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Weed management approaches for dry-seeded rice in India: a review

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ABSTRACT

Rice (*Oryza sativa* L.) is an important staple crop in India, where it is mainly grown by manual transplanting of seedlings into puddled soil. Recently, however, there is a trend toward dry-seeded rice (DSR) because of labour and water scarcity. In DSR, weeds are the main biological constraint. Herbicides are used to manage weeds in DSR systems, but the use of herbicides alone does not provide effective and sustainable weed control. Therefore, there is a need to integrate herbicide use with cultural weed management approaches, such as the use of a stale seedbed technique, different tillage systems, weed-competitive cultivars, cultivars capable of emerging under anaerobic conditions, crop residue for mulches, high seeding rates, narrow rows, and optimum time and depth of flooding.

Key words: Direct-seeded rice, Chemical control, Herbicide, Weed management

Rice (*Oryza sativa* L.) is one of the most important crops in India, where it is grown in rice-rice, rice-maize, rice-wheat, *etc*., cropping systems. In irrigated areas, rice is mainly grown by transplanting seedlings into puddled soil. Such a rice production system, however, requires a large amount of water during puddling and transplanting (Chauhan 2012a, Chauhan *et al.* 2012b). In general, rice accounts for 34-43% of the world's irrigation water (Bouman *et al.* 2007). In India, water use for rice has been reported as 1140 mm in Bihar and 1560 mm in Haryana (Gupta *et al.* 2002). Water, however, is becoming an increasingly scarce resource in India (Kumar and Ladha 2011, Mahajan *et al.* 2012). In north-western India, for example, increased use of groundwater for rice cultivation has led to a decline in the water table by up to 1 m per year (Hira 2009, Rodell *et al.* 2009). Therefore, the increasing water scarcity threatens the productivity and sustainability of the irrigated rice system in India.

In addition to the concerns over water scarcity, labour scarcity is also a concern. In the traditional establishment method, both puddling and transplanting operations need a large amount of labour. Because of the increasing demand for labour in non-agricultural sectors and increasing labour costs resulting from the migration of rural labour to the cities, it is difficult to find labour at the critical time of transplanting (Chauhan 2012b). Government policies, for example, 100 days of work in people's home village, are also creating a labour scarcity in some regions, especially where farmers depend on migrant labourers from other states (Mahajan *et al.* 2013). Therefore, farmers in some areas are shifting from traditional transplanted rice to mechanized-sown dry-seeded rice (DSR) in response to the rising production costs and shortages of labour and water. A DSR crop can be sown under zero-till (ZT) conditions or after tillage using a seed drill.

DSR has several advantages over puddled transplanted rice. However, weeds are the main biological constraint to the production of DSR (Chauhan 2012b, Chauhan and Johnson 2010, Chauhan and Opeña 2012, Chauhan *et al.* 2012b). In a recent survey in Punjab, the dominant weed species reported by the farmers in DSR fields were *Cyperus iria* L., *Echinochloa colona* (L.) Link, *Eragrostis* spp., *Leptochloa chinensis* (L.) Nees, *Digitaria sanguinallis* (L.) Scop., *Dactyloctenium aegyptium* (L.) Willd., *Cyperus rotundus* L., and *Eleusine indica* (L.) Gaertn. (Mahajan *et al.* 2013). The main reasons for high weed pressure in DSR are the absence of a weed-suppressive effect of standing water at the time of crop emergence and the absence of a seedling size advantage to suppress newly emerged weed seedlings. Weeds in DSR systems are mainly managed by using herbicides and manual weeding. Manual weeding, however, is becoming less popular because of the labour scarcity and high wages. In the absence of manual weeding, farmers in irrigated areas mainly rely on herbicides to control weeds in DSR systems. The use of herbicides alone may not provide effective and season-long weed control. Because of the increased use of herbicides, the risk of herbicide resistance, and concerns about environmental contamination, there is an interest in integrating herbicide use with cultural weed management approaches (Kumar and Ladha 201, Chauhan 2012b, 2013, Mahajan and Chauhan 2013).

