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Continuous practice of conservation agriculture for 3-5 years reduces soil weed seedbanks size in intensive rice-based cropping patterns

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ABSTRACT

When farmers first shift from conventional tillage (CT) to conservation agriculture (CA) practice the control of weeds may be more difficult due to the absence of tillage. However, in the longer term (3-5 years), CA changes to weed dynamics may alter the weed seedbank. The nature of weed seedbank changes over time in intensively cropped rice-based rotations, that are typical of the Eastern Gangetic Plain, are not well understood. Three long term CA experiments were sampled (at Rajbari after 3 years and Rajshahi after 5 years) for effects of decreased soil disturbance strip planting (SP) and bed planting (BP) at both sites and Zero tillage (ZT) at Rajbari, increased retention of standing residues of previous crops (20 vs 50 %). The weed seedbank in 0-15 cm soil was quantified by assessing emergence from trays a net-house experiment during January-December 2016. The year-round count of emerged weeds revealed the fewest number of weed species (especially broadleaf weeds) and lowest weed density in SP followed by CT, BP, and ZT with 50% crop residues. The SP, BP, and ZT produced a higher number of perennials weeds than annual weeds, which was the opposite of CT. The continuous practice of SP and increased crop residue retention for 3 or more years decreased the size of weed seedbank but increased the relative proliferation of perennial weeds compared to CT. Weed seedbank size in SP was even smaller than BP and ZT.

Keywords: annual weeds, conservation agriculture, perennial weeds, reduced tillage, weed seedbank

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1. Introduction

Conservation Agriculture (CA) has a major influence on the relative abundance of weed species and weed control is perceived as one of the most challenging issues with the initial adoption of CA (Nichols et al., 2015). Due to a reduction in tillage, the composition and dynamics of weeds in the soil weed seedbank will change compared to conventional tillage that led to shifts in the weed communities (Pittelkow et al., 2015). Minimum soil disturbance of the CA system favors the emergence of perennial weed species relative to annual weed species in the seedbank (Singh et al., 2015). It is reported to encourage perennial weeds like *Cyperus rotundus* L., *Saccharum spontaneum* L., *Sorghum halepense* (L.) Pers, in the soil weed seedbank of minimally disturbed soil, which are generally reproduced from tubers and rhizomes present underground in soil and by not burying them to depths or by failing to uproot and kill them (Aweto, 2013). According to Woźniak (2018), annual grass populations usually increase in no-tillage systems concurrent with a decrease in populations of dicotyledonous weeds. On the other hand, Nichols et al. (2015) reported annual and perennial grasses, perennial dicot species, wind disseminated species and volunteer crop would increase and annual dicot species would decrease in reduced tillage (RT) system. Moreover, Moonen & Barberi (2004) found fivefold higher seedbank density in reduced tillage systems compared to traditional tillage practice supporting Bàrberi & Lo Cascio (2001) who observed *Amaranthus* spp. seedling density was much higher in no-till soils than tilled soils. Notwithstanding the above effects of RT in CA on the weed seedbank, there have been no comparable studies in the intensive, triple cropping systems where there is an annual period of soil submergence for wetland rice crops.

Despite the widespread promotion, in Bangladesh, the practice of CA began in 2005 (Hossain et al., 2015) to validate its' principles for small farm hold. But information is not available on weed species composition in the soil seedbank is expected to become a problem after several years. Tillage practices, crop rotation and weed control practices change weed seed density in the soil, which affects the soil weed seedbank and the efficacy of weed control practices. Changes in the weed seedbank due to crop production practices are an important element of subsequent weed problems. Information on the effect of strip tillage, crop residue retention in the intensive cropping pattern on the soil weed seedbank might be a useful tool for sustainable weed management in CA. Hence, in this ever the first-time study of soil weed seedbank was assessed from the 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 seedbanks could be used to fill the gaps in weed seedbank information and the best managing of weeds to trigger the widespread adoption of CA.

2. Materials and Methods

2.1. Experimental site, edaphic and climatic environments

Net-house experiment was conducted during January 02- December 29, 2016, at the Department of Agronomy, Bangladesh Agricultural University, geographically at 24.75° N and 90.50° E. This site is situated on the Old Brahmaputra Floodplain of predominantly dark grey non-calcareous sandy clay loam soil (50% sand, 23% silt, 27% clay) having pH 7.2.

