species in different tillage types and residue levels at Mymensingh

Weed type	Scientific name	Life cycle	Tillage types and residue levels			
			CT		ST	
			R20	R40	R20	R40
Broadleaf	*Alternanthera sessilis* L.	P	Y	Y	Y	Y
	Amaranthus viridis L.	A	Y	Y	Y	Y
	A. spinosus L.	A	Y	Y	Y	Y
	Chenopodium album L.	A	Y	N	Y	N
	Commelina benghalensis L.	A	Y	Y	Y	N
	Cyanotis axillaris Roem.	A	Y	Y	Y	Y
	Dentella repens L.	P	Y	Y	Y	N
	Eclipta alba L.	A	Y	Y	N	Y
	Euphorbia parviflora L.	A	Y	Y	N	Y
	E. hirta L.	A	Y	N	Y	Y
	Hedyotis corymbosa Lamk.	A	Y	Y	Y	N
	Jussia deccurence Walt.	P	N	N	Y	Y
	Lindernia hyssopifolia L.	A	Y	Y	Y	N
	L. antipoda Alston.	A	Y	Y	Y	N
	Monochoria hastata L.	A	Y	Y	N	N
	Physalis minima L.	A	Y	Y	N	N
	Rotala ramosior (L.) Koehne.	A	Y	N	Y	Y
	Solanum torvum Sw.	P	N	N	Y	N
	Sphenoclea zeylanica Gaertn.	A	Y	Y	Y	N
	Spilanthes acmella Murr.	A	Y	Y	Y	Y
Sub-total			18	15	15	10
Grass	*Digitaria sanguinalis* L.	A	Y	Y	Y	Y
	Echinochloa colonum L.	A	Y	Y	Y	Y
	E. crusgalli L.	A	Y	N	Y	Y
	Eleusine indica L.	A	Y	Y	Y	Y
	Leersia hexandra L.	P	Y	Y	Y	N
Sub-total			5	4	5	4
Sedge	*Cyperus difformis* L.	A	Y	Y	Y	N
	C. iria L.	A	Y	Y	Y	N
	C. rotundus L.	P	N	N	Y	Y
	Eleocharisatro purpurea Retz.	A	Y	Y	Y	Y
	Fimbristylis miliacea L.	A	Y	Y	N	Y
	Scripus supinus L.	P	Y	Y	Y	Y
Sub-total			5	5	5	4
Grand-Total			28	24	25	18

CT = Conventional tillage, ST = Strip tillage A = Annual, P = Perennial, R20 = 20% residue, R40 = 40% residue, Y = present, N = absent

Table 4. Composition of weed species in different tillage types and residue levels at Durgapur and Godagari

Weed type	Scientific name	LC	Tillage types and residue levels (%)											
			CT-Durgapur		ST-Durgapur		BP-Durgapur		CT-Godagari		ST-Godagari		BP-Godagari	
			R20	R50	R20	R50	R20	R50	R20	R50	R20	R50	R20	R50
Broad leaf	*Alternanther asessilis* L.	P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
	Amaranthus viridis L.	A	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	A. spinosus L.	A	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Chenopodium album L.	A	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
	Commelina benghalensis L.	A	Y	Y	Y	N	Y	N	Y	Y	N	N	Y	N
	Cyanotis axillaris Roem.	A	Y	Y	N	Y	N	Y	Y	Y	N	Y	N	Y
	Dentella repens L.	A	Y	Y	Y	N	Y	Y	Y	Y	N	N	Y	Y
	Eclipta alba L.	A	Y	Y	N	Y	N	Y	Y	Y	N	Y	N	Y
	Euphorbia parviflora L.	A	Y	Y	N	N	N	Y	Y	Y	N	Y	N	Y
	E. hirta L.	A	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	Hedyotis corymbosa Lamk.	A	Y	Y	Y	N	Y	Y	Y	Y	N	N	Y	Y
	Jussia deccurence Walt.	P	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Lindernia hyssopifolia L.	A	Y	Y	Y	N	Y	Y	Y	Y	N	N	Y	Y
	L. antipoda Alston.	A	Y	Y	Y	N	Y	N	Y	Y	Y	N	Y	N
	Monochoria hastata L.	A	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
	M. vaginalis Burm.	A	Y	Y	N	N	N	Y	Y	Y	N	Y	N	Y
	Physalis minima L.	A	Y	Y	N	N	N	N	Y	Y	N	N	N	N
	Rotala ramosior (L.) Koehne.	A	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Solanum torvum Sw.	P	N	Y	Y	Y	N	N	Y	Y	Y	N	N	N
	Sphenoclea zeylanica Gaertn.	A	Y	Y	N	N	Y	N	Y	Y	N	N	Y	N
	Spilanthes acmella Murr.	A	Y	Y	N	N	Y	Y	Y	Y	N	N	Y	Y
Sub-Total			19	17	14	10	15	15	21	19	10	10	15	14
Grass	*Digitaria sanguinalis* L.	A	Y	Y	N	Y	N	Y	Y	Y	N	Y	N	Y
	Echinochloa colonum L.	A	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	E. crusgalli L.	A	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Eleusine indica L.	A	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Leersia hexandra L.	P	Y	Y	Y	N	Y	N	Y	Y	Y	N	Y	N
Sub-Total			5	3	4	4	4	4	5	4	4	4	4	4
Sedge	*Cyperus difformis* L.	A	Y	Y	Y	N	Y	N	Y	Y	Y	N	Y	N
	C. iria L.	A	Y	Y	N	N	Y	N	Y	Y	Y	N	Y	N
	C. rotundus L.	P	N	N	Y	Y	Y	Y	N	N	Y	Y	N	Y
	Eleocharisatro purpurea Retz.	A	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Fimbristylis miliacea L.	A	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Scripus supinus L.	P	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Sub-Total			5	5	5	4	6	4	5	6	6	3	6	4
Grand-Total			29	25	23	18	25	23	31	29	20	17	25	22

