Can knowledge in seed ecology contribute to improved weed management in direct-seeded rice?

*Bhagirath Singh Chauhan**

Direct-seeded rice is an emerging production technology in Asia due to labour and water scarcity. However, weeds are an important biotic constraint in the production of direct-seeded rice. Manual weeding is becoming less common and herbicides are replacing manual weeding to manage weeds in direct-seeded systems. However, there are concerns about the evolution of herbicide resistance in weeds and shifts in weed flora. Therefore, there is an interest among scientists to evaluate cultural weed management strategies to improve weed management in direct-seeded rice systems. Weed seed banks are the main source of weed infestation in any crop. Depleting the weed seed bank should be the main aim of cultural weed management strategies. Better understanding of the factors affecting seed germination and seedling emergence could help in the development of effective cultural weed management strategies through either suppressing germination or encouraging germination when emerged seedlings can be easily killed. Weed seed germination and emergence are influenced by light exposure, seed burial depth, use of residue as mulches and flooding of soils. However, the factors affecting weed seed germination and seedling emergence are poorly understood in Asia.

Keywords: Burial depth, flooding, light, residue, seed germination.

Rice is a principal source of food for more than half the world population and more than 90% of the rice worldwide is grown and consumed in Asia. In Asia, it is commonly grown by transplanting seedlings into puddled soil. In recent years, however, manual transplanting of rice in many Asian countries, including India, is being replaced by direct seeding as farmers respond to increased costs of labour and water[1]. Weeds are major biotic constraints to direct-seeded rice production systems. The risk of crop yield losses due to weeds is greater in direct-seeded rice than in puddled-transplanted rice because of the absence of a suppressive effect of standing water at crop establishment and the absence of a size advantage of crop seedlings over weeds[1]. In direct-seeded rice systems, the crop and weeds emerge simultaneously. Weed control in many regions in Asia is achieved by manual weeding, but this is becoming less common because of the increasing costs of labour resulting from migration of rural labour to the cities. In other regions, herbicides are used to manage weeds in direct-seeded systems. However, there are concerns about the development of resistance in weeds, the increased cost of chemical control, population shifts in weed species, reduced availability of new herbicide molecules and issues related to environmental pollution. These concerns have increased interest in the use of cultural practices in integrated weed management programmes[1]. In some regions, attention towards the use of chemicals is being given to change the thinking of farmers away from a ‘yes, provided that’ to a ‘no, unless’ attitude[2].

Weed seed banks are the main source of weed infestation in any crop and they are depleted by germination, decay, and/or predation[3–5]. However, the factors affecting weed seed germination and emergence are not well-understood, especially for direct-seeded rice systems in Asia. Until recently, the focus of weed science as a discipline in Asia has been on ‘how to control weeds’ rather than to know ‘how weeds germinate’[2]. A recent study suggested that integrated weed management research in India must broaden beyond herbicide-centred weed management[6]. The authors also suggested that research in India must focus on decision-making processes, weed biology and ecology, and environmentally and economically viable components of integrated weed management practices in cropping systems. Greater understanding of the factors affecting weed seed germination would help in improving cultural management strategies through either stimulating germination at times when seedlings can be

Bhagirath Singh Chauhan is in the International Rice Research Institute, Los Baños 4031, The Philippines.
*e-mail: b.chauhan@irri.org

readily killed or suppressing germination[4,7]. Weed seeds, for example, cannot germinate at deeper soil depths and such information could be incorporated in decision-making tools for designing tillage systems for direct-seeded rice. Tillage systems, weed seed predation, seed burial depths, surface mulch and soil flooding are some of the important factors that affect weed seed germination and emergence in direct-seeded rice.

Tillage systems

Tillage affects vertical weed seed distribution in a soil profile and this seed distribution affects weed seed germination by influencing the soil environment surrounding the seeds[8,9]. Weed seeds present at different depths experience differential moisture, diurnal temperature fluctuation, light availability and predator activity[9]. Systems with less soil disturbance, for example, zero-till, concentrate most of the weed seeds on or near the soil surface after crop planting, whereas systems with high soil disturbance, for example, conventional tillage, mix weed seeds uniformly in the tilled-soil depth[8]. In a recent study on direct-seeded rice, 77% of the weed seeds were retained in the top 2 cm soil layer under a zero-till system, whereas soil disturbance under a conventional tillage system resulted in 62% of the seeds being buried to a depth of 2–5 cm (Table 1). The seeds were not present in the 5–10 cm soil layer in the zero-till system.

