Direct Seeded Rice in North West India

Opportunities, Scope and Research Gaps

ICAR-Agricultural Technology Application Research Institute

Zone-1, PAU Campus, Ludhiana-141 004

Citation:

Rajbir Singh, Gulshan Mahajan and M.S. Bhullar. 2016. Direct Seeded Rice in North West India – Opportunities, Scope and Research Gaps. ICAR-Agricultural Technology Application Research Institute, Ludhiana. Pages:52

Authors:

Rajbir Singh
Gulshan Mahajan
M.S. Bhullar

Published by:

Director, ICAR-Agricultural Technology Application Research Institute, Zone-1, PAU Campus, Ludhiana, Punjab.
Tel: 0161 - 2401018; Fax: 0161 - 2412719
E-mail: zcu1ldh@gmail.com; Atari.ludhiana@icar.gov.in
Website: http://atari1icar.res.in

Year of Publication:

2016

Direct Seeded Rice in North West India

Opportunities, Scope and Research Gaps

Rice (*Oryza sativa* L.), a staple food for more than half of the world population (Khush, 2004), is commonly grown by transplanting rice seedlings into puddled soil (wet tillage) in the Indo-Gangetic Plains (IGP), which is considered the food bowl of India. The method of growing rice via puddling is labor-, water-, and energy-intensive, and thus is becoming less sustainable as these resources are becoming increasingly scarce. Heavy competition for water from different sectors (agriculture, industry, household needs in cities, etc.) is causing water scarcity for sustainable rice production. Rice cultivation requires large amounts of water, especially for light-textured soils of the N-W IGP. In the N-W IGP, groundwater is the main source of supplemental irrigation over and above the rain and canal water. Because there is no tax on water usage and electricity is free for pumping water, there is a tendency to over-irrigate rice fields and consequently that results in wastage of water. In a recent study jointly carried out by NASA and the German Aerospace Center (DLR) in N-W IGP, satellite data showed a groundwater table decline rate of 0.33 m per year (Rodell et al., 2009; UC Irvine, 2009). Another study also showed lowering of the water table, and in some pockets of the N-W IGP, groundwater depletion has reached an alarming situation (Hira, 2009).

Puddling deteriorate soil structure

Farmers' facing labour scarcity for rice transplanting (Courtesy : The Tribune)

Direct seeded rice crop

Transplanted crop

Such an alarming rate of groundwater decline and water crisis is forcing researchers and farmers to consider the dry direct-seeded rice (DSR) production system. In N-W India, rice transplanting is highly dependent on migrant labor from eastern UP and Bihar. Implementation of the Mahatma Gandhi National Rural Employment Guarantee Act, introduced by the Indian government in 2005 (GOI, 2011), promising 100 days of paid work in one's home village, has been the cause of the labor scarcity in this region. Because of high labor demand at the time of transplanting, increasing labor scarcity and rising wage rates are forcing farmers to shift from transplanting of rice, which requires 25–50 person-days ha^{-1}, to direct seeding, which needs only about 5 person-days ha^{-1} (Balasubramanian and Hill, 2002; Dawe et al. , 2005).

The DSR is a new and an emerging rice-production system in the N-W IGP. Our recent research in N-W India has indicated higher crop, water, and labor productivity from DSR compared with puddle-transplanted rice (PTR)) (Mahajan et al, 2011). Similar results were also obtained in China (Zhang et al., 2009) and the Philippines (Peng et al., 2006). The lack of suitable varieties for dry-DSR and the associated production technologies is a major constraint for achieving maximum potential from dry-DSR. The objectives of this bulletin are to discuss management practices that are currently being used by the DSR's farmers, review overall crop performance, including resource-use efficiencies in DSR; and lessons learnt. Based on the existing evidence, we present an research gaps where fine tuning is needed with the attainment of optimum grain yield with Dry-DSR.

Precision land levelling

Land levelling is a precursor to good agronomic, soil, and crop management practices and the levelness of the land surface has a significant influence on direct seeded rice crop. Unevenness of the soil surface influences drill operation and may cause poor establishment and crop performance mainly through nutrient-water and weed interactions. Traditionally, farmers perform land levelling by using plankers (wooden boards) drawn by tractors. Traditionally levelled fields have frequent dikes and ditches within the fields and, even with best efforts by conventional levelling practices, field slopes vary from 1º to 3º in transects I and II (Pakistan Punjab, Indian Punjab, Haryana, and Western Uttar Pradesh) to 3º to 5º in transects IV and V of the IGP (Jat et al., 2006a) led to poor establishment of direct seeded rice crop. Undulating land hampers seed placement, germination and also requires more power for machines, which leads to the consumption of more energy, and ultimately to more cost of production and low productivity (Jat et al., 2006a; Jat et al., 2009a). Poor management and uneven fields lead to 10-25% irrigation water loss during application (Kahlown et al., 2002), which results in lower crop yields, higher irrigation costs, and poor resource-use efficiency (Jat et al., 2006a); so ultimately aim of direct seeded rice crop failed .

Crop yields in DSR depend on optimum seedling emergence, better crop stand, and early crop vigor. Laser land levelling is also reported to improve crop stand and crop productivity (up to 30%) and reduce the labor requirement for weeding (from 21 to 5 days ha $^{-1}$) in rice (Jat et al., 2006a; Jat et al., 2009b; Rickman et al., 2001). Kahlown et al. (2002) reported that precision land levelling improved the performance of rice and water productivity in non-puddled soil, with no-till surface seeding and seeding on permanent beds compared with conventional tillage. If immediately rain comes after seeding, laser levelled field assist in good emergence due to proper drainage. In IGP of India, mostly traditionally levelled fields varied on an average 8-15 cm deviation that affects establish-

Direct seeded rice crop

Transplanted crop

ment of DSR because of unequal distribution of water in soil profile and inundation of newly germinating seedlings at initial stages. Therefore, Laser land-levelling is a precursor technology and rather an entry point for successfulness of DSR through improved water, weed and crop management.

Type of soil

Direct seeding of rice should preferably be practiced on medium to heavy textured soils. Light textured sandy soils are more prone to iron and zinc deficiency, resulting in reduced yields. The water retention capacity of these soils is low due to high infiltration rate. Sowing method in DSR and herbicide efficacy (pre-emergence) is highly influenced by soil type. To increase the efficacy of pre-emergence herbicide for weed control in DSR, following sowing technique are suggested according to the soil type:

- In medium textured soil, do the sowing in dry condition, and irrigate the field immediately. In such soil, *vattar* conditions came 3 days after sowing (DAS) and apply pre-emergence herbicide with in 3 DAS.
- In heavy soil, *vattar* condition did not come within 3 DAS if irrigation immediately followed after dry seeding, so in such soil, it is advisable to sow the crop in *vattar* condition and apply pre-emergence herbicide immediately after sowing in order to utilize the available moisture for increasing the efficacy of pre-emergence herbicide.

Sowing of DSR in dry soil

Emergence of DSR sown in Vattar

Seed bed preparation

The method of seedbed preparation varied with tillage method for instance conven-

Farmer showing appearing of volunteer rice in DSR

tional and conservation tillage systems. For successful DSR crop, seed beds should be free from weeds and precisely levelled at the time of sowing. Soil disturbance during land preparation or sowing operation influenced the vertical distribution of weed seeds in the soil. For example zero tillage or minimum tillage helps in retaining most of the weeds seeds in the top soil. Whereas high soil –disturbance resulted in uniform distribution of weeds within the cultivation layer. The germination of weeds seeds is congenial, when the weeds seeds are on the top layer of the soil as compared to when they are buried deep in the soil layer. In minimum or zero tillage, as the soil is not disturbed, therefore buried seeds are not brought to the top soil. Weed seeds present on the top soil are prone to rapid desiccation and predation by insects and are also sensitive to stale seed bed practices (Chauhan 2012). The seed bank of weedy rice and other weeds can be reduced by adopting stale seed bed technique in DSR. In this practice, after irrigation, weedy rice, volunteer rice and other weeds seeds are allowed to germinate and then are killed using nonselective herbicides (paraquat or glyphosate) or tillage practice. No doubt, use of stale seed bank technique helps in reducing weed seed bank in the soil but efficacy of this practice is influenced by dormancy of weed seeds, as dormant seeds showed protracted emergence response. However, farmers need to decide themselves whether they have enough time to explore the benefit of stale-seed bed technique in DSR in limited window period of rice-wheat.

