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Integrated Weed Management in Direct Seeded Rice; A Review

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ABSTRACT

Rice yield losses due to uncontrolled weed growth were least in transplanted rice (12%) but otherwise large (cal.85%) where rice had been sown to dry cultivated fields or to puddle soil, rising to 98% in DSR sown without soil tillage. Weed competition reduced multiple rice yield components, and weed biomass in wet-seeded rice was six-fold greater that in rice transplanted into puddled soil and twice as much again in dry-seeded rice sown either after dry tillage or without tillage. Weeds are responsible for heavy rice yield losses, to the extent of complete crop loss under extreme conditions. Out of the losses due to various biotic stresses, weeds are known to account for nearly one third. Weed competition would be less severe under transplanting than those under direct-seeding. Uncontrolled weeds reduced the grain yield by 75.8%, 70.6% and 62.6% under dry-seeded rice (DSR), wet seeded rice (WSR) and transplanted rice (TPR) respectively). The risk of greater crop yield losses due to weed competition in DSR systems than in TPR is mainly because of the absence of the seedling size differential between rice and weeds and the absence of the suppressive effect of standing water on weed\ emergence and growth at crop emergence time. Paddy yield reduction is up to 48, 53 and 74% in transplanted, direct-seeded flooded and direct-seeded aerobic rice, respectively. Aerobic rice is subject to much higher weed pressure with a broader weed spectrum than flood-irrigated rice. Season-long weed competition in DSR may cause yield reduction up to 80%. Weed problem is sought to be addressed from two basic points of view: weed control and weed management. Control approach only emphasizes on reduction of weed pressure and the management approach, by contrast, focuses on keeping weed infestation at a level compatible with environmentally and economically sustainable production. However, different weed control options are available for rice. Physical control is eco-friendly but tedious and labor-intensive. Other problems include delayed weeding due to unavailability of labor damage to the rice seedlings and mistaken removal of rice seedlings. Biological control by using different bio-agents and mycoherbicides are practiced in irrigated lowland rice, but these may not be effective under aerobic soil\ conditions. Chemical control, on the contrary, is the most effective, economic and practical way of weed management.

Proper weed management technologies if well adapted can result in an additional rice production. Thus weed management would continue to play a key role to meet the growing food demands of increasing population. As the weed problems are multi-pronged, a holistic multi-disciplinary integrated approach would be imperative. In this context, integrated weed

management (IWM) may provide a more sustainable approach to rice production. Weed management must aim at reducing the weed population to a level at which weeds occurrence has no effect on farmers' economic and ecological interests. By using different appropriate management practices against weeds, farmers have more options for controlling weeds, thereby reducing the possibility of escapes and weed adaptation to any single weed management tactic. IWM is a science-based decision-making process that coordinates the use of environmental information, \weed biology and ecology, and all available technologies to control weeds by the most economical means, while posing the least possible risk to people and the environment. The concept of IWM is not new. the traditional practice of piddling soil to kill existing weeds and aid water retention, transplanting rice seedlings into standing water to achieve an optimum stand density, and maintaining standing water to suppress weeds, followed by one or several periods of manual weeding, is a well established example of integrated weed management (IWM). Before the advent of the green revolution and adoption of irrigation, rain fed rice was often used to be broadcasted into moist soil and yields were low, variable, and highly prone to weed competition, as is still experienced today, particularly in upland rice.

Key Words; Direct seeded Rice, Transplanted Rice; Integrated weed reduction techniques; Socio economic values

INTRODUCTION AND REVIEW

Rice is cultivated in Indonesia in a very wide range of ecosystems from irrigated to rain fed, flood prone (shallow, mid-deep, and deep water), swampy land, to uplands, but irrigated land stills the largest planted rice area. Transplanting is the major method of rice cultivation in Indonesia. However, transplanting is becoming increasingly difficult due to shortage and high cost of labor, scarcity of water, and reduced on-farm profit. Thus, direct-seeding is gaining popularity and highly prospective among farmers of Indonesia as in other Asian countries. Direct-seeding constitutes both wet-seeding and dry-seeding, and it does away with the need for, nursery preparation, uprooting of seedlings and transplanting. In the rice agro-ecosystems ideal environment conditions are provided for optimal rice productivity are being exploited by the associated weeds. Irrespective of the method of rice establishment, weeds are a major impediment to rice production through their ability to compete for resources and their impact on product quality.