The conditions are conducive for seed germination near the soil surface and therefore high germination is expected for the weed seeds present close to the soil surface under zero-till systems. Recently, the seedling emergence of many weeds, including *Ageratum conyzoides*, *Eclipta prostrata*, *Echinochloa colona*, *Digitaria ciliaris* and *Portulaca oleracea* was greater when rice was planted under zero-till system than under conventional tillage system[8]. The weed seeds present on the soil surface are sensitive to the stale seedbed practice, provided that they are not dormant. In this practice, weed seeds are allowed to germinate after a light irrigation or shower and are then killed by using a non-selective herbicide or shallow tillage. This practice helps to reduce the size of the weed seed bank in the soil.

Table 1. Effect of tillage systems (conventional tillage and zero-till) on vertical seed distribution of weed seeds

Depth (cm)	Seeds recovered (%) Conventional tillage	Zero-till
0–2	13.3	76.8
2–5	61.9	23.2
5–10	27.8	0.0
LSD (5%)	8.4	

Weed seed predation and seed burial depth

Weed seeds present on the soil surface are also prone to rapid desiccation due to unfavourable weather conditions (extreme changes in temperature and moisture fluctuations) and predation by ants, beetles, crickets and rodents[9]. Weed seeds are most vulnerable to surface-dwelling predators when present on the soil surface[10]. In a recent study in the Philippines, more than 80% of the seeds of *E. colona*, *D. ciliaris* and *Eleusine indica* were lost due to predation (mainly by ants) within a period of 14 days when left on the soil surface[11]. However, information on such studies is very limited in the literature, especially under direct-seeded rice systems in Asia. Nevertheless, the overall results suggest that weed seed predation by insects and seed decay can help reduce the size of weed seed banks and can reduce weed density in the subsequent crops[12]. Therefore, adopting no-till systems or delaying tillage operations to prolong seed exposure to predators could be incorporated into cultural weed management strategies. The management of bunds around fields, for example, creating favourable environments for seed predators by accumulating crop and weed residue on bunds rather than burning them, could be a more promising approach to encouraging weed seed predation. As it may be possible to achieve this with no additional costs, these strategies could easily be incorporated in existing practices[11].

Even after seed predation and decay, a large weed seed bank may accumulate on or near the soil surface after adopting continuous no-till or reduced-till systems. In such situations, a one-off deep ploughing could be used to bury most of the weed seeds below their maximum depth of emergence. Subsequent tillage operations, however, should be shallow to avoid bringing back viable weed seeds to the soil surface. Weed species with small seed size generally germinate better from the soil surface. The ability of seedlings to emerge from deeper depths depends on the energy reserves in the seeds; larger weed seeds with greater reserves can support seedling emergence from deep depths better than small weed seeds. Most of the weed seedlings emerge from the top 0.5–2 cm soil layer, but some weed species (e.g. *Mimosa invisa* and *Echinochloa crus-galli*) can emerge from 8-cm burial depth also.

In addition, rotation of crop establishment methods could help reduce weed populations in the next crop and delay weed population shifts toward problematic weeds. Build-up of a particular weed species in dry-seeded rice, for example, could be discouraged by rotating the establishment method to wet-seeded rice[13]. Many weeds, including *Amaranthus spinosus*, *Cyperus rotundus* and *Rottboellia cochinchinensis*, are problematic weeds in dry-seeded rice, but not in wet-seeded rice systems. In India, comparisons of the weed flora in unweeded plots after four crop seasons indicated that *E. colona* densities were lower in the rice crop seeded after puddling (wet-seeded rice) than in the crop seeded under no-till conditions[14].

Crop residue

Crop residue as mulch present on the soil surface can influence germination and emergence of weeds. Seedling emergence of many weeds can be suppressed by using crop residue as mulch; however, the extent of suppression depends on the quantity and allelopathic potential of the residue and the weed species. In general, higher levels of residue increasingly reduce and delay weed seedling emergence, most likely by preventing light penetration and decreasing thermal amplitude[15], and a longer time needed for seedlings to emerge through the residue cover[16]. Recently, it was reported that rice residue of up to 6 tonne ha^{-1} can suppress the emergence and growth of many weeds[1]. However, the response was species-specific (Table 2). Seedlings of *E. prostrata*, *E. colona*, *E. indica* and *P. oleracea*, for example, were suppressed more by 6 tonne ha^{-1} of residue compared with the seedlings of *Amaranthus viridis* and *R. cochinchinensis*.