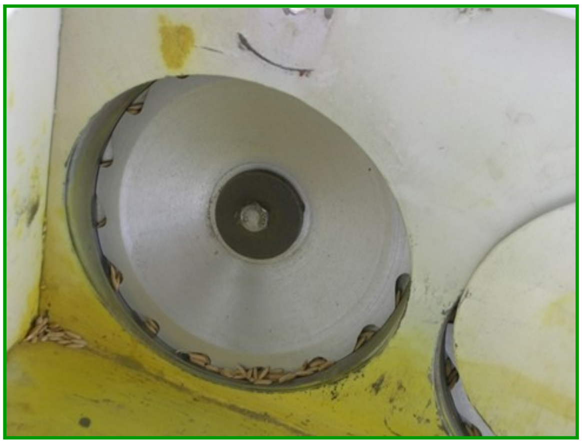
Seeding depth

Seeding depth is very critical in DSR and varied with the rice varieties because of their shorter mesocotyl length in semi dwarf varieties as compared to conventional tall varieties (Blanche and Saichusk, 2009). Seed placement at too deep or shallow soil depth adversely affects the dynamics of seed germination due to weak coleoptiles and rapid drying of the soil surface in peak summers (Gopal et al., 2010) . Therefore, rice should not be drilled deeper than 2.5 cm to maximize uniform crop establishment (Basra et al., 2005). In heavy soil, particularly when DSR crop is sown in *vattar* condition, depth is not controlled if not taken care of resulted in poor establishment. So, farmers must be cautious about seeding depth in such soil. Recent study at PAU showed that Pusa Basmati 1509 had the longer coleoptiles and capacity to emerge from deeper depth (Unpublished data), despite of their shorter plant height. So, such varieties could be useful for direct seeding. However, breeding efforts are being made for the development of DSR cultivars that could provide uniform establishment even when seeds were sown deeper than 2.5 cm.

Cultivar difference for seedling emergence from 6 cm depth (On right side, seedling of PR-122 did not emerge)

Planting machinery

Direct seeding should be done with a multi-crop planter fitted with inclined plate's seed metering systems and inverted T-type tynes to sow seeds at a depth of 2-3 cm to have good germination. Precise seed rate and plant-to-plant spacing is not possible with



normal fluted roller-type seed-cum fertilizer drills due to breakage and continuous seeds fall (Gupta et al., 2006). With precise seed-metering planters, DSR crop is planted with a lower seed rate (15-20 kg ha^{-1}) and more precise plant-to-plant spacing.

Cultivars

For the successful direct seeding system, it is necessary to select short duration rice cultivars that can produce high yields in aerobic conditions. Cultivars should be weed competitive, tolerant to moisture stress in early growth stages and should have greater translocation efficiency after flowering.

Table1. Cultivar choices for DSR in different production environments

Sr. No.	Areas/cropping systems	Preferred Cultivars
1.	Punjab (Rice-wheat)	PR-111, PR 115,PR-123, Pusa Basmati 1509, Pusa Basmati 1121, PR 120
2.	Western UP and Haryana (Rice-wheat, Rice-potato-wheat/maize/ sunflower)	CSR 30, Pusa 1121, Pusa 2511 (Sugandha 5), PRH10, PR 115, Pant Dhan 12, Sharbati, Arize 6129, Proagro 6444, PR-111, PR 115,PR-123, Pusa Basmati 1509, Pusa Basmati 1121, PR 120
3.	Tarai of Uttrakhand (Rice-wheat)	Nidhi, UPRI 92-79, Narendra 359, Sarbati, PR 115, PR 120, HKR 120, Sarjoo 52, Sadbhagi

Upland rice cultivars produced lower yields even under relatively high-input conditions as compared to lowland cultivars (Atlin et al. 2006). High-yielding lowland cultivars under aerobic conditions may save water, but they do so while sacrificing yield. Many workers have reported that water-use efficiency (WUE) can be increased by adopting different water-saving practices, such as improved irrigation management (Bouman & Tuong 2001), use of short-duration cultivars (Mahajan et al, 2009; Humphreys et al. 2010), and rice cultivars adapted to aerobic conditions (Bouman et al. 2005). Mahajan et al. (2011) reported genotypic differences in grain yield between DSR and PTR. In general, short-duration cultivars had greater WUE in both the water regimes (rice production systems).

The WUE of the medium-duration cultivars PAU-201 was high in DSR because of its higher yields. Larger sink size and vigorous crop growth that give higher dry matter and greater plant height at early growth stages were important traits contributing to closing the yield gap between DSR and PTR. They also reported that although for some cultivars the water requirement was less in DSR than PTR, the yield loss in DSR outweighed the benefits of saving water, resulting in similar WUEs between DSR and PTR. For a more economical use of water in NW-IGP, growing cultivars such as Fang-ai-zan, RH-257, RH- 664, PR-120, and PAU-201 could be a better choice under DSR because of their higher values of stress tolerance index. In north- west India rice is mainly grown during the monsoon season, establishment of direct-seeded rice can be adversely affected by untimely extended rains immediately after sowing. Emergence is poor if continuous rain prevails immediately after sowing or because of the mortality of young seedlings caused by submergence (Ismail et al., 2009). Therefore, ability to germinate under anaerobic conditions and tolerance of early submergence are important for establishing a good crop (Ismail et al., 2009). Cultivars having seedling vigor are desirable for optimal establishment of a DSR crop, and also for weed competitiveness (Redon˜a and Mackill, 1996). A longer mesocotyl will minimize sensitiveness to seeding depth in drill seeding and improve seedling establishment. The modern semi-dwarf cultivars have a short mesocotyl, and this is disadvantageous for good CE, especially when seeds are drilled deeper in the soil (Dilday et al., 1990; Fukai, 2002; Turner et al., 1982). Weed competitiveness in direct seeded rice varieties is the most important plant traits required for the success of DSR.

The traits that are likely to be most helpful for weed management in direct seeding include seed germination in anaerobic conditions and tolerance of early submergence for uniform crop establishment, high and early seedling vigour with rapid leaf area development during the early vegetative stage for weed suppression, cultivars having an allelopathic effect, and herbicide-resistant rice cultivars (Mahajan and Chauhan , 2013).

Weeds are a major constraint in DSR cultivation. The development of weed-competitive cultivars is an wise and effective strategy of an overall IWM program . systems (Cousens, 1996; Dingkuhn et al., 1999), and the most efficient way of delivery to farmers (Caton et al., 2003). Cultivar differences in weed competitiveness have been reported in many crops, including rice (Chavez, 1989; Fischer et al., 2001; Garrity et al., 1992; Haefele et al., 2004; Quintero, 1986). Cultivar–weed competitiveness has two components: weed tolerance and weed-suppressive ability (Jannink et al., 2000; Zhao et al., 2006). Weed tolerance is the ability of plants to maintain high yields despite weed competition, whereas weed suppressive ability is the ability to suppress the growth of weeds through competition.

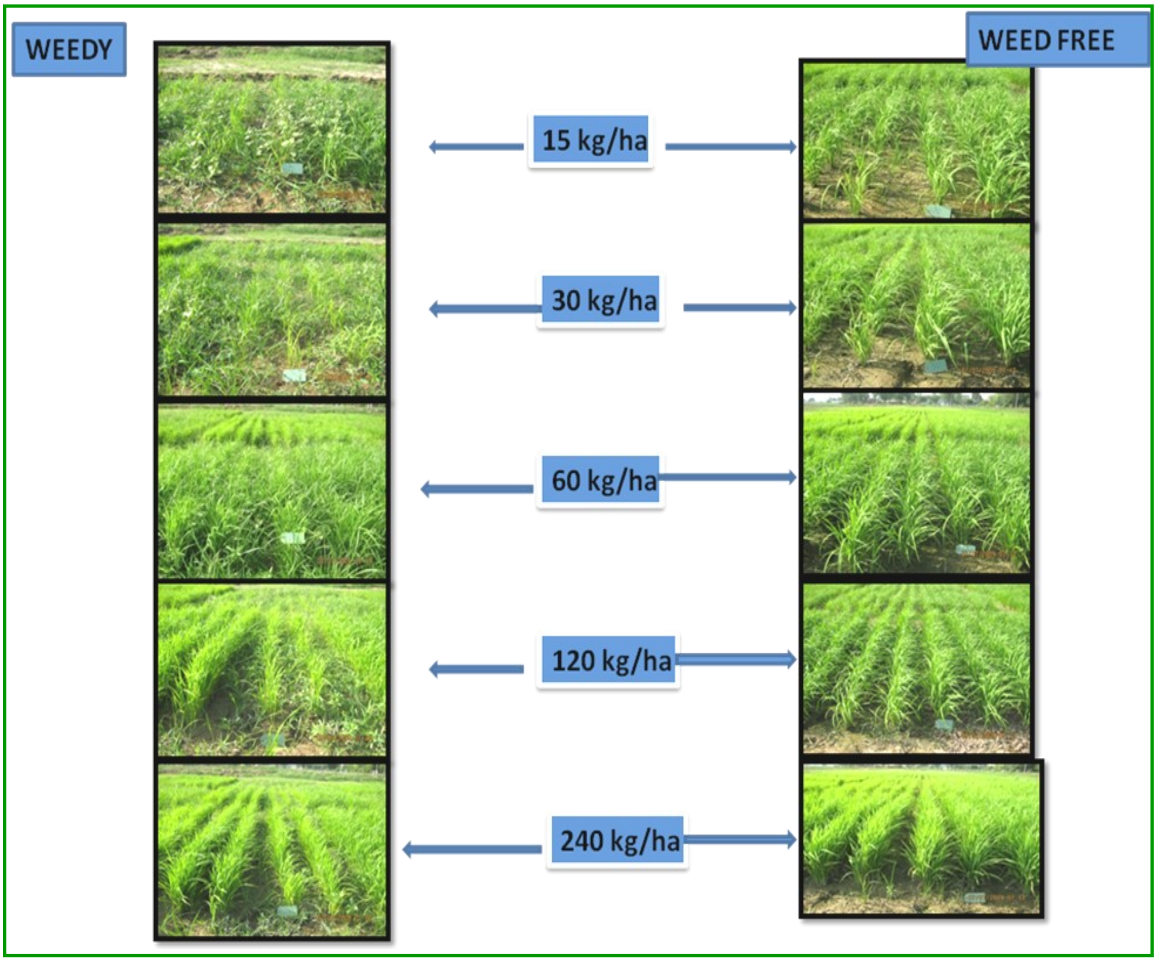
Breeding for weed-suppressive ability is being advocated over weed tolerance because suppressing weed growth will reduce weed seed production and minimize contributions to the weed seed bank (Jannink et al., 2000; Jordan, 1993). In DSR, due to aerobic condition, soil is not subjected to reduced condition. Under oxidized conditions in DSR, availability of Fe to the crop is very low. The roots of plants, especially those belonging to Graminae family, produce phytosiderophores (mugineic acid, etc.; Romheld and Marschner, 1990), which chelate Fe^{2+} and make it available to plants. However, production of phytosiderophores is very low in rice and partly explains its sensitivity to Fe deficiency (Mori et al., 1991). Fe deficiency can spring up in upland rice nurseries (authors' observation) or during preflooding seedling establishment (Synder and Jones, 1991). Flooding the nursery area or fields can overcome such deficiency. Rice varieties differ in their tolerance to Fe deficiency (Singh et al., 2003). For example, Pal et al. (2008) reported that cultivars CT6510- 24-1-2 (V1) and IR71525-19-1-1 (V2) performed better than IR36 (V3) and IR64 (V4) under partial aerobic rice system. Fe^{2+} concentration, which is a better indicator of Fe deficiency or sufficiency (Katyal and Sharma, 1980), in whole rice plants was 68.8, 64.5, 50.7, and 43.3 mg/kg DM in V1, V2, V3, and V4 plants, respectively, when 61 kg ferrous sulfate was applied to soil at sowing.