The amount of water allocation in plants depends on climate, soil type, the availability of water in the soil, the water requirement of the crop and farming practices (Susi et al. 2010). Rice grown under traditional practices in Asia including Indonesia requires between 700 and 1500 mm of water during a cropping season, depending on the soil texture (Tuong and Bouman, 2001; Farooq *et al*., 2009;Talpur *et al*., 2011). The actual amount of water used by farmers for land preparation and during crop growth is much higher than the actual field requirement. Water resources for agricultural production are becoming increasingly scarce and the development of new water resources involves very high costs. Thus, an improvement and increase in WUE are required for future food security.

Proper weed management technologies if well adapted can result in an additional rice production. Thus weed management would continue to play a key role to meet the growing food demands of increasing population. As the weed problems are multi-pronged, a holistic multi-disciplinary integrated approach would be imperative. In this context, integrated weed management (IWM) may provide a more sustainable approach to rice production (Rao, 2011).

Weed management must aim at reducing the weed population to a level at which weeds occurrence has no effect on farmers' economic and ecological interests. By using different appropriate management practices against weeds, farmers have more options for controlling weeds, thereby reducing the possibility of escapes and weed adaptation to any single weed management tactic. IWM is a science-based decision-making process that coordinates the use of environmental information, \weed biology and ecology, and all available technologies to control weeds by the most economical means, while posing the least possible risk to people and the environment (Sanyal, 2008). The concept of IWM is not new. For example, the traditional practice of piddling soil to kill existing weeds and aid water retention, transplanting rice seedlings into standing water to achieve an optimum stand density, and maintaining standing water to suppress weeds, followed by one or several periods of manual weeding, is a well established example of integrated weed management (IWM) (Rao *et al*., 2007).

Weeds are responsible for heavy rice yield losses, to the extent of complete crop loss under extreme conditions. Out of the losses due to various biotic stresses, weeds are known to account for nearly one third. Weed competition would be less severe under transplanting than those under direct-seeding (Singh *et al*., 2005; Savary *et al*., 2005; Rao and Nagamani, 2007; Rao *et al*., 2007). Uncontrolled weeds reduced the grain yield by 75.8%, 70.6% and 62.6% under dry-seeded rice (DSR), wet seeded rice (WSR) and transplanted rice (TPR) respectively (Singh et al., 2005).

Rice yield losses due to uncontrolled weed growth were least in transplanted rice (12%) but otherwise large (cal.85%) where rice had been sown to dry cultivated fields or to puddle soil, rising to 98% in DSR sown without soil tillage. Weed competition reduced multiple rice yield components, and weed biomass in wet-seeded rice was six-fold greater that in rice transplanted into puddled soil and twice as much again in dry-seeded rice sown either after dry tillage or without tillage\ (Singh *et al*., 2011).

