Review article

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Direct seeded rice: research strategies and opportunities for water and weed management

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ABSTRACT

Anticipated water crisis, traditional rice cultivation having standing water for most of the growth stages and mounting labour shortage necessitates the search for alternative water management methods to increase the water productivity in rice cultivation. The major benefit of direct seeded rice (DSR) is its low- input demand. DSR with non- puddled and non- flooded conditions has the potential to maximize the water productivity under deficit soil moisture conditions. The major constraint for DSR is water and weed management for sustaining the yield. Exposure of rice plants to water deficit stress leads to the nutrient deficiency and panicle sterility, which ultimately leads to reduction in yield. One of the prominent reasons for yield penalty under DSR is weed infestation, which accounts for enormous losses in economic terms and sometimes crop failures. High weed density not only compete with the rice plant but often provides a shelter for growth of various harmful insect, pest and pathogens, which adversely affect the rice production. Compared to manual weeding, weed control by herbicides are considered to be more efficient and economical in wet direct seeded rice. Hence, the identification and selection of cultivars based on their competitive ability with weeds coupled with drought tolerance is of paramount importance. In order to achieve long term sustainable and economic weed control in DSR, an integration of different weed management strategies involving cultural, mechanical, biological and chemical methods are very much essential. In this review, we discuss the experiences, potential benefits and major challenges associated with DSR, and suggest sustainable management practices for direct seeded rice cultivation.

Key words: *Direct seeded rice, weed control, water management, breeding approach*

Rice is the vital staple food of Asia, where ~92% of the global rice is produced and consumed. It is the source for ~35-80% of total calorie intake of Asian population (IRRI 1997). Nearly 133 Mha out of the total of 156 Mha of global rice growing area is in Asia producing ~540 million tonnes (Mt) out of the total global production of 660 Mt of rice. India is the 2nd largest producer of rice next to China, where it is grown in an area of 45 Mha annually with a production of 90 Mt and accounts for~45% of food grain production in the country (Singh *et al.* 2013). Worldwide, rice demand is increasing @ 6.0% due to change in the dietary habit of majority of the population of western and central Africa (Carriger and Vallee 2007). The most common methods of rice crop establishment are direct sowing (dry direct seeding and wet direct seeding) and transplanting (Kumar *et al.* 2015 a, b; Chatterjee *et al.* 2016; Kumar *et al.* 2016e). Presently, in direct seeded rice (DSR) is gaining momentum due to labour shortage during peak season of transplanting and availability of water for short periods (Kumar *et al.* 2016c,d; Kumar *et al.* 2015a, b; Singh *et al.* 2017;

Prakash *et al.* 2014). Direct seeding involves sowing of pre-germinated seeds in wet (saturated) puddled/ dry soils. In recent years there is a serious concern about the availability of water for rice production due to sharp decrease in water table (Hugar *et al.* 2009). It has been reported that ~2 M ha of fully irrigated and 13 M ha of partially irrigated lands in Asia during wet season experience physical water scarcity and 22 M ha of irrigated lands in the dry season would face economic water scarcity by 2025 (Ali *et al.* 2014). These facts lead to shift from transplanting to DSR in many Asian countries including India.

According to Lafitte *et al.* (2002), concept of DSR comprises of use of rice varieties, which are nutrient-responsive and well adapted to aerobic soils with yield potential of 70-80% of high-input flooded rice. The irrigation scheduling in DSR done through surface irrigation aims at keeping the soil wet, but not flooded or saturated. In practice, irrigation is applied to bring the soil water content up to the field capacity, once the lower threshold limit has been reached. For most of the upland crops, the threshold limit of irrigation are usually when the soil water content reached halfway between field capacity and wilting point (Doorenbos and Pruitt 1984). The greatest problem with DSR system is yield sustainability issue as frequent yield declines even failures have been reported from different parts of world (George *et al.* 2002).In the current scenario of shrinking agricultural land, acute shortage of irrigation water and decreased availability of labour, the adoption of improved rice varieties having higher water productivity and modern agronomic technology are the only way out to meet the global rice demand (Leeper 2010).

Constraints in DSR

In DSR system, dry rice seeds are sown with or without tillage and irrigation is applied periodically to maintain soil moisture at field capacity. So, this method enhances water productivity and conserve considerable amount of irrigation water (Kumar *et al.* 2016c) and method of planting also reduces the total labour requirement by 11-66% compared to puddled transplanted rice (PTR), depending on season, location, and type of DSR. It allows faster and easier planting and often DSR rice matures ~7-10 days earlier than the PTR, facilitating timely planting of the succeeding rabi crop (Singh *et al.* 2006). Additionally, DSR improves the soil health, emits less methane and often ensure higher profit in area with assured irrigation supply (Kumar *et al.* 2016c). Weeds are the one of the major cause of yield loss in DSR as well as in low-land transplanted condition (Roy *et al.* 2011). Yield loss of ~17-24% takes place if weeds were allowed to compete till 4 week after seeding (Chauhan and Johnson 2011). Weed management practices under DSR system may vary depending upon the socio-economic conditions of growers and several other factors associated with them (Mandal *et al*. 2011a, b; Chatterjee *et al.* 2016). Traditionally, hand-weeding was the most common method to control weed, and presently weeding through hand hoeing is not economical as it takes time and requires more man days (Chatterjee *et al*. 2016). Surface mulching through crops residue may selectively provide weed suppression through their physical presence on soil surface and can be a part of integrated water management (IWM) program.