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Some cultural weed management approaches are the use of a stale seedbed technique, different tillage systems, weed-competitive cultivars, cultivars capable of emerging under anaerobic conditions, crop residue for mulches, high seeding rates, narrow crop rows, and optimum time and depth of flooding.

Stale seedbed technique

In the stale seedbed technique, weed seeds are allowed to germinate using a pre-sowing irrigation or after rainfall. After this, emerged weed seedlings are killed using a non-selective herbicide (e.g., paraquat or glyphosate) or cultivation (Chauhan 2012b, Kumar and Ladha 2011). The use of a stale seedbed practice not only reduces the weed population in the crop but also helps to significantly reduce the size of the weed seed bank. In a study, a stale seedbed reduced the weed population by 50% compared with the treatments in which this practice was not used (Singh *et al.* 2007). The success of the stale seedbed practice depends on the weed species, the position of weed seeds relative to the soil surface, and environmental conditions. In general, weed species sensitive to the stale seedbed practice are those that are present in the topsoil layer, have low initial dormancy, and require light to germinate (Chauhan 2012b). Examples of such weed species are *C. iria*, *Digitaria ciliaris* (Retz.) Koel., *Eclipta prostrata* (L.), *L. chinensis*, and *Ludwigia hyssopifolia* (G. Don) Exell. Weed species with high initial dormancy may be difficult to manage using the stale seedbed practice.

In the rice-wheat cropping system in northern India, the success of the stale seedbed practice will mainly depend on environmental conditions, especially temperature and the management practices adopted in the non-rice crop. In ZT wheat, for example, weed seeds shed in the previous rice crop remain near the soil surface and these weed seeds may be more prone to be exhausted by the stale seedbed practice. In conventional tilled wheat, on the other hand, tillage operations may bury weed seeds very deep. Despite the advantage of the stale seedbed practice, the practical importance of this practice should be evaluated by farmers themselves. Such decisions are particularly applicable for areas where the period between the harvesting of the preceding crop and sowing of the DSR crop is short or where farmers use diesel pumps (*i.e*. cost involved) to irrigate their fields.

Tillage systems

As mentioned previously, DSR can be sown under ZT conditions or after thorough land preparation. In continuous ZT systems, most of the weed seeds remain on or near the soil surface after crop planting (Chauhan and Johnson 2009, Chauhan *et al.* 2006, Yenish *et al.* 1992). Such a weed seed bank is prone to rapid desiccation and seed predation (Chauhan *et al.* 2010, Mohler 1993). Furthermore, environmental conditions are more favourable for the germination of weed seeds present on the soil (Banting 1966). These observations suggest that the weed seed bank in ZT systems can be exhausted very easily. However, results may differ in different conditions, especially for wind-disseminated and perennial weed species. Because of a lack of seed burial by tillage, wind-dispersed species have been found dominant in ZT systems (Froud-Williams *et al.* 1981). Similarly, because of the lack of disturbance of the root systems of established weeds, perennial weed species can become dominant in ZT systems (Triplett 1985). In continuous ZT systems, annual weed seeds may also accumulate on or near the soil surface. In such situations, a deep tillage operation can be used to bury most of the seeds below the maximum depth of their emergence (Chauhan and Johnson 2010). Frequent tillage operations may also stimulate weed seed germination by exposing buried weed seeds to light and reduce the weed seed bank in the soil (Mohler 1993). In general, weed response to tillage systems is not well understood in DSR systems, especially in India. Therefore, there is a need to enhance our understanding of the effect of tillage systems on weed management.

Nowadays, different kinds of seeding machines are used for DSR sowing. These machines may have tines or discs, and the thickness of the tines and discs may also differ. In ZT systems, different sowing points are known to cause differential vertical seed distribution (Chauhan *et al.* 2006). Vertical weed seed distribution can affect weed seedling emergence by influencing the conditions for weed seeds. Therefore, there is a need to better understand the effect of different tillage systems on vertical weed seed distribution in DSR systems in India.

