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Opportunities for Weed Control in Dry Seeded Rice in North-Western Indo-Gangetic Plains

Gulshan Mahajan[1], Bhagirath Singh Chauhan[2] and Jagadish Timsina[3]
[1]Punjab Agricultural University, Ludhiana
[2]International Rice Research Institute, Los Baños
[3]International Rice Research Institute , IRRI-Bangladesh Office, Dhaka
[1]India
[2]Philippines
[3]Bangladesh

1. Introduction

North-western Indo-Gangetic Plain (NW-IGP) of India has played a leading role in the agricultural transformation of India and is considered as the most fertile plain for the livelihood of millions of peoples of India (Dhillon et al., 2010). Its contribution to the national food basket over years has also registered a remarkable increase compared to other regions. Food security of the nation is highly dependent on the NW-IGP as evident from the contribution of this region to the national buffer stock of food grains, which has generally been 50–75% in wheat and 30–48% in rice (Timsina and Connor, 2001). Sustainable production of rice and wheat in the region is very important for the food security of India. Cultivation of rice requires huge labour and large amount of water. Water and labour, however, are becoming increasingly scarce in the region raising the questions of environmental sustainability and sustainability of rice production systems. In NW-IGP, increasing use of groundwater for rice cultivation has led to declines in water table by 0.1 to 1.0 m yr^{-1}, resulting in water scarcity and increased cost for pumping water (Hira, 2009; Rodell et al., 2009; Humpherys et al., 2010). Implementation of the Mahatma Gandhi National Rural Employment Guarantee Act, introduced by the Indian government in 2005 (GOI, 2011), promising 100 days of paid work in people's home village, has been creating a labour scarcity in Punjab and Haryana which are the cereal bowl of northwest India. Rice transplanting in northwest India, particularly in the Punjab and Haryana, is dependent on millions of migrant labourers from eastern Uttar Pradesh and Bihar (Kumar & Ladha, 2011).

Since rice is primarily grown by transplanting seedlings in puddled fields it requires a large amount of water (~150 cm), of which 20-25 cm is used for puddling (intensive cultivation in wet conditions) only. This suggests that alternatives to puddled transplanted rice are required to save water and increase crop and labour productivity. One way to reduce water and labor demand is to grow dry seeded rice (DSR) instead of the puddled transplanted rice (Mahajan et al., 2009; Sudhir-Yadav et al., 2010). In DSR crop, dry seeds are sown into a prepared seedbed after tillage or under zero-till conditions and depending on water availability soils are kept aerobic, continuously saturated, or flooded. A DSR crop grown without standing water, intended to use less irrigation water than conventional flooded rice, is referred as aerobic rice. Dry seeding of rice with subsequent aerobic soil conditions eliminates the need of puddling and maintains submerged soil conditions, thus reducing the overall water demand and providing opportunities for water and labour savings (Bouman, 2001; Sharma et al., 2002). However, weeds are a serious problem because dry tillage practices and aerobic soil conditions are conducive for germination and growth of weeds, which can cause grain yield losses from 50 to 90% (Rao et al., 2007; Chauhan & Johnson, 2011; Chauhan et al., 2011; Prasad, 2011). The development and adoption of DSR may enable good crop growth but the lack of sustained flooding will greatly increase potential losses from weeds. These systems may integrate direct seeding and herbicide use, yet, to be sustainable, effective weed management strategies are required. A multitude of prerequisites, including level land, effective weed control, efficient water management, and timely water supply in relation to crop water demand, need to be met to ensure a successful DSR crop. In most places, insufficient attention is given to the importance of weeding. In DSR fields, it is not uncommon to see fields full of weeds, mainly grasses. When weed control in rice is neglected, there is a decrease in yield because of weeds, even if other means of increasing production, including application of fertilizers, are practiced. In the NW-IGP, DSR is an emerging production system. The transition from the puddle transplanted rice to DSR can therefore only be successful if accompanied by effective integrated weed management practices.