LC = Life cycle, CT = Conventional tillage, ST = Strip tillage, BP = Bed planting, R20 = 20% residue, R50 = 50% residue, A = Annual, P = Perennial, Y = present, N = absent

Mohler (2001) quoted dormant seeds in CT become viable to germinate by scarification, ambient CO_2 concentrations, and higher nitrate concentrations, which may lead to producing higher weed emergence of new weed species in CT. The research finding of Cardina et al. (2002) also revealed the increase of weed species composition in CT offered from the higher rate of seed viability occurred from weed seed burial in the soil profile. Such a higher rate of weed seed survivability might lead to an increase in weed composition in CT. Gallandt et al. (2004) found germination stimulus is generally higher near the soil surface and decreases with depth. In the reduced tillage system of ST, seed banks are concentrated in the top layer of the soil; thus, a higher proportion of reduced tilled seedbanks will germinate compared with CT, which led to reduce seed bank size in ST than CT.

The reduction of the number of weed species in ST might also be due to minimizing the weed seed bank status in the soil by increasing non-viable or dormant weed seeds in the seed bank. Due to minimal soil disturbance (only 20%) at the upper soil layer in ST, most of the weed seeds remain on the soil surface. They can lose viability due to desiccation and adverse climate, as reported by Nichols et al. (2015). Losing of seed viability in ST may also be attributed to increased seed dormancy at an undisturbed deeper soil layer. Seeds remain dormant (Oziegbe et al., 2010) at a deeper layer suffer from suffocation for less oxygen pressure and darkness for feeble light, as weed seeds required oxygen and light for maximum germination (Benvenuti, 1995).

Surface accumulation of weed seeds in ST would increase predator (ants, insects, rodents, and birds) (Blubaugh and Kaplan, 2015) access to weed seeds and could increase their removal rates. For example, common ground beetles or crickets can reduce weed seed emergence by 5 to 15% (White et al., 2007). Overall, the adoption of ST may encourage seed losses *via* predation by increasing the availability of seeds to predators, and by minimizing mortality and forced relocation of predators, therefore, represent a potentially valuable tool for reducing weed seed bank size in ST. Higher dispersal of weed seeds may also lead to an increase in the seed bank in CT over ST. Barroso et al. (2006) found the weed seeds traveled 2–3 m in

Table 5. Composition of weed species in different tillage types and residue levels at Baliakandi