The risk of greater crop yield losses due to weed competition in DSR systems than in TPR is mainly because of the absence of the seedling size differential between rice and weeds and the absence of the suppressive effect of standing water on weed\ emergence and growth at crop emergence time. Ramzan (2003) reported yield reduction up to 48, 53 and 74% in transplanted, direct-seeded flooded and direct-seeded aerobic rice, respectively. Aerobic rice is subject to much higher weed pressure with a broader weed spectrum than flood-irrigated rice (Balasubramanian and Hill, 2002). Sunil et al. (2010) as stated, season-long weed competition in DSR may cause yield reduction up to 80%. Weed problem is sought to be addressed from two basic points of view: weed control and weed management. Control approach only emphasizes on reduction of weed pressure and the management approach, by contrast, focuses on keeping weed infestation at a level compatible with environmentally and economically sustainable production. However, different weed control options are available for rice. Physical control is eco-friendly but tedious and labor-intensive. Other problems include delayed weeding due to unavailability of labor damage to the rice seedlings and mistaken removal of rice seedlings. Biological control by using different bio-agents and mycoherbicides are practiced in irrigated lowland rice, but these may not be effective under aerobic soil\ conditions. Chemical control, on the contrary, is the most effective, economic and practical way of weed management (Hussain *et al*., 2008, Anwar *et al*., 2012a).

Before the advent of the green revolution and adoption of irrigation, rain fed rice was often used to be broadcasted into moist soil (Pandey and Velasco 2002) and yields were low, variable, and highly prone to weed competition, as is still experienced today, particularly in upland rice (Roder *et al*., 2001).

Community composition of 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 co*lona and E. *crusgalli* 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 *Paspalum* spp., *Ischaemum rugosum*, *Leptochloa chinensis*, *Digitaria sanguinalis*, *Dactyloct-enium aegyptium*, *C. ommelina* spp., *Caesulia axillaris*, *Cyperus iri*a, *Fimbristylis miliacea* and *Cyperus difformis*.

In DSR during the first 30 days after sowing, non-grassy weeds (broad-leaf) dominated the grassy weeds and sedges, contributing more than 62% of the total weed population where *Trianthema monogyna* alone contributed more than 50 and 60% at 150 and 30 days after sowing, respectively. At later stages, grasses dominated over non-grasses and sedges, contributing more than 90% of the total weed population at 75 DAS, at which *E. colona* alone contributed more than 80% of the total weed population at 60 DAS and beyond (Singh , 2008).

Studies conducted at Pantnagar in station trail and on farm trails indicated that *C. rotundus* may pose a severe threat to direct-seeded rice system where\ regular flooding is absent (Singh, 2008).

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, rice ecosystems, weed species association, their density\ and duration of competition. The greatest loss caused by the weeds, resulted from their competition with crop for growth factors, viz. nutrients, soil moisture,\ light, space, etc (Walia, 2006).*Trianthema monogyna* 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). Globally, actual yield losses due to pests have been estimated ~ 40%, of which weeds caused the highest loss (32%) (Rao *et al*., 2007). Yield\ losses are largely dependent on the season, weed density, weed species, rice cultivars, growth rate, management practices and rice ecosystem. Weedy rice *(Oryza sativa F. spontanea*), also known as red rice, has emerged as a serious threat. It is highly competitive and causes severe rice yield losses ranging from 15% to 100% (Farooq et *al*., 2009).

Weedy rice also reduces milling quality if it gets mixed with rice seeds during harvesting (Ottis *et al*., 2005). In 2004, yield loss equivalent to RM90\ million was estimated due to weedy rice infestation in direct-seeded rice in Malaysia (Azmi and Rezaul, 2008). However, water regimes in rice fields might determine the extent of yield loss due to weed competition. On average, estimated losses from weeds in rice are around 10% of total grain yield; however, can be in the range of 30 to 90%, reduces grain quality and enhances the cost of production]\ (Rao et al. 2007). In Bangladesh, rice yield losses due to weeds were estimated by 70-80% in Aus. rice (early summer), 30-40% in transplanted A. man rice (late summer) and 22-36% in Boro rice (winter rice) (BRRI, 2006).