Cultivars

The integrated use of rice cultivars with other management practices may help to reduce selection pressure and delay the development of herbicide resistance in weeds. A recent review discussed the role of cultivars in managing weeds in DSR systems (Mahajan and Chauhan 2013). The authors suggested that the traits likely to be most helpful for weed management in DSR included seed germination in anaerobic conditions and tolerance of early submergence for uniform crop emergence, high and early seedling vigour with rapid leaf area development, and cultivars having an allelopathic effect. The significance of allelopathy for weed management is well known for crops such as wheat. However, in rice, the significance of allelopathy will remain conjectural until it is clearly shown that results observed in bioassay studies also occur in fields (Mahajan and Chauhan 2013)

In India, not much work has been done on the development of weed-competitive rice cultivars for DSR systems. In other regions (*e.g.*, Philippines), cultivars, such as '*Apo*' and '*UPLRi-7'*, have been reported with superior weed competitiveness (Zhao 2006) and these could be tested throughout India in the future, where DSR is being promoted. In most of the regions, cultivars bred for transplanted rice are being used in DSR systems. The availability of weed-competitive cultivars might help in curtailing herbicide doses in DSR systems by suppressing weed emergence and growth (Mahajan and Chauhan 2013). In DSR systems, two herbicides (pre- and post-emergence) are usually applied and, in addition, farmers need to perform one hand weeding. The use of weed-competitive cultivars may help to get rid of the hand weeding and reduce herbicide use. Short-duration cultivars and hybrids can also be used to suppress weed growth due to their high vigour and tendency to close the canopy faster. Seedling vigour helps in better crop establishment and it offers successful competition with weeds in favour of the crop (Mahajan and Chauhan 2013). Very little is known about the relative importance of above ground (shoot) and below ground (root) competition of rice cultivars in DSR systems. Breeders and weed scientists should work together to explore different traits in rice-weed competitive interactions in DSR systems.

DSR is a labour-saving establishment method and it has the potential to spread throughout India in the wake of labour scarcity. In some regions, however, the risk of uncertainty of rainfall and possible flooding during crop emergence hinders the large-scale adoption of DSR as cultivars capable of germinating under flooded conditions are not available in India. Work is in progress at the International Rice Research Institute (IRRI) and, very soon, cultivars having tolerance of anaerobic conditions during emergence will be available for farmers. The availability of such cultivars will not only increase the overall area under DSR systems in India but will also provide economical and environmentally friendly weed control as DSR fields will be easily submerged immediately after crop sowing (Chauhan 2012b, Mahajan and Chauhan 2013).

Use of crop residue as mulch

As mentioned in a previous section, DSR can be grown under ZT conditions. Depending on the cropping system (rice-rice, rice-wheat, rice-maize, *etc*.) and farmers' need for crop straw, there may be intact and loose residue on the soil surface. The crop residue present on the soil surface can influence weed and crop growth (Chauhan 2012b, Chauhan and Mahajan 2012, Chauhan and Abugho 2013, Chauhan *et al.* 2012a). In general, crop residue in a normal amount can effectively suppress the emergence of small-seeded weed species. For large-seeded species, a high amount of residue may be needed to substantially affect seedling emergence.

In the rice-wheat cropping system in northern India, wheat residue at 4 t/ha reduced annual and broad-leaved weed densities in DSR compared with no residue (Singh *et al.* 2007). The study also suggested that crop residue can be used as mulch in integrated weed management programmes to reduce herbicide doses. Direct drilling of rice into the anchored and loose residue load of up to 7-8 t/ha has been reported in the rice-wheat system in India (Gupta *et al.* 2006). For sowing in such a high amount of residue, however, there is a need for drills, such as the turbo seeder and disc opener, which can be attached only with four-wheel tractors. In eastern India or where the farm size is very small, there is a need to invest in research and development on different scales of drills, attached with two-wheel as well as four-wheel tractors.

In some countries, cover crops are used to suppress weed emergence and growth. A cover crop can produce residue to create an unfavourable environment for weed germination and crop emergence (Teasdale 1996). In India, too, legume crops such as *Sesbania* and blackgram (mungbean) can be used to reduce weed emergence in DSR crops. The legume crops are then killed by non-selective herbicides before sowing the rice crop. There are numerous advantages of using legume crops; however, farmers may not consider such practices to be economical (Chauhan 2012b). Therefore, there is a need to evaluate such options while working with farmers.