Weed type	Scientific name	Life cycle	Tillage type and residue levels (%)							
			CT		ST		BP		ZT	
			R20	R50	R20	R50	R20	R50	R20	R50
Broadleaf	*Alternanthera sessilis* L.	P	N	N	Y	Y	N	N	Y	Y
	Amaranthus viridis L.	A	Y	Y	N	N	Y	N	Y	N
	Commelina benghalensis L.	A	N	Y	N	N	Y	Y	N	N
	Cyanotis axillaris Roem.	A	N	N	N	N	Y	Y	Y	N
	Dentella repens L.	P	Y	Y	Y	Y	N	N	Y	Y
	Eclipta alba L.	A	Y	Y	N	N	Y	Y	Y	Y
	Euphorbia parviflora L.	A	N	N	N	N	Y	Y	N	Y
	Hedyotis corymbosa (L.) Lamk.	A	N	N	Y	Y	Y	Y	Y	Y
	Jussia deccurence Walt.	P	Y	Y	Y	Y	N	N	Y	Y
	Lindernia hyssopifolia L.	A	Y	Y	Y	Y	Y	Y	Y	Y
	Lindenia antipoda Alston.	A	Y	Y	Y	Y	Y	Y	Y	Y
	Monochoria hastata L.	A	Y	Y	N	N	Y	Y	N	N
	Rotala ramosior (L.) Koehne.	A	N	N	N	N	N	N	Y	Y
	Solanum torvum Sw.	P	Y	N	Y	Y	N	N	N	N
	Spilanthes acmella Murr.	A	N	N	N	N	Y	N	Y	N
Sub-total			8	8	7	7	10	8	11	9
Grass	*Digitaria sanguinalis* L.	A	Y	Y	N	N	Y	Y	Y	Y
	Echinochloa colonum L.	A	Y	Y	Y	Y	Y	Y	Y	Y
	E. crusgalli L.	A	N	N	N	N	N	N	Y	N
	Eleusine indica L.	A	N	N	N	N	Y	Y	Y	Y
	Leersia hexandra L.	P	Y	N	Y	N	N	N	N	N
Sub-total			3	2	2	1	3	3	4	3
Sedge	*Cyperus difformis* L.	A	Y	N	N	N	Y	Y	Y	Y
	C. iria L.	A	Y	N	N	N	Y	Y	Y	Y
	C. rotundus L.	P	N	N	Y	Y	Y	Y	Y	Y
	Fimbristylis miliacea L.	A	Y	Y	N	N	Y	Y	Y	Y
Sub-total			3	1	1	1	4	4	4	4
Grand-total			14	11	10	9	17	15	19	16

CT = Conventional tillage, ST = Strip tillage, BP = Bed planting, ZT = Zero tillage, R20 = 20% residue, R50 = 50% residue, A = Annual, P = Perennial, Y = present, N= absent

Table 6. Effect of tillage types and residue levels on the density (number m^{-2}) of different weed types at different locations

		Broadleaf			Grass			Sedge		
	Tillage type	R20	R40/50	Mean	R20	R40/50	Mean	R20	R40/50	Mean
Mymensingh	CT	2616	2402	2509	643	764	703	765	838	801
	ST	2249	1775	2012	703	601	652	562	583	572
	Mean	2433	2089	–	673	682	–	663	710	–
Durgapur	CT	1900	1575	1738	760	630	695	506	422	464
	ST	1805	1421	1613	779	456	617	528	459	493
	BP	2243	2359	2301	615	426	520	760	823	791
	Mean	1983	1785	–	718	504	–	598	568	–
Godagari	CT	2261	1897	2079	895	542	718	613	556	584
	ST	2067	1704	1885	617	561	589	943	398	670
	BP	2635	2714	2674	897	864	880	672	535	603
	Mean	2321	2105	–	803	656	–	743	496	–
Baliakandi	CT	2019	1317	1668	650	497	573.5	446	671	558
	ST	1405	1272	1339	619	417	518	468	298	383
	BP	1989	1613	1801	768	720	744	733	547	640
	ZT	2891	2854	2873	1908	1376	1642	983	866	924
	Mean	2076	1764	–	986	752	–	657	595	–
		Annual			Perennial			Total		
		R20	R40/50	Mean	R20	R40/50	Mean	R20	R40/50	Mean
Mymensingh	CT	2683	2397	2540	1341	1607	1474	4024	4004	4014
	ST	1663	1281	1472	1851	1678	1765	3514	2959	3237
	Mean	2173	1839	–	1596	1643	–	3769	3481	–
Durgapur	CT	1631	1429	1530	1535	1198	1366	3166	2627	2896
	ST	1462	864	1163	1650	1472	1561	3112	2336	2724
	BP	1681	1739	1710	1937	1869	1903	3618	3608	3613
	Mean	1592	1344	–	1707	1513	–	3299	2857	–
Godagari	CT	1926	1689	1807	1843	1306	1575	3769	2995	3382
	ST	1674	1077	1375	1953	1586	1770	3627	2663	3145
	BP	1811	1954	1882	2393	2159	2276	4204	4112	4158
	Mean	1803	1573	–	2063	1683	–	3867	3256	–
Baliakandi	CT	2407	1863	2135	708	621	664	3115	2484	2799
	ST	1112	833	972	1380	1154	1267	2492	1987	2240
	BP	1651	1307	1479	1839	1573	1706	3490	2880	3185
	ZT	2378	1889	2134	3403	3207	3305	5781	5096	5438
	Mean	1887	1473	–	1832	1638	–	3719	3111	–

CT = Conventional tillage, ST = Strip tillage, BP = Bed planting, ZT = Zero tillage, R20 = 20% residue, R40 = 40% residue, R50 = 50% residue the direction of full tillage, while in reduced tillage soils, the distance is negligible. Reducing tillage in ST, therefore, reduced the spread of weed seed both within and across fields and reduced seed bank size in this study. The reduced weed seed bank in ST may also have occurred from more lavish weed seed burial as strips were made in the same location over the years because the field layout and all the treatments were the same in the field study.