Dominant weed flora in DSR

Echinochloa colona and *E. crusgalli* are most serious weeds affecting significantly in all methods of rice establishment (Mandal *et al*. 2011a, b). Other weeds of major concern in rice includes, *Ammannia baccifera*, *Cyperus iria*, *Cyperus difformis*, *Eclipta alba*, *Fimbristylis miliacea*, *Ischaemum rugosum*, *Leptochloa chinensis*, *Monochoria vaginalis*, *Paspalum distichum* and *Spaenoclea zeylanica*. *E. colona* is predominantly observed in dry seeded rice as it requires less moisture than *E. crusgalli*. *Cyperus rotundus* and *Cynodon dactylon* are other major weeds posing problems in upland conditions, particularly in poorly managed fields. Enormous amount of variations occur in dominance and abundance of weed species with change in crop establishment and weed control methods (Singh *et al.* 2005). In recent era, weedy rice is emerging as a major problem in DSR. Javier *et al.* (2005) has observed a shift in weed flora by the change in crop establishment method. Yaduraju and Mishra (2005) has reported that direct seeding also favours sedges such as *Cyperus difformis*, *Cyperus iria*, *Cyperus rotundus* and *Fimbristylis miliacea*. Several weed management strategies was exploited in India depending upon weed flora as well as critical period of crop-weed competition (Prasad *et al*. 2013). Weed management strategies includes physical, chemical and biological methods

Weed management system

Various cultural methods are available depending on location and availability of resources. Some of the methods are discussed as below:

Sanitation

Rice seeds infested with noxious weed seeds have a chance to introduce the problematic weed species to a new field and increase the seed numbers in the soil weed seed bank. Other than clean crop seed, farm machinery and tools used for tillage, sowing, harvesting or threshing operations should also be cleaned before moving it from one field to another. Movement of seeds or weeds of propagules should be avoided to some extent by cleaning of bunds and irrigation canals.

Land leveling

A well prepared land helps in minimizing the weed densities by providing a weed free seed bed at the time of sowing. Proper land leveling also ensures uniform plant stand in the field. Rickman (2002) reported that laser land levelling reduces the weed population by up to 40% and the labor requirement for weeding by 75% (16 man-days ha^{-1}).

Stale seedbed method

Stale seedbed is a technique in which weed seeds are forced to germinate and then they are killed by either through use of non-selective herbicide (paraquat, glyphosate, or glufosinate) or by shallow tillage before sowing of direct seeded rice. This technique offers a great potential for suppressing weeds and is feasible under zero till (ZT)-DSR as there is ~ 45-60 days of fallow period between wheat harvests and sowing of rice. Stale seedbed reduced weed population by 50% compared with treatments in which this was not used (Singh *et al.* 2007). Additionally, this technique is equally effective in reducing weed seed bank.

Crop rotation and cropping system

In age old practices of traditional farming, crop rotations comprised of crops with different life cycles were a key component of weed management. Manipulation in date of planting and harvesting of different crops in rotation may provide opportunities for farmers to prevent either weed plant establishment or seed production. Weedy rice, which has become a major threat in rice tract can be controlled to the some extent through crop rotation with other crops such as soybean, mungbean, cotton, maize etc., which allow using other herbicides and cultural practices that cannot be used in rice (Singh *et al.* 2013). Rotating rice with mungbean was found to be very much effective for weedy rice control because volunteer rice seedlings failed to survive in mungbean (Watanabe *et al.* 1998). Intercropping of rice with sunhemp (*Crotalaria juncea* L.), cowpea [*Vigna unguiculata* (L.) Walpers], soybean [*Glycine max* (L.) Merr.], and prostrate sesbania (*Sesbania rostrata* Brem.) along with one inter-cultivation at 15 days after emergence (DAE) and one hand-weeding at 40 DAE, was found to be much effective in managing weeds (Angadi and Umapathy 1997) in rice.

Seed priming

In seed priming, seeds are allowed to be hydrated partially to that point where germination-related metabolic activities occur, but seeds do not reach the irreversible point of radicle emergence (Bradford, 1986). Seed priming had beneficial effects on inert seed as it enhanced the germination and seedling emergence ability (Anwar *et al*. 2012b). It can improve the traits closely associated with weed competitiveness of rice i.e. growth rate, early crop biomass and early vigour. Various priming techniques employed to improve speed and synchrony of seed germination are pre-soaking, hardening, hormonal priming, hydro priming, halo priming, osmo-conditioning, and ascorbate priming.

Brown manuring through Sesbania co-culture

Brown manuring is a practice, which involves, co-cultivation of rice crops along with green manure crops (sesbania), thereafter, 25-30 days of growth, it is killed by application of 2, 4-D ester @ 0.50 kg ha^{-1}. This technique is efficiently able to manage weed population by nearly half without any adverse effect on yield of rice (Singh *et al.* 2007). Other than weed suppressions, several additional benefits of sesbania co-culture are atmospheric nitrogen fixation and facilitation of crop emergence in areas, where soil crust formation is a problem. The best time for sowing sesbania to get maximum weed suppression is on the day of rice sowing (Singh *et al.* 2007).

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. Soil solarisation using plastic mulch increases soil temperature at 5 cm depth by 10- 15°C and at 10 cm depth by 10-12° C. Other than weed control, soil solarization also improves the soil structure, availability of essential plant nutrients and control of soil borne pathogens such as nematode, Fusarium, Rhizoctonia *etc*. Khan *et al.* (2003) reported that covering soil prior to planting with 100 µ thickness (400 gauge) LPDE sheets for 30 days was effective in reducing density of grassy and broad leaved weeds.

Mechanical method of weed control

Mechanical method of weed control involves use of implements that either destroys weeds or make environment less favorable for weed seed germination and weed survival. These methods include hand-pulling, hoeing, mowing, ploughing, disking, cultivating and digging. Mechanical weeding is most commonly practiced on row seeded rice since, inter row cultivation with either hand tools/animal traction equipment reduces time in weeding and minimizes crop damage. However, weeds within row are difficult to remove by this method. The sufficient soil moisture is another critical factor to achieve satisfactory results by using these weeders. Although mechanical weeding using hand pushed weeders (*e.g.,* cono-weeder) is tedious and time consuming, but still it is very much common for many small and marginal farmers of Asia and Africa. Sarma and Gogoi (1996) reported that in rainfed upland rice, manually operated peg type dryland weeder and a twin wheel hoe were effective in controlling weed when used twice at 20 and 30 day of emergence (DOE). The use of mechanical weeders is feasible only where rice is planted in rows. Weedy rice is generally taller than cultivated rice and chopping must be done before seed setting takes place. In many countries, weedy rice, panicles are cut with the help of a machete or a special knife attached to a stick (Singh *et al.* 2013).

