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Herbicides combinations for sustainable weed management on complex weed flora in dry and irrigated direct seeded rice: A review

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Abstract
The weed-rice ecological relationship is very complex and dynamic. Weed distribution and successions are always affected by management and environmental factors. Weed spectrum and degree of infestation in rice field are often determined by rice ecosystems and establishment methods. Due to high weed pressure, weed management in direct seeded rice has been a major issue for the researchers and farmers as well. Integrated weed management approach based on critical period of crop weed competition, involving different direct and indirect control measures, has been developed and widely adopted by farmers to overcome weed problem in direct seeded rice in a sustainable way. Weed control methods must be sought that are friendlier to the environment and substantially reduce the cost of weed management to farmers. Weed competitive and allelopathic rice varieties, seed priming for increased weed competitiveness, higher seeding density should be considered as a management strategy. In order to devise a sustainable weed management strategy for dry and irrigated dry seeded rice, detailed studies need to be done on the biology and ecology of notorious rice weeds, particularly *Oryza sativa* L. (weedy rice), *Echinochloa* spp., *Leptochloa chinensis* (L.) Nees, *Limnocharis flava* (L.) Buch. *Commelina benghalensis, Ipomoea aquatic, Cyperus iria* and Fimbristylis miliacea. This review paper describes different approaches, including preventive, cultural approaches, mechanical approach and biological approach to manage weeds in dry seeded rice as well as irrigated DSR culture systems.

Keywords: direct seeded rice, critical period of weed control, weed flora

Introduction
Rice is considered one of the most important staple foods in the world as it supplies the major food requirement for more than one half of the world's population. Traditionally, rice is grown by raising rice nursery and transplanting one month old nursery seedlings in a puddle and flooded field (Ehsanullah *et al*., 2007) [22]. This method not only effectively suppresses the rice weeds by preventing the light to reach the weeds through a layer of the standing water and also provides the rice plants with a better growing environment (Farooq *et al*., 2011) [24]. However, this method of rice establishment requires immense labour and water (Bouman *et al*., 2007) [12]. Out of the total amount of water (~150cm), 20-25cm is used only for puddling (intensive cultivation in wet conditions). Puddling breaks soil aggregates, and soil becomes hard after drying, leading to the development of cracks and thereafter the water requirement increases manifold because of deep percolation through cracks. Puddling also results in poor soil physical conditions for establishing and raising succeeding crops (Tripathi *et al*., 2003) [58]. In the backdrop of the declining water resources and reduced availability of the labour, the conventionally flooded rice system is losing its sustainability and economic viability. Declined water table, increasing costs of diesel and electricity and climatic changes have further aggravated the problem. Due to these reasons there is a need to shift from the conventionally flooded transplantation to direct seeding. Direct-seeded rice (DSR) is the oldest method of rice establishment and prior to the late 1950s, direct seeding was the major method used in developing countries (Pandey and Velasco, 2005) [45].
In India, direct seeding of rice is largely a low-productivity system more common in rainfed areas. Direct seeding offers such advantages as faster and easier planting, reduced labour and drudgery, earlier crop maturity by 7–10 days, more efficient water use and higher tolerance of water deficit, fewer methane emission (Dry-seeded-DSR<Wet-seeded-DSR<Transplanted Rice), and often higher profit in areas with an assured water supply (Balasubramanian and Hill, 2002) [6]. Direct seeding also eliminates the use of seedlings and related operations such as seeding, nursery preparation and care of seedlings, pulling, bundling, transporting, and transplanting (Serrano, 1975) [52].

Direct seeding is a good alternative of transplanting and yield potential of DSR is equivalent to the transplanted rice under good water management and weed control conditions (Awan *et al*., 2011) [4]. Direct seeding of rice is accomplished by either of the methods as water seeding, wet seeding and dry seeding (Farooq *et al*., 2011) [24]. 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 (Sharma *et al*., 2002) [53]. 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% (Prasad *et al*., 2011) [47]. The productivity of the DSR is often reported to be lower, mainly due to problems associated with weed management. In order to save water and labour and promote conservation agriculture, with no/reduced tillage, it is absolutely essential to replace puddled transplanting with direct seeding.