1.1 Weed species association

Weed flora in DSR consists of various kinds of grasses, broad leaf weeds and sedges (Mahajan et al., 2009) . Community composition of these weeds varies according to crop establishment methods, cultural methods, crop rotation, water and soil management, location, weed control measures, climatic conditions, and inherent weed flora in the area. *Echinochloa colona* and *E. crus-galli* are the most serious weeds affecting DSR. The density of these weeds in DSR depends upon moisture condition in the field. *E. colona* requires less water, so it is more abundant in DSR. *Cyperus rotundus* and *Cynodon dactylon* may be major problems in poorly managed fields or where un-decomposed farm yard manure has been applied. The other weeds of major concern in DSR are *Leptochloa chinensis, Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Caesulia axillaris*, *Paspalum spp*., *Alternanthera spp*., *Trianthema monogyna*, *Cyperus iria*, *Cyperus difformis*, and *Fimbristylis miliacea.*

1.2 Losses and critical duration of weed crop competition

Weeds in DSR adversely affect yield, quality and cost of production as a result of competition for various growth factors. Extent of loss may vary depending upon cultural methods, rice cultivars, weed species association, and their density and duration of competition. *Trianthema monogyn*a was found to grow faster than other weeds during early stage due to shorter life cycle and contributed much more to the competition as compared to other weeds (Singh, 2008). Relativity yield losses are higher for DSR than for transplanted rice as the rice and weed seedlings emerge simultaneously in DSR. The competitive advantage of transplanted rice over DSR is due to the use of 4-5 weeks old seedlings (20-30 cm tall) in transplanted rice and also that the weeds emerging after rice transplanting are controlled by flooding after transplanting in transplanted rice compared to DSR. In Asia, yield losses due to uncontrolled weeds in DSR are between 45 and 75% and in transplanted rice of approximately 50%. In a recent study, yield losses due to weeds (with one weeding at 28 days after sowing) in aerobic rice were about 50% relative to weed-free rice (Chauhan et al., 2011). In order to formulate an effective and economical weed management system for DSR, it is essential to establish critical duration of weed-crop competition and a limit for an acceptable presence of weeds. In DSR, the longer the presence of competition during the initial period the lower the yield, while at later stages yield might not change since the maximum damage has already accurred. The effective period of weed-crop competition in DSR occurs in two phases; i.e. between 15-30 days, and 45-60 days after seeding. The competition beyond 15 days after seeding may cause significant reduction in the grain yield. However, competition for the first 15 days only may not have much adverse effect on crop (Singh, 2008). In a recent study, critical periods for weed control, to obtain 95% of a weed-free yield, were estimated as between 17 to 56 days after sowing of the DSR crops at 15-cm row spacing (Chauhan & Johnson, 2011).

2. Opportunity

2.1 Prevention

Sowing of clean seed is perhaps the most important weed management technique in any crops. Rice seed contaminated with weed seeds may introduce a new species to a given field or add to an existing weed population. Preventing weeds from entering an area may be easier than trying to control them once they have established. Weeds which mature at the same time as rice are harvested and threshed with the crop resulting in the contamination of rice seed with weed seeds. Therefore, by using clean seed, infestation of weeds can be reduced to a considerable extent. Irrigation water is one of the major means of spread of weed seeds and vegetative propagules. Flowing water moves millions of weed seeds from one place to another. The amount and the type of weed seeds moved depend on the volume and the velocity of the water and the size and weight of the seed or the vegetative propagules. In case of heavy weed infestation, it is advisable to rotate the DSR crop with transplanted rice or other methods of rice planting. A continuous DSR crop may result in a shift to emergence of new weeds like *D. sanguinalis* and *L. chinensis* (Mahajan & Chauhan, 2011a).