Chemical method of weed control

Chemical method of weed control should not be considered as a replacement for other weed control methods, however, should be integrated with them (Mishra *et al.* 2016;Kumar *et al.* 2016 a, b; Chatterjee *et al.* 2016). Hill *et al.* (2001) reported that the success of herbicidal method of weed control is closely linked to water management to provide suitable condition for achieving specificity in weed control and minimizing the risk of phytotoxicity to rice seedlings. Judicious selection of herbicide, correct time of application, proper dose and right method of application are the important criteria for achieving higher weed control efficiency and crop yield. Jacob *et al.* (2014) reported that the major advantage with herbicidal control of weeds in DSR is the reduction in cost of cultivation. De Datta (1981) opined that despite of some adverse environmental effects, herbicides are considered to be the most effective, practical and economical means of weed management in DSR. Chemical method of weed control is becoming more popular day by day and is the best alternative to hand weeding as hand weeding needs high labour involvement (190 man days ha^{-1}), is tedious; time consuming and impractical under adverse weather conditions (Begum *et al.* 2011).

Sunil and Shankaralingappa (2014) reported that application of pyrazosulfuron @ 25 g a.i./ha alone was unable to control heavily infested weeds and it failed to control goose grass (*Eleusine indica* (L.) Gaertn.). The herbicide mixtures (both tank and proprietary mixture) broaden spectrum of weed control in a single application (Damalas 2005). A narrow leaved effective herbicide in combination with a herbicide that kill broad leaf weeds would be effective in controlling both types of weed. Similarly, a grass effective herbicide in combination with herbicide that control both broad leaf weeds and sedges will provide a wider spectrum of weed control (Mukherjee 2006). Aurora and De Datta (1992) reported herbicides used in combination reduced the usage rate as compared to single herbicide use. Chauhan and Yadav (2013) opined that in future, combination of two or more herbicides may become an effective and integrated approach to control complex weed flora in DSR. Application of 10% common salt (NaCl) were found to be effective weed management in upland direct seeded jhum rice especially broad leaved weeds in acidic soils of Nagaland (Chatterjee *et al.* 2016).

Biological method of weed control

Biological method of weed control offers environmental friendly approach that supplements conventional method. It involves deliberate use of insects, nematodes, bacteria, fungi or other bio-agent that reduce weed populations. Different herbivorous bio-agents like fish, tadpoles, shrimps, ducks and pigs were utilized for control of weeds in irrigated lowland rice in a few countries (Smith 1992). However, these bio-agents could not be utilized in DSR because, there is no standing water. Recently micro-herbicides are being evaluated and validated to reduce the herbicide dependency. Collego, a powder formulation of *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. aeschynomene, controls northern joint vetch weeds (*Aeschynomene virginica* (L.) B.S.P.) in rice (Smith 1992). Other useful fungi identified for bio-control of barnyard grass are *Exserohilum monocerus* and *Cocholiobolus lunatus* (Khadir *et al*. 2008), *Alternaria alternata* for control of barnyard grass (Jyothi *et al.* 2013). *Setosphaeria sp* cf rostrata for the control of *Leptochloa chinensis* (Thi *et al*. 1999). In future, attention must be paid for extensive research in order to develop the broad spectrum micro-herbicide formulation for effective control of weeds in DSR.

Water management in transplanted rice Vs DSR cultivation

As compared to wheat and maize, the water productivity (Wp) of transplanted rice is very low, which ranges from 0.33 g kg^{-1} to 0.20 g kg^{-1} (Kumar *et al*. 2016c). Average water requirement to produce 1 kg of rice is ~2350 liters (L), which varies in the range of 1700-3000 L. The Wp of rice crop depends on a number of factors like water availability (rains + irrigation), soil type (texture, organic matter content, hydraulic conductivity, percolation rate etc.), and climate (temperature, sunshine hours, humidity, wind velocity *etc*.). Gupta *et al.* (2002) reported that there was an increase in total water required by rice crop from 1566 mm in a sandy clay loam soil texture to 2262 mm in sandy loam soil texture. Beside other factors, this increase in water requirement was mainly due to an increase in percolation loss from 57% in clay loam to 66.9% in sandy loam soil. Due to indiscriminate use of surface or ground water by industrial, domestic and agricultural sectors, availability of water is getting scarce day by day and it is predicted that by 2025, only 50-55% of the total world water will be available for agriculture as against 66-68% in 1993 (Sivannapan 2009). Saving of water has demanded attention of irrigation scientists worldwide and hence efforts are underway to develop water saving technologies in rice such as alternate wetting and drying (AWD), keeping soil saturated continuously, irrigation based on soil moisture tensions varying from 0 to 40 kPa at root zone depth or irrigation at an interval of 1-5 days after disappearance of ponding water (Bouman and Tuong 2001; Kumar *et al*. 2016c, 2017, Pal *et al.* 2013).

During the growth period of rice plant, some phases are highly sensitive to moisture stress, and moisture stress at these phases' results in yield loss. Several workers reported that effect of water stress on rice yield was more severe (50% yield loss), when drought occurred during the reproductive phase, whereas water stress at the vegetative phase resulted in less yield loss (34%). The main reason for yield decrease was delayed anthesis and reduced number of spikelets/panicle with reduced number of filled grains (Kumar *et al.* 2017; Datta *et al*. 1975). Mendoza (2010) also reported that when rice field was kept flooded during vegetative phase and under AWD condition in reproductive phase of growing period, it resulted in maximum yield and water productivity.

In Aerobic Rice System (ARS), soils are kept aerobic almost throughout crop growing season. Like upland crops such as maize, wheat and sugarcane, ARS aims at growing rice without puddling and flooding under non-saturated soil conditions. To optimise the water economy is the main motto behind adopting ARS, which is reported to give a water saving of 73% in land preparation and 56% during crop growth (Castaneda *et al*. 2003). Yadav *et al.* (2011) reported 30-50% irrigation water saving in DSR irrigated at 20 kPa compared with PTR irrigated at 20 kPa due to reduced seepage and runoff losses. Yields of PTR and DSR with daily irrigation and 20 kPa irrigation threshold were similar. Further, tiller density, leaf area index and growth rate was better in DSR than PTR with daily and 20 kPa irrigation scheduling. No effect on crop yield was noticed up to soil moisture suction of 160±20 cm, while increasing soil matric suction to 200 and 240±20 cm decreased rice grain yield non-significantly by 0-7% and 2-15%, respectively, over different years compared to recommended practice of 2-days interval for scheduling irrigation. Irrigation at 160±20 cm soil matric suction saved 30-35% irrigation water as compared to that used with 2-day interval irrigation (Kukal *et al*.