Therefore, an efficient and economic weed management program is necessary to control different types of weeds throughout the cropping period. Hand weeding though efficient is expensive, time consuming, difficult and often limited by scarcity of labour in time. On the other hand, herbicides offer economic and efficient weed control if applied at proper dose and stage. However, the continuous use of single herbicide or herbicides having the same mode of action may lead to the weed resistance problem and also weed shifts. Hence it is necessary to test some high efficacy herbicides to control mixed weed flora in direct seeded rice.

Status of DSR

The yield levels of DSR are comparable to the conventional tillage-transplanted rice (CT-TPR) in many studies. Some reports claim similar or even higher yields of DSR with good management practices. For instance, substantially higher grain yield was recorded in DSR (3.15 t/ha) than TPR (2.99 t/ha), which was attributed to the increased panicle number, higher 1000 kernel weight and lower sterility percentage (Sarkar *et al*., 2003) [51]. In addition to higher economic returns, DSR crops are faster and easier to plant, having shorter duration, less labour intensive, consume less water (Bhushan *et al*., 2007) [10], conducive to mechanization (Khade *et al*., 1993), have less methane emissions (Wassmann *et al*., 2004) [59] and hence offer an opportunity for farmers to earn from carbon credits than TPR system (Balasubramanian and Hill, 2002) [6]. Dry-seeding reduces the overall water demand by reducing losses due to evaporation, leaching, percolation and amount of water needed for land preparation etc. (Bouman and Tuong, 2001) [1]. Direct-seeding also offers the option to resolve edaphic conflicts (between rice and the subsequent non-rice crop) and enhance sustainability of the rice based cropping system and succeeding winter crops (Farooq *et al*., 2008) [23] in India.

Yield loss due to weeds in DSR:

The concurrent emergence of competitive weeds, absence of water to suppress the weeds at the time of seedling emergence and prevalence of difficult to control weeds are the major reasons for the severe infestation of weeds in DSR. Weeds will adversely affect the yield, quality and cost of production due to competition for various growth factors (Singh, 2008). Because of wide adaptability and faster growth, weeds dominate the crops habitat and reduce the yield potential (Rao, 2011). Yield loss depends on several factors such as associated weed flora, degree of infestation, rice ecosystem, growing season, cultivar raised, cultural and management practices followed. On an average, yield loss, due to weed competition ranges from 15 to20 per cent, but in severe cases it may exceed 50 per cent (Hasanuzzaman *et al*., 2009) or even complete crop failure (Jayadeva *et al*., 2011). Based on studies conducted at Rice Research Station, Moncompu, Raj *et al*. (2013b) reported that, season long weed competition in wet seeded rice caused 69.71 and 67.40 per cent reduction in grain yield during kharif and rabi season, respectively. The risk of yield loss from weeds in direct- seeded rice is greater than transplanted rice (Rao *et al*., 2007) [49]. Ramzan (2003) [48] 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) [6]. In tropic, average rice yield losses from weeds is 35% (Oerke and Dehne, 2004) [43], while in direct seeded aerobic rice, yield penalty is as high as 50-91% (Rao *et al*., 2007) [49]. Sunil *et al*. (2010) [56] as stated, season-long weed competition in direct seeded rice 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 are eco-friendly but tedious and labor-intensive (Roder and Keobulapha, 1997) [50]. 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 (Smith, 1992) [54] and mycoherbicides (Thi *et al*., 1999) [57] 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 (Anwar *et al*., 2012a) [1].

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. Therefore, adoption of diverse technology is essential for weed management because weed communities are highly responsive to management practices (Buhler *et al*., 1997) [17]. Besides, farmers are now becoming increasingly interested in more inclusive weed management strategy to reduce herbicide dependence (Blackshaw *et al*., 2005) [9]. 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).