2.2 Stale seed bed technique

In this technique, after pre-sowing irrigation, fields are left as such and weeds are allowed to germinate and thereafter are killed through cultivation or with the use of non-selective herbicide (e.g., glyphosate) application. This technique is quite effective in DSR, especially for controlling weeds such as *C. rotundus*. Herbicides may destroy weeds without disturbing the soil, which would be advantageous and hence reducing the possibilities of bringing new seeds to the upper soil surface. The rice seeds should be sown with minimum soil disturbance after destroying the emerged weeds. The use of zero-till-ferti-seed drills may be useful to serve this purpose. A reduction of 59% in the density and by 78% in the fresh weight of *E. colona* was recorded after using stale bed technique in the Philippines (Moody, 1982). Information on the effectiveness of stale seedbed technique is, however, very limited in the literature on DSR.

2.3 Land preparation

In DSR, the fields should be well levelled, if possible by using a laser leveller. Uneven land levelling may result in poor crop establishment (Jat et al., 2009). Developing rice seedlings can be killed or greatly retarded in their growth if ponding occurs due to unevenness of field or due to accumulation of toxic concentrations of applied herbicides. Also, weeds invade the vacant spaces where there are no rice plants, and hence there could be yield losses due to weed competition. Therefore, if the field is not levelled, the rice seedlings cannot establish quickly in the low spots and weeds will grow abundantly in the high spots (Singh et al., 2009). These conditions may result in stunted rice plants with low tiller production. Good field drainage and good water control are essential for the successful crop establishment and reduction of pre-emergence herbicide phytotoxicity. Tillage, however, serves only as a temporary means of weed control because the soil contains many ungerminated weed seeds. Ploughing buries weed seeds at a depth from where they cannot emerge but also brings deeply buried seeds to the surface where the conditions are conducive for germination (Chauhan & Johnson, 2010).

2.4 Choice of cultivar

Cultivars play an important role in crop-weed competition because of their diverse morphological traits, canopy structure and relative growth rate. A quick growing and early canopy cover enables a cultivar to compete better against weeds. Research evidences have shown that traditional tall cultivars like Nerica rice exert effective smothering effect on weeds (Prasad, 2011). Further, it has been observed that early maturing rice cultivars and rice hybrids also have a smothering effect on weeds due to improved vigour and having the tendency of early canopy cover (Mahajan et al., 2011). Little is known about the relative importance of shoot and root competition of hybrids and inbreds in field conditions in DSR and this may be the subject of future research. Most importantly, there is a need to develop rice varieties suitable for DSR as currently, varieties bred for transplanted rice are being used in DSR.

2.5 Seeding rate

For direct drilling of rice, 30-60 kg ha^{-1} seed rates are enough for a healthy crop. Only 30 kg ha^{-1} seed rate could be used if there was minimal weed pressure in the previous crops. Seed rate could be increased up to 60 kg ha^{-1} to compensate for the damages by rats and birds, to partially overcome the adverse effects of herbicides, and to compensate for poor stand establishment if rains occurs immediately after sowing (Mahajan et al., 2010). Low plant density and high gaps encourage the growth of weeds, and in many cultivars, result in less uniform ripening and poor grain quality. On the other hand, very high plant stand should be avoided because it tends to have less productive tillers, increases lodging, prevents the full benefit of nitrogen application, and increases the chances of rat damage. In DSR, Chauhan et al. (2011) found a significant decrease in weed weight as the seeding rate increased from 15 to 125 kg ha^{-1} (Fig. 1). Thus, high seeding rate could partly control weeds. An increase in grain yield was observed in the untreated check plot but not in the weeded plot as a result of increased seeding rate (Chauhan et al., 2011). Increased panicle numbers with increased seed rate was offset by decrease in panicle length and panicle grain weight. Higher seeding rates would be beneficial if no weed control is planned or if only partial weed control is expected. In conclusion, different studies suggest that increasing seeding rates of the crop suppresses weed growth and reduced grain yield losses from weed competition. However, it is not necessary to use high seeding rates to suppress weeds in DSR if effective herbicides are used.