Flooding

Flooding is considered the best weed management option in rice. If irrigation water is plentiful, farmers can submerge their DSR fields immediately after crop emergence. Flooding can suppress the emergence and growth of several weed species (Chauhan and Johnson 2010). Early and continuous flooding at a shallow depth (*e.g.*, 2 cm) can also help to suppress the emergence and growth of problematic weeds, such as *L. chinensis* (Chauhan and Johnson 2008). Because of competition with non-agricultural sectors for water, farmers in India may not be able to flood their rice fields in the future. This may restrict farmers' capacity to use continuous flooding as a weed control mechanism (Chauhan 2012b, Tuong *et al.* 2005). In water-limited environments, farmers should aim for early flooding to make the best use of water to suppress weeds in DSR systems. Flooding after herbicide application or hand weeding could also prevent the further growth of weeds.

Agronomic manipulations

In DSR systems, weeds can also be managed by manipulating agronomic practices. For example, the proper management of fertilizer, especially nitrogen (N), reduces the weed competition and therefore fertilizer should be applied as per the requirement of the crop (Mahajan and Chauhan 2011a). A study in Punjab reported that, when weeds were controlled, the DSR crop responded to a higher N application but, under weedy and partially weedy situations, rice grain yield declined markedly with higher amounts of N fertilization (Mahajan and Timsina 2011). The banding of fertilizer in the soil rather than broadcasting can also help to reduce the weed population in DSR.

DSR in India is grown at seeding rates of 25-30 kg/ha. Farmers who grow hybrid seeds use a seeding rate of 15-20 kg/ha. In some parts, farmers use their own stored seed. In such cases, the seeding rate could be increased not only to suppress weeds but also to compensate for poor seed quality and crop emergence. In some regions of India, there is a chance for poor stand establishment if rain occurs immediately after sowing. Low plant density encourages the growth of weeds if effective weed control measures are not undertaken. A study in DSR systems in India showed that there was no effect of seeding rates, ranging from 15 to 125 kg/ha, on the grain yield of rice grown in weed-free conditions (Chauhan *et al.* 2011). In the presence of weeds, however, maximum grain yield was achieved at 95 to 125 kg seed/ha. Results from various studies in other parts of the world have shown that increasing seeding rates suppresses weed growth and reduces grain losses from weed competition (Zhao 2006, Chauhan *et al.* 2011). Farmers in countries such as Uruguay use very high seeding rates (approximately 165 kg/ha) in DSR, mainly to close the canopy faster.

It is well known that narrow rows improve weed-competitive ability of a crop by closing the canopy faster and allowing less light penetration to the soil surface (Chauhan 2012b, Liebman *et al.* 2001). Because of the availability of suitable seed drills, most farmers in India already plant their DSR crop at a narrow row spacing, that is, 20 cm. However, some farmers (*e.g.* in Tamil Nadu) still use a wider row spacing to accommodate mechanical or hand weeding. The row spacing in the DSR crop can be further reduced to around 15 cm to suppress weeds after herbicide application. In such a narrow row spacing, however, there is a need to evaluate in humid regions whether insect and disease infestations increase. Narrow row spacing results in lower weed biomass than wider row spacing. The yield of some cultivars may be improved by exploring paired-row planting systems. In a study in Punjab, paired-row planting patterns of 15-30-15 cm spacing had a greater influence on weeds than a normal row of 23 cm spacing (Mahajan and Chauhan 2011b). The study suggested that paired-row planting suppressed weeds by maintaining crop plants' dominant position over weeds through a modification in canopy structure. In conclusion, narrow rows and modifying crop geometry can help to suppress weeds through rapid canopy closure.

Herbicides

In DSR systems, herbicide use is must and their use is likely to increase further with the rising labour scarcity. Herbicide use in DSR systems becomes even more important as rice and weed seedlings emerge simultaneously and some weed seedlings (*e.g.*, *Echinochloa* spp.) are morphologically similar to rice seedlings (Chauhan 2012b). Herbicides should not be considered as a replacement for other weed control methods, however, but should be integrated with them.