It may be pointed out that for lowland conditions, IR36 has been reported to be tolerant to Fe deficiency (Naidu et al., 1981). Thus, ranking of rice cultivars to Fe deficiency sensitiveness may not be the same under aerobic /partial aerobic rice system as under continuous flooding. Since most of the soil of north western IGP are coarse textured and Fe deficiency is the main hurdle, which frequently occur at seedling stage and cause substantial reduction in yield. So, future research in DSR should be focussed on evolving Fe efficient cultivars.


Cultivar differences for vigour and nutrient uptake

Seed rate

Previous literature supports the use of high seed rate (80- 120 kg ha^{-1}) for establishment of DSR. However, high seed rate resulted nitrogen deficiency, an increased proportion of ineffective tillers, lead to attack of brown plant hopers, and increase the probability of crop lodging caused substantial reduction in grain yield. Castin and Moody (1989) found that rice-grain yield increased in weedy plots as a result of increasing seed rate. Similar results were reported by Romyen et al. (2002). However, Gibson et al. (2001) found no significant effect of rice-seeding rate on weed growth. However, in aerobic rice, seed rates are highly variable. With high N application, use of seed rates varying from 67 kg ha^{-1} to 303 kg ha^{-1} did not show any yield difference, whereas with high N application, 67 kg ha^{-1} seeding rate produced more yield than seed rate of 303 kg ha^{-1} (Wells and Faw 1978). These researchers also reported that as rice seeding rates increased, panicle density increased and filled grains per panicle decreased, with no change in yield (Jones and Snyder 1987; Gravois and Helms 1992). The recent development and commercialization of aromatic rice and patented input traits (hybrid) have led to increased seed costs. These developments have led rice researcher to revisit seeding-rate recommendations and deter-



Showing effect of seed rate on crop performance of DSR under weedy and weed free situation mine the optimum seed rate for weed suppression to save input cost, including herbicides. Based on multi-year research trials, in Punjab, using a drill having inclined plates for seeding, the seed rate has been decreased drastically without causing any adverse effect on yield provided weeds are controlled effectively. Based on recent experience with on-farm farmer participatory trials in the IGP, a seed rate of 20–25 kg ha^{-1} has been found optimum for medium-fine-grain rice cultivars with a spacing of 20 cm between rows and 5 cm within rows (Gopal et al., 2010; Gupta et al., 2006). Recent study of Mahajan et al. (2011) revealed that high seed rate is not needed in DSR to achieve high yields. In this study, it was found that seeding rate in DSR had inverse correlation with weed interference. Authors suggested that higher seed rates caused significant reductions in weed dry matter, whereas higher than optimum seed rate (15–30 kg ha^{-1}) caused reduction in yield. Of all the seeding rates used, 15–30 kg/ha had the lowest grain-yield losses caused by weeds. Sudhir-Yadav et al. (2007) evaluated seed rates of 30, 40, and 50 kg ha^{-1} for basmati rice (wet-DSR) in Punjab, India, and found that a seed rate of 30 kg ha^{-1} yielded the highest. Wu et al. (2008) in China found a seed rate of 20–25 kg ha^{-1} as optimum for DSR, including under zero-till conditions (ZT-dry-DSR). However, others found no difference in yield with a range of seed rates (Gravois and Helms, 1992; Johnson et al., 2003; Jones and Snyder, 1987; Xue et al., 2008). They emphasized that more research is needed, however, to study the interaction of seed rate, variety, seed depth, spacing, and geometry. In India, under alluvial loamy sand soil, 50 kg seed ha^{-1} produced maximum grain yield, which was found at par with 100 kg ha^{-1} and 150 kg ha^{-1} (Gill et al. 2006). Reduced seed rate in DSR has further widened the scope of direct-seeded rice in that DSR can be grown using seed rates of 15 to 30 kg ha^{-1}. This proposition should save farmers' input costs, particularly when farmers use hybrid rice seed (to exploit vigour trait) in DSR, which is very costly. It id pertinent to mention that use of lower seed rate (15 to 30 kg ha^{-1}) in DSR is possible only with the direct seeded rice drill that has seed metering device.

Seed priming

Due to high temperature at sowing time and shallow sowing of seeds, soil moisture content reduces from the level required for proper germination. Therefore, a pre-hydration technique (seed priming) for 8-10 hours is advisable to initiate the internal process of seed germination. Seed priming is a controlled hydration technique in which, seeds are soaked in solutions of low-osmotic potential before the actual germination take place and then re-dried near to their original weight to facilitate routine handling. It accelerates the germination and seedling emergence when the seeds are re-imbibed in soil.

In Punjab, earlier attempts to grow DSR have not been very successful because of poor germination, uneven crop stand, high weed infestation, and yield penalty caused by lack of adaptation to aerobic environment. One of the short-term and most pragmatic approaches to overcome poor crop establishment and water-stress effects in DSR is seed priming, which involves partial hydration to a point where germination-related metabolic processes begin, but radicle emergence does not occur (Farooq, Basra, & Wahid 2006). This approach has been applied to overcome water-stress effects in a range of crop species. Primed seeds usually exhibit increased germination rate, greater germination uniformity, and sometimes greater total germination percentage (Farooq, Basra, & Wahid 2006; Kaya et al. 2006). Hence, improvement of DSR for growing in water-deficit areas through seed priming is of interest. Recent study of Mahajan et al. (2011) confirmed that hydro-priming and water-hardening treatments improved germination percentage and the seed vigor index, which appeared to be related to earlier and uniform emergence and subsequent seedling growth, and ultimately resulted in more panicles m^{-2} and higher grain yield in dry direct-seeded rice culture. As DSR is sown at shallow depth (2-3 cm) and advance of the monsoon rains and dry soil conditions are commonly the main constraint to rapid establishment of a good crop stand. In such situations, hydropriming can improve germination. Primed seeds are subsequently dried in shade to decrease moisture content, which facilitates the proper functioning of seed metering mechanisms during planting.

Literature showed that seed priming technique allows some metabolic processes to occur without actual germination (Basra et al., 2005). Seed priming techniques, such as hydro-priming (Farooq et al., 2006); on-farm priming (Harris et al., 1999); osmo-hardening (Farooq et al. a, b, c); hardening (Farooq et al., 2004); and priming with

Seed priming in research trials

Seed priming (Courtesy google)

growth promoters like growth regulators and vitamins have been successfully employed in DSR (Farooq et al., a,b).

Osmo-hardening with KCl or $CaCl_2$ resulted in faster and uniform seedling emergence from primed seeds, which was attributed to improved alpha amylase activity and increased levels of soluble sugars in these seeds. It also enhanced the starch hydrolysis, making more sugars available for embryo growth, vigorous seedling production and improved growth, kernel yield and quality attributes at maturity (Farooq et al, a,b).

For primed seed, treatment with fungicide or insecticide should be done post-soaking to control seed borne diseases / insects. The seed can also be soaked in solution having fungicide and antibiotics (Bavistin/ Emisan and Streptomycin) for 15-20 hours . Some studies showed that priming with imidacloprid resulted in increased plant height, root weight, dry matter production, root length, increased yield by 2.1 t ha^{-1} compared with control (non-primed), which was attributed to higher panicle numbers and more filled grains per panicle (Gupta et al., 2006; Kreye et al, 2009). Seed priming also reduced the need for high seeding rates, but was detrimental for seedling establishment when soil was at or near saturation (Farooq et al, 2011). Priming rice seeds for 12 and 24 h improved crop establishment and subsequent growth (larger leaf area, taller plants, higher root and shoot dry weights measured 4 weeks after sowing) and also had significantly more tillers, panicles and grains per panicle in Ghana (Harris et al., 1999; Warda, 2002).

