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RESEARCH ARTICLE

Impact of crop establishment on major weeds and their vertical distribution in rice

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ABSTRACT

Weed management strategies across diverse cropping systems must address weed seed distribution and emergence behaviour. Various agronomic practices, including tillage, have been documented to influence these factors, thus assuming a critical role in the formulation of weed management strategies. In a study during the rainy (*Kharif*) seasons of 2021 and 2022, the impact of different crop establishment methods: puddled transplanted rice (PuTTR); direct-seeded rice on permanent beds (PBDSR)-with residue (+R); zero till direct-seeded rice (ZTDSR)+R/-R; ZTDSR with inversion (+I)+R/-R; unpuddled transplanted rice (UPTR); (+R); (R) on the vertical spatial distribution of weed seeds within the soil and the emergence dynamics of distinct weed species was systematically assessed. The results unveiled that vertical distribution in PBDSR+R and ZTR +R/-R had 84% of beads (simulated weed seeds) in 0-3 cm and 16% in 3-6 cm. None of the beads were found in the lower depth of lesser disturbed soil. In contrast, conventional tillage (PuTTR and UPTR) had higher soil disturbance resulting in only 12.75% and 22.5% beads on top layer (0-3 cm) and 19.4 % and 34.5 % in 3-6 cm, 36.16 % and 24.8 % in 6-9 cm, 28 % and 14.3% in 9-12 cm, respectively. PuTTR and UPTR systems reduce the weed incidence by bury the high proportion of weed seeds below 3 cm. Furthermore, the study delineated that the maximal seedling emergence of *Leptochloa cheninsis, Ammannia baccifera, Echinochloa crus-galli* and *Caesulia axillaris* in ZT without residue followed by ZT+R. R egardless of weed species, the average emergence was 14%. The minimal germination of weeds was in PuTTR and UPTR. This investigation furnishes invaluable insights that may inform judicious decision-making in the realm of weed management, with an emphasis on the judicious integration of tillage methodologies and complementary weed control measures.

Keywords: *Ammannia baccifera,* Crop establishment, *Echinochloa crus-galli, Leptochloa chinensis,* Vertical distribution, Weed emergence pattern

INTRODUCTION

Rice is a staple food in many parts of India and is a significant component of the Indian diet. Conventional puddled rice was more common in India. However, conventional practices are associated with several drawbacks. Input costs rise, putting farmers under financial strain, mainly due to tillage and high labour cost for manual transplanting. Furthermore, these practices delay the subsequent wheat sowing process. A further disadvantage of conventional farming practices is to disrupt the natural state of the soil, thereby creating an unfavorable physical environment that hampers the growth and development of the following wheat crop (Dhanda *et al.* 2022). Disturbed soil conditions become a significant impediment to wheat cultivation, preventing it from progressing smoothly. But, presence of standing water during crop establishment, which suppresses weed growth. In contrast, direct-seeded rice (DSR) production is hindered by the presence of weeds and because of cultivated crops and weeds are not distinguished by distinct size variations, effective differentiation is difficult (Chauhan 2012, Hossain *et al.* 2020). However, direct seeding with dry seed, especially under ZT has numerous benefits, including reducing soil erosion, improving soil properties, conserving soil moisture and reduce fuel costs (Chauhan *et al.* 2012, Chaudhary *et al.* 2022). DSR systems had gained wide adoption among Indian farmers. DSR systems also increase crop yields, reduce the need for chemical fertilizers and improve water availability (ADB 2019). Furthermore, this technology helps to improve air quality and reduce greenhouse gas emissions (Pathak *et al.* 2013, de Araújo Santos *et al.* 2019).

This changes in tillage practices, however, can affect weed seed vertical distribution in the soil, thereby affecting weed species abundance. A

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significant portion of the weed seed bank found in ZT systems remains near the soil surface, resulting in predominance of light-dependent weed species such as *Leptochloa chinensis, Ammannia baccifera and Echinochloa crus-galli* (Singh *et al.* 2016, Yadav *et al.* 2018, Padmakumari *et al.* 2019, Hossain *et al.* 2020). As an alternative, conventional tillage may favour the growth of weed species that can tolerate deeper burial depths. This could change the composition of the weed seed bank. A limited knowledge available on weed emergence of *Leptochloa chinensis, Ammannia baccifera, Caesulia axillaris and Echinochloa crus-galli* in both conventional and DSR. Research is essential to understand the impacts of reduced tillage on weed species. Our study's aim was to investigate how different establishment method influence weed emergence pattern and changes in the vertical weed distribution. This helps to understand the germination ecology, ultimately in decision making for early weed management.