Various pre- and post-emergence herbicides are used in DSR systems to control weeds (Table 1). Pendimethalin has been found to be superior to oxadiargyl, particularly against *D. aegyptium*, *L. chinensis*, and *Eragrostis* spp., but it requires extra precaution to avoid possibilities of its phytotoxicity (reduced germination), particularly under high soil moisture conditions and when seeds are not properly covered with a thin soil layer. In general, sequential applications of a pre-emergence herbicide (*e.g.*, pendimethalin or oxadiargyl) followed by post-emergence herbicide (*e.g.*, bispyribac-sodium) can provide effective weed control in DSR, if coupled with some other weed management strategies. In future, the combination of two or more herbicides [*e.g.*, bispyribac + pyrazosulfuron, bispyribac + azimsulfuron, bispyribac + ethoxysulfuron, bispyribac + fenoxaprop (with safener), penoxsulam + cyhalofop, pendimethalin followed by bispyribac + pyrazosulfuron, pendimethalin followed by bispyribac + azimsulfuron, pendimethalin followed by bispyribac + ethoxysulfuron, pendimethalin followed by bispyribac + fenoxaprop (with safener)] may become a part of an effective and integrated approach to achieve more satisfactory control of complex weed flora in DSR.

Flooding after the post-emergence herbicide application, for example, could suppress subsequent growth of

Table 1. Different pre- and post-emergence herbicides used in dry-seeded rice

Herbicide	Dose (g/ha)	Application time (days after sowing)
Pendimethalin	1000	1-3
Oxadiargyl	100	1-3
Bispyribac-sodium	25	15-25
Pyrazosulfuron	25	15-25
Penoxsulam	25	15-25
Azimsulfuron	30	15-25
Fenoxaprop (with safener)	60	15-25
Cyhalofop	90	15-25
2,4-D ester or amine	500	15-25
Metsulfuron	4	15-25
Ethoxysulfuron	18.75	15-25
Metsulfuron + chlorimuron	4	15-25

weeds. Because of a lack of continuous standing water in DSR fields, some problematic weed species (*e.g.*, *C. rotundus*) are increasing. Furthermore, because of the continuous use of the same herbicide, there is a shift toward problematic weed species. Bispyribac-sodium, for example, is effective on grasses, but it does not provide effective control of *L. chinensis* and *D. aegyptium* (Gopal *et al.* 2010, Chauhan and Abugho 2012). In such situations, there is a need to evaluate effective tank-mix herbicides.

As mentioned earlier, herbicide use is expected to increase in the future. Therefore, it is important to understand the right application methods for herbicides as improper and ineffective herbicide application methods may result in a waste of chemicals and environmental pollution, damage to non-targeted plants, and harm to human health (Chauhan 2012a). There is a need to use the right nozzles and right spray patterns. Spraying herbicides in a “swinging” way across the field may result in poor weed control. In our view, public-private partnership can greatly help in improving herbicide spray techniques in various parts of India.

Weedy rice

In some countries (*e.g.* Malaysia, Vietnam, and Sri Lanka), the adoption of direct-seeded rice systems has made weedy rice infestation one of the most serious problems. In India, weedy rice may also become a problematic weed with the spread of DSR systems. Selective herbicides to manage weedy rice in cultivated rice are not available and therefore managing weedy rice would be a challenging problem for farmers in India. In the absence of selective herbicides, various cultural approaches may be exploited to reduce the problem of weedy rice. A recent review discussed different strategies (the use of clean seeds and machinery, use of stale seedbed practice, thorough land preparation, rotation of different rice establishment methods, use of high seeding rate and row-seeded crop, use of purple-coloured cultivars, use of flooding, and adoption of crop rotation) to manage weedy rice in Asia (Chauhan 2013).

Conclusion

Weeds are the major constraint in DSR production systems. In this article, we discussed several approaches to managing weeds in DSR systems. The use of any single approach, however, would not provide season-long and sustainable weed control because of the variation in dormancy and growth habits of weeds (Chauhan 2012b). There is a need to integrate as many weed management approaches as possible to achieve effective, sustainable, and long-term weed control in DSR. In India, future research in DSR systems should focus on the integration of appropriate management practices with suitable cultivars and appropriate herbicide application timing and combinations. There is also a need to study weed biology and ecology in DSR systems in different rice ecosystems.

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