Planting time

First fortnight of June is the optimum sowing time for non-basmati cultivars and second fortnight of June is the optimum time basmati rice. In DSR, crop should be sown at optimum time to ensure high crop water productivity . Vigorous early growth of rice crop before the arrival of inundating monsoon rains reduces seeding mortality due to submergence and, by hastening crop development, makes its easier to ensure timely planting of wheat after rice harvest. Water requirement may increase in case crop sown early in the month of May. Early planting also resulted in poor establishment.

Rice in north - west India grown during the monsoon season (wet season). For effective use of monsoon rain, in general, the optimum time for DSR is about 10–15 days prior to the onset of monsoon (based on forecast or historical weather data) (Gopal et al., 2010; Gupta et al., 2006). After the onset of rain when soil gets wet, movement of machinery becomes difficult, which makes seeding tedious. Moreover, if rain continues for a few days, seed rotting and seedling mortality can occur due to submergence, resulting in poor crop establishment. The sowing time of the rice crop is important for three major reasons. Firstly, it ensures that vegetative growth occurs during a period of satisfactory temperatures and high levels of solar radiation. Secondly, the optimum sowing time for each cultivar ensures the quality of the crop. Thirdly, sowing on time guarantees that grain filling occurs when milder autumn temperatures are more likely, hence good grain quality is achieved (Farrell et al., 2003). The delayed sowing resulted in the poor emergence and reduced heading panicle per meter square and spikelets per panicle and ultimately yield is affected (Hayat et al., 2003). Recent study of Singh et al. (2010) revealed that direct-seeded rice sown at the same time as the nursery had the same grain yield as transplanted rice and delay in direct seeding by 7 or more days after nursery sowing (DANS) significantly reduced grain yield. In this experiment they evaluated six sowing dates (five for direct seeding at 0, 7, 14, 21, and 28 d after nursery sowing (DANS) and one for transplanting at 28 DANS. A study comprised of six different sowing dates (31st May, 10th June, 20th June, 30th June, 10th July and 20th July) at Pakistan revealed that the direct seeding of super basmati on 20th June gave the best results in term of entire yield and yield components (Akwar et al., 2010).

View of timely planted DSR crop (First week of June)

Nutrient Management

Optimum dose and schedule of fertilizer application is necessary to achieve higher yields, minimize lodging and minimize damage from insect pests. Fertilizer application should only favour the crop not weeds. Split application of nitrogen (N) synchronizes with the demand of rice growth and prevents N loss. Research evidences at PAU revealed that, in DSR, (N) should be applied at the rate of 150 kg ha^{-1} in four equal splits at 2, 4, 6 and 8 weeks after sowing. Recommended phosphorus (60 kg ha^{-1}) and potassium (40 kg ha^{-1}) should be applied as basal dose on soil test basis.

Leaf Colour Chart (LCC) may also be used for need-based nitrogen fertilizer application. Match the colour of the youngest fully expanded leaf (second from the top) of 10 randomly selected disease free rice plants with the colour strip of LCC every 7-10 days starting from 6 weeks after sowing till the initiation of flowering. Every time the greenness of 6 or more out of 10 leaves is less than shade 4 on the LCC, top dress another split dose of N. If the colour of 6 or more plants out of 10 is greener than shade 4, the split application may be omitted at that time. Micronutrient deficiency is commonly seen in DSR due to absence of reduced conditions in the soil. Symptoms of Fe deficiency include interveinal chlorosis of new leaves, decreased dry matter production; entire plant becomes chlorotic and dies if deficiency is severe. To overcome this, Fe-efficient cultivars in DSR should be grown. Addition of organic matter (crop residues, FYM etc.) and a foliar spray of 1% solution of ferrous sulphate in water or ferrous ammonium sulphate are recommended for the management of iron deficiency. Water should be kept standing in the field if acute deficiency persists. Zn deficiencies in DSR appear 4-6 weeks after sowing and are mostly characterized by dusty brown spots on upper and middle leaves, uneven plant growth, chlorotic midribs and decreased tillering and leaf blade size. Zn deficiency can be efficiently corrected by soil application of $ZnSO_4$ (Zinc sulphate). $ZnSO_4$ being highly water soluble is preferred over ZnO. In case, deficiency symptoms appear in the field, a dose of 10-25 kg ha^{-1} of $ZnSO_4.7H_2O$ mixed with sand (1:3) should be applied over the soil surface. Do not apply DAP with $ZnSO_4$ to avoid Zn deficiency. For the emergency treatment, a foliar spray of 0.5-1.0 kg Zn ha^{-1} (0.5-1.0% $ZnSO_4$ solution at about 200 L water/ha) may be necessary.

Since the concept of DSR in northwestern IGP is new, rela-tively few insights into N dynamics and fertilizer N use exist. In puddled soils, ammonium is the dominant form of available N and is lost through ammonia volatilization (Vlek and Craswell, 1981). Some of the ammonia is nitrified in oxidized soil zones and in floodwater (De Datta, 1981). This nitrate moves into reduced layers, where it denitrifies and is subsequently lost to the atmo-sphere as N_2 and N_2O (De Datta, 1981). Since nitrate is barely present in flooded rice soils, very little nitrate N is leached to the groundwater (Bouman et al., 2002). In aerobic systems, on the ammonia volatilization is expected after fertilizer N ap-plica-tion. The alternate moist and dry soil conditions may stimulate nitrification–denitrification processes in DSR, resulting in a loss of N through N_2 and N_2O (Prasad, 2011). The differences in soil N dynamics and pathways of N losses in DSR systems may result in different fertilizer N recoveries. With even high N applications in aerobic rice, grain filling may be limited by a low contribution of postanthesis assimilates (Zhang et al., 2009). In addition, in the absence of transplanting, the roots of DSR are located in the shallow surface soil, which results in a relatively low uptake of N (Zhang and Wang, 2002). These observations suggest that tradi-tional lowland rice fertilizer schedules are not optimal for DSR. Recent study of Mahajan et al (2011) revealed that DSR responded up to 150 kg N ha^{-1} applied in four splits resulting in increased LAI, higher RWC of the flag leaf, and pre-anthesis dry matter accumulation of the crop. Compared with the three splits, the four split treatment with 150 kg N ha^{-1} resulted in greater dry matter transloca-tion from preanthesis biomass to grain yield. With 150 kg N ha^{-1} applied in four splits, the highest contribution to preanthesis assimilate to grain yield was observed due to higher NHI and N translocation efficiency. Application of 150 kg N ha^{-1} applied in four splits with and without N dose at sowing time increased preanthesis dry matter accumula-tion, sink size, and ultimately grain yield. Application of N at sowing time could be skipped in DSR as it may not be used immediately by rice plants. Application of N fertil-izer at or after anthesis may increase postanthesis dry matter accumulation and grain fill-ing in DSR; however, this needs to be verified by using various rice cultivars.

The fertilizing schemes for DSR have become the focus of new studies to ensure rice yield and to reduce environmental influence on water bodies. The rate and timing of N fertilizer should be adjusted to balance the crop's demand before and after anthesis; therefore, proper management of crop nutrition in DSR is of immense importance. Timely and split applica-tion of N allows for more efficient use of N throughout the growing season as it provides specific amounts of nutrients to the crop during peak peri-ods of growth and may reduce leach-ing of nitrate N in the soil (Fageria, 2010; Lampayan et al., 2010). Making accurate N fertilizer recommendations for rice is becoming more important as concern grows about the high cost of this input and nitrate pollution of sur-face and ground- waters in agricultural areas (Xue et al., 2008).

In studying crop response to nutrients, interactions of nutrient and water may play a significant role. In puddled-transplanted rice, ammonium is the dominant form of avail-able N while in aerobic rice systems, the dominant form of N is nitrate, which results in different pathways of N losses and N availability (Belder et al., 2005; Prasad, 2011).

Belder et al. (2005) reported that yield of rice grown under aerobic conditions is more limited by N than yield under flooded conditions. A recent study also showed that N requirement is higher for the DSR than for the transplanted rice (Mahajan et al., 2011a). In the rice-wheat cropping system, which is the most predominant system in the NW-IGP, the general trend is to apply P to wheat and skip P application to rice if it is grown under puddled conditions (Prasad, 2005). Rice soils in the IGPs are rich in illites, which fix K^+ both under dry and moist conditions. Malvolta (1983) reported that when soils were shaken with a K solution, K^+ fixation was 25%, while it was 68% when K^+ saturated soils were dried. K^+ fixation was 2-3 times greater after drying than after wetting. This suggests that intermittent drying conditions in DSR may cause temporary K deficiency in rice. It is expected that excessive irrigation in DSR may increase N loss in soil through leaching and may increase nitrate pollution in underground water. Since it is not possible to prevent nitrate leaching, improved management practices leading to increased fertilizer

Use of LCC in DSR

Green mauring in DSR

Fe deficiency in DSR

N use efficiency can reduce the potential for nitrate pollution in groundwater (Bijay-Singh et al., 1995; Cassman et al., 2002). The utilization of N can be increased by balanced application of N, P, and K and by more frequent light irrigation (Bijay-Singh et al., 1995; Bijay-Singh and Sekhon, 1997). Recent study of Mahajan et al. (2012) revealed that in DSR, addition/supply of P and K along N could compensate the yield loss with increasing water stress. Therefore, addition of P and K along N application may help in relieving water stress in DSR.