MATERIALS AND METHODS

Field investigations were conducted in 2021 and 2022 growing seasons in ongoing (since 2006) experiment "Long-term Research on Conservation Agriculture in a Rice-Wheat Cropping System of Eastern Indo-Gangetic Plains" by CIMMYT at Research farm in Dr. Rajendra Prasad Central Agricultural University, Pusa situated in North of Bihar, India. The research evaluated different type of crop establishment method listed in **Table 1**. Composite sample was taken before initiating the experiment, soil pH, electrical conductivity (EC) and organic carbon (OC) was 8.53, 0.58 dS/m and 0.72%. Primary available nutrients in soil were N (210 kg/ha), P (12.29 kg/ha) and K (129.41 kg/ha). The annual rainfall received during rice cultivation was 1592 mm and 675 mm in 2021 and 2022, respectively.

For seedling emergence pattern

The rice from major weeds taken for study, *viz. Ammannia baccifera, Caesulia axillaris, Echinochloa crusgalli, Leptochloa chinensis*. All the weed seeds collected from mature plants from Research farm, RPCAU, Pusa. Collected seeds were stored at room temperature. Selected weed Seeds (@100/m^2) were spread evenly 3 months before initiating tillage for rice crop in 2 m x 2 m plot size, and with subsequent seedlings emerging after crop sowing were observed at 7 days interval up to 56 days. Rice sowing was also done on which emergence of weed had been studied. However, the other species weeds were allowed to grow in the sampling area. Additionally, control plots were established in both years without introducing seeds of weeds, and seedling emergence was measured to determine the natural seed bank. Data presented in emergence rate after subtracting the control plot and expressed in the percentage of emergence.

For vertical seed (plastic beads) distribution

Plastic beads (1.5 mm x 1 mm) serving as proxies for weed seeds, were uniformly scattered in 2 x 2 m area 100/m^{-2} just before of tillage were employed to evaluate the influence of tillage on the vertical distribution of seeds within the soil. The crop establishment methods adopted during rice crop season in different treatments was explain in detail under **Table 1**. After planting, soil sampled and washed with water to separate and count the distribution at different depth (*i.e.* 0-3 cm, 3-6 cm, 6-9 cm and 9-12 cm) and presented as a percentage relative to the total bead count across all depths.

Table 1. Treatment details

Treatment	Tillage	Crop establishment	Residue management
PuTTR–CTW	3 passes of dry tillage with harrow, 2 passes of cultivator in ponded water followed by 1 planking	Manually transplanted, random geometry	All removed
PuTTR–ZTW	3 passes of dry tillage with harrow, 2 passes of cultivator in ponded water followed by 1 planking	Manually transplanted, random geometry	All removed
PBDSR–PBDDW (+R)	Zero till	Direct dry seeding on permanent beds	50% rice residue retained in wheat cycle
ZTR–ZTW	Zero till	Direct dry seeding on flat soil, row geometry	All removed
ZTR- ZTW-R (+I)	Zero till	Direct dry seeding on flat soil, row geometry	All removed
ZTR- ZTW+R (+I)	Zero till	Direct dry seeding on flat soil, row geometry	50% rice residue retained
UPTR-ZTW	3 passes of dry tillage with harrow, 1 pass of cultivator followed by 1 planking	Manually transplanted, random geometry	All removed
ZTR (+SBM)- ZTW	Zero till	Direct dry seeding on flat soil, row geometry	All removed

Statistical analysis

A two-way ANOVA was used in order to analyse vertical seed distribution across different tillage systems based on a randomized block design, which consisted of incorporating tillage as a factor and depth as the other, using the SigmaPlot 15.0 statistical software package. Due to the presence of different significant time (DAS) in the different year, the results for each year of the study were analyzed individually in order to determine when seedling emergence was influenced by different tillage systems at each sampling time (DAS). An application of SigmaPlot 15.0 software was used to implement a functional three-parameter sigmoid model of seedling emergence for each species, under varying tillage systems. The model, which was applied to SigmaPlot 15.0 software, was expressed as follows:

$$E\ (\%) = E_{max} / (1 + \exp((x - T_{50}) / E_{rate})) \quad ....1$$

In this equation, E represents the total seedling emergence (%) at time x, E_{max} represents the highest percentage of seedling emergence ever recorded (%), T_{50} represents the time required (in days) to obtain 50% emergence, and E_{rate} represents the slope around T_{50}.