2005). One more method of scheduling irrigation is based on IW/CPE ratio. Irrigation at IW/CPE ratio of 1.2 recorded higher crop growth and yield with no moisture stress, minimal proline accumulation and sterility coefficient (Maheswari *et al*. 2007). In Japan, under aerobic rice condition total amount of water supplied (irrigation plus rainfall) was 800-1300 mm when irrigation was scheduled based on tensiometer reading between 15 and 30 kPa at 20-cm depth and average yield under aerobic conditions was similar to or even higher than that achieved with flooded conditions (7.9 - 9.4 t /ha for aerobic versus 8.2 t/ha for flooded), whereas average water productivity in aerobic conditions was 0.8-1.0 kg grain/m^3 water (Kumar *et al*. 2016c).

The effect of manipulating irrigation schedule on grain yield, water use efficiency and irrigation efficiency of rice was investigated by Nwadukwe and Chaude (1998) and reported significantly higher grain yield and water use efficiency with irrigation schedule, which maintained the soil moisture regime at saturation rather than at submergence or field capacity. Experiments were conducted in Wagner pots by Anbumozhi *et al*. (1998) to evaluate the effect of different ponding depths (0, 3, 6, 9, 12, 15 and 18 cm) on rice growth and yield and results revealed that ponding depth of 9 cm was found to give higher plant height, grain yield and water productivity. Water saving irrigation has profound effect on yield as well as various phenological and biochemical components of rice plant. Yang *et al.* (2007) proposed limiting values of soil water potential as irrigation indices. These indices were related to specific growth stages, so that wetting and drying could meet the growth and development of rice. He compared the conventional irrigation where drainage was in mid-season to flood at other times, and observed that the water-saving irrigation increased grain yield by 7.4 to 11.3%, reduced irrigation water by 24.5 to 29.2%, and increased water productivity by 43.1 to 50.3%.

Breeding approaches for Direct-Seeded Rice

Conventional puddled transplanted rice is facing water and labour scarcity hence DSR can be a possible answer because of high potential for saving water, reduced labour needs, and acclimatizing to climatic risks. Few varieties have been developed for aerobic condition like CR Dhan 200, CR Dhan 203, CR Dhan 205, CR Dhan 206, CR Dhan 207, CR Dhan 209 that has considerable yield potential. Still further improvement is required to develop variety that possesses traits specifically needed to produce high yield under dry direct-seeded conditions that may be prone to drought and low fertility. The major yield and productivity contributing traits (genes/ QTLs) than can be introgessed in line through molecular breeding for DSR is being discussed.

Anaerobic germination and tolerance of early submergence

The untimely extended rains immediately after sowing during monsoon season adversely affect establishment of DSR and causes mortality of young seedlings due to submergence (Ismail *et al.* 2009). Therefore, ability for anaerobic germination (AG) and flash floods (early submergence) will help in weed suppression too. The QTLs responsible for a significant percentage of variation in submergence tolerance (Sub1) and anaerobic germination tolerance (qAG-9-2 or AG1) in rice have been previously identified. Sub1, accounts for about 69% of the variation (Xu and Mackill 1996), while qAG-9-2 for anaerobic germination tolerance accounts for ~ 33% of the variation (Angaji *et al.* 2010). Initially, IR64- Sub1+AG1 and IR64-AG1 has not shown any difference with original line of IR64, in terms of yield and agronomic traits evaluated under normal conditions. Later changing genetics background of parents like in Ciherang-Sub1+ AG1 showed significantly higher yield compared to Ciherang.

Early vigor

Early seedling vigor is the essential desirable trait for DSR to dominate and smoother the weed growth. Rapid germination, rapid shoot and root growth, and long mesocotyls and coleoptiles are important seedling vigor-related traits (Cui *et al*. 2002). Some important QTLs for seedling vigour traits have been identified recently by Anandan *et al.* (2016). They reported that marker alleles on chromosome 2 were associated with shoot dry weight on 28 DAS. Further, they also identified QTL for leaf length on 14 DAS on chromosome 1 (RM13); SSR genomic region RM230 and RM125 mapped on chromosome 8 and 7 were QTLs controlling leaf width variation on 14 DAS; the marker RM230 allele associated with root length on 14 DAS. The root dry weight QTL was detected on chromosome 5 (by linked marker allele RM249) on 14 DAS coincided with QTL of root length on 28 DAS. For root dry weight at 28 DAS, marker RM250 on chromosome 2 is responsible. Zhang *et al.* (2005) also reported RM230 allele marker on chromosome 8 as contributing to root length. Karla *et al.* (2016) identified one major effect QTL, qFW1, on chromosome 1 and contributed to about 35% of the phenotypic variation for seedling fresh weight. Further, region on the distal end of the long arm of chromosome 1, which is about 4 Mb away from the sd1 gene (position 38,381,339), harbors a gene or genes that contribute to seedling vigor in both *Indica* and *Japonica* rice. Improvement in the early vigor was identified in varieties like 'Sabita' (a known early vigor genotype), Varshadhan, Vandana, AC4387 and Pyari which can be used for identifying rice genotypes acquiescent to direct seeded.