Yield reduction due to weeds is more critical in\ direct-seeded rice than in transplanted rice (Karim *et al*., 2004). The competitive advantage of TPR over\ DSR is due to the use of 4-5 weeks old seedlings (20-30 cm tall) in TPR and also that the weeds emerging after rice transplanting are controlled by flooding after transplanting in TPR compared to DSR. In dry-seeded aerobic rice, relative yield loss caused by\ weeds is as high as 50-91% (Rao *et al*., 2007), while\ in TPR, yield loss has been estimated to be only 13% . Among the different establishment\ systems, yield losses are the slightly lesser in DSR (6.10 t/ha) as compared to wet-seeded rice (6.75 tha^{-1}) and TPR (6.35 tha^{-1}) under irrigated ecosystem (Singh *et al*., 2006a). Dhyani et al. 2010 recorded lowest density and dry weight of *E.colona* in TPR as compared to DSR. Season-long weed competition indirect- seeded aerobic rice may cause yield reduction up to 80% (Sunil *et al*., 2010). In extreme cases, weed\ infestation may cause complete failure of aerobic rice\ (Jayadeva et *al*., 2011). Thus direct-seeded aerobic rice is highly vulnerable to weeds compared with other rice ecosystems (Anwar *et al*., 2011).

Extensive use of herbicides has been reported to promote shifts in the weed population (Azmi and Baki, 2002).

With direct-seeding of rice there was a rapid increase in annual grasses, *Echinocloa colona*, *E.crusgalli*, *Leptochloa chinensis*: perennial sedge *Cyperus rotundus* and certain broad-leaf weeds such as *Caesulia axillaris*. Research on farmers field showed that direct-seeding of rice is accompanied by a rapid shift in weed flora with an increase in abundance of *E.colona*, *E. crusgalli*, *Ischaemum rugosum* and *Leptochloa chinensis* and on more freely draining soil *C. rotundus* (Singh *et al*., 2006). Singh et al. (2013) reported that replacing transplanted rice to direct seeding rice resulted an increase in weed growth and also shift in the relative abundance of particular species. Direct seeded rice is accompanied by a rapid\ shift in weed flora with an increase in *E. colona*, *E .crusgalli* and *Ischaemum rugosum*.

Many researchers working on weed management in DSR opined that herbicide may be considered to be a viable alternative/supplement to hand weeding (Chauhan and Johnson, 2011, Anwar *et al*., 2012). The other\ option left is cultural weed control through adoption of different agronomic practices including tillage\ (Rao *et al*., 2007), competitive cultivar (Zhao *et al*., 2006a), seeding density (Anwar *et al*., 2011), water management (Rao *et al*., 2007), fertilizer management\ (Blackshaw *et al*., 2005), seed invigoration (Ghiyasi *et al*., 2008), mulching (Singh *et al*., 2007a). Although\ these agronomic tools help to increase competitive ability of crop against weeds and at the same time are eco-friendly and economic, but may not provide acceptable level of weed control, especially under aerobic soil conditions, where weed pressure is very high. A single weed control approach may not be able to keep weeds below the threshold level of economic damage, and may results in shift in the weed flora, res stance development and environmental hazards.

Therefore, adoption of diverse technology is essential for weed management because weed communities are highly responsive to management practices. Besides, farmers are now becoming increasingly interested in more inclusive weed management strategy to reduce herbicide dependence (Blackshaw *et al*., 2005).Therefore, while addressing environmental concern, all the methods that are ecologically and economically justifiable should be integrated in a comprehensive way, known as integrated weed management (IWM). The IWM involves the selection, integration, and implementation of effective weed control means with\ due consideration of economics, environmental, and

Concern over long-term efficacy of herbicide dependent weed management has reinforced the need for IWM. A substantial impact of IWM on rice farming has been documented\ by many researchers (Sunil et *al*., 2010, Jayadeva *et al*., 2011). Therefore, there is need to integrate\ herbicide use with other management strategies to\ achieve effective, long term and sustainable weed control in direct seeded rice systems. Management (Rao *et al*., 2007), fertilizer management (Blackshaw *et al*., 2005), seed invigoration (Ghiyasi *et al*., 2008), mulching (Singh *et al*., 2007a). Although\these agronomic tools help to increase competitive\ ability of crop against weeds and at the same time are\ eco-friendly and economic, but may not provide\ acceptable level of weed control, especially under aerobic soil conditions, where weed pressure is very high. A single weed control approach may not be able to keep weeds below the threshold level of economic damage, and may results in shift in the weed flora,\ resistance development and environmental hazards.