The research site was characterized by high temperature, high humidity, and heavy monsoon rainfall with occasional gusty wind during April-September and low precipitation with moderately low temperature during October-March. The maximum temperature varies from 32.3-33.5 °C during April-June while January was the coldest month. About 95% rainfall and relative humidity was received during April-September. Sunshine hours differed much in during the months of rainfall due the cloudy weather.

2.2. Cropping history at the sites of long-term CA trials

2.2.1. Locations

CA trials were conducted at two locations at Rajbari and Rajshahi district of Bangladesh. At Rajbari district, CA trials conducted under T. *aman* rice-wheat-jute cropping pattern at Baliakandi area situated at 23°39′45′′ N and 89°29′39′′ E during 2012 - 2015. At Rajshahi district the site was at Durgapur area at 24°22′ N and 88°36′ E. Trials under T. *aman* rice-mustard-*Boro* rice, T. *aman* rice-mungbean-lentil, and lentil-jute-T. *aman* rice patterns during 2010-2015.

2.2.2. Treatments

At Rajshahi, crops were grown under conventional tillage (CT), strip planting (SP) and bed planting (BP) while at Rajbari, apart these three tillage types additional zero tillage (ZT) was included. At both sites, 20 and 50% standing residues of previous crops were retained with four replications.

2.2.3. Tillage operations

The CT was done by a two-wheel tractor (2WT) by four plowings and cross plowing followed by sun-drying for two days (in non-rice crops), finally by inundation and laddering (in rice). The SP 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 was remained untilled.

2.2.4. Crop residue retention

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. In 40/50% residue levels, previous crops were harvested keeping plants at 40/50% standing from the ground levels.

2.2.5. Weeding regimes

In CT, weeds were controlled by hand weeding in all crops. Here, three hand weeding were done at 25, 45, and 65 DAT/S in rice and wheat, while two HW were done at 25 and 45 DAS in mustard, jute, mungbean, lentil and chickpea. On the other hand, in SP, BP, and ZT weeds were controlled using different herbicides for different crops. Here, glyphosate @ 3.7 L was applied at 3 days before tillage/planting. Pendimethalin @ 2.7 L was applied at 3 DAT/S in rice and wheat while immediately after seeding of mustard, jute, lentil, mungbean and chickpea. Isoproturon was applied in mustard at 15 DAS @ 2.5 L. Ethoxysulfuron-ethyl and Carfentrazon-ethyl + isoproteuron was applied at 25 DAT/S @ 100 g and 1.25 kg in rice and wheat, respectively. Fenoxaprop-p-ethyl at 25 DAS @ 650 ml was applied at jute, mungbean, lentil, chickpea. The dose of all herbicides was their product ha^{-1}.

2.3. Soil sampling procedure and experimental set-up

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 the net-house. After that, 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 at 3 cm depth. Trays were set in the net-house following a completely randomized design, replicated four times. Each tray represented a plot and there was total 272 trays in the net-house.

2.4. Weed seed emergence and 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:

$$\text{Area} = \pi r^2 \quad \text{where, } \pi = 3.1416,\ r = \text{radius of the tray} = 33 \text{ cm}$$

3. Results

3.1. Floristic composition of weed species as affected by tillage types and residue levels

At Rajbari, CT with 20% residue produced 14 species, of which eight broadleaf, three grass, and sedges each, consisting of 10 annuals and four perennials (Table 1). But at 50% residue, 12 species found having eight broadleaf, two grass, and sedge each, including nine annuals and three perennials. The SP 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 to have less number annual broadleaf, annual grass. There were four sedges and four perennial weeds.

Table 1- Composition of weed species in different tillage types and residue levels after three years at Rajbari

Weed type, species, and life cycle			CT		SP		BP		ZT	
			R_{20}	R_{50}	R_{20}	R_{50}	R_{20}	R_{50}	R_{20}	R_{50}
Broad leaf	*Alternanthera sessilis* L.	Perennial	×	×	√	√	×	×	√	√
	Amaranthus viridis L.	Annual	√	√	×	×	√	×	√	×
	Commelina benghalensis L.	Annual	×	√	×	×	√	√	×	×
	Cyanotis axillaris Roem.	Annual	×	×	×	×	√	√	√	×
	Dentella repens L.	Perennial	√	√	√	√	×	×	√	√
	Eclipta alba L.	Annual	√	√	×	×	√	√	√	√
	Euphorbia parviflora L.	Annual	×	×	×	×	√	√	×	√
	Hedyotis corymbosa (L.) Lamk.	Annual	×	×	√	√	√	√	√	√
	Jussia deccurence Walt.	Perennial	√	√	√	√	×	×	√	√
	Lindernia hyssopifolia L.	Annual	√	√	√	√	√	√	√	√
	Lindenia antipoda Alston.	Annual	√	√	√	√	√	√	√	√