Critical period of crop-weed competition:

Crop-weed competition is more severe in DSR than in transplanted rice. Because weeds and rice seedlings emerge simultaneously, competitive advantage of the crop is reduced and also the alternate events of wetting and drying enhance growth of weeds. When competing, plants have similar vegetative habits and demand on resources, and then competition becomes severe. The severity of competition depends not only on competing species but also on its density, duration and the fertility status of the soil. According to Singh

(2008), in DSR it is important to minimize the crop-weed competition during the early stages of the crop before it forms a closed leaf canopy. Weed control during the critical weed-free period is essential to reduce the weed competition and for effective utilization of available resources for enhanced productivity. In DSR, the critical period of weed competition has been reported to be 14- 41 days after sowing (Chauhan and Johnson, 2011). Azmi *et al*. (2007) reported that critical period for weed control under mixed weed infestation in DSR was from 12 to 60 DAS. The effective control of weeds at initial stages of rice growth (0 to 40 DAS) could help in improving the productivity of DSR (Maity and Mukherjee, 2008). Singh (2008) opined that a weed free situation for first 60 or 70 DAS produced yield comparable with weed free situation until harvesting. The competition in DSR beyond 15 days after seeding may cause significant reduction in grain yield.

Weed-competitive cultivar

Rice cultivar with strong weed competitiveness is deemed to be a low-cost safe tool for weed management (Gibson and Fischer, 2004). Extensive variation in weed competitiveness among rice genotypes have been documented (Zhao *et al*., 2006a) [60]. Differences in weed suppressive ability among rice genotypes have been recorded up to 75% (Garrity *et al*., 1992) [27]. Competitive rice cultivar effectively suppressed the infestation of *Echinochloa* spp. and helped reduce herbicide dependency (Gibson *et al*., 2001) [25]. Allelopathic rice cultivars can contribute to weed suppression (Olofsdotter, 2001) [44]. Many potential allelopathic rice cultivars have been reported to inhibit weed growth significantly (Lin *et al*., 2000) [39]. Weed competitiveness of rice is often associated with traits like early plant height (Caton *et al*., 2003) [18], tillering ability (Fischer *et al*., 1997), early crop biomass (Ni *et al*., 2000), early vigor (Zhao *et al*., 2006a) [60], leaf area index (Dingkuhn *et al*., 1999) [3], specific leaf area (Audebert *et al*., 1999) [3], root characteristics (Fofana and Rauber, 2000) [26] and allelopathy (Dilday *et al*., 1994) [20].

Seeding density

Crop seeding density can be viewed as a possible strategy to decrease weed pressure and reduce herbicide dependence (Anwar *et al*., 2011). Seeding density of a crop determines solar radiation interception, canopy coverage and biomass accumulation which have cumulative effect on its weed suppressive ability. Higher seeding rate develops canopy rapidly and consequently suppresses weeds more effectively, and in contrast, lower seeding rate results in sparse stands and encourage weed growth (Guillermo *et al*., 2009) [30]. Higher seeding rate favors rice more than weeds and increases yield under weedy conditions (Phuong *et al*., 2005) [46]. It is evident that *Echinochloa crussgalli* and *Leptochloa chinensis* densities were reduced at higher rice seeding rates of 200 kg/ha and 100 kg/ha, respectively (Hiraoka *et al*., 1998). Higher seeding rate of rice, especially under aerobic soil conditions has been advocated not only for weed control but also for avoiding higher risk of poor seedling establishment associated with lower seeding rates (Anwar *et al*., 2011). Under aerobic soil conditions, higher seeding rate of 500 seeds/m^2 reduced weed growth and increased crop yield compared to a lower seeding rate of 300 seeds/m^2 (Zhao *et al*. 2007). Anwar *et al*. (2011) opined that direct seeding with 300 rice seeds/m^2 successfully suppressed weeds under aerobic soil conditions. Influence of rice seeding method on weed growth, and row seeding in east-west direction resulted in lower yield loss under weedy condition (Phuong *et al*., 2005) [46]. Boyd *et al*. (2009) [13] also reported that planting uniformity shows a positive impact on the competitive ability of a crop. Combination of increased crop density and more uniform plating for better weed suppression has been emphasized by many researchers (Weiner *et al*., 2001; Boyd *et al*., 2009) [13], who concluded that row seeding allows for weeds to utilize the light between the rows, while evenly distributed crops compete better with weeds. In contrast, Castin and Moody (1989) did not suggest higher seeding rates for rice when herbicides are available for effective weed control. As stated in several studies higher seed rate may bring about problems of mutual shading and intra-specific competition for resources, and may cause problems like lodging, insect and disease infestation and rat damage (Bond *et al*., 2005).