In the case where DSR results in less continuous flooding and reducing soil conditions, the rice crop often suffers from iron chlorosis, particularly in sandy soils. Study conducted by Mahajan et al. (2012) revealed that deficiency of N and Fe significantly influenced performance of rice, especially on coarse texture soil. This study leads to the conclusion that grain yield of DSR can be increased by green manuring and foliar application of Fe. Green manuring also resulted in increase in yield of PTR. Green manured DSR plots recorded same yield as PTR plots without green manuring.

Water management

Due to differences in moisture regimes and puddling operation, there is a considerable difference in soil physical, chemical and biological properties between direct seeded and puddled rice. A heavy pre-sowing irrigation 2-3 days before is advisable. Due to high temperature in the month of June, there is rapid loss of moisture from the surface soil, therefore, immediate light irrigation (50 mm) after seeding is necessary to facilitate germination particularly if DSR is to be sown in medium textured soil. Subsequent irrigation depends on the soil moisture status and the amount of each irrigation application should be adequate enough to bring the upper 20 cm soil layer to field capacity. Field should be kept moistened (not flooded) throughout the season to avoid moisture stress.

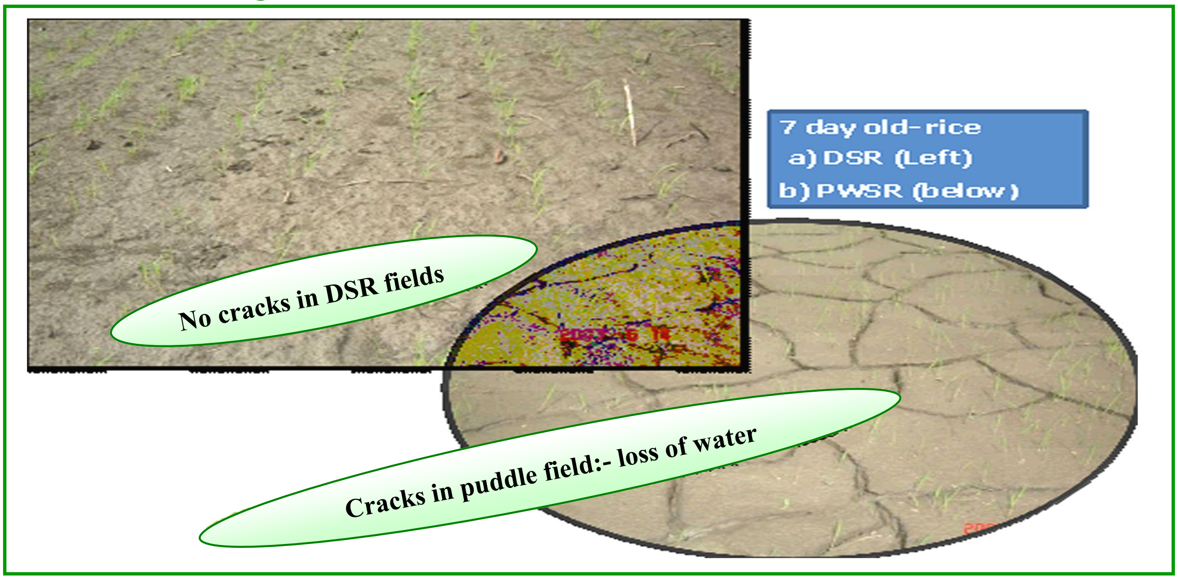
Information on economizing water use in Dry-DSR is scarce (Humphreys et al., 2010). Gupta et al. (2006) and Gopal et al. (2010) recommended for harnessing full yield potential in dry-DSR, avoid water stress at important growth stages (tillering, panicle initiation, and grain filling) . Bouman et al. (2007) suggested that the flowering is the most critical stage of rice to water stress and they recommended that the field should be flooded 1 week before and after peak flowering to avoid water stress around flowering, . After establishment of crop, the following water management options are available: (1) continuous flooding; (2) frequent irrigation, that is, DSR with safe alternate wetting and drying (AWD), which involves flooding the field with shallow depth (5 cm) and re-irrigating a few days after water disappearance; (3) infrequent irrigation where scarcity of irrigation water limits rice yields; and (4) no irrigation under rainfed conditions

(Humphreys et al., 2010). Option 2 is most preferred for high crop water productivity but this is subject to the availability of irrigation water. Like PTR, for more economize use of water , Dry-DSR can also be irrigated using safe AWD . But till date, our knowledge to implement safe AWD in Dry-DSR is still limiting. Nevertheless, farmers and researchers reported that a safe AWD irrigation interval in Dry-DSR is longer than that in CT-TPR because of less soil cracking in the former than in the latter (Humphreys et al., 2010). In a 6-year study conducted in Modipuram, India on sandy-loam soil, it was observed that Dry-DSR can be irrigated safely at the appearance of soil hairline cracks (Bhushan et al., 2007; Gathala et al., 2011). This study reported an average savings of 9% irrigation water when irrigation was applied on the appearance of soil hairline cracks (this coincided with 25 to 35 kPa at 15-cm depth). Another study conducted by Sudhir-Yadav et al.(2011a,b) in Punjab, India on clay loam soil observed that 20 kPa soil tension at 20 cm depth as safe for AWD irrigation scheduling. They reported 33–53% irrigation water saving in Dry-DSR with AWD compared with PTR without compromising grain yield loss. Further simulated studies are needed to determine the optimum threshold for irrigation at different growth stages and for a wider range of rainfall and evaporative demand conditions and varietal types.

Most of the area of rice–wheat cropping system of IGP is irrigated primarily from groundwater. Any attempt to reduce deep drainage losses in these areas would neither save water nor reduce groundwater decline (Humphreys et al., 2010) because often that water is reused/pumped. But, reductions in deep percolation losses can save energy (energy needed to pump) and reduce groundwater pollution. To have a significant impact on true water savings, we need technologies that can resulted in real water saving means increase water productivity of evapo-transpired water (WPET) (Humphreys et al., 2010). For example, residue mulch in Dry-DSR may significantly reduce E and ET, especially prior to the start of monsoon when evaporation is very high and plants are very small (Jalota and Arora, 2002). The development of new cultivars of short to medium duration adapted to water limitations is another approach to reducing irrigation water use (Humphreys et al., 2010; Mahajan et al., 2009). Recently, interest has been increasing in using pressurized irrigation method to grow rice in areas where water is limited (Spanu et al., 1996). Limited studies in the region have shown that sprinkler systems have potential to improve on-farm irrigation efficiency up to 80% in other crops under the prevailing conditions in the Indian subcontinent (Sharma, 1984). Sprinkler systems can be used in rice to apply a desired depth of water during pre- and post-sowing irrigations (Kahlown et al., 2007). In Pakistan, Kahlown et al. (2007) found that sprinkler irrigation increased the grain yield of CT-TPR by 18% and reduced water application by 35% compared with the traditional irrigation system. Similarly, Kato et al. (2009) in Japan found that Dry-DSR when irrigated with a sprinkler system (30–40 mm) whenever soil water potential fell below _60 kPa at 20-cm depth produced equal or higher yield than transplanted or dry direct-seeded rice under a flooded system, with total water savings ranging from 21% to 74%. Although some of these studies show potential, much needs to be done to understand the feasibility and economics of pressurized irrigation methods in farmers' fields when land holdings are small. This area seems to have huge untapped potential which should be explored in close collaboration with various partners, especially in the private sector.

Farmer in action for applying irrigation through tubewell

Tensiometer use in DSR



Weed Management

Weed infestation is a vital constraint to pervasive adoption of DSR. In the transplanted rice, seedlings have a head start of 3-4 weeks over weeds and weed infestation is not a potential threat. However, in direct seeded rice, weeds and rice seeds germinate at the same time, which creates a serious weed-crop competition. The problem of grassy weeds is more associated with direct seeded rice. Therefore, integrated weed and water management practices, with selective herbicide usage have to be adopted to curtail these weeds. Application of pre-emergence herbicide, Pendimethalin (Stomp 30 EC) @ 0.75 kg ha^{-1} (2.5 l/ha) in 500 L water helps in minimizing weed establishment for 2-3 weeks after sowing. At later stages, 20-30 days after sowing (DAS), to control weeds, a spray of Bispyribac (Nominee Gold10 SC) @ 25 g ha^{-1} (250 ml/ha) in 375 L water is recommended. The soil moisture conditions should be optimum at the time of application of these herbicides. For the management of broad leaf weeds, spray Azimsulfuron (Segment 50 DF) @ 40 g ha-1 in 500 L of water at 30-35 DAS. Herbicide spray should preferably be done with flat fan or flood jet nozzles. Manual hand weeding is recommended whenever the weed infestation is high even after herbicide application. An efficient weed management strategy therefore becomes the most essential component of successful cultivation of direct seeded crop.