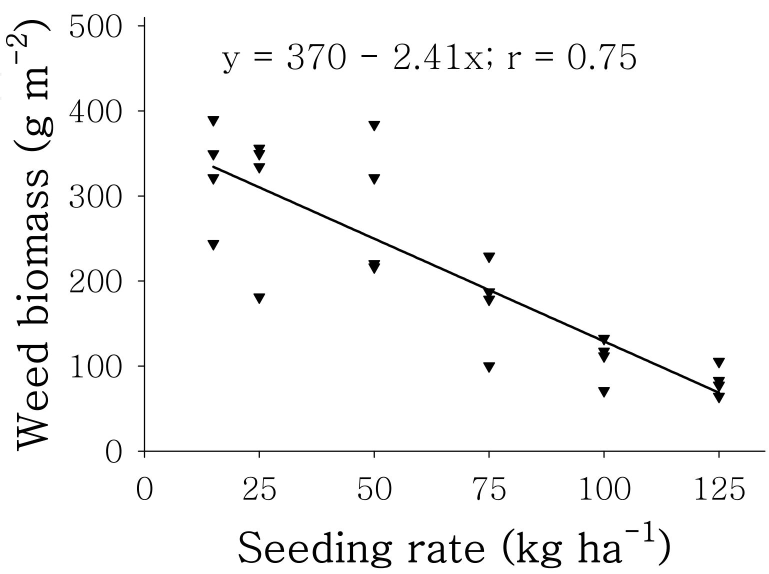

Fig. 1. The relation of weed biomass and rice seed rate at crop harvest (Chauhan et al., 2011).

2.6 Row spacing

The effect of crop geometry on weed incidence is a different issue from seeding rate. Mahajan & Chauhan (2011a) observed that paired row planting pattern (15-30-15-cm row spacing) in DSR had a great influence on weeds as compared to normal row planting system (23-cm row spacing) (Table 1). Paired row planting greatly facilitates weed suppression by maintaining rice plant's dominant position over weeds through modification in canopy structure. Earlier, Chauhan & Johnson (2010) reported that cultural management techniques, such as reduced crop row spacing, can increase the rice ability to compete against weeds for light.

Row spacing	Cultivar	
	Punjab Mehak 1	PR 115
	---------Dry matter (g m^{-2})---------	
35 days after sowing		
15-30-15-cm row spacing	131	136
23-cm row spacing	145	191
LSD (P = 0.05)	20	
Flowering stage		
15-30-15-cm row spacing	131	183
23-cm row spacing	140	244
LSD (P = 0.05)	21	

Table 1. Effect of planting pattern and cultivar on weed dry matter (g m^{-2}) at 35 days after sowing and at flowering stage (Mahajan & Chauhan, 2011a).

2.7 Water Management

Water management is an important component of any weed control program, whether any herbicide is used or not. Herbicides which give excellent control when applied into water may perform poorly in the absence of standing water (Kumar et al., 2009). There should be enough moisture in the field during the application of pre-emergence herbicides in DSR. In case of post-emergence application of herbicide, fields should be drained at the time of herbicide application and should not be irrigated immediately after its application. Good water management together with chemical weed control offers an unusual opportunity for conserving moisture and lowering the cost of rice production (Rao et al., 2007; Singh et al., 2009).

2.8 Nitrogen management

The proper management of N in DSR reduces the weed competition, and hence should be applied as per the requirement of the crop. The application of excess amount of N fertilizer, on the other hand, encourages weed growth and reduces yield. Recently, Mahajan & Timsina (2011) reported that when weeds were controlled, rice crop responded to higher amount of N application but under weedy and partially-weedy conditions, grain yield reduced drastically with higher amount of N fertilization.

2.9 Hand weeding

Many farmers do not realize that weed control is a limiting factor in crop production. Traditionally, they depend on manual labour to control weeds. By the time weeds are large enough to be removed by hand, damage has already occurred, and hand weeding alone cannot revert the yield loss. Maximum yields can only be achieved if weeds are controlled early because most damage takes place when crop plants are small. Hand weeding can only be done at a time when labour is available but this may not coincide with the best time for weed control. Improving weed management by alleviating labour constraints has repercussions for all aspects of crop production, the sustainability of cropping systems, and the social conditions of farming families.