Seed quality

Direct seeding method is expected to continue in the future because of scarcity in labor supply and escalation in overall production cost. As a result, the amount of seeds required per hectare of land is increased by several folds. Certified seeds produced through transplanting method, which is the recommended practice for seed production. Rice seeds contaminated with weedy rice seeds are important contributory factors to weedy rice infestation in the rice fields (Mai *et al*., 1998). The spread of weedy rice to uninfected fields has occurred in Europe and Southeast Asian countries by the distribution of rice seeds contaminated with weedy rice seeds to the farmers (Ferrero. 2003).

Seed priming

Beneficial effects of seed priming include increased germination rate, synchronized germination and faster emergence of seedlings (Anwar *et al*., 2012b). The traits closely associated with weed competitiveness of rice include early height growth rate, early crop biomass (Ni *et al*., 2000) and early vigor (Zhao *et al*., 2006b), which can be obtained through higher and faster germination of primed seeds. Therefore, seed priming is supposed to play a significant role in weed suppression. Besides, poor germination under aerobic soil condition (Balasubramanian and Hill, 2002) [6] results in sparse and patchy stands, which encourages weed growth (Guillermo *et al*., 2009) [30] and reduces the competitive ability of rice against weeds (Boyd *et al*., 2009) [13]. Higher and synchronized emergence of primed seeds can ensure vigorous crop stand with rapid canopy development giving rice plants a preliminary advantage over weeds (Anwar *et al*., 2012b) [2]. Due to seed priming, rice seedlings could compete more successfully with weeds (Harris *et al*., 2002) [33]. A robust seedling stand obtained from primed seeds enhanced rice competitiveness against weeds and improved tolerance to environmental stress (Ghiyasi *et al*. 2008) [28].

Tillage

The importance of thorough land preparation to minimize weed pressure is well recognized. Tillage can affect weed community through the changes in weed seed distribution in the soil. Primary tillage can reduce annual weed populations, especially when planting is delayed to allow weed seeds to emerge before final tillage (Buhler and Gunsolus, 1996) [16]. While shallow tillage before crop emergence and post plant tillage after crop establishment help remove annual weeds and inhibit the growth of perennial weeds (Buhler, 2002) [15]. On the other hand, zero tillage favors weed infestation (Hach,

1999) [31]. Conservation tillage has been criticized particularly in relation to lower yields and perennial weed problems which results in an increase in herbicide application (Koskinen and McWhorter, 1986) [37]. In contrast, presence of crop residue in conventional tillage increases weed suppression and tillage in darkness can delay and reduce the emergence of certain weed species (Jensen, 1995) [35].

Water management

Water is the "best herbicide". Every weed species has an optimum soil moisture level, below or above which its growth is hampered, and therefore time, depth and duration of flooding could play an important role in suppressing weeds. The importance of water management for controlling weeds in rice is well-known but water management is yet to achieve its full potential (Hill *et al*., 2001) [34]. In wet-seeded rice, early flooding at 4 DAS can reduce weed infestation, particularly barnyard grass densities (Hach, 1999) [31]. Water depth influence on the efficacy of herbicide has been reported by Hach *et al*. (1997) [32] who found that increased water depth enhanced the efficiency of early post emergence application of pyrazosulfuron-ethyl but not butachlor and thiobencarb.