RESULTS AND DISCUSSION

Seedling emergence pattern

Caesulia axillaris: The size of the seed has a significant impact on the germination from depth. This may positively affect germination in this species since most of seeds remain on top of the soil surface under ZTR conditions. After 21 days in 2021 and 14 days in 2022, seedling recruitment of pink node flower (*Caesulia axillaris*) after ZTR approached (with or without residue) was significantly higher ($P>0.05$) in comparison to transplanted plots till 56 days in both years (**Figure 1a**). As compared to ZT with residue (3-8%) or without residue (10-13%), the Sigmoid fitted model (Equation 1) estimated lower recruitment under transplanted system (2-3%) in both years. In the PuTTR and UPTR, 50% of seedlings emerged within a shorter timeframe (T_{50}) (**Table 2**). While seedling recruitment rate (E_{rate}) varied across systems, it was strikingly similar.

Pink node flower seeds require almost equal periods of imbibition, which could equalize germination rates. Singh and Amritphale (1992) stated that *Caesulia axillaris* require 5 days for imbibition. Singh and Amritphale (1992), demonstrated that there is absolute requirement of light for germination, resulting in a 50% reduction in residue presence compared with absence of crop residue over surface.

***Echinochloa crus-galli*:** The cumulative emergence of *E. crus-galli* seedlings was significantly higher under zero-tillage (ZT) rice during both observation years ($P<0.05$). Puddled transplanted rice (PuTTR) and unpuddled transplanted rice (UPTR) displayed significantly higher emergence rates around T_{50} than ZTDSR with or without residue (**Figure 1b**). However, peak seedling emergence varied, with 20% to 24% of initially sown seeds emerging under ZTR (-R), 10% to 12% emerging under crop residue (PBDSR+R and ZTDSR +R), and 2% to 6% emerging under transplanted rice (**Table 3**). Transplanted system (Puddled and Unpuddled) had achieved T_{50} at least 3 days earlier than no till system.

This heightened seedling emergence experienced under ZT can likely be attributed to the comparatively smaller size of *E. crus-galli* seeds (**Table 3**). The diminutive seed size rendered them incapable of emerging from deeper burial caused by UPTR and PuTTR practices. Greater depth reduces the seedling emergence as observed in other weed specie *i.e Rumex obtusifolius*, there was no germination below 8 cm (Benvenuti *et al.* 2001a). In the ZTW(+R) and PPDSR (+R), however, there may be less emergence because there is less light which inhibit seedling emergence. Similar observations have been made in other weed species, where the emergence of seeds buried deeply is inversely correlated with their weight (Benvenuti *et al.* 2001b).

***Ammannia baccifera*:** Emergence pattern of *A. baccifera* was found significantly higher throughout study period in ZTR than transplanted system. Blisteting ammania seeds were very tiny with a test weight of 0.0198g (**Table 4**). So, Emergence was limited to 1% in PuTTR and UPTR whereas, 5-6% seedling recruitment in the ZTR (+R) and PBDSR (+R) and 12-17% emergence in 2021 (**Figure 1c**). 3 parameter sigmoid fit model had given lesser E_{rate} for transplanted system than DSR approach. T_{50} in the ZTR (+R) and PBDSR (+R) were lower than other system (**Table 4**).