	Monochoria hastata L.	Annual	√	√	×	×	√	√	×	×
	Rotala ramosior (L.) Koehne.	Annual	×	×	×	×	×	×	√	√
	Solanum torvum Sw.	Perennial	√	×	√	√	×	×	×	×
	Spilanthes acmella Murr.	Annual	×	×	×	×	√	×	√	×
Sub-total			8	8	7	7	10	8	11	9
Grass	*Digitaria sanguinalis* L.	Annual	√	√	×	×	√	√	√	√
	Echinochloa colonum L.	Annual	√	√	√	√	√	√	√	√
	E. crusgalli L.	Annual	×	×	×	×	×	×	√	×
	Eleusine indica L.	Annual	×	×	×	×	√	√	√	√
	Leersia hexandra L.	Perennial	√	×	√	×	×	×	×	×
Sub-total			3	2	2	1	3	3	4	3
Sedges	*Cyperus difformis* L.	Annual	√	×	×	×	√	√	√	√
	C. iria L.	Annual	√	×	×	×	√	√	√	√
	C. rotundus L.	Perennial	×	×	√	√	√	√	√	√
	Fimbristylis miliacea L.	Annual	√	√	×	×	√	√	√	√
Sub-Total			3	1	1	1	4	4	4	4
Grand-Total			14	11	10	9	17	15	19	16

CT = Conventional tillage, SP = Strip planting, BP = Bed planting, ZT = Zero tillage, R_{20} = 20% residue, R_{50} = 50% residue, √ = Emerged, × = Disappeared

At Rajshahi, 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 2). Retention of 50% residue generated 21 annuals and four perennials. SP with 20% residue produced 23 species, including 14 broadleaf, four grass, and five sedges. Annuals were outnumbered than perennials. In SP 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. The 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 SP, followed by BP and CT. Retention of 50% residue produced lower weeds than 20% residue.

Table 2- Composition of weed species in different tillage types and residue levels after five years at Rajshahi

Weed type, species, and life cycle			CT		SP		BP
			R_{20}	R_{50}	R_{20}	R_{50}	R_{20}
Broad leaf	*Alternanther asessilis* L.	Perennial	√	√	√	√	√
	Amaranthus viridis L.	Annual	√	√	√	√	√
	A. spinosus L.	Annual	√	√	√	√	√
	Chenopodium album L.	Annual	√	×	√	×	√
	Commelina benghalensis L.	Annual	√	√	√	×	√
	Cyanotis axillaris Roem.	Annual	√	√	×	√	×
	Dentella repens L.	Annual	√	√	√	×	√
	Eclipta alba L.	Annual	√	√	×	√	×
	Euphorbia parviflora L.	Annual	√	√	×	×	×
	E. hirta L.	Annual	√	×	√	√	√
	Hedyotis corymbosa Lamk.	Annual	√	√	√	×	√
	Jussia deccurence Walt.	Perennial	√	×	√	√	√
	Lindernia hyssopifolia L.	Annual	√	√	√	×	√
	L. antipoda Alston.	Annual	√	√	√	×	√
	Monochoria hastata L.	Annual	×	√	√	√	√

	M. vaginalis Burm.	Annual	√	√	×	×	×
	Physalis minima L.	Annual	√	√	×	×	×
	Rotala ramosior (L.) Koehne.	Annual	√	×	√	√	√
	Solanum torvum Sw.	Perennial	×	√	√	√	×
	Sphenoclea zeylanica Gaertn.	Annual	√	√	×	×	√
	Spilanthes acmella Murr.	Annual	√	√	×	×	√
Sub-Total			19	17	14	10	15
Grass	*Digitaria sanguinalis* L.	Annual	√	√	×	√	×
	Echinochloa colonum L.	Annual	√	×	√	√	√
	E. crusgalli L.	Annual	√	×	√	√	√
	Eleusine indica L.	Annual	√	√	√	√	√
	Leersia hexandra L.	Perennial	√	√	√	×	√
Sub-Total			5	3	4	4	4
Sedges	*Cyperus difformis* L.	Annual	√	√	√	×	√
	C. iria L.	Annual	√	√	×	×	√
	C. rotundus L.	Perennial	×	×	√	√	√
	Eleocharisatro purpurea Re.	Annual	√	√	√	√	√
	Fimbristylis miliacea L.	Annual	√	√	√	√	√
	Scripus supinus L.	Perennial	√	√	√	√	√
Sub-Total			5	5	5	4	6
Grand-Total			29	25	23	18	25

