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# POSSIBLE APPROACHES FOR ECOLOGICAL WEED MANAGEMENT IN DIRECT-SEEDED RICE IN A CHANGING WORLD

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## ABSTRACT

*Labour and water scarcity are the major drivers for shifting the method of rice establishment from traditional transplanting to direct-seeding in many nations of Asia, where about 90% of world's rice is produced and consumed. The risk of crop yield loss due to competition from weeds by all direct-seeding methods is higher than for transplanted rice. Changes in rice establishment method as well as water, tillage and weed management practices in direct-seeded rice (DSR) lead to shifts in weed communities and evolution of adoptive traits of individual weed species which present a further challenge for effective management of weeds in DSR based cropping systems. Recently, weedy rice is posing a serious challenge to DSR farming community. Effective and economic weed management is key for sustainable rice production to meet increasing food demand in changing world. The objective of this research was to summarise available ecological weed management options for managing weeds in direct-seeded rice for making direct-seeded rice more productive, profitable and sustainable in a changing world, and to identify areas where additional research is needed to bridge the gap. Ecological management of weeds in direct-seeded rice stresses on shifting the crop-weed balance in favour of rice by adapting in an integrated manner all available cultural, physical and biological weed management strategies and judiciously using herbicides as last resort rather than as only resort.*


**Key words:** Direct-seeded rice, ecological weed management

## INTRODUCTION

Rice is a staple food for more than half of the word population providing 21% of global human per capita energy. About 90% of world's rice is grown and produced (143 million ha of area with a production of 612 million tons of paddy) in Asia (FAO, 2009). In Asia, rice is commonly grown by transplanting seedlings into puddled soil (land preparation with wet tillage). However, in addition to adverse effects of puddling on soil physical properties, puddling and transplanting require large amount of water and labor, both of which


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are becoming increasingly scarce and expensive, making rice production less profitable. Also, the drudgery involved in transplanting—a job largely done by women—is of serious concern. The increase in production costs, shortage of labor and increased wages, decreased water availability resulted in to shift from transplanting to direct-seeding. Direct-seeding (especially wet-seeding) is fast spreading in Asian countries. In addition, upland rice is mostly dry-seeded. To meet the needs of increasing population of world, it is estimated that about 114 million tons of additional milled rice need to be produced by 2035, which is equivalent to an overall increase of 26% in next 25 years.

Weeds are a major impediment to direct-seeded rice (DSR) production through their ability to compete for resources and their impact on product quality (Rao and Nagamani, 2007; Rao *et al*., 2007; Kumar and Ladha, 2011). The risk of crop yield loss due to competition from weeds by all seeding methods is higher than for transplanted rice because of absence of size differential between crop and weeds and concurrent emergence of competitive weeds along with rice seedlings (Rao *et al*., 2007).The change in method of rice establishment in many Asian countries, in turn resulted change in method of weed control from hand weeding to greater herbicide use (Naylor, 1994; Azmi *et al*., 2005; Rao *et al*., 2007; Weerakoon *et al*., 2011). The change in weed control methodology resulted in evolution of herbicide resistance among weeds (Rao *et al*., 2007), shifts in dominance of associated weeds (Azmi *et al*., 2005; Rao *et al*., 2007), emergence of difficult to control weeds, such as weedy rice as major weed threats (Rao *et al*., 2007; Kumar and Ladha, 2011). In addition, there is overall climate change impact on rice production and weed community (Rodenburg *et al*., 2011). Effective and economic weed management is key for sustainable rice production. Through development and adoption of improved weed management technologies, improved rice productivity and production could be achieved to meet the demands of increasing population.

The objectives of the research were to summarise the current methods of weed management in DSR, bring to light factors necessitating ecological weed management approaches in DSR, to summarise available ecological weed management options for managing weeds in DSR for making DSR more productive, profitable and sustainable, and to identify areas where additional research is needed to bridge the gap.