Various weed management strategies are available and, depending on the location and resource availability, there is need to include as many strategies as possible for sustainable weed control in DSR. Suggested integrated weed management strategies for management of weeds in DSR are below:

Hand weeding in poor managed DSR field

Weed pressure in DSR, if not controlled

Integrated Weed Management Strategies

Land Preparation

The field should be well levelled, if possible use laser leveller for levelling. Poor land preparation can result in poor stand establishment in dry direct seeded rice. Developing rice seedlings can be killed or greatly retarded in their growth when ponding of water occurs due to unevenness of field and accumulation of toxic concentrations of applied herbicides. Also, weeds invade the vacant spaces where the rice does not grow resulting in yield losses due to competition. A poorly prepared field does not provide a suitable medium for optimum plant growth. If the field is not levelled, the seedlings cannot establish quickly in the low spots and weeds will grow abundantly in the high spots. These conditions will result in stunted plants with low tiller production. Good field drainage and good water control are essential for successful crop and for reduction of pre-emergence herbicide phytotoxicity. Tillage serves only as a temporary means of weed control because the soil contains many ungerminated weed seeds. Plowing may bury weed seeds at

Poor management in DSR

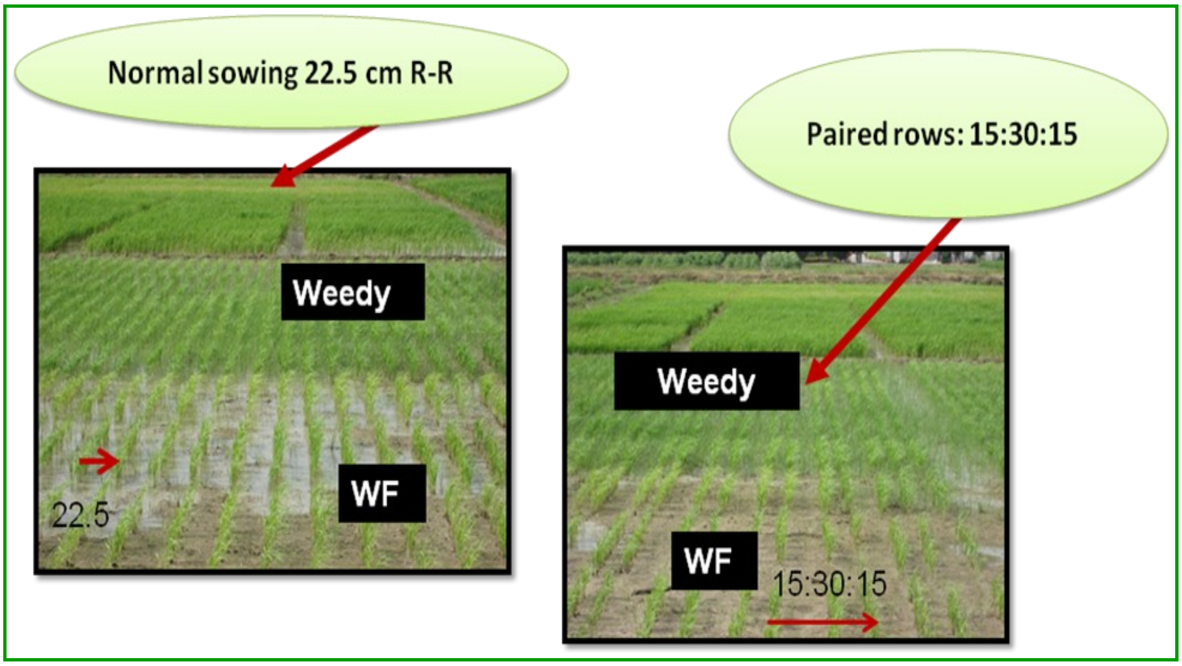
a depth that prevents germination but may also expose other, once deeply buried seeds to conditions inducive to germination . A well-levelled field without numerous depressions or elevations is essential for good weed control. Fields with many low and high spots result in water depths that are too deep for the rice in the low spots and too shallow for weed control in the high spots.

Seeding Rate

For direct drilling 30-60 kg ha^{-1} seed rate is enough for healthy crop. Use 30 kg ha^{-1} seed rate, if there is not enough pressure of weeds in the previous history of field. Farmers' may increase the seed rate upto 60 kg ha^{-1} to compensate for damage by rats and birds, to partially overcome the adverse effects of herbicides and to compensate for poor stand establishment if rains occurs after sowing. Low plant density and the presence of gaps encourages the growth of weeds. Such a stand resulted in less uniform ripening and poor grain quality. On the other hand, too thick a stand should be avoided because it tends to less productive tillers, increase lodging, prevents the full benefit of nitrogen application and increases the chances of rat damage. The study conducted at Punjab Agricultural University revealed that there was a significant decrease in weed weight as the seeding rate increased from 30 to 240 kg ha^{-1}. Thus, high seeding rate can compensate partly for poor weed control. It was seen that there was an increase in grain yield in the untreated check plots but not in the weeded plots as a result of an increased seeding rate. Increase in panicle number as seed rate increased was offset by a decrease in panicle length and grain weight per panicle. Higher seeding rates would be beneficial if no weed control is planned or only partial weed control is expected. However, it is not necessary to use high seeding rates to suppress weeds in dry direct seeded rice if a herbicide that is effective in controlling weeds is used.

Crop density/Geometry

Row to row spacing recommended for DSR is 20 cm. Plant spacing, of course is affected by seed rate. However, the effect of crop geometry is an issue distinct from seeding rate. It has been observed that twin row planting (15:30:15 cm for row to row) pattern in dry direct seeded rice had a great influence on weeds as compared to single row planting system (22.5 cm for row-row). Twin row planting greatly facilitate weed suppression by maintaining dominant position over weeds through modification in canopy structure (Mahajan and Chauhan, 2012, Mahajan et al., 2014). Recent studies at PAU revealed that (Mahajan and Chauhan, 2012, Mahajan et al., 2014) yield of some rice cultivars may be improved by exploring competitiveness of rice cultivars through paired row planting patterns. There is a need to study plasticity changes for cultivars which respond with more competiveness in paired rows. The identified traits could be useful as selection criteria for screening weed-competitive cultivars in paired row pattern with less load of herbicides in DSR.



Prevention

Planting of clean seed is perhaps the most important weed-management technique to control losses. Rice seed contaminated with weed seeds may introduce a new species to a given field or add to an existing weed population. Preventing weeds from entering an area may be easier than trying to control them once they have become established. Weeds which mature at the same time as rice are harvested and threshed with the rice resulting in the contamination of rice seed with weed seeds. Therefore, by using clean seed before sowing the crop, infestation of weeds can be reduced to a considerable extent. Irrigation water is one of the major means of spread of weed seeds and vegetative propagules. Flowing water moves millions of weed seeds from one place to another. The amount of seed and the type of seed moved depends on the volume and the velocity of the water and the size and the weight of the seed or the vegetative propagules. It is advisable to rotate the DSR field with conventional puddle transplanted system after 2 years of taking DSR crop there. Otherwise it would lead to emergence of new weeds like Weedy rice, *Digitaria sangunalis* and *Leptochloa* etc.

Choice of Cultivar

Cultivars play an important role in crop-weed competition because of morphological feature, canopy structure and relative growth rate. A quick growing and early canopy cover enable cultivar to compete better against weeds. Research evidences have shown that traditional tall cultivars like Nerica rice exerts effective smothering effect on weeds. Further it has been observed that early maturing cultivars of rice also have a smothering effect on weeds due to vigour and having tendency of early canopy cover. In DSR, the use of weed competitive cultivars would be integrated with one herbicide application (pre or post). The idea is that use of herbicide would take care of weeds at the early stage and the traits of weed competitive cultivars would help in suppressing weed growth at later stage. Till date- information is very limited regarding role of root competition for nutrient and water in rice-weed interactions. So, there is need to study both aboveground and belowground traits while examining rice-weed interactions.

Experiment assessing rice cultivars for weed competitiveness in DSR

Stale seed bed technique

This technique was found very effective in DSR. This method has been found quite helpful particularly when the field was infested with perennial weeds and weedy rice.

Water Management

Water management is a major component of any weed control program, whether a herbicide is used or not. Herbicides which give excellent control when applied into water may perform poorly in the absence of standing water. During pre-emergence application of herbicide in direct dry seeded crop, there should be enough moisture in the field. Drain off the water during post emergence application of herbicide. Do not irrigate the field immediately after the application of post-emergence herbicides. Good water management together with chemical weed control offers an unusual opportunity for conserving moisture and lowering the cost of rice production. The critical period of crop-weed competition is highly influenced by water management.

Nutrient Management

The application of fertilizer in excess encourages weed growth and should be avoided. The proper management of N in dry direct seeded rice reduces the weed competition. The fertilizer should be applied as per the requirement of the crop. Research evidences revealed that when the weeds were under control, crop gave a response to higher amount of N application, however under weedy and partially weedy condition, grain yield reduced drastically with higher amount of N fertilization (Mahajan et al., 2011).

Hand Weeding

Many farmers do not realize that weed control is a limiting factor in crop production. Traditionally, they depend on manual labor to remove weeds. By the time weeds are large enough to be removed by hand damage has been done, yield loss is certain and hand labor cannot undo it. Maximum yields can only be obtained if weeds are controlled early because most damage is done when crop plants and weeds are small.