Crop competitiveness against weeds

Weeds are one of major constraints in DSR. Differences in cultivar for weed competitiveness exist in many crops, including rice (Haefele *et al*. 2004). This crop weed competitiveness can minimized with the ability of crop plants to a) weed tolerance and b) weed-suppressive ability (Zhao *et al*. 2006). The competitiveness in plants is judged by growth and development in a particular time and the allelopathy reponse. Ebana *et al*. (2001) mapped QTLs using RFLP markers controlling allelopathy (F_2 population using PI 312777 (Cross of Taichung 65x2 and TN-1), a highly allopathic accession). Seven allelopathy QTLs on chromosomes 1, 3, 5, 6, 7, 11, and 12 were identified. The major QTL is on chromosome 6 explained 16 % of the total phenotypic variation. But, multiple QTLs considered jointly explained 5 important QTLs explained 36.6 % of phenotypic variation. A genotypes IAC165, an allelopathic *Japonica* upland rice cultivar from Brazil, and CO39, a weakly allelopathic *Indica* cultivar from India were used to develop RILs to map allelopathy. Four main effect QTLs on chromosomes 2, 3, and 8 explained 35% of the phenotypic variation observed in population (Jensen *et al*. 2001). Lee *et al*. (2005) identified nine QTLs controlling allelopathic effects of rice on *E. crusgalli* on chromosomes 1, 2, 3, 4, 5, 8, 9 and 12. Of these, QTLs on chromosomes 1 and 5 were the most allelopathic and explained 36.5% of total phenotypic variation. An ideal plant type with an ability to compete against weeds would have early seedling vigor, high specific leaf area in vegetative growth, high chlorophyll producing ability compatible with high yield and weed competitiveness. The lines RU9701151 (cross of PI 338046 and Katy) (Moldenhauer *et al*. 1999), PI 312777 (Cross of Taichung 65x2 and TN-1) were identified for weed competitiveness in rice.

Modified panicle architecture

Direct seeding in dry season can face dry spell even in complete irrigated conditions, which adversely affecting spikelet fertility. Increase in sink size is a priority trait to increase yield potential in rice (Dingkuhn *et al*. 2015), which can be possible by increase the number of spikletes/panicle (Peng *et al*. 1999). Several genes/ QTLs related to panicle architecture and number of spikelets/panicle like, Gn1a, OsSPS1, and SPIKE were identified. Rebolledo *et al*. (2016) reported 25 new loci that involved in the genotypic variation for number of spikelets/panicle. SNPs with high association probabilities were closer as previously identified candidate genes, *e.g.*, Osjag in q-1 and OsCKX2 in q-3. They also reported that the genes such as MOC1, LAX1/2, OsCKX2, SP1, DEP1/2/3, and IPA1/WFP were found to modify panicle architecture (Qiao *et al*. 2011), likewise for panicle density (q-22, gene GSK22) or floral organ identity (q-25, gene NL1) and two genes with a function on tillering ability (q-23, OsHRZ2 gene) or carbon and nitrogen content (q-6, gene OSAAT7). These genes may be suggested as candidates gene to improve the number of spikelets per panicle in rice through molecular breeding

Modified root system

A clear-cut difference in rooting pattern of direct-seeded or transplanted rice plants can be seen. Sandhu *et al*. (2015) developed BC_2F_4 mapping populations (crosses of Aus276, a drought-tolerant variety, with MTU1010 and IR64, high-yielding *indica*) to identify traits and QTLs for development of dry direct-seeded rainfed rice varieties. They identified 26 QTLs in Aus276/3 x IR64 associated with 23 traits and 20 QTLs associated with 13 traits in Aus276/3 x MTU1010 populations. The QTLs like qGY6.1, qGY10.1, qGY1.1, and qEVV9.1 were found to be effective for both populations under a wide range of conditions. The colocation of QTLs for grain yield with root hair length on chromosome 9 and early vegetative vigour on chromosome 1 were identified. Whereas, QTLs for root hair density and phosphorus uptake were co-located in this study on chromosome 5. QTLs previously reported for root length (Sandhu *et al*. 2013), root thickness, and root number (Li *et al*. 2005) were located near qEVV9.1 and qGY9.1. Introgression of these QTLs may increase nutrient uptake in rice to improve rice yield under dry direct-seeded conditions.

Present day rice cultivation is under threat by anticipated water scarcity and mounting labour crisis, so direct seeded rice (DSR) offers an attractive alternative. A successful DSR demands breeding of special rice varieties and developing appropriate management practices. Under DSR, optimization of irrigation scheduling and occurrence of diverse range of weeds is a serious problem. Identification of optimum water management practices may help in maximizing water productivity under DSR system. Weeds are dynamic in nature and a shift in their abundance and dominance in DSR is a major challenge for the researchers. Herbicide is the smartest and most economic tool to fight against the weeds. But recurrent use of one herbicide for a long time may result in development of herbicide resistant weed biotypes. The use of any single strategy cannot provide effective, season-long and sustainable weed control as weeds vary in their dormancy and growth habit. To achieve effective, viable and long term sustainable weed control, integrated weed management practices are to be wisely utilized in such a compatible way as to reduce weed population below the economic threshold levels without deteriorating environment quality.

REFERENCES

Ali A, Erenstein O and Rahut DB 2014. Impact of direct rice sowing technology on rice producer's earning: empirical evidence from Pakistan. Dev. Res. Stud. 1: 244-254. Available: http: //dx. Doi.org/10.1080/ 21665095.2014.943777

Anandan A, Anumalla M, Pradhan SK and Ali J 2016. Population structure, diversity and trait association analysis in rice (*Oryza sativa* L.) germplasm for early seedling vigor (ESV) using trait linked SSR markers. PLOS ONE 11(3):0152406. doi:10.1371/ journal.pone.0152406

Anbumozhi V, Yamaji E and Tabuchi T 1998. Rice crop growth and yield as influenced by changes in ponding water depth, water regime and fertigation level. Agricultural Water Management 37: 241-253

Angadi VV and Umapathy PN 1997. Integrated weed management through smother intercrops in rainfed lowland rice. International Rice Research Notes 22: 47-48

Angaji SA, Septiningsih EM, Mackill DJ and Ismail AM 2010. QTLs associated with tolerance of flooding during germination in rice (*Oryza sativa* L.) Euphytica 172: 159-168

Anwar MP, Juraimi AS, Puteh A, Selamat A, Rahman MM and Samedani M 2012b. Seed priming influences weed competitiveness and productivity of aerobic rice. Acta Agricultural Scandin 62: 499-509

Aurora MB and De Datta SK 1992. Weed management in rice. Weed Abstract 41: 495-508