**Weed management methods currently in use in DSR**

Hand weeding continues to be used in rice production either solely or as component of weed management in Asia (Rao *et al*., 2007) and West Africa (Rodenburg *et al*., 2011). In Asian countries where direct-seeding became the major method of rice establishment (e.g. Korea, Malaysia, Philippines, Sri Lanka and Vietnam), the use of herbicides increased (Naylor, 1994; Azmi *et al*., 2005; Rao *et al*., 2007; Weerakoon *et al*., 2011). In China, around 20 million hectares of rice fields are applied with herbicides (Zhang, 2003). It was estimated that approximately 98% of U.S. rice acres are treated with herbicides and rice production would drop by 38%, if no herbicides were used in U.S.A. (Gianessi and Reigner, 2006). In Europe and Australia, chemical control has been operative since long in direct-seeded rice (Bocchi *et al*., 2005; Taylor, 2007). The high costs of weed control could be a major factor constraining widespread adoption of direct-seeding. High weed-inflicted yield losses in direct-seeded rice in Asia are due to limited number of effective and affordable weed control options available to farmers. The key to success of direct-seeded rice is availability of efficient weed control techniques that ate economically and ecologically viable. Alternative weed management technologies are therefore much needed (Rao *et al*., 2007) in changing world. Drivers necessitating development of alternative weed management strategies such as integrated ecological weed management in DSR are described below briefly.

**Factors necessitating the ecological weed management approach in DSR in changing world**

Ecological management of weeds in DSR stresses on shifting crop-weed balance in favour of rice by adapting in an integrated manner the strategies that: modify weeds microenvironment placing stress at multiple growth stages in weeds life cycle, enhancing weed seedling mortality, to increase competitive ability of rice for attaining optimum rice productivity, to minimize weed seed production and dispersal, and to accelerate weed seed bank depletion, and judiciously using herbicides as the last resort rather than as the only resort.

Major drivers for the need of ecological weed management in DSR include: a) global water scarcity; b) labor shortage and increasing wages; c) enhanced interest in conservation agriculture; d) shits in weed flora and development of resistance against weeds; e) emergence of new weed problems such as weedy rice (O. sativa) (Rao *et al*., 2007) and f) global climate change i.e. changes in atmospheric carbon dioxide ($CO_2$), rainfall and temperature will affect weed communities (Rodenburg *et al*., 2011). Thus in a changing world, it is essential to identify practical components of integrated ecological weed management strategies for effectively managing weeds in DSR in an ecologically and economically sustainable manner.

**Ecological weed management options for DSR**

The principles that underline ecological weed management system are: (a) adapting weed management options that suits to environment of the region, including soil, water, climate and biota present at the site; (b) optimizing use of biological and chemical/physical resources for effective weed management in DSR. Several components of ecological weed management have the ability to reduced weed density, minimise weeds competitive ability, avoid undesirable shifts in weed community towards difficult to control weeds, improve rice productivity through improving rice competitiveness against weeds with minimal adverse impact on environment in DSR ecosystem.

**Non-chemical components of ecological weed management**

Non-chemical components of ecological weed management involve any aspect of non-herbicidal weed management that favors the crop relative to the weed. They include:

(a) Avoiding weed seed contamination in rice seed and the use of certified seed: Sowing seed contaminated by weedy rice is likely the primary cause of invasiveness of weedy rice in rice fields (Rao *et al*., 2007). Rice seed soaking in herbicide solution for controlling rice seed contaminants (Rao and Moody, 1996) or use of certified seed have proved to be an essential component in weed management (Rao *et al*., 2007).

b) Sanitation: Sanitation is one means of minimizing the likelihood of weed introductions and dispersal of existing weeds throughout a farm, especially herbicide-resistant weeds. All farm machinery should be washed well to remove weed seeds and propagules of perennials in attached-soils from neighbouring weed infested fields before being moved into clean paddy fields.

c) Soil solarisation: Soil solarisation is a method of heating the soil's surface by using transparent low-density polyethylene (LDPE film) sheets placed on the soil's surface to trap solar radiation (Khan *et al*., 2003). The use of transparent and black LDPE sheets reduces weed growth and increases rice yield (Khan *et al*., 2003).

d) Weed management during fallow period: A clean fallow period is best strategy for drawing down the seedbank. Shallow tillage coincident with weed emergence periodicity will stimulate germination of weeds, and subsequent tillage kills these seedlings. Tillage combined with *Stylosanthes guianensis* (stylo) fallow were recommended to farmers of small holdings for improving upland dry-seeded rice productivity (Saito *et al*., 2010).

e) Cultural practices: Cultural practices such as tillage, mulching, and burning are used by certain traditional farmers to control weeds.