Weeding can only be done at a time when labor is available, but this may not coincide with the best time to do it to minimize weed competition. Improving weed management by alleviating labor constraints has repercussions for all aspects of crop production, the sustainability of cropping systems and the social conditions of farming families.

The weeders damage the rice as they move through the field, especially during early crop growth, and they fail to remove some of the grassy weeds or they remove rice by mistake, because of the difficulty in distinguishing grassy weeds from rice. Also hand weeding is at least five times more expensive than herbicides for weed control in wet-seeded rice. Hand weeding in dry direct seeded rice should only be done when there are typical weeds that were not controlled by either pre or post emergence herbicide application.

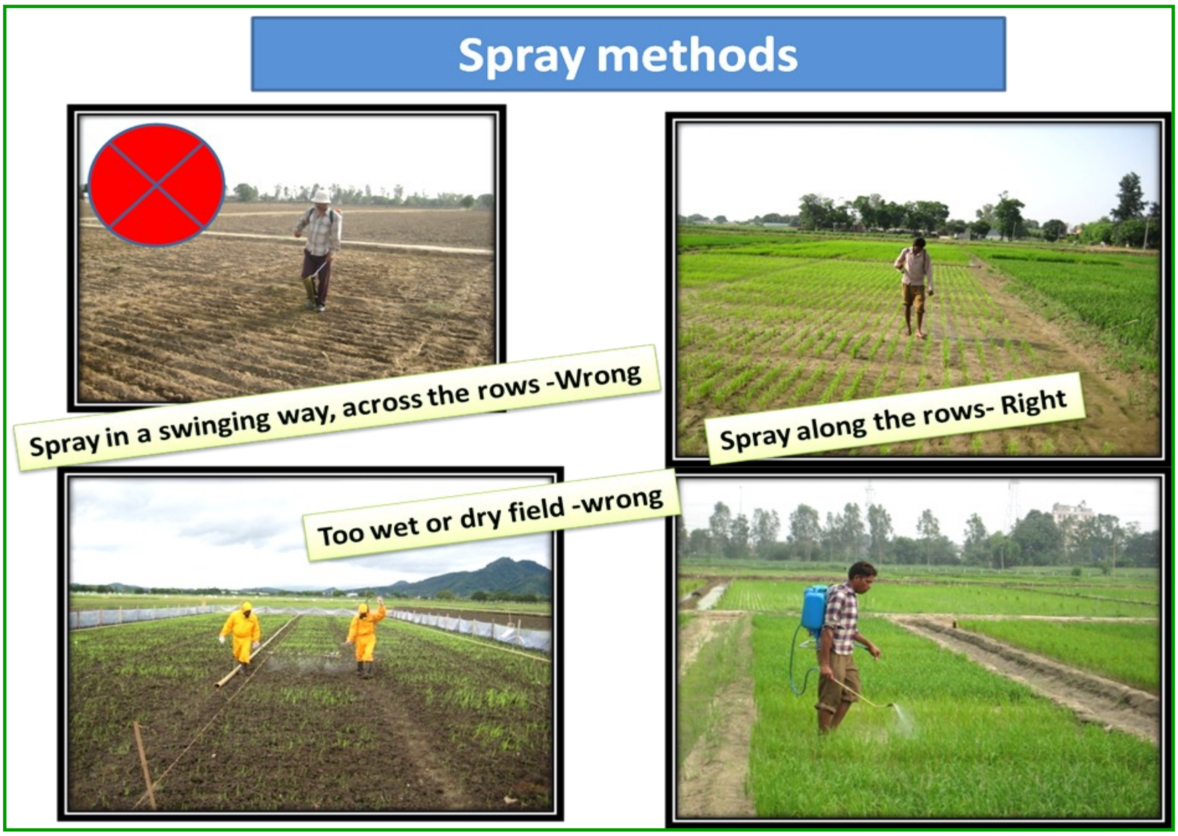
Inter-row Cultivation

Recently there are many reports about the successful adoption of dry direct seeding using a seed drill. The practice can replace transplanting without any reduction in yield. Costs are also reduced. The time taken for drilling seeds in unpuddled field using a manually-operated planter was one-third of that required for transplanting. In India, under lowland conditions, it takes about 200-250 hours ha^{-1} to hand weed depending on the weed infestation. In row seeded rice where weeds can be controlled by the use of mechanical weeders, it takes about 50-60 hours ha^{-1} depending upon weed infestation and soil conditions. Some farmers use higher seed rate to suppress weeds during the initial growth of crop. When the rice is 10-14 days old, a they do one mechanical weeding with hand hoe. Athough mechanical weeding using hand hoe or cono- weeder is tedious and time consuming, it is also common with the farmers.

Herbicides

The success of dry direct-seeded rice is dependent upon weed control with herbicides. However, herbicides should not be regarded as replacements for other weed control practices but should be used in conjunction with them. Herbicide use should coincide with the presence of sufficient weeds to warrant treatment, and take place when weeds are most vulnerable. The optimum rate depends on such factors as cultural practices, soil type and environmental conditions. Factors which must be considered when developing a herbicide program are the herbicide itself, weed flora, application method and time, crop tolerance and cost effectiveness. The use of herbicides assures effective weed control during periods of labor shortage when weeding coincides with other farm work.

Some herbicides and herbicide combinations that have shown promise for weed control in dry direct seeded rice are listed in Table. Temporary rice injury manifested as leaf chlorosis and inhibition of plant growth frequently occurs, but the rice usually recovers after two or three weeks and produces satisfactory grain yields. Recently, sequential spray of pre-emergence application of Pendimethalin (1 kg ha^{-1}) followed by Bispyribac Na (25g ha^{-1}) at 20 DAS found best for the control of weeds in dry direct seeded rice. Intensive use of herbicides in DSR is expected to increase in future. New herbicides are also costly. Therefore, for the promotion of DSR, it is necessary to understand the right application method of herbicides to save cost and for effective control of weeds. Herbi-



cides should be sprayed with cut or flat fan nozzle. Herbicides can be sprayed with knapsack, foot sprayer or pedal pump, and tractor-mounted;however knapsack sprayer are the most popular in IGP. In DSR, spray with multiple nozzle beam is advantageous, as it has flat fan nozzles and spray is tapered from the centre to the edges. This provides uniform coverage through overlapping between adjacent nozzles. Herbicide spraying with knapsack sprayer in a "swinging way" across the spray site provides poor weed control. During spray, it is important to wear boots, long trousers, rubber gloves, and goggles. Avoid eat, drink and smoke during the herbicide spray.

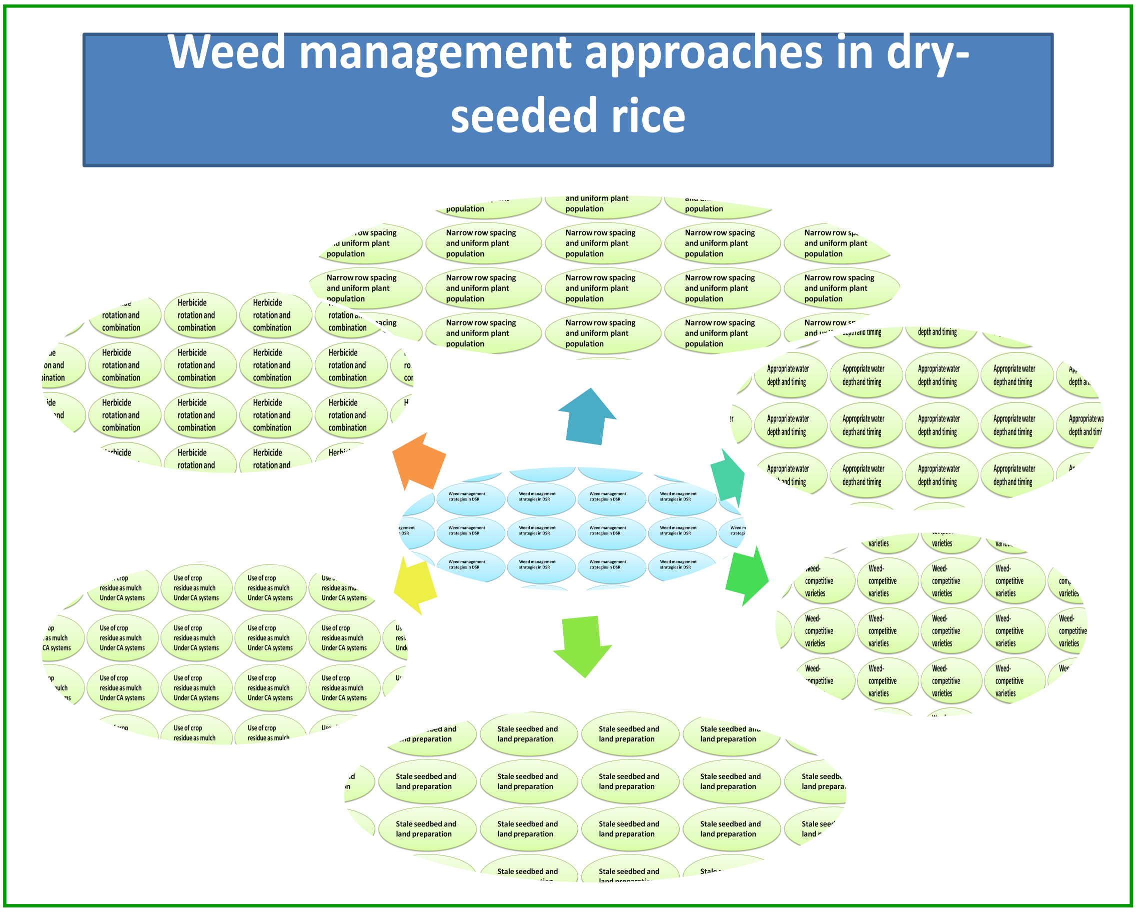
Different types of nozzles for herbicide spray

Integrated Weed Management

Herbicide use moves the agroecosystem to low species diversity with new problem weeds appearing, so that there is a need for an ecological approach to weed control instead of relying totally on chemical control methods .It was noted that reliance on a single herbicide could result in quantitative changes in the structure of the weed population in as few as five years. As weed population stresses are shifted by herbicides, weeds formerly of secondary importance emerge as primary weed problems. Such problems may be avoided by an integrated system of weed management, possibly rotation of chemicals as well as rotation of crops. Many scientists advocated the alternative usage of herbicides with different grass control spectra over seasons to prevent the emergence of tolerant weeds. Cultural and mechanical control has been the cornerstone of many pest control practices, in agriculture throughout the world. They remain the most widely used control practices in industrial and developing countries, even though many such controls have been eroded by substitution by pesticides.