Crop residue inhibits light reaching on the surface resulting lesser seed emergence even though larger number of seed remains on the surface. Crop residue inhibits light reaching the surface, which results in lesser seed emergence (Sepat *et al.* 2017; Jat *et al.* 2019), despite the presence of a larger number of seeds on the surface. This might be due to the fact that light-induced inhibition of germination has been documented in a closely related species, *Ammannia coccinnea*, as noted by Gibson *et al.* (2001). Furthermore, Shen *et al.* (2010) showed more emergence at shallower depths of 3 cm and

Table 2. Responses of *Caesulia axillaris* to seedling emergence under different crop establishment method

Crop establishment method	2021				2022			
	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
PuTTR- CTW	1.7(0.04)	4.4(0.7)	19.9(0.6)	0.99	2.2(0.3)	10.7(4.1)	29.7(2.8)	0.96
PuTTR- ZTW	1.7(0)	4.5(0.6)	22.3(0.5)	0.99	2.6(0.3)	9.2(2.9)	30(2.1)	0.97
PBDSR-PBDDW (+R)	5.9(0.2)	4.4(0.9)	20(0.8)	0.98	7.8(0.6)	9.6(2.1)	37.4(1.2)	0.99
ZTR- ZTW	10.4(0.5)	6(1.2)	26.8(1)	0.98	12.1(0.9)	9.5(2.2)	29.9(1.5)	0.98
ZTR- ZTW-(I)(-R)	12.7(0.4)	6.2(0.9)	28.7(0.7)	0.99	12.9(0.9)	9(2.1)	29(1.5)	0.98
ZTR- ZTW-(I)(+R)	4.8(0.1)	4.6(0.8)	22.8(0.7)	0.99	5.2(0.6)	10.8(3.8)	32.1(2.4)	0.97
UPTR- ZTW	3.4(0.1)	2.6(0.4)	23(0.3)	0.99	2(0)	5.8(0.7)	24.8(0.6)	0.99
ZTR (+SBM) – ZTW	12.6(0.6)	7.6(1.2)	31.2(0.9)	0.99	11.7(0.6)	8.4(1.4)	30.7(1)	0.99

Table 3. Responses of *Echinochloa crus-galli* to seedling emergence in different crop establishment method

Crop establishment method	2021				2022			
	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
PuTTR- CTW	5.2(0.3)	5.6(1.5)	21.8(1.3)	0.971	6.3(0.03)	2.3(0.1)	15.9(0.1)	0.99
PuTTR- ZTW	4.4(0.4)	8.8(2.5)	25.3(2)	0.968	5.9(0.1)	2.9(0.5)	16.1(0.4)	0.99
PBDSR-PBDDW (+R)	11.8(0.1)	4.4(0.3)	13.9(0.3)	0.996	12.4(0.1)	3.3(0.3)	11.7(0.3)	0.99
ZTR- ZTW	23.2(0.8)	7.5(1.1)	15.4(1.2)	0.98	20.2(0.1)	3.2(0.1)	11.7(0.1)	0.95
ZTR- ZTW-(I)(-R)	24(0.4)	6.7(0.6)	14.6(0.6)	0.992	22.2(0.1)	4.1(0.2)	14(0.2)	0.98
ZTR- ZTW-(I)(+R)	10.9(0.2)	4.3(0.5)	15.5(0.5)	0.993	10.4(0.04)	2.6(0.1)	11.3(0.1)	0.99
UPTR- ZTW	6.1(0.5)	8.8(2.6)	27.1(2)	0.969	6.7(0.1)	3.7(0.4)	17.6(0.3)	0.99
ZTR (+SBM) – ZTW	26.3(0.9)	7.5(1.1)	20.8(1)	0.987	24(0.5)	4.4(0.7)	14.2(0.6)	0.99

Table 4. Responses of *Ammannia baccifera* to seedling emergence under different crop establishment method

Crop establishment method	2021				2022			
	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
PuTTR- CTW	0.7(0)	0.4(0)	14(0)	1	1.3(0)	0.4(0)	14(0)	1
PuTTR- ZTW	0.3(0)	0.3(0.2)	10.6(0)	1	0.7(0)	0.4(0)	7(0)	1
PBDSR-PBDDW (+R)	5.1(0)	7.5(0.4)	8.4(0.5)	0.99	6.3(0)	2.9(0.2)	9.2(0.2)	0.99
ZTR- ZTW	12.1(0.2)	6(0.6)	15.3(0.6)	0.99	14.4(0)	2.9(0.1)	14.7(0.1)	0.99
ZTR- ZTW-(I)(-R)	13(0.2)	4.5(0.4)	13.7(0.3)	0.99	17.5(0.3)	5(0.6)	16.2(0.5)	0.99
ZTR- ZTW-(I)(+R)	4.3(0)	3.2(0.1)	8.5(0.1)	0.99	5.4(0)	3.1(0.1)	9.5(0.1)	0.99
UPTR- ZTW	0.7(0)	0.4(0)	14(0)	1	1(0)	0.6(0)	13.6(0)	1
ZTR (+SBM) – ZTW	12.9(0.1)	3.3(0.3)	13.4(0.3)	0.99	16.8(0.2)	4.5(0.4)	13(0.4)	0.99