Tillage: The need for thorough land preparation to ensure a vigorous rice stand and to suppress weeds is well known. Tillage increases germination of seeds in soil seed bank, reducing seed reserves in soil (Chauhan *et al*., 2009). Harrowing and puddling are done for a range of reasons including weed control (Rao *et al*., 2007; Satoshi *et al*., 2009). Precision land leveling, obtained with laser-directed equipment, has made an important contribution to weedy rice management in European rice production (Ferrero and Videtto, 2007). Level or regularly sloping fields enable appropriate water management, which limits weed growth and guarantees uniform emergence of weeds, which in turn makes herbicides more effective.

Reduced tillage and stale seedbed: With dry direct-seeding under Zero tillage (ZT) or reduced tillage conditions, fuel and labor costs are reduced (Kumar and Ladha, 2011). A large proportion of weed seed bank remains on or close to soil surface after crop planting in ZT systems, which may promote greater emergence of weed species that require light to germinate (Chauhan *et al*., 2009). In stale seedbed weeds are encouraged to germinate prior to seeding the crop then eliminated with glyphosate (Rao *et al.*, 2007).

Alternating rice establishment systems from aerobic (dry-seeding) to anaerobic (water-seeding) regimes (and vice versa) combined with use prior to seeding of a non-selective herbicide for which resistance does not yet exist in weeds of rice (such as Roundup) allows for a major reduction of: herbicide resistant weed infestations; overall herbicide use and costs (Fischer *et al*., 2009).

Water management: The importance of water management in weed control in DSR is well known (Rao *et al*., 2007). The construction of field bunds, which retains water in paddy, has the potential to significantly increase rice production in West Africa, while also possibly reducing labor requirements for hand weeding (Becker and Johnson, 2001). Appearance of red rice (*Oryza sativa*) as main weed problem in rice production in southern US has led many producers to use Pin-Point (PP) irrigation, originally developed in Louisiana, to control the weed (Noldin, 2000).

Fertilizer and weeds: To achieve high rice yields, both nitrogen fertilization and weed management are essential (Begum *et al*., 2009). Losses from weeds progressively decreased with higher fertility levels due to the greater competitive ability of rice (Rao *et al*., 2007). Judicious use of fertilizers during early growth stage in combination with other weed management practices may help DSR to compete with weeds.

f) Improving rice competitiveness: One cultural weed management approach is to reduce effects of weeds on crop by either making weeds less competitive or by making crop more competitive. Improving rice competitiveness against weeds would provide a low-cost and safe tool for an ecological weed management strategy. Any cultural practice that facilitates rapid rice growth and results in rice canopy covering soil surface, and shade out weeds, increase crop competitiveness. Practices that contribute DSR competitiveness include: early sowing, selection of varieties with early growth, optimal seed rates; close spacing; adequate plant population and fertilization (Rao *et al*., 2007).

g) Cover crops: Cover crops grown in period between two main crops have potential as an important component of a system-oriented ecological weed management strategy (Kruidhof *et al*., 2008). Cover crops fill inter-crop periods in cropping systems that would otherwise be occupied by weeds and thus reduce weed pressure and labor required for weeding.

h) Intercropping: Intercropping is practiced by farmers in both developing and developed countries. Weed growth was lower in upland dry-seeded rice/cowpea intercrop than in rice sole crop due to successful smothering effect of cowpea inter crop because of its broader leaves and early rapid growth which blocked light from reaching the ground (Musthafa and Potty, 2001). Smother crops like Amaranthus, Indian till was found to be much effective in reducing weed growth without affecting productivity of aerobic rice (Umeshanaika *et al*., 2009).

i) Crop Rotations: It is now evident that crop rotation reduces weed growth and increases crop yield and that practice is essential in sustainable agriculture systems (Rao *et al*., 2007). Increasing cropping system diversity has been advocated as a potential means of decreasing the need for intensive chemical inputs for weed control (Liebman and Staver, 2001). Successful weed management requires cropping sequences that minimizes weed seed additions and maximise weed seed depletion in DSR soil weed seed bank.

j) Mulching: The spreading of mulch on soil surface reduces evaporation, saves water, protects from wind and water erosion, and suppresses weed growth (Singh *et al*., 2007). Mulching + dry land weeder at 20 DAS proved more effective in dry-seeded rice grown without herbicide use (Hussain and Gogoi, 1996).