Fertilizer management

Manipulation of crop fertilization is a promising approach to reduce weed infestation (Di Tomaso, 1995) [19], and may contribute to long-term weed management (Blackshaw *et al*., 2004) [8]. Fertilizer management should be aimed at maximizing nutrient uptake by crop and minimizing nutrient availability to weeds (Di Tomaso, 1995) [19]. Since most of the annual weeds germinate from the top few millimeters of the soil, fertilizers broadcast on the top soil would give the weeds equal chance to utilize nutrient together with the crop (Melander *et al*., 2005) [40]. Nitrogen fertilizer has been reported to break weed seed dormancy and influence weed densities. Many weed species consume high amount of N and; thus, reduces N availability for crops. Several researchers observed that weeds became less competitive when N was applied at early growth stages of crop compared with later application, and weeds are found to be more responsive to added N than that of crop (Blackshaw *et al*., 2000) [7]. However, review on fertilizer management and crop-weed interaction has generated conflicting conclusion (Blackshaw *et al*., 2004) [8]. It is not always recognized that fertilizer management can affect crop weed competitiveness, and results may be crop and weed specific (Blackshaw *et al*., 2004) [8]. Fertilizer management can definitely alter the competitive balance between crops and weeds, but methods to incorporate it into integrated weed management are yet to be developed (Buhler, 2002) [15].

Integrated weed management

Until 1940s, weed control was accomplished through physical, cultural and biological means. Since the introduction of herbicides in late 1940s, their amazing performance led to the belief that herbicide would solve the weed problem forever. But, after over 50 years of extensive use of herbicides, it is now clear that sole reliance on herbicide is a losing strategy. Herbicides are often blamed for environmental pollution (Spliid and Koeppen, 1998) [55] and impoverishment of the natural flora and fauna and therefore, over reliance on herbicides may bring unwarranted environmental decay and shift in weed species dominance (Azmi and Baki, 2002) [5]. This demands resurgence of physical, cultural and biological weed management, combined with judicious application of herbicides- known as integrated weed management (IWM). The IWM was first introduced and defined by Buchanan (1976) [14] as "the application of many kinds of technology in a mutually supportive manner. It involves the selection, integration, and implementation of effective weed control means with due consideration of economics, environmental, and sociological consequences. The IWM better utilizes resources and offers a wider range of management options (Buhler *et al*., 2000). Integration of diverse technologies is essential for weed management because weed communities are highly responsive to management practices and environmental conditions (Buhler *et al*., 1997). A theoretical model of IWM has been suggested by Noda, (1977) [42]. None of the control measures in single can provide acceptable levels of weed control, and therefore, if various components are integrated in a logical sequence, considerable advances in weed management can be accomplished (Swanton and Weise, 1991). 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) [9]. 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) [9].

Conclusions

Weed management is a fundamental practice, failure of which may result in severe losses in terms of yield and economic return. Weed is a serious problem in direct seeded rice and weed management has been a huge challenge for the weed researchers and rice farmers as well. Weeds are dynamic in nature and a shift in their abundance and dominance is likely with the changes in management practices. Herbicide is the smartest and most economic tool to fight against weeds. But recurrent use of one herbicide for a long time may result in development of herbicide resistant weed biotypes. Integrated approaches are suggested for sustainable weed control in direct seeded rice, such as the use of clean certified seeds, higher seeding densities, cultivation of competitive variety, seed invigoration, stale seed bed preparation, crop rotation, water and fertilizer management along with rotation of herbicides with different mode of actions followed by manual weeding and rouging after mid stage of rice growth. Moreover, any weed management approach should be aimed at controlling weeds only during critical period of weed competition for a more cost-effective and eco-friendly weed management. A long term changes in weed flora, herbicide efficacy, resistance, residual toxicity and environmental implications of continuous use of herbicides should be properly addressed for sustainability of direct seeded rice culture.