Table 5. Responses of *Leptochloa chinensis* to seedling emergence in different crop establishment method

Crop establishment method	2021				2022			
	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
PuTTR- CTW	4.7(0)	0.5(0.02)	20.5(0.02)	1	2.3(0)	0.5(0)	20.5(0)	1
PuTTR- ZTW	3.3(0.1)	2.2(0.5)	15.8(0.4)	0.99	2.3(0)	0.5(0)	20.1(0)	1
PBDSR-PBDDW (+R)	12.8(0.2)	3.5(0.5)	12.4(0.5)	9.98	9.8(0.1)	4.5(0.5)	8.9(0.6)	0.98
ZTR- ZTW	18.2(0.1)	2.7(0.2)	9.3(0.2)	0.99	22.7(0.1)	3.3(0.1)	12.2(0.1)	0.99
ZTR- ZTW-(I)(-R)	19.2(0.2)	2.9(0.2)	10.2(0.2)	0.99	21.8(0.2)	3.4(0.3)	12.1(0.3)	0.99
ZTR- ZTW-(I)(+R)	8.6(0.1)	2.1(0.3)	10.4(0.2)	0.99	8.4(0.1)	3.8(0.3)	16.4(0.2)	0.99
UPTR- ZTW	6.4(0.1)	3.7(0.3)	15.2(0.3)	0.99	7.4(0.1)	2.4(0.2)	20.5(0.3)	0.99
ZTR (+SBM) – ZTW	21.7(0.03)	3.3(0.04)	11.3(0.03)	0.99	19.9(0.4)	3.6(0.6)	12.5(0.5)	0.98

Standard error (SE) is included with parameter estimates in parenthesis. A three-parameter sigmoid model was fitted to the seeding emergence data. $\mathbf{E_{max}}$ is the maximum seedling emergence (%), $\mathbf{E_{rate}}$ denotes slope around T_{50} and $\mathbf{T_{50}}$ is the time (days) to reach 50% of maximum seedling