k) Brown manuring: Brown manuring is a 'no-till' version of green manuring, using a herbicide to desiccate the intercrop (and weeds) at flowering instead of using cultivation. The plant residues are left standing. In '‘Brown Manuring' practice both rice and *Sesbania* crops are seeded together and allowed to grow for 30 days. Subsequently *Sesbania* intercrop is knocked down with 2, 4-D at 500 g $ha^{-1}$ (Singh *et al*., 2007). This technology reduces weed population by nearly half without any adverse effect on rice yield. *Sesbania* surface mulch decomposes very fast to supply N and other recycled nutrients.

l) Mechanical weeding: Weeding by mechanical devices reduces the cost of labor and also saves time (Subudhi, 2004). The labor involved was least with Phulbani weeder (57 person-days $ha^{-1}$), saving nearly 57% labor compared with hand weeding (127 person-days $ha^{-1}$). It also had better weed control efficiency (Subudhi, 2004). Dry-seeded rice row seeding with interrow weeding using hoes and without any herbicide achieved higher grain yield (Satoshi *et al*., 2009). Mnguu (2010) opined that rice farmers can use rotary weeding instead of herbicide in controlling weeds and achieve same grain yield of wet-seeded rice.

m) Bioherbicides: Micro-organisms are also used as tools for weed management and have a range of properties that make them desirable for ecological weed management in direct-seeded rice. COLLEGO, a powder formulation of *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *aeschynomene*, was registered in 1982 for control of northern jointvetch (*Aeschynomene virginica* (L.) B.S.P.) in rice. The successful mycoherbicide, *Rhynchosporium alismatis* had synergistic controlling effect on *Damasonium minus* (R.Br.) Buch. when bensulfuron-methyl was applied before fungal inoculation (Jahromi *et al*., 2001). In Asia, the bioherbicide research is yet to reach the practical usage stage.

In addition to above methods, usage of ducks (Furuno, 2001) and water birds (Kendig *et al*., 2003) was also found effective in managing weeds and hence may be used as a components of ecological weed management in DSR systems.

**Herbicide based components of ecological weed management**

Herbicides are not ruled out in ecological weed management in direct-seeded rice. However, in ecological weed management, herbicides are treated less as a blanket solution to weed management and more as a precious resource, to be used selectively in ways that complement other weed management methods. Phenoxy and sulfonylurea compounds are widely used herbicides in Malaysia, Vietnam, and Thailand to control broadleaf weeds and sedges in direct-seeded rice (Azmi *et al*., 2005). Propanil, thiobencarb, molinate, butachlor, quinclorac, acetochlor and oxadiazon have been widely used for grass weed control. Several herbicides are now available for effectively managing specific problematic weeds in direct-seeded rice and herbicides used in different methods of DSR were listed by Rao *et al*. (2007). Integration of herbicides with other components of ecological weed management is needed to avoid environmental, health hazards as well as risk of evolution of herbicide resistant weeds. Effective weed control in DSR was reported by integration of herbicides with: a) crop rotations; (b) crop competitiveness; (c) mulching; and (d) hand weeding (Singh *et al*., 2007/2008; Rao *et al*., 2007).

Herbicides may continue to play key role in weed control of direct-seeded rice in developed countries and in majority of direct-seeded rice growing developing countries as a component of ecological weed management. It is essential, however, to evaluate environmental and health consequences of potential technologies that are based on chemical means of weed control.

**Future research needs**

Ecological weed management strategies that suit to farmers needs in different agro-ecological regions need to be developed for varying methods of direct-seeding based on the knowledge of weed ecology and biology. A few areas of research that needs emphasis include: (a) Understanding weed ecology and biology and utilising knowledge for evolving effective and economical ecological weed management strategies; (b) Continuous monitoring of weed populations to predict/identify undesirable shifts in weed communities; (c) Simple methods of decision making to enable farmers to choose right components of ecological weed management to manage weeds in their DSR fields; (d) Identifying farmers' weed control needs and developing ecological weed management approaches to solve location specific weed problems in DSR.

No single management technique provides complete weed control and is ideal for all conditions. Simultaneous use of multiple components of ecological weed management methods in a scientific manner, instead of focusing on single method, with a common goal of shifting crop weed balance in favor of direct-seeded rice, is essential.

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