References

1. Anwar MP, Juraimi AS, Puteh A, Man A, Rahman MM. Efficacy, phytotoxicity and economics of different herbicides in aerobic rice. Acta Agric Scandin 2012a;62:604-615.
2. Anwar MP, Juraimi AS, Puteh A, Selamat A, Rahman MM, Samedani M. Seed priming influences weed competitiveness and productivity of aerobic rice. Acta Agric Scandin 2012b 62:499-509.
3. Audebert A, Dingkuhn M, Jones MP, Johnson DE. Physiological mechanisms for vegetative vigor of interspecific upland rice-implications for weed

competitiveness. Paper presented at the International Symposium on World Food Security, Kyoto, Japan 1999
4. Awan IU, Alizai HU, Chaudhry FM. Comparative study of direct seeding and transplanting methods on the grain yield of rice. Sarhad Journal of Agriculture. 1989;5:119-124.
5. Azmi M, Baki BB. Impact of continuous direct seeding rice culture on weed species diversity in the Malaysian rice ecosystem. In Proceedings of the regional symposium on environment and natural resources. Hotel Renaissance, Kuala Lumpur, Malaysia 2002;1:61-67
6. Balasubramanian V, Hill JE. Direct seeding of rice in Asia: Emerging issues and strategic research needs for the 21st century. In Direct Seeding: Research strategies and opportunities. Pandey *et al* Eds. IRRI, Los Banos, Philippines, 2002, 15-39.
7. Blackshaw RE, Semach G, Li X, O' Donovan JT, Harker KN. Tillage, fertilizer and glyphosphate timing effects on foxtail barley management in wheat. Can J Plant Sci 2000;80:655-660
8. Blackshaw RE, Molnar LJ, Janzen HH. Nitrogen fertilizer timing and application method affect weed growth and competition with spring wheat. Weed Sci 2004;52:614-622
9. Blackshaw RE, Moyer JR, Harker KN, Clayton GW. Integration of agronomic practices and herbicides for sustainable weed management in a zero-till barley field pea rotation. Weed Technol 2005;19:190-196.
10. Bhushan L, Ladha JK, Gupta RK, Singh S, Tirol-Padre A, Saharawat YS *et al*. Saving of water and labor in a rice-wheat system with no-tillage and direct seeding technologies. Agron J 2007;99:1288-1296.
11. Bouman BAM, Tuong TP. Field water management to save water and increase its productivity in irrigated lowland rice. Agri Water Manag. 2001;49:11-30.
12. Bouman BAM, Humphreys E, Tuong TP *et al*. Rice and water. Adv Agron. 2007;97:187-237.
13. Boyd NS, Brennan EB, Smith RF, Yokota R. Effect of seeding rate and planting arrangement on rye cover crop and weed growth. Agron J 2009;101:47-51
14. Buchanan GA. Management of the weed pests of cotton *(Gossypium hirsutum)*. In Proceedings of the U.S.-U.S.S.R. Symposium: The integrated control of the arthropod, disease and weed pests of cotton, grain sorghum and deciduous fruit, Lubbock, TX. 1976, 168-184.
15. Buhler DD. Challenges and opportunities for integrated weed management. Weed Sci. 2002;50:273-280
16. Buhler DD, Gunsolus JL. Effect of date of preplant tillage and planting on weed populations and mechanical weed control in soybean (*Glycine max*). Weed Sci 1996;44:373-379
17. Buhler DD, Hartzler RG, Forcella F. Implications of weed seed bank dynamics to weed management. Weed Sci. 1997;45:329-336.
18. Caton BP, Cope AE, Mortimer M. Growth traits of diverse rice cultivars unde severe competition: implications for screening for competitiveness. Field Crops Res 2003;83:157-172