Begum M, Juraimi AS, Syed Omer SR, Rajan A and Azmi M 2011. Effect of herbicides for the control of *Fimbristylis mlilaceae* (L.) Vahl. in rice. Agronomy Journal 7: 251-267

Bohra JS and Kumar R 2015. Effect of crop establishment methods on productivity, economics and energetics in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system. Indian Journal of Agricultural Sciences 85 (2): 217-223

Bouman BAM and Tuong TP 2001. Field water management to save water and increase its productivity in irrigated rice. Agricultural Water Management 49: 11-30

Bradford KJ 1986. Manipulation of seed water relations via osmotic priming to improve germination under stress conditions. Horticultural Sciences 21: 1105-1111

Carriger S and Vallee D 2007. More crop per drop. Rice Today 6 (2): 10-13

Castaneda AR, Bouman BAM, Peng S and Visperas RM 2003.The potential of aerobic rice to reduce water use in water-scarce irrigated low-lands in the tropics. In "Water-Wise Rice Production" (B. A. M. Bouman, H. Hengsdijk, B. Hardy, P. S. Bindraban, T. P. Tuong, and J. K. Ladha, Eds.), IRRI, Los Banos, Philippines

Chatterjee D, Kumar R, Kuotsu R and Deka BC 2016.Validation of traditional weed control method through common salt application in hill region of Nagaland. Current Science. 110 (8): 1159-1167. doi: 10.18520/cs/v110/i8/1459-1467

Chauhan BS and Johnson DE 2011. Growth response of direct seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. Weed Science 59: 119-122

Chauhan BS and Yadav A 2013. Weed management approaches for dry seeded rice in India- a review. Indian Journal of Weed Science 45: 1-6

Cui KH, Peng SB, Xing YZ, Xu CG, Yu SB and Zhang Q 2002. Molecular dissection of seedling-vigor and associated physiological traits in rice. Theoretical Applied Genetics 105: 745-753

Damalas CA 2005. Herbicide tank mixture: common interactions. International Journal of Agricultural Biology 6: 209-212

De Datta SK 1981. Principles and practices of rice production. John Wiley & Sons, Inc. pp.485

De Datta SK, Fuye FG and Mallick RN 1975. Soil water relations in rice. In "Proceedings of the Seminar on. Soil Management in Tropical America" (E. Bornamisze and A. Alvarado, Eds.), pp. 168-185. CIAT, USAID, Cali, Columbia

Dingkuhn M, Laza MRC, Kumar U, Mendez KS, Collard B and Jagadish KSV 2015. Improving yield potential of tropical rice: achieved levels and perspectives through improved ideotypes. Field Crop Research. 182:43-59. 10.1016/j.fcr.2015.05.025

Doorenbos L and Pruitt WO 1984. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 24. FAO, Rome

Ebana, K, Yan WG, Dilday RH, Namai H and Okuno K 2001. Analysis of QTL associated with the allelopathic effect of rice using water-soluble extracts. Breeding Science 51: 47-51

George T, Magabanua R, Garrity DP, Tubana BS and Quiton J 2002. Rapid yield loss of rice cropped successively in aerobic soil. Agronomy Journal 84: 981-989

Guerra LC, Bhuiyan SL, Tuong TP, Barker R 1998.Producing More Rice with Less Water from Irrigated Systems. SWIM Paper 5, IWMI, Colombo, Sri Lanka

Gupta RK, Naresh RK, Hobbs PR and Ladha JK.2002. Adopting conservative agriculture in the rice-wheat system of the Indo-Gangetic Plain: New opportunities for saving water. In "Water-Wise Rice Production" (BAM Bouman, H Hengsdijk, B Hardy, P. S. Bindraban, TP Tuong, and JK Ladha, Ed.), p. 207-222. IRRI, Los Banos, Philippines

Haefele SM, Johnson DE, M'bodj, DM, Wopereis, MCS and Miezan KM 2004. Field screening of diverse rice genotypes for weed competitiveness in irrigated lowland ecosystems. Field Crops Research 88: 39-56

Hill JE, Mortimer AM, Namuco OS and Janiya JD 2001. Water and weed management in DSR: Are we headed in right direction? In: Peng, S. and Hardy, B (eds), Rice research for food security and poverty alleviation, IRRI, Los Banos, Philippines, pp.491-510

Hugar AY, Chandrappa H, Jayadeva HM, Satish A and Mallikarjun GB 2009. Comparative performance of different rice establishment methods in Bhadra command area. Karnataka Journal of Agricultural Sciences. 22: 992-994

IRRI 1997. Rice Almanac 2nd edn. IRRI, Los Banos, Philippines, pp.181

IRRI 2006. Bringing Hope, Improving Lives-Strategies. Plan 2007-2015, IRRI, Los Banos, Philippines, pp. 61

Ismail AM, Ella ES, Vergara GV and Mackill DJ 2009. Mechanisms associated with tolerance to flooding during germination and early seedling growth in rice (*Oryza sativa*). Annals of Botany 103: 197-209

Jacob G, Menon MV and Abraham CT 2014. Comparative efficacy of new herbicides in direct seeded rice. Journal of Tropical Agriculture 52: 174-177

Javier FE, Furuya S, Soriano R and Garcia F 2005. Management of wet direct seeded rice. II: weed control by water and herbicides.Philipines Journal of Crop Sciences 30: 11-17

Jensen LB, Cortois B, Shen LS, Li ZK, Olofsdotter M and Mauleon RP 2001. Locating genes controlling allelopathic effects against barnyard grass in rice. Agronomy Journal 93: 21-26

Jyothi G, Reddy KRN, Reddy KRK and Podile AR 2013. Exploration of suitable solid media for mass multiplication of Cochliobolus lunatus and Alternaria alternata used as mycoherbicide for weed management (barnyard grass) in rice. Journal of Experimental Biology and Agricultural Sciences1: 281-284

Karla IC, HyunJung K and Thomas HT 2016. Identification of Seedling Vigor-Associated Quantitative Trait Loci in Temperate Japonica Rice. Plant Breeding and Biotechnology. 4 (4):426-440. https://doi.org/10.9787/PBB.2016.4.4.426