CT = Conventional tillage, SP = Strip planting, BP = Bed planting, R_{20} = 20% residue, R_{50} = 50% residue, √ = Emerged, × = Disappeared

3.2. Effect of tillage types and residue levels on density (plants m^{-2}) of different weed types

At Rajbari, the highest number of weeds m^{-2} was recorded in ZT followed by BP and CT while the lowest weed density was found in SP. Compared to CT (1668), SP 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 SP, BP, and ZT (Figure 1).

Table 3- Effect of tillage types and residue levels on the density (no. m^{-2}) of different weed types at different locations

Sites	Tillage / Residue	Broadleaf		Grass		Sedges	
		R_{20}	R_{50}	R_{20}	R_{50}	R_{20}	R_{50}
Rajbari (after three years)	Conventional tillage (CT)	2019^{cd}	1317^{d}	650^{b}	497^{d}	446^{d}	671^{b}
	Strip planting (SP)	1405^{e}	1272^{de}	619^{b}	417^{d}	468^{d}	298^{de}
	Bed planting (BP)	1989^{d}	1613^{bc}	768^{b}	720^{b}	733^{b}	547^{bc}
	Zero tillage (ZT)	2891^{a}	2854^{a}	1908^{a}	1376^{a}	983^{a}	866^{a}
Rajshahi (after five years)	CT	2261^{bc}	1897^{bc}	895^{b}	542^{c}	613^{bc}	556^{b}
	SP	2067^{cd}	1704^{c}	617^{b}	561^{c}	943^{a}	398^{d}
	BP	2635^{b}	2714^{a}	897^{b}	864^{b}	672^{b}	535^{bc}
Standard deviation		405.9	542.7	356.8	266.0	177.4	183.7
Co-efficient of variance (%)		18.6	28.4	43.4	40.6	26.7	31.5
Standard error		117.2	156.6	103.0	76.7	51.2	53.1

R_{20} = 20% residue, R_{50} = 50% residue

At Rajshahi, BP generated the highest weed density, followed by CT and SP. Compared to CT (2079), SP had 237 fewer weeds, but BP had 776 more number of weeds. Retention of 50% residue produced 610 fewer numbers of weeds than 20% residue. Broadleaf weeds were the most dominant in all types of tillage at both locations, while grass was outnumbered than sedges in BP but reverse in SP. Annuals led over perennials in CT, but perennials led over annuals both in SP and BP (Figure 1).

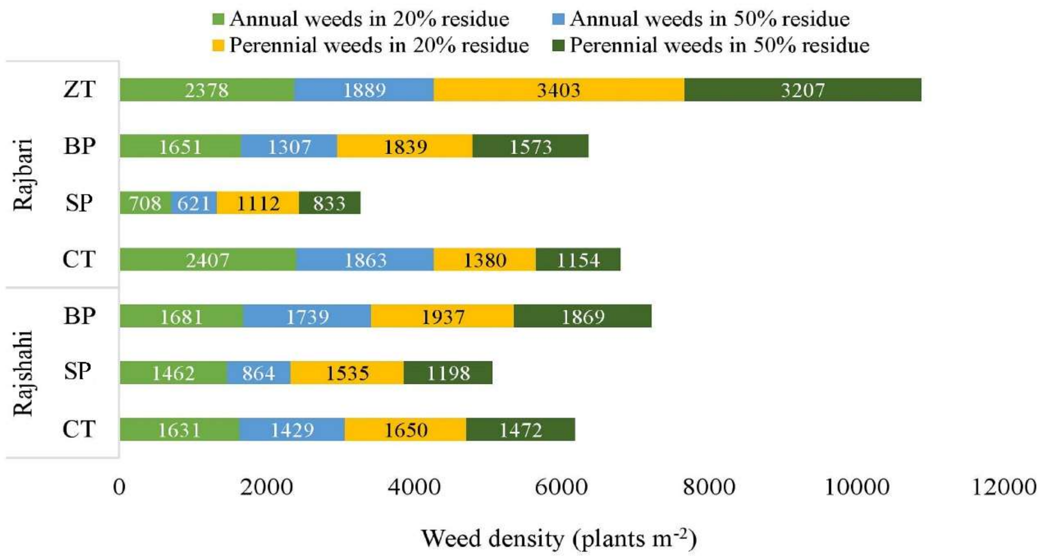

Figure 1- Distribution of annual and perennial weeds at Rajbari and Rajshahi under conservation agricultural practices