19. Di Tomaso JM. Approaches for improving crop competitiveness through the manipulation of fertilization strategies. Weed Sci. 1995;43:491-497.
20. Dilday RH, Lin J, Yan W. Identification of allelopathy in the USDA-ARS rice germoplasm collection. Aust J Exp Agric. 1994;34:901-910
21. Dingkuhn M, Johnson DE, Sow A, Audebert AY. Relationship between upland rice canopy characteristics and weed competitiveness. Field Crops Res 1999;61:79-95.
22. Ehsanullah AN, Jabran K, Habib T. Comparison of different planting methods for optimization of plant population of rice (*Oryza sativa* L.) in Punjab (Pakistan). Pak J Agri Sci. 2007;44:597-599.
23. Farooq M, Basra SMA, Asad SA. Comparison of conventional puddling and dry tillage in rice-wheat system. Paddy Water Environ. 2008;6:397-404.
24. Farooq M, Kadambot, Siddique HM *et al*. Rice direct seeding: Experiences, challenges and opportunities. Soil Tillage Research. 2011;111(2):87–98.
25. Fischer AJ, Ramierz HV, Gibson KD, Pinheiro BDS. Competitiveness of semi dwarf rice cultivars against palisadegrass (*Brachiaria brizantha*) and signalgrass (*Brachiaria decumeans*). Agron J 2001;93:967-973.
26. Fofana B, Rauber R. Weed suppression ability of rice under low-input conditions in West Africa. Weed Res 2000;40:271-280.
27. Garrity DP, Movillon M, Moody K. Differential weed suppression ability in upland rice cultivars. Agron J 1992;84:586-591
28. Ghiyasi M, Abbasi AM, Tajbakhsh A, Sallehzade R. Effect of osmo priming with poly ethylene glycol8000 (PEG8000) on germination and seedling growth of wheat (*Triticum aestivum* L.) seeds under salt stress. Res J Biol Sci 2008;3(9):1249-1251.
29. Gibson KD, Hil JE, Foin TC, Caton BP, Fischer AJ. Water seeded rice cultivars differ in ability to interfere with water grass. Agron J 2001;93:326-332
30. Guillermo DA, Pedersen P, Hartzler RG. Soybean seeding rate effects on weed management. Weed Technol 2009;23:17-22
31. Hach CV. Study on some weed control methods in wet seeded rice in Mekong delta. Ph. D. thesis. Vietnam Institute of Agricultural Science and Technology, Hanoi 1999, 183.
32. Hach CV, Chin DV, Dien TV, Luat NV. Study the effect of water depths and herbicides on weeds and grain yield of rice. In Scientific Proceedings of the Vietnam Institute of Agricultural Science and Technology. 1997;5:20-21.
33. Harris D, Tripathi RS, Joshi A. On-farm seed priming to improve crop establishment and yield in dry direct-seeded rice, In Proceedings of the International workshop on Direct Seeding in Asian Rice systems: Strategic Research Issues and Opportunities. Pandey, S., Mortimer, M., Wade, L., Tuong, T.P., Lopes, K. and Hardy, B. Eds. 25-28 January 2000. Bangkok, Thailand, 2002, 383.
34. Hill JE, Mortimer AM, Namuco OS, Janiya JD. Water and weed management in direct seeded rice: Are we ahead in the rigt decision? In Proceeding of the International Rice Research Conference, 31 March-3 April, 2000, International Rice Research institute, los banos, Philippines 2001, 491-510.
35. Jensen PK. Effect of light environment during soil disturbance on germination and emergence pattern of weeds. Ann Applied Biol. 1995;127:561-571.
36. Khade VN, Patil BD, Khanvilkar SA, Chavan LS. Effect of seeding rates and level of N on yield of direct seeded (Rahu) summer rice in Konkan. J Maharashtra Agri Uni 1993;18:32-35.