Khadir A, Sajilli MH, Juraimi AS and Napis S 2008. Effect of Exserohilum monocerus (Dreshslera) Leonard and Suggs on the competitiveness of *Echinochloa crusgalli* (L.) P. Beauv. Pertanika J Tropical Agric. Sci. 3: 19-26

Khan AR, Srivastava RC, Ghorai AK and Singh SR 2003. Efficient soil solarization for weed control in the rain-fed upland rice ecosystem. International Agrophysiology. 17: 99-103

Kukal SS, Hira GS and Sidhu AS 2005. Soil matric potential-based irrigation scheduling to rice. Irrigation Sciences 23: 153-159

Kumar A, Nayak AK, Mohanty S and Das BS 2016c. Greenhouse gas emission from direct seeded paddy fields under different soil water potentials in Eastern India. Agriculture Environment and Ecosystems 228: 111-123

Kumar A, Nayak AK, Pani DR, Das BS 2017. Physiological and morphological responses of four different rice cultivars to soil water potential based deficit irrigation management strategies. Field Crops Research, DOI 10.1016/j.fcr. 2017.01.026

Kumar M, Kumar R, Meena KL, Rajkhowa DJ and Kumar A 2016d. Productivity enhancement of rice through crop establishment for livelihood improvement in Eastern Himalaya. Oryza 53 (3): 300-308

Kumar P, Singh Y and Singh UP 2013. Evaluation of cultivars and herbicides for control of barnyard grass and nut sedge in boro rice. Indian Journal of Weed Science 45(2): 76-79

Kumar P, Singh Y and Kumar R 2016. Productivity, profitability, nutrient uptake and soil health of boro rice as influenced by cultivars and herbicides. International Journal of Agricultural and Statistical Sciences 12 (S 1): 177-183

Kumar R, Chatterjee D, Deka BC, Kumar M, Kuotsu R, Ao M and Ngachan SV 2016a. Weed management practices in upland direct seeded jhum rice under the Eastern Himalayas. Research on Crops. 17 (2): 199-204. doi: 10.5958/2348-7542.2016.00035.8

Kumar R, Hangsing N, Zeliang PK and Deka BC 2016b. Exploration, collection and conservation of local rice germplasm of Nagaland. Environment and Ecology 34 (4D): 2514-2517

Kumar R, Kumar M, Kumar A and Pandey A 2015a. Productivity, profitability, nutrient uptake and soil health as influenced by establishment methods and nutrient management practices in transplanted rice (*Oryza sativa*) under hill ecosystem of North East India. Indian Journal of Agricultural Sciences 85 (5): 634-639

Kumar R, Kumar M and Deka BC 2015b. Production potential, profitability and energetics of transplanted rice as influenced by establishment methods and nutrient management practices in Eastern Himalaya. Research on Crops. 16 (4): 625-633. doi:10.5958/2348-7542.2015.00088.1

Lafitte HR, Courtois B and Arraudeau M 2002. Genetic improvement of rice in aerobic systems: Progress from yield to genes. Field Crops Research 75:171-190

Lee SB, Seo KI, Koo JH, Hur HS and Shin JC 2005. QTLs and molecular markers associated with rice allelopathy. In: Harper JDI, An M, Wu H, and Kent JH. (eds.) Fourth World Congress on Allelopathy "Establishing the Scientific Base"Wagga Wagga, Australia: Charles Sturt University pp. 505-507

Leeper JR 2010. Back to basics in improving yield by controlling weeds. Rice Today 9 (3): 12-14

Li ZC, Mu P, Li CP, Zhang HL, Li ZK, Gao YM and Wang XQ 2005. QTL mapping of root traits in a doubled haploid population from a cross between upland and lowland japonica rice in three environments. Theoretical Applied Genetics 110: 1244-1252

Maheswari J, Maragatham N and Martin GJ 2007. Relatively simple irrigation scheduling and N application enhances the productivity of aerobic rice. American Journal of Plant Physiology 2 (4): 261- 268

Mandal D, Kumar R, Singh D and Kumar P 2011a. Growth and yield of direct seeded rice as affected by sowing date and weed management methods. International Journal of Bio-resource and Stress Management 2 (3):273-276

Mandal D, Singh D, Kumar R, Kumari A and Kumar V 2011b. Production potential and economics of direct seeded rice as affected by sowing date and weed management methods. Indian Journal of Weed Sciences 43 (3&4): 139-144

Mendoza TL2010. AWD goes top Africa. Ripple 5(2): 7

Mishra JS, Rao AN, Singh VP and Kumar R 2016. Weed management in major crops. In: Weed Science and Management (Eds. NT Yaduraju, AR Sharma and TK Das). Indian Society of Weed Science & Indian

Society of Agronomy, pp. 169-190.ISBN No. 13:976-61-931978-9-9

Moldenhauer KAK, Gibbons JW, Lee FN, Norman RJ, Bernhardt J, Dilday RH, Rutger JN, Blocker MM and Tolbert AC 1999. Breeding and evaluation for improved rice varieties in the Arkansas rice breeding and development program, pp. 20-27, in R. J. Norman and T. H. Johnson (eds.), Bobby R. Wells Rice Research Studies 1998. Arkansas Agricultural Experiment Station, Series 468. Fayetteville, AR

Mukherjee D 2006. Weed management strategy in rice-a review. Agric. Rev. 27 (4): 247-257

Nwadukwe PO and Chude VO 1998. Manipulation of the irrigation schedule of rice. Journal of Arid Environments 40: 331-339

Pal V, Singh MM, Kumar Rakesh and Verma SS. 2013.Response of irrigation scheduling and integrated nutrition on scented rice (*Oryza sativa* L.). Bioinfolet 10 (4C): 1528 -1530

Peng S, Cassman KG, Virmani SS, Sheehy J and Khush GS 1999. Yield potential trends of tropical rice since the release of IR8 and the challenge of increasing rice yield potential. Crop Sciences 39: 1552-1559 doi:10.2135/cropsci1999.3961552x

Prakash C, Koli NR, Shivran RK, Sharma JC and Kumar R 2014. Response of nitrogen levels and weed management practices on productivity of rice under aerobic condition. Bioinfolet 11 (1A): 145-148