Furthermore, the application of different herbicides might lead to having less amount of weed in ST, BP, and ZT. We used glyphosate and pendimethalin herbicide in all crops. Besides, we used ethoxysulfuron-ethyl in rice; oxadiazon in mustard; carfentrazon-ethyl in wheat while fenoxaprop-p-ethyl in jute, lentil, mungbean, and chickpea. These herbicides are previously reported to reduce seed viability or induced seed dormancy in weed, which might have led to reducing weed pressure in ST than CT. It was reported that a range of herbicides could reduce seed production and germination by several folds depending on the biotypes. Glyphosate is registered to affected pollen and seed production almost 100% in *Ambrosia artemisiifolia* L. (Gauvrit and Chauvel, 2010) and *Bromus japonicus* Thunb. (Rinella et al., 2010) while and 69.8% in *Conyza bonariensis* L. (Wu et al., 2007). Findings of previous studies reported that herbicides could reduce the germination of weeds seeds. Tanveer et al. (2009) found pendimethalin herbicide exerted only 30.57 % seed germination of *Chenopodium album* L. Furthermore, ethoxysulfuron-ethyl killed 98-100 % seeds of *Echinochloa glabrescens* L. (Opeña et al., 2014). Moreover, oxadiazon waived 85.81% seeds of *Fimbristylis cymosa* R.Br. (Baldos et al., 2012). In contrast, carfentrazon-ethyl destroyed 100% seeds of *Emex spinosa* L. (Javaid et al., 2012) while fenoxaprop-p-ethyl wrecked 96.78% seeds of *Phalaris minor* L. (Singh, 2017).

The results of these studies agree the findings of the present study demonstrated that herbicides could potentially reduce seed production and viability of weeds, thereby reducing seed bank size in ST than CT, followed by BP and ZT. On the other hand, herbicide induced seed dormancy could contribute to the altered seed dormancy found in *Hordeum murinum* L., *Bromus diandrus* Roth., and *Lolium rigidum* Gaud., in intensive cropping systems that relied heavily on herbicidal weed control reported by Kleemann and Gill (2013) and Owen et al. (2014). The above-discussed reasons might lead to a decline in the size of the weed seed bank in ST in a trend of weed species composition following ST<CT at Mymensingh, ST<CT<BP at Durgapur and Godagari, and ST<CT<BP<ZT at Baliakandi. Barberi and Cascio (2001) agree with the findings of the present study as stated the higher weed density at ZT, followed by reduced tillage because of taller weeds seedlings recruitment from the topsoil in ZT.

In the present study, annual weeds led over perennials in CT, but perennial weeds led over annuals in ST, BP, and ZT. Boscutti et al. (2014) agree this finding in support with Erenstein and Laxmi (2008) concluded that altering the tillage regimes changes the disturbance frequency of the field, which results in shifts in weed vegetation of that field. Many studies support our survey with the reports, CT systems favor annuals, while reduced tillage systems favor perennial weeds (Tuesca et al., 2001; Taa et al., 2004). Ecological succession theory (Aweto, 2013) also agrees with our research finding suggesting the dominancy of perennials weeds in less disturbed systems. Because CT kills most of the underground vegetative reproduction structures (rhizomes, tubers, bulbs, runner, and stolons) of perennials weeds, hence, reserves only annuals weeds which reproduce mostly by seeds (matured ovules). On the other hand, the vice-versa phenomenon generally occurs in tillage was minimized in ST and BP while absent in ZT, which favored perennial weeds here in the soil weed seed bank.

In this study, retention of 40 or 50% crop residue had fewer above ground weed taxa than 20% residue. This phenomenon might be due to the drastic effect of suppressing weed seed germination caused by a physical barrier, lowering soil temperatures and allelochemicals released from decaying plant tissues, as suggested by Curran (1999). Moreover, reduced light penetration stating cooler average soil temperatures could reduce weed seed germination or causing delay germination, damage of weed seeds upon predation and decomposition by macro and microbial populations (Conklin et al., 2002) and massive moisture conservation (Manici et al., 2004); delay the emergence of etiolated plants producing lower seeds as stated earlier (Begum et al., 2006) might have reduced weed seed bank size in 40-50% residue over 20% residue.

5 Conclusion

Based on the results of this study, it might be concluded that long-term strip tillage-based conservation agriculture with 40-50% crop residue retention leads to reduce weed seed banks in terms of weed species composition and weed density. This reduction is much higher than bed planting and zero tillage. Strip tillage also increases perennial weeds in the weed seed bank while conventional tillage increases annual weeds.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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