Results of a trial in India showed that mulching of wheat residue reduced the total dry matter of weeds by 42% and increased the grain yield of direct-seeded rice over no mulching[17]. Adopting an integrated system using mulch may be a possible means to reduce the dosage of herbicide and cost. In addition to reducing seedling emergence, the use of mulch may also delay weed seedling emergence. Late-emerging seedlings may be less competitive with rice and produce fewer weed seeds than seedlings emerging simultaneously with rice.

Rice straw for livestock has little value and many farmers in Asian countries (e.g. India, Sri Lanka, the Philippines, Pakistan) burn the straw in the field. The use of rice straw as a mulch, however, may become more relevant in the future because of concerns about environmental pollution and depletion of soil organic matter after burning. Incorporating the use of residue as mulch in cultural weed management tools has the potential to reduce herbicide use and cost. Residue, however, does not suppress weeds completely and therefore there is a need to integrate the use of mulch with other control measures. Crop residue may intercept a proportion of pre-emergence herbicides, which may result in reduced herbicide efficacy. There is a need to understand the effect of pre-emergence herbicides on weed control when applied in the presence of residue. In addition, there is a need to invest in research and development on different drills capable of seeding in high amount of residue.

Table 2. Effect of rice residue amounts on the percentage of reduction in seedling emergence of different weed species compared with no residue

Weed species	Seedling emergence (% reduction compared with no residue) 1 tonne ha^{-1}	2 tonne ha^{-1}
Amaranthus viridis	–12	18
Digitaria ciliaris	7	41
Echinochloa colona	45	87
Eclipta prostrata	25	91
Eleusine indica	47	90
Melochia concatenata	10	48
Portulaca oleracea	50	87
Rottboellia cochinchinensis	14	56

Soil flooding

Flooding is an important component of weed management in rice. In irrigated and flooded systems, the environment in which weed seeds have to germinate is characterized by the existence of low oxygen concentrations[15]. Differential responses between rice and weeds to flooding could be an important component of weed management for the direct-seeded rice crop as rice is tolerant to flooding, but many weeds are not. However, the timing, duration and depth of flooding are critical in suppressing germination and growth of a number of weed species. Published studies showed that early and continuous, but shallow (2–4 cm) flooding may help to suppress the emergence and growth of *Cyperus iria*, *Fimbristylis miliacea*, *Leptochloa chinensis*, *Ludwigia hyssopifolia* (Table 3) and similar weed species[4].

Once weed seedlings have emerged and passed the seedling stage, their growth may not be reduced by flooding. In a study on irrigated environment, there was no emergence of *L. chinensis* when rice was flooded 5 days after seeding, but its emergence increased to more than 70 plants m^{-2} when flooding was delayed until 20 days after seeding[18], suggesting the importance of early flooding. Similar results were reported for *E. crus-galli*, *E. colona* and *L. hyssopifolia*[19]. In the future, rice farmers may not have sufficient water to flood their fields continuously as a weed control technique. In such situations, early flooding would make the best use of water to control weeds. Introducing flooding after herbicide application or weeding or hoeing could help reduce future weed growth and the need for additional interventions. Once the canopy of rice has closed, shading and interference from the crop are likely to suppress weed growth. Fast-growing cultivars and the use of narrow row spacing and high seeding rates could help with rapid canopy closure and these strategies could be incorporated in cultural weed management strategies for direct-seeded rice systems.

Concluding remarks

Seed production is an important component of a weed species to ensure its persistence in the next growing

Table 3. Effect of flooding depth (2, 4 and 10 cm) and duration (intermittent, Int: 2 out of 7 days for 28 days, and continuous, Con: for 28 days) on seedling emergence (percentage of 0 cm flooding depth) of different weed species