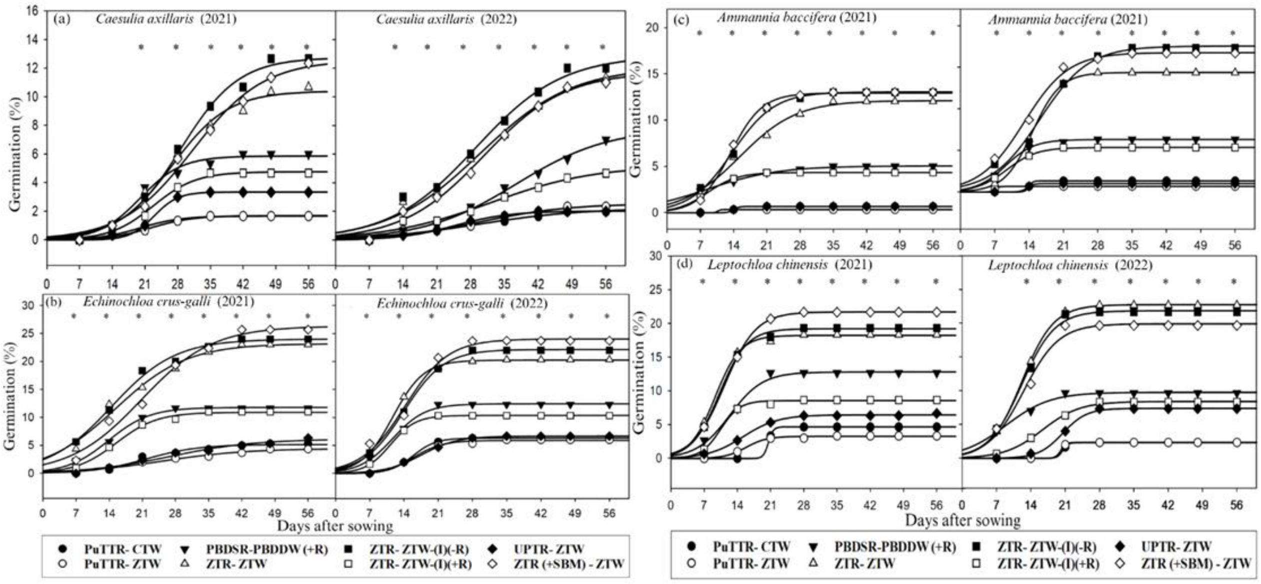

Figure 1. Seedling emergence pattern of (a) *Caesulia axillaris*, (b) *Echinochloa crus-galli* (c) *Ammannia baccifera* and (d) *Leptochloa chinensis* in different crop establishment method; The asterisk was used to indicate significant differences among different crop establishment method was observed ($p < 0.05$).

conforming to its photoblastic nature. DSR allowed *A. baccifera* germinate and establish more rapidly due to the fact that conserve moisture and seed remain on surface in the field.

***Leptochloa chinensis*:** The results of our study showed that plots subjected to the ZTR approach displayed significantly higher levels of seedling recruitment for the *Leptochloa chinensis* than plots subjected to the PuTTR or UPTR approach during both years of our investigation (as shown in **Figure 1d**). There was a maximum of 18-23% of seedling recruitment in ZTR(-R) plots for the years 2021 and 2022, contrasting with 9-13% and 2-7% in ZT with residue (PBDSR+R, ZTDSR+R) plots and transplanting plots (PuTTR or UPTR) plots (**Table 5**). The increased burial depth within the more disturbed plot (PuTTR and UPTR) could contribute to a longer time period required to reach the T_{50} (15-20 days) value in comparison to the less disturbed plot (ZTR) system (**Table 5**).

The higher seedling recruitment observed under ZTR may be due to the fact that there are the higher seed residues on the surface (Chauhan and Johnson 2009) in combination with the stimulation caused by exposure to light and higher temperature fluctuation (Benvenuti *et al.* 2004). On the other hand, puddled and unpuddled soil had lesser germination due to the higher percentage of seeds buried, higher than 0.5 cm, incapable of receiving light more than 1% (Chauhan and Johnson 2008), to a greater depth. Aulakh *et al.* (2006) had also confirmed the validity of this conjecture, claiming that seeds placed deeper than 2.5 cm did not emerge to the surface. Another, *Leptochloa fusca*, a diploid closely related species (Farooq 1989) had reduced germination in absence of light (Altop *et al.* 2015).

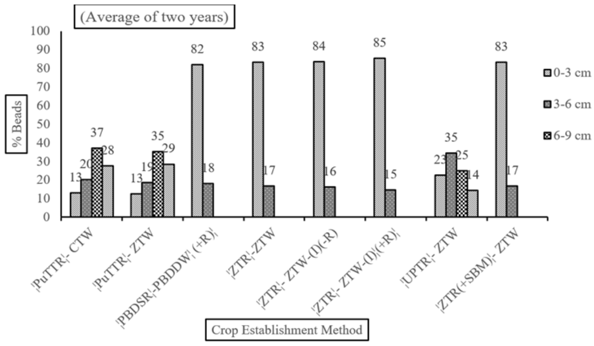

Figure 2. Vertical distribution of weed seeds as affected by crop establishment methods

Vertical seed distribution influences by crop establishment method

Vertical distribution was not found significant under different tillage system. However, vertical distribution of beads found significant ($P<0.001$) with respect to soil depth and interaction between tillage practices and depth. The tillage with lesser disturbance with PBDDR+R and ZTR+R or without residue (ZTR) had 84% of beads in 0-3cm and 16% in 3-6 cm. None of the beads were found in the lower depth of lesser disturbed soil. In contrast, conventional tillage (PuTTR and UPTR) resulted in higher soil disturbance resulting in only 12.75% and 22.5% beads on top layer (0-3 cm) and 19.4% and 34.5% in 3-6 cm, 36.16% and 24.8% in 6-9 cm, 28% and 14.3% in 9-12 cm, respectively (**Figure 2**).