Hand weeding in DSR is more time consuming and not as thorough as in transplanted rice. The weeders damage the rice plants as they move through the fields, especially during early crop growth. They fail to remove some of the grassy weeds or remove rice plants by mistake because of the difficulty in distinguishing some grassy weeds from rice. Also hand weeding is at least five times more expensive than herbicides for weed control in DSR, especially under labour-scarce or high labour cost environments (Rao et al., 2007). Hand weeding in DSR should only be done when there are typical weeds that cannot be controlled by either pre- or post-emergence herbicide application, or when labours are cheap and are in abundant supply.

2.10 Interrow cultivation

Recently, there have been many reports about the adaptation of DSR using a seed drill. The time taken for drilling rice seeds in an unpuddled field using a manually-operated planter is less than that required for seedling transplanting. Thus, this practice has potential to replace transplanting without any reduction in yield (Dixit et al., 2010). In India, under lowland conditions, it takes about 200-250 hours ha^{-1} for hand weeding in a DSR field, depending on the weed infestation. In a row-seeded or transplanted rice field, where weeds can be controlled by the use of mechanical weeders, it takes only about 50-60 hours ha^{-1} depending upon weed infestation and soil conditions. When the rice plants are 10-14 days old, a rotary weeder is passed through the field incorporating strips of rice seedlings into the soil so that the rice that is left appears as a row sown crop.

2.11 Herbicides

The success of DSR is dependent upon weed control with herbicides. However, herbicides should not be regarded as replacements for other weed control practices but should be used in conjunction with them. Herbicide use should be justified to coincide with the presence of sufficient weeds so as to warrant treatment, and should be used when weeds are most vulnerable. The optimum herbicide rate depends on factors such as cultural practices, soil type, and environmental conditions. Factors which must be considered when developing a herbicide program are the availability of herbicides, incidence of weed flora, application method and time, crop tolerance level, and cost effectiveness. The use of herbicides ensures effective weed control during periods of labour shortage when weeding coincides with other farm work. Temporary rice injury manifested as leaf chlorosis and inhibition of plant growth frequently occurs, but the crop usually recovers after two to three weeks and produces desired grain yield. Recently, sequential spray of pre-emergence application of pendimethalin (1 kg ha^{-1}) followed by bispyribac sodium (30 g ha^{-1}) at 15 days after sowing was found best for the control of weeds in DSR (Mahajan et al., 2009). Other herbicides that are found effective in DSR are pyrazosulfuron and oxadiragyl as pre-emergence and azimsulfuron, penoxsulam, cyhalopfop-butyl, and ethoxysulfuron as post-emergence (Rao et al., 2007). It must never be overlooked that all pesticides are toxic; they must be handled safely so as to reduce or avoid excessive and costly wastes, environmental concerns, crop damage, damage to adjacent crops by spray drift, injury to the applicator, excessive contamination and residues, and injury to beneficial organisms. It is advisable to rotate the herbicide combination in each year for delaying the development of herbicide resistance in weeds.

2.12 Integrated weed management

Herbicide use moves the agroecosystem to low species diversity with the possibility of appearance of new problem weeds, so there is a need for an ecological approach to control weeds instead of relying totally on chemical control methods. It was noted that reliance on a single herbicide could result in quantitative changes in the structure of the weed population in as few as five years (Singh, 2008). As weed populations are shifted by herbicides, weeds formerly of secondary importance emerge as primary weed problems. Such problems may be avoided by an integrated system of weed management, possibly by rotation of chemicals as well as rotation of crops. Many scientists advocate the alternative usage of herbicides to prevent the emergence of tolerant weeds.