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Cultural approaches play significant role to determine the competitiveness of a crop with weeds for above ground and below ground resources and hence might influence weed management (Grichar et al. 2004). Singh et al. 2009 reported 53% lower density in Dry- DSR after a stale seed bed than without this practice. Stale seedbed combined with herbicide (paraquat) and zero-till results in better weed control because of low seed dormancy of weeds and their inability to emerge from a depth >1 cm (Chauhan and Johnson, 2010). Conservation tillage has been criticized particularly in relation to lower yields and perennial weed problems which results in an increase in herbicide application (Singh et *al*., 2011).

Brown manuring" practice involves seeding of rice and Sesbania crops together and killing the Sesbania crop 25-30 days after sowing (DAS) by application of 2,4-D-ester at 0.40-0.50 $kgha^{-1}$. This will also help in\ meeting early N requirement of the crops and avoid early nitrogen and moisture stress (CIMMYT, 2010, Gurjeet *et al*., 2013). Methane gas emission and global warming potential was maximum under conventional- TPR and emission of N_2O was maximum under DSR crop with conservation practice of brown manuring as the addition of organic matter to soil increased the decomposition rate, which resulted in higher emission of GHGs (Bhatia *et al*., 2011).

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).

Manipulation of crop\ fertilization is a promising approach to reduce weed infestation and may contribute to long-term weed management (Blackshaw *et al*., 2004).

Many weed species consume high amount of N and; thus, reduces N availability for crops. 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 and 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. With inadequate weed control, it is best not to apply N or to apply N at low amounts.

Rice cultivar with strong weed competitiveness is deemed to be a low-cost safe tool for weed management (Gibson and Fischer, 2004). Short stature, early maturing, erect rice cultivars are less competitive with weeds than cultivars that are tall and have fast and vigorous early vegetative growth, a vigorous root system, high tillering and drooping leaves. It has been observed that early maturing rice cultivars and rice hybrids also have a smothering effect on weeds due to improved vigor and having the tendency of early canopy cover (Mahajan *et al*., 2011). Competitive rice cultivar effectively supp-ressed the infestation of *Echinochloa* spp. and helped reduce herbicide dependency (Gibson et *al*., 2001).

At present, no varieties are available that are targeted for alternate tillage and establishment methods, especially in unpuddled or ZT soil conditions with direct-seeding (Dry-DSR) in Asia (Fukai, 2002). Direct dry-seeded rice requires specially bred cultivars having good mechanical strength in the coleoptiles to facilitate early emergence of the seedlings under crust conditions (generally formed after light rains), early seedling vigor for weed competitiveness (Jannink *et al*., 2000, Zhao *et al*., 2006a), efficient root system for anchorage and to tap soil moisture from lower layers in peak evaporative demands (Clark *et al*., 2000. Pantuwan *et al*., 2002) and yield stability over planting times are desirable traits for DSR.

Seeding rate: High seeding rates are used in DSR systems. Farmers used high seed rate to compensate for poor seed quality and poor crop emergence as they use their own stored seeds and compensate for losses due to rodents, birds, insects etc. In addition, the use of high seed rates can also help in suppressing weed growth. 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. A study was conducted in the Philippines and India in 2008 and 2009 to assess the relations of seeding rate (15-125 $kgha^{-1}$) of hybrid and inbred varieties to crop and weed growth in aerobic rice. Plant densities, tillers and biomass of rice increased linearly with increased in seeding rates under both weedy and weed free environments. Weed biomass decreased linearly with increasing seed rate\ from 15 to 125 $kgha^{-1}$. Panicles and grain yield of rice in competition with weeds increased in a quadratic relation with increased seeding rates at both locations: however, the response was flat in the weed free plots.