Prasad D, Yadava M S and Kumar A 2013. Weed dynamics in transplanted rice after intensification of rice-fallow cropping system in Jharkhand. Oryza 50 (2): 146-150

Qiao Y, Piao R, Shi J, Lee SI, Jiang W, Kim BK, Lee J, Han L, Ma W and Koh HJ 2011. Fine mapping and candidate gene analysis of dense and erect panicle 3, DEP3, which confers high grain yield in rice (Oryza sativa L.). Theoretical Applied Genetics. 122:1439-1449. doi:10.1007/s00122-011-1543-6

Rebolledo MC, Alexandra LP, Jorge D, Daniel FC, Michael D, Cecile G and Joe T 2016. Combining Image Analysis, Genome Wide Association Studies and Different Field Trials to Reveal Stable Genetic Regions Related to Panicle Architecture and Number of Spikelets per Panicle in Rice.Front Plant Sci.7: 1384.doi: 10.3389/fpls.2016.01384

Rickman, JF 2002. Manual for Laser Land Leveling. Rice-Wheat Consortium Technical Bulletin Series 5. Rice-Wheat Consortium for the IGPs, New Delhi, India, pp. 24

Roy DK, Kumar R and Kumar A 2011. Production potentiality and sustainability of rice based cropping sequences under flood prone situation of North Bihar. Oryza 48 (1): 47-51

Roy DK, Kumar R and Kumar A 2011. Production potentiality and sustainability of rice based cropping sequences under flood prone situation of North Bihar.Oryza. 48 (1): 47-51

Sandhu N, Jain S, Kumar A, Mehla BS and Jain R 2013. Genetic variation, linkage mapping of QTL and correlation studies for yield, root, and agronomic traits for aerobic adaptation. BMC Genetics 14:104-119

Sandhu N, Torres RO, Cruz MTS, Maturan PC, Jain R, Kumar A and Henry A 2015. Traits and QTLs for development of dry direct-seeded rainfed rice varieties. J. ournal of Experimental Botany 66(1): 225-244 doi: 10.1093/jxb/eru413

Sarma A and Gogoi AK 1996. Performance of different weeders in rainfed upland rice. Oryza 33: 178-182

Singh A, Singh RK, Kumar P and Singh S 2013. Growth, weed control and yield of DSR as influenced by different herbicides. Indian Journal of Weed Science 45(4): 235-238

Singh AK, Chinnusamy V 2007. Aerobic rice-A success story. Indian Farming 57 (8): 7-10

Singh K, Kumar V, Saharawat YS, Gathala M, and Ladha JK 2013. Weedy Rice: An Emerging Threat for DSR Production Systems in India. Journal of Rice Research 1: 106

Singh S, Bhushan L, Ladha JK, Gupta RK, Rao AN and Sivaprasad B 2006. Weed management in dry-seeded rice (*Oryza sativa* L.) cultivated on furrow irrigated raised bed planting system. Crop Protection 25: 487-495

Singh S, Ladha JK, Gupta RK, Bhusan L, Rao AN, Sivaprasad B and Singh PP 2007. Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (*Oryza sativa*). Crop Protection 26: 518-524

Singh S, Singh G, Singh VP and Singh AP 2005. Effect of establishment methods and weed management practices on weeds and rice in rice-wheat cropping system. Indian Journal of Weed Sciences 37: 51-57

Singh SK, Abraham T, Singh AK, Kumar S and Kumar R 2017. Response of crop establishment methods and split application of nitrogen on productivity of rice.

Environment & Ecology 35 (2A): 859-862

Sivannapan RK 2009.Advances in micro irrigation in India. In "Micro Irrigation. Proceedings of the Winter School on Micro Irrigation, 2-4 March 2009, New Delhi" (TBS Rajput and N Patel, Eds.), pp. 8-18. Water Technology Centre, IARI, New Delhi

Smith RJJ 1992. Biological controls as components of IWM 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, pp. 335-351

Sunil CM and Shankaralingappa BC 2014. Impact of integrated package of agro-techniques on growth and yield of aerobic rice. Agricultural Sciences 5: 60-65

Thi HL, Man LH, Chin DV, Auld BA and Hetherington SD 1999. Research on some fungi to control barnyard grass and red sprangle top in rice. In: Proceedings of the Seventeenth Asian-pacific Weed Science Society conference, Bangkok, Thailand, pp. 562-566

Watanabe H, Vaughan DA and Tomooka N 1998. Weedy rice complexes: Case study form Malaysia, Vietnam and Suriname. Paper presented at the Int. symposium on wild and weedy rice in agro-ecosystems, 10-11Aug., 1998, Ho Chi Minch City, Vietnam

Xu K and Mackill DJ 1996. A major locus for submergence tolerance mapped on rice chromosome 9. Molecular Breeding 2: 219-224

Yadav S, Humphreys E, Kukal SS, Gill G and Rangarajan R2011. Effect of water management on dry seeded and puddled transplanted rice. Part 2: Water balance and water productivity. Field Crops Research 120: 123-132

Yaduraju NT and Mishra JS 2005. Sedges in rice culture and their management. In: Singh, Y, Singh VP, Chauhan B, Orr A, Mortimer AM, Johnson DE. and Hardy B (eds), Direct seeding of rice and weed management in the irrigated rice-wheat cropping system of the Indo-Gangetic plains, Directorate of Experimental Station, G. B. Pant University of Agriculture and Technology, Pantnagar, India pp.17

Yang JL, You JF, Li YY, Wu P and Zhang SJ 2007. Magnesium enhances aluminium induced citrate excretion in rice beans (Vigna umbellata) roots by restoring plasma membrane Hþ-ATPase activity. Plant Cell Physiolology 48: 66-73

Zhang ZH, Qu XS, Wan S, Chen LH and Zhu YG 2005. Comparison of QTL controlling seedling vigor under different temperature conditions using recombinant inbred lines in rice (*Oryza sativa*). Annals of Botany 95(3): 423-429

Zhao DL, Atlin GN, Bastiaans L and Spiertz JHJ 2006. Cultivar weeds competitiveness in aerobic rice: Heritability, correlated traits, and the potential for indirect selection in weed-free environment. Crop Sciences 46: 372-380