Cultural and mechanical control methods have been the cornerstone of many pest control practices, in agriculture throughout the world. They remain the most widely used control practices in industrial and developing countries, even though many such controls have been eroded by pesticide substitution. Until the advent of herbicides, cultural practices through crop rotation and mechanical or hand weeding were virtually the only control mechanisms available against weeds. They remain vitally important but much more serious consideration is needed in establishing how they can be integrated with judicious herbicide use in order to minimize the constraint of untimely availability of labour for crop production. Weed control, whether done consciously or not by farmers, is often achieved by a combination of crop production practices and specific weed management activities. Integrated weed and crop management is not a new concept so, in theory, improved techniques need not be alien to farmers. However, farmers tend to be conservative and reluctant to change traditional practices, especially if they perceive risks. Weed problem in rice has been observed to be reduced by planting cowpea during dry season, rather than keeping the field fallow. Planting mungbean in dry season in northern India also reduced weed growth and weeding time and increased herbicide performance. Direct drilling under zero tillage is advantageous as far as weed control is concerned, but severe yield penalties were also noted by many workers (Brar et al., 2002). The practice of zero-till allows the retention of previous crop residues in the field and it is well known that mulches are a good tool for weed management. Mulches normally exclude light penetration and serve as a physical barrier to weed seedling emergence. However, efforts are underway to further improve this technique for better weed control and higher productivity. "Brown manuring" technique is also being utilized by many farmers for controlling weeds in DSR in northwest India. In this technique, sesbania and rice are grown together for 25-30 days and thereafter, sesbania is knocked down with the use of 2,4-D herbicide (Singh et al., 2007). The brown leaves of sesbania after the herbicide application would serve the purpose of mulch and hence smother the weed flora in rice. However, there are also reports that sesbania suppresses the rice crop too (Kumar & Ladha, 2011).

3. Conclusion

There is an increasing trend in NW-IGP to replace transplanting of rice by DSR. In effect, farmers are substituting capital in the form of seed and herbicides for labour. The results also suggest that the labour cost advantage of DSR more than compensates for the increase in herbicide cost. The adoption of DSR, being the farmers' friendly technology, is increasing even though herbicide costs are rising. DSR is expected to become increasingly more important in the next decade. However, the problems of weed control may become more important due to emergence of new weeds. Appropriate weed management strategies and technologies are needed to maintain yield stability and reduce the cost of production. Further studies are needed on weed species, population dynamics, and control practices by innovative cultural practices in conjunction with biological and chemical weed control. A dynamic research program is needed to develop the innovative and effective weed management strategies for DSR to maintain yield stability. There is also a need for more economical herbicides with reduced handling and environmental hazards, without reduction in herbicidal efficacy, for DSR. Worldwide concerns over safe handling of pesticides, environmental issues, and sustainable agriculture need to be addressed.

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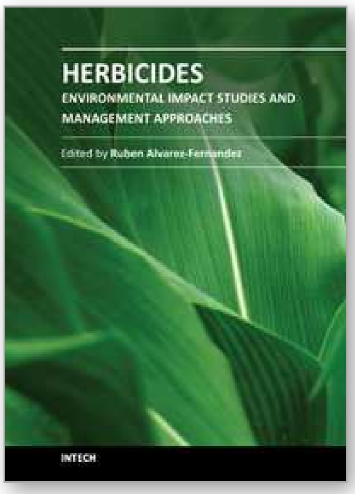

Herbicides - Environmental Impact Studies and Management Approaches
Edited by Dr. Ruben Alvarez-Fernandez

ISBN 978-953-307-892-2
Hard cover, 248 pages
Publisher InTech
Published online 20, January, 2012
Published in print edition January, 2012

Weeds severely affect crop quality and yield. Therefore, successful farming relies on their control by coordinated management approaches. Among these, chemical herbicides are of key importance. Their development and commercialization began in the 1940's and they allowed for a qualitative increase in crop yield and quality when it was most needed. This book blends review chapters with scientific studies, creating an overview of some the current trends in the field of herbicides. Included are environmental studies on their toxicity and impact on natural populations, methods to reduce herbicide inputs and therefore overall non-target toxicity, and the use of bioherbicides as natural alternatives.