	Seedling emergence (% of 0 cm flooding depth)							
	Cyperus iria		*Fimbristylis miliacea*		*Leptochloa chinensis*		*Ludwigia hyssopifolia*	
Flooding depth (cm)	Int	Con	Int	Con	Int	Con	Int	Con
2	90.2	6.0	76.9	0.0	74.3	27.7	94.5	1.2
4	57.6	0.0	31.9	0.0	74.3	18.4	69.5	0.0
10	46.4	0.0	12.1	0.0	69.0	14.2	56.3	0.0

season. Different studies clearly suggest that weed management strategies in direct-seeded rice systems should target the weed seed bank in the soil and minimize the size of the seed bank. Improved knowledge on the factors affecting seed germination and seedling emergence could help in suppressing germination or encouraging germination of weeds when emerged seedlings can be easily killed. Therefore, it can be concluded that knowledge gained from seed ecology can contribute to improved weed management strategies in direct-seeded rice. However, any single method or strategy of weed management cannot provide effective and sustainable weed control in direct-seeded rice. Therefore, based on the available resources and possibilities, different weed management strategies need to be integrated to improve the effectiveness of weed control.

1. Chauhan, B. S., Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technol.*, 2012, **26**, 1–13.
2. Mortensen, D. A., Bastiaans, L. and Sattin, M., The role of ecology in the development of weed management systems: an outlook. *Weed Res.*, 2000, **40**, 49–62.
3. Buhler, D. D., Hartzler, R. G. and Forcella, F., Implications of weed seed bank dynamics to weed management. *Weed Sci.*, 1997, **45**, 329–336.
4. Chauhan, B. S. and Johnson, D. E., The role of seed ecology in improving weed management strategies in the tropics. *Adv. Agron.*, 2010, **105**, 221–262.
5. Sanyal, D. *et al.*, Revisiting the perspective and progress of integrated weed management. *Weed Sci.*, 2008, **56**, 161–167.
6. Rao, A. N. and Nagamani, A., Integrated weed management in India – revisited. *Indian J. Weed Sci.*, 2010, **42**, 123–135.
7. Gallandt, E. R., How can we target the weed seedbank? *Weed Sci.*, 2006, **54**, 588–596.
8. Chauhan, B. S. and Johnson, D. E., Influence of tillage systems on weed seedling emergence pattern in rainfed rice. *Soil Till. Res.*, 2009, **106**, 15–21.
9. Mohler, C. L., A model of the effects of tillage on emergence of weed seedlings. *Eco. Appl.*, 1993, **3**, 53–73.
10. Hulme, P. E., Post-dispersal seed predation in grassland: its magnitude and sources of variation. *J. Ecol.*, 1994, **81**, 645–652.
11. Chauhan, B. S. *et al.*, Post-dispersal predation of weed seeds in rice fields. *Weed Res.*, 2010, **50**, 553–560.
12. Westerman, P. R. *et al.*, Relative importance of vertebrates and invertebrates in epigaeic weed seed predation in organic cereal fields. *Agric. Ecos. Environ.*, 2003, **95**, 417–425.
13. Singh, G. *et al.*, System level effects in weed management in rice–wheat cropping in India. In *BCPC International Congress on Crop Science and Technology*, Glasgow, SECC, UK, 2005.
14. Singh, V. P. *et al.*, Weed species shifts in response to direct seeding in rice. In *Direct Seeding of Rice and Weed Management in the Irrigated Rice–Wheat Cropping System of the Indo-Gangetic Plains* (eds Singh, Y. *et al.*), Los Baños (Philippines): International Rice Research Institute, and Pantnagar (India): Directorate of Experiment Station, G.B. Pant University of Agriculture and Technology, 2008, pp. 213–219.
15. Benech-Arnold, R. L. *et al.*, Environmental control of dormancy in weed seed banks in soil. *Field Crop Res.*, 2000, **67**, 105–122.
16. Buhler, D. D., Mester, T. C. and Kohler, K. A., The effect of maize residues and tillage on emergence of *Setaria faberi*, *Abutilon theophrasti*, *Amaranthus retroflexus* and *Chenopodium album*. *Weed Res.*, 1996, **36**, 153–165.
17. Singh, S. *et al.*, Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (*Oryza sativa*). *Crop Prot.*, 2007, **26**, 518–524.
18. Moody, K. and Drost, D. C., The role of cropping systems on weeds in rice. In Proceedings of the Conference on Weed Control in Rice, Los Baños, International Rice Research Institute, Philippines, 1983.
19. Ismail, B. S. and Hossain, M. S., The effects of flooding and sowing depth on the survival and growth of five rice-weed species. *Plant Prot. Quart.*, 1995, **10**, 1–4.

Received 3 May 2012; revised accepted 9 July 2012