37. Koskinen WC, McWhorter CG. Weed control in conservation til1age. J Soil Water Conser 1986;41:365-370
38. Liebman M, Mohler CL, Staver CP. Ecological management of agricultural weeds. Cambridge University Press, Cambridge. 2001, 532.
39. Lin WX, Kim KU, Shin DH. Rice allelopathic potential and its modes of action on barnyard grass. Allelopathy J 2000;792:215-224
40. Melander B, Rasmussen IA, Barberi P. Integrating physical and cultural methods of weed control-examples from Euro Res. Weed Sci 2005;53:369-381.
41. Ni H, Moody K, Robles RP, Paller EC, Lales JS. *Oryza sativa* plant traits conferring competitive ability against weeds. Weed Sci 2000;48:200-204
42. Noda K. Integrated weed control in rice. In integrated control of weeds. Frayer, J.D. and Matsunaka, S. Eds. Tokyo (Japan): University of Tokyo Press 1977, 17-46.
43. Oerke EC, Dehne HW. Safeguarding production- Losses in major crops and the role of crop protection. Crop Prod 2004;23(4):275-285.
44. Olofsdotter M. Rice- a step toward to use allelopathy. Agron J 2001;93(1):3-8
45. Pandey S, Velasco l. Trends in crop establishment methods in Asia and research issues. In: Toriyama K, editor. Rice is life: perspectives for the 21st century. International Rice Research Institute, Los Baños, Philippines and japan international research center for agricultural sciences: Japan 2005, 178-181.
46. Phuong LT, Denich M, Vlek PLG, Balasubramanian V. Suppressing weeds in direct seeded lowland rice: effects of methods and rates of seeding. J Agron Crop Sci. 2005;191:185-194
47. Prasad R. Aerobic rice systems. Adv Agron. 2011; 111:207-247.
48. Ramzan M. Evaluation of various planting methods in rice-wheat cropping systems, Punjab, Pakistan. Rice Crop Report 2003-2004. 2003, 4-5.
49. Rao AN, Joshson DE, Sivaprasad B, Ladha JK, Mortimer AM. Weed management in direct-seeded rice. Adv Agron 2007;93:153-255
50. Roder W, Keobulapha B. Weeds in slash-and-burn rice fields in northern Laos. Weed Res 1997;37:111-119.
51. Sarkar RK, Sanjukta D, Das S. Yield of rainfed lowland rice with medium water depth under anaerobic direct seeding and transplanting. Tropical Sci 2003;43:192-198.
52. Serrano FB. Twenty-six years of rice research and development. Philippines: National Research Council of the Philippines 1975, 122.
53. Sharma PK, Bhushan L, Ladha JK. Crop water relations in rice–wheat cropping under different tillage systems and water management practices in a marginally sodic, medium-textured soil. In: Bouman, BAM, *et al*. editors. Water-wise Rice Production. Philippines: Proceedings of the International Workshop on Water-Wise Rice Production 2002, 223-235
54. Smith Jr RJ. Biological controls as components of integrated weed management for rice in the U.S. In Proceedings of the International Symposium on Biological Control and Integrated Management of Paddy and Aquatic Weeds in Asia. sukuba, Japan, 1992, 335-351.
55. Spliid NH, Koeppen B. Occurrence of pesticides in Danish shallow ground water. Chemosp. 1998; 37:1307–1316
56. Sunil CM, Shekara BG, Kalyanmurthy KN, Shankaralingapa BC. Growth and yield of aerobic rice as influenced by integrated weed management practices. Ind J Weed Sci 2010; 42(3&4):180-183
57. Thi HL, Man LH, Chin DV, Auld BA, Hetherington SD. Research on some fungi to control barnyard grass and red sprangletop in rice. In Proceedings of the 17th Asian pacific Weed Science Society conference, Bangkok, Thailand, 1999, 562-566
58. Tripathi RP, Gaur MK, Rawat MS. Puddling effect on soil physical properties and rice performance under shallow water table conditions of Tarai. J Indian Soc Soil Sci. 2003;51(2):118-124.
59. Wassmann R, Neue HU, Ladha JK, Aulakh MS. Mitigating greenhouse gas emissions from rice-wheat cropping systems in Asia. Environ. Deve Sust. 2004;6:65-90.
60. Zhao DL, Atlin GN, Bastiaans L, Spiertz JHJ. Developing selection protocols for weed competitiveness in aerobic rice. Field Crops Res 2006a;97:272-285
61. Zhao DL, Atlin GN, Bastiaans, L, Spiertz JHJ. Cultivar weeds competitiveness in aerobic rice: heritability, correlated traits, and the potential for indirect selection in weed-free environments. Crop Sci 2006b;46:372-380.