A quadratic model predicted that seeding rates of 48-80 $kgha^{-1}$ for the inbred varieties and 47-67 $kgha^{-1}$ for the hybrid varieties were needed to achieve maximum\ grain yield when grown in the absence of weeds, while rates of 95-125 kg $seedha^{-1}$ for the inbred varieties and 83-92 kg $seedha^{-1}$for the hybrid varieties were needed to achieve maximum yields in\ competition with weeds. On the basis of these results, seeding rates > 80 $kgha^{-1}$ are advisable where there are risks of severe weed competition. Such high seeding rates may be prohibitive when using expensive seed, and maximum yields are not the only consideration for developing recommendations for optimizing economic returns for farmers. (Chauhan *et al*., 2011). Higher seeding rates would be beneficial if no weed control is planned or if only partial weed control is expected. However, it is not necessary to use high seeding rates to suppress weeds in DSR if effective herbicides are used.

The direct-seeded CT plots had similar grain yield as the direct-seeded ZT plots of rice and wheat after 4years of cropping (Bhattacharyya et al., 2008).However, the ZT practice had lower cultivation costs and crops under ZT could be sown earlier than CT (Singh *et al*., 2002). However, the significantly same\ grain, straw and biological yield was recorded with ZT in standing stubbles after removal of loose straw, CT with and without mulching (Singh 2010).

Sesbania co-culture technology can reduce the weed population by nearly half without any adverse effect on rice yield (Dhyani *et al*., 2007). It involves seeding rice and Sesbania crops together and then killing Sesbania with 2, 4-D ester about 25-30 DAS. Sesbania grows rapidly and suppresses weed. This practice is found more effective in suppressing weeds therefore if combined with pre-emergence application of pendimethalin, its performance in suppressing weeds increases. In yet another study (Singh and Singh, 2007), Sesbaniaco-culture reduced broad-leaf and grass weed density by 76-83% and 20-33%, respectively, and total weed biomass by 37-80% compared with sole rice crop. Sesbania knocked down by the application 2, 4-D 0.5kg/ha at 30 DAS was found more effective towards the density of weeds than application of pretilachlor, butachlor and fenoxaprop in DSR (Singh et al. 2012).

It has been estimated that 150 -200-labor-day/ha are required to keep rice crop free of weeds (Roder, 2001).

Many researchers working on weed management in DSR opined that herbicide may be considered to be a viable alternative/ supplement to hand weeding (Chauhan and Johnson, 2011, Anwar et al. 2012).

Application of penoxsulam at 20, 22.5 and 25 g/ha have better control over the density of grasses and broad-leaf weeds in DSR (Singh et al. 2012). Singh et al.(2010) found effective control over the density of *C. rotundus* with the application of azimsulfuron + MSMetsulfuron-methyl. Lowest population of E. colona was recorded with application of pendimethalin at 2.0 kg while of C. axillaris was with combined application of bentazone with pendamethalin (Singh et al .2005). Therefore, it is must to use herbicide judiciously (Anwar *et al*., 2012).

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).

Various agronomic tools have been evaluated for their potentiality in managing weeds (Liebman *et al*., 2001). But, all the agronomic tools may not work perfectly with every crop or weed species (Blackshaw et al. 2005). Integration of higher seed rate and spring-applied fertilizer in conjunction with limited herbicide use managed weeds efficiently and maintained high yields (Blackshaw et al.2005). Adoption of IWM approach for sustainable rice production has been advocated by many researchers (Azmi and Baki, 2002, Sunil *et al*., 2010, Jayadeva *et al*., 2011). Singh (2008) recorded that the sequential application of pre-emergence herbicides such as pendimethalin, in dry-seeded rice or early post-emergence application of anilofos/thiobencarb for the control of annual grasses in wet-seeded rice and post-emergence application of 2,4-D against sedges and non-grassy weeds in wet and dry-seeded rice may be a better option than the use of one herbicide.

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