4. Discussion

In this study, the higher number of weeds composting broadleaf, grass, and sedge types was found in CT than SP. This phenomenon might be attributed to the emergence of more weed species in CT over SP. The earlier research suggests that about 80% disturbed soil of CT (Dahlin & Rusinamhodzi, 2019) 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 SP that may increase the weed species composition in the weed seedbank of CT than SP. Liebman & Mohler (2001) quoted that 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. By contrast Gallandt et al. (2004) found a higher proportion of seedbanks will germinate in reduced tilled soil compared with CT due to the presence of higher rate of germination stimulus near the soil surface and decreases with depth. That might led to larger seedbank size in ZT than CT followed by BP and SP in this study

The reduction of the number of weed species in SP might also be due to minimizing the weed seedbank status in the soil by increasing non-viable or dormant weed seeds in the seedbank. Due to minimal soil disturbance (only 20%) at the upper soil layer in SP, 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 SP may also be attributed to increased seed dormancy at an undisturbed deeper soil layer. Seeds remain dormant 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 (Oziegbe et al., 2010).

Surface accumulation of weed seeds in SP would increase predator (ants, insects, rodents, and birds) 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 SP 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 seedbank size in SP. Higher dispersal of weed seeds may also lead to an increase in the seedbank in CT over SP followed by BP and ZT. Barroso et al. (2006) found the weed seeds traveled 2–3 m in the direction of full tillage, while in reduced tillage soils, the distance is negligible. Reducing tillage in SP, BP and nil in ZT, therefore, reduced the spread of weed seed both within and across fields and increased seedbank size ZT followed by BP and SP in this study. The reduced weed seedbank in SP 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 SP followed by BP, and ZT. In the long-term CA glyphosate and pendimethalin herbicide were used in all crops. Besides, ethoxysulfuron-ethyl in rice, isoproturon in mustard, carfentrazon-ethyl + isoproteuron in wheat while fenoxaprop-p-ethyl in jute, lentil, mungbean, and chickpea. These herbicides are previously reported to reduce seed viability / induced seed dormancy in weed, which might have led to reducing weed pressure in SP than CT. It was reported that a range of herbicides could reduce seed production and germination by several folds depending on the biotypes. Glyphosate was found to affect the pollen and seed production almost 100% in *Ambrosia artemisiifolia* L. (Gauvrit & Chauvel, 2010); pendimethalin herbicide reported to hamper 30.57 % seed germination of *Chenopodium album* L. (Tanveer et al., 2009), while ethoxysulfuron-ethyl killed 98-100 % seeds of *Echinochloa glabrescens* L. (Opeña et al., 2014). Moreover, carfentrazon-ethyl + isoproteuron damaged 100% seeds of *Emex spinosa* L. (Javaid et al., 2012) and fenoxaprop-p-ethyl wrecked 96.78% seeds of *Phalaris minor* L. (Singh et al., 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 seedbank size in SP 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. as reported by (Kleemann & Gill, 2013) and (Owen et al., 2015). The above-discussed reasons might lead to a decline in the size of the weed seedbank in SP in a trend of weed species composition in SP than CT followed by BP at Rajshahi and ZT at Rajbari. Bàrberi & Lo Cascio (2001) agreed the findings of the present study as stated the higher weed density at ZT, followed by CT, SP and BP because of higher weed seedlings recruitment from the topsoil in ZT than other tillage types of CA practice.

In the present study, annual weeds led over perennials in CT, but perennial weeds led over annuals in SP, BP, and ZT. Many studies support our study reporting that CT systems favor annuals, while reduced tillage systems favor perennial weeds Tuesca et al. (2001). 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 SP and BP while absent in ZT, which favored perennial weeds here in the soil weed seedbank.

In this study, retention 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 (2016). 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); delay the emergence of etiolated plants producing lower seeds as stated earlier (Begum et al., 2006) might have reduced weed seedbank size in 50% residue over 20% residue.

5. Conclusion

Based on the results of this study, it might be concluded that long-term strip planting-based conservation agriculture with 50% crop residue retention leads to reduce weed seedbanks status in the soil. This reduction is much higher than bed planting and zero tillage. Strip planting, bed plating and zero tillage increases perennial weeds in the weed seedbank while conventional tillage increases annual weeds.

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Conflict of Interest

No conflicts of interest have been declared.

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