Depending on the species, there are differences in the weed seed size, seed weight, and other morphological characteristics that influence the burial process of the weed seeds (Chauhan and Johnson 2009). Weed seedling emergence patterns are largely determined by how seeds are distributed vertically in soil as a consequence of different tillage methods (Chauhan *et al.*2006). As a result of soil tillage, seeds are placed differently within soil layers, which then affects the emergence pattern of weed seedlings and the overall weed population. Use of plastic beads for stimulating the weed seeds might not give the most accurate description of the seed distribution of the weed seeds. There is no doubt that stimulation can explain the system with less interference resulted in a greater portion of weed seeds near the soil surface than those that were buried. Above ground seeds more likely subjected to predation or loose viability early due to high weather fluctuation. But conventional tillage helps to weed seed buried and continued to persist for a longer period of time or, thus becoming a part of the long-term weed seed bank.

Conclusion

Based on the results of this study, it may be possible to develop models and determine optimal weed control timings within crops. Regardless of the type of tillage system used or the weed species present, the maximum seedling emergence observed was 14%. In ZT systems as well as in permanent bed systems, weeds appear to be promoted, suggesting that they may become a significant problem. Therefore, management strategies may be needed to address this issue. Alternatively, adopting PuTTR and UPTR methods might be effective in slowing down the buildup of weed populations. Weed seedling emergence patterns are largely determined by how seeds are distributed vertically in soil as a consequence of different tillage methods. PuTTR and UPTR helps to bury weed seeds in greater depth while, PBDSR and DSR keep close to the soil surface. These result raises important questions about the fate of seeds remaining in the seed bank when seedling emergence is limited. Do these seeds decompose before the start of the next growing season, or do they become part of a more persistent seed bank? Further research is required to address this crucial knowledge gap in our understanding of the ecology of these weed species.

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REFERENCES

Asian Development Bank (ADB) 2019. Climate-smart practices for intensive rice-based systems in bangladesh, cambodia, and nepal. 1–56. http://dx.doi.org/10.22617/TCS190468-2

Altop EK, Mennan H, Phillippo CJ and Zandstra BH. 2015. Effect of the burial depth and environmental factors on the seasonal germination of bearded sprangletop (*Leptochloa fusca*[L.] Kunth ssp.*fascicularis*[Lam.] N. Snow). *Weed Biology and Management* **4**: 147–158. https://doi.org/10.1111/wbm.12078

Aulakh CS, Mehra SP, Bhatia RK. 2006. Effect of temperature, submergence and seed placement depths on germination behaviour of Red Sprangletop [*Leptochloa chinensis* (L.) Nees]. *Indian Journal of Weed Science* **38**(1&2): 108–111.

Benvenuti S, Dinelli G and Bonetti A. 2004. Germination ecology of *Leptochloa chinensis*: a new weed in the Italian rice agro-environment. *Weed Research* **2**: 87–96. https://doi.org/10.1111/j.1365-3180.2003.00376.x

Benvenuti S, Macchia M and Miele S. 2001a. Light, temperature and burial depth effects on Rumex obtusifolius seed germination and emergence. *Weed Research* **2**: 177–186. https://doi.org/10.1046/j.1365-3180.2001.00230.x

Benvenuti S, Macchia M and Miele S. 2001b. Quantitative analysis of emergence of seedlings from buried weed seeds with increasing soil depth. *Weed Science* **4**: 528–535. https://doi.org/10.1614/0043-1745(2001)049[0528:qaoeos]2.0.co;2

Chaudhary A, Venkatramanan V, Kumar Mishra A, and Sharma S. 2022. Agronomic and Environmental Determinants of Direct Seeded Rice in South Asia. *Circular Economy and Sustainability* **1**: 253–290. https://doi.org/10.1007/s43615-022-00173-x

Chauhan BS and Johnson ED. 2009. Influence of tillage systems on weed seedling emergence pattern in rainfed rice. *Soil and Tillage Research*, **106**(1): 15–21. https://doi.org/10.1016/j.still.2009.10.004

Chauhan BS, Gill G and Preston C. 2006. Influence of tillage systems on vertical distribution, seedling recruitment and persistence of rigid ryegrass (*Lolium rigidum*) seed bank. *Weed Science* **4**: 669–676. doi:10.1614/ws-05-184r.1

Chauhan BS and Johnson DE. 2008. Germination ecology of Chinese Sprangletop (*Leptochloa chinensis*) in the Philippines. *Weed Science* **6**: 820–825. https://doi.org/10.1614/ws-08-070.1

Chauhan BS. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technology* **1**: 1–13. https://doi.org/10.1614/wt-d-11-00105.1

Chauhan BS, Singh RG and Mahajan G (2012). Ecology and management of weeds under conservation agriculture: A review. *Crop Protection* **38**: 57–65. https://doi.org/10.1016/j.cropro.2012.03.010

Dhanda S, Yadav A, Yadav DB and Chauhan BS. 2022. Emerging issues and potential ppportunities in the rice–wheat cropping system of North-Western India. *Frontiers in Plant Science*. https://doi.org/10.3389/fpls.2022.832683

de Araújo Santos GA, Moitinho MR, de Oliveira Silva B, Xavier CV, Teixeira DDB, Corá J E and Júnior NLS (2019). Effects of long-term no-tillage systems with different succession cropping strategies on the variation of soil CO_2 emission. *Science of The Total Environment* 413–424. https://doi.org/10.1016/j.scitotenv.2019.05.398

Farooq S. 1989. Karyological studies of kallar grass (*Leptochloa fusca* L.). *CYTOLOGIA*: **2**: 381–384. https://doi.org/10.1508/cytologia.54.381

Gibson KD, Fischer AJ and Foin TC. 2001. Shading and the growth and photosynthetic responses of *Ammannia coccinnea*. *Weed Research* **1**: 59–67. https://doi.org/10.1046/j.1365-3180.2001.00223.x

Hossain K, Timsina J, Johnson DE, Gathala MK and Krupnik TJ. 2020. Multi-year weed community dynamics and rice yields as influenced by tillage, crop establishment, and weed control: Implications for rice-maize rotations in the eastern Gangetic plains. *Crop Protection*: 105334. https://doi.org/10.1016/j.cropro.2020.105334

Jat RK, Singh RG, Gupta RK, Gill G, Chauhan BS and Pooniya V. 2019. Tillage, crop establishment, residue management and herbicide applications for effective weed control in direct seeded rice of eastern Indo–Gangetic Plains of South Asia. *Crop Protection* 12–20. https://doi.org/10.1016/j.cropro.2019.05.007

Padmakumari AP, Sreedevi B, Sivakrishna K. 2019. Effect of herbicides on feeding, survival and development of *Haltica cyanea*, a biocontrol agent of dicot weed, *Ammania baccifera* L. in rice ecosystem. *Journal of Biological Control* **2**:117–121. https://doi.org/10.18311/jbc/2019/22698

Pathak H, Sankhyan S, Dubey DS, Bhatia A, Jain N. 2013. Dry direct-seeding of rice for mitigating greenhouse gas emission: field experimentation and simulation. *Paddy Water Environment* **11**: 593–601. https://doi.org/10.1007/s10333-012–0352-0

Sepat S, Thierfelder C, Sharma AR, Pavuluri K, Kumar D, Iquebal MA and Verma A. 2017. Effects of weed control strategy on weed dynamics, soybean productivity and profitability under conservation agriculture in India. *Field Crops Research* 61–70. https://doi.org/10.1016/j.fcr.2017.05.017

Shen X, Pyon JY and Kim DS. 2010. Germination and seedling emergence of *Ammannia coccinea* as influenced by environmental factors. *Korean Journal of Weed Science* 2: 84–93. doi:10.5660/kjws.2010.30.2.084

Singh B and Amritphale D. 1992. Effect of light and its interaction with nitrate and ammoniumions in seed germination of *Caesulia axillaris*. *Physiologia Plantarum* **85**(1): 43–48. https://doi.org/10.1111/j.1399-3054.1992.tb05261.x

Singh VP, Singh SP, Dhyani VC, Banga A, Kumar A, Satyawali K and Bisht N. 2016. Weed management in direct-seeded rice. *Indian Journal of Weed Science* **3**: 233. https://doi.org/10.5958/0974-8164.2016.00059.9

Yadav RI, Singh MK, Singh RK and Nagargade M. 2018. Planting methods and weed management to improve yield in dry-seeded rice. *Indian Journal of Weed Science* **1**: 22. https://doi.org/10.5958/0974-8164.2018.00005.9