Until the advent of herbicides, cultural practices through crop rotation and mechanical or hand weeding were virtually the only control mechanisms available against weeds. They remain vitally important but much more serious consideration is needed in establishing how they can be integrated with judicious herbicide use in order to help remove the single most important constraint to crop production (timely availability of labor) in many farming situations . More than for other groups of pests, farmers have many options for the control of weeds. Weed control, whether done consciously or not by farmers, is often achieved by a combination of crop production practices and specific weed management activities. Integrated weed and crop management is not a new concept so, in theory, improved techniques need not be alien to farmers. However, farmers tend to be conservative and reluctant to change traditional practices, especially if they perceive risks. Weed problem in rice has been observed to be reduced by planting cowpea during dry season, rather than keeping the field fallow.

Planting mungbean in dry season in Northern India reduced weed growth, weeding time and increased herbicide performance and rice yields in the following season as compared with the plots kept weed free by using paraquat or being maintained as weedy fallow. Direct drilling under zero tillage is advantageous as for as weed control is concerned, but severe yield penalty was noted by many worker. The practice of ZT allows the retention of previous crop residues in the field and it is well known that mulches are a good tool for weed management. Mulches normally exclude light and serve as a physical barrier to weed seedling emergence. However, efforts are underway to further improve this technique for better weed control and higher productivity. Brown manuring technique is also being utilized by many farmers for controlling weeds in dry direct seeded rice. In this technique sesbania and rice are grown together for 30 days and thereafter, sesbania will be knock down with 2,4 D, and then its brown leaves after the spray application would serve the purpose of mulch and hence smother the weed flora in rice. However, there are also reports that sesbania also suppress the rice crop.



Hazards of Herbicide Use

Despite the problems and limitations of pesticides, there can be no doubt that they are essential for the maintenance and expansion of world food production, especially in areas favorable for pest development and survival . It must never be overlooked, however, that all pesticides are toxic; they must be handled safely so as to reduce or avoid excessive and costly waste, environmental concerns, crop damage, damage to adjacent crops by spray drift, injury to the applicator, excessive contamination and residues and injury to beneficial organisms. It is advisable to rotate the herbicide combination in each year for delaying herbicide resistance .

Pest and Disease Management

Literature falls short off the information about changing pest and diseasing scenario in response to shifting from PTR to DSR. **Scientif**ic community believed that with the adoption of DSR, the incidence of pests especially leaf folder and brown plant hopper may increase. It is also expected that diseases such as brown leaf spot, sheath blight may also increases. As DSR is very sensitive to weed pressure, if weeds are not controlled properly, so this may lead to increase in incidence of sheath blight. However, some farmers believed that DSR helped in reducing in bakane diseases in basmati rice, while no systematic study has been reported for this type of incidence. Water deficit and shift from transplanting to direct seeding promoted neck blast spread (Kim, 1987). Water management directly affects the crop microclimate particularly dew deposition, which affects the lifecycle of the pathogens (Sah and Bonman, 2008), and indirectly affects crop physiology, thereby influencing host susceptibility (Bonman, 1992). Sometimes the attack of arthropod insect pests is reduced in DSR compared with TPR (Oyediran and Heiririchs, 20010, but a higher frequency of ragged stunt virus, yellow orange leaf virus, sheath blight and dirty panicle have been observed in DSR (Pongprasert,1995). The increased attack of brown spot disease and plant hoppers in DSR compared with PTR was also reported in one more study (Savary et al., 2005). The soil borne pathogenic fungus *Gaeumannomyces graminis var. graminis* has been observed in dry-seeded rice without supplemental irrigation in Brazil (Prabhu et al, 2002). The most damaging soil-borne pathogen for aerobic rice is root-knot nematode (RKN) *Meloidogyne graminicola* (MG) (Podgham et al., 2004; Sorianao and Riversat, 2003). MG is incapable of entering the rice roots under flooded conditions, although it can survive for extended periods under such conditions and attacks rice roots when aerobic conditions come up. In a study in Philippines, root knot nematodes (RKN's) were found to be most damaging pathogen for aerobic rice Apo (Kukal and Aggarwal, 2002). Heating soil at 120^0 C for 4 hr is also reported to control soil pathogens (Nie et al., 2007).

Optimum rate of nitrogenous fertilizers avoid the incidence of brown hopper and blast attack. Soil application of bio agent as *Trichoderma harzianum*@ 4 g ha-1 and *T. virens*@ 8 g ha-1 after one week of nematode infestation results in better control and optimum yield of DSR crop (Pankaj et al., 2012) .Effect of nematicides and biocides on the grain yield was studied (Kreye et al, 2009b)at flowering and root knot nematode (RKN) galling in the roots of aerobic rice and concluded that the grain yield was maximum under

DSR crop treated with biocide (nemagel or dazomet @ 50 g a.i. m-2) and less galling of root knot nematode in roots compared to DSR crop and transplanted puddle rice.

Research Gaps in DSR

Many positive benefits are claimed to have accrued from DSR including labour and energy saving, better plant stand, improved soil fertility, better water relations, soil organic matter accumulation, reduced soil compaction, increased soil biodiversity, resilience to climate change and greenhouse gas mitigation, all of which interact in an intricate manner to increase rice productivity and systems' sustainability under irrigated ecology of north-west India. There are many potential benefits of dry-seeded rice not only for improving labour and water productivity with many off-farm benefits, but also to enhance food security for millions of people in India due to increased rice productivity. However, weeds, nutrient management including tolerance to new biotic and abiotic stresses need to be overcome on priority for its sustainability.

The shift in weed flora, reduced sink size, appearance of volunteer rice seedlings and poor crop emergence particularly when the field is not levelled, and rain occurs immediately after sowing are the main obstacles to the promotion of DSR. There is an urgent need to develop criteria for identifying traits that are likely to be most helpful for weed management in direct seeding include seed germination in anaerobic conditions and tolerance of early submergence for uniform crop establishment, high and early seedling vigour with rapid leaf area development during the early vegetative stage for weed suppression, cultivars having an allelopathic effect, and herbicide-resistant rice cultivars.

Research efforts are also needed to fill the physiological gaps for improved nutrient uptake under moisture stress so that sink size in DSR could be increased. Grain filling in DSR is limited by a low contribution of post-anthesis assimilates. In addition, in the absence of transplanting, the roots of DSR are located in the shallow surface soil, which results in a relatively low uptake of N. The need of the hour is to find agronomic tools for identifying nutrient-efficient genotypes to augment improved and sustainable agro-management options in DSR.

The major concern of low to moderate nutrient-use efficiency in rice that ranged between 25-40% for nitrogen (N) and phosphorus (P) needs to be addressed. Water mining or maximization of water uptake from deeper layers of the soils is one of the most important mechanisms in DSR. The roots play a pivotal role in water and nutrient uptake, and act as sensors of water and nutrient status of the soil. During the interval between two rainfall event and irrigation, efficiency with which plant extracts soil moisture from deep layers is critical for maintenance of water and nutrient requirements of crops. Agronomic efforts are needed to improve yield stability under theses stresses in DSR. Sufficient root length and surface area in deep soil layer is currently the most accepted target trait for improving water use efficiency in DSR. This project will focus on root zone investigation to find agronomic cues to promote root zone development and resistance to lodging under low moisture in the soil. Agronomic efforts are also needed to reduce the evapo-transpiration losses with the help of soil amendments for high water use efficiency in DSR.

Besides low water availability, availability of nutrients such as nitrogen, phosphorous and iron is also low in DSR. Attempts would be made in identifying genotypes or for improving the plasticity of genotypes with better root system can acquire N, P and Fe better and thus yield better.

There is a need to understand the photosynthetic characteristics of rice genotypes adapted to DSR with different N use efficiency (NUE) and explain the difference of N absorption and utilization between N-efficient and N-inefficient rice. Some recent studies suggested that, at high N levels, some rice cultivars could absorb more NO_2 than NH_4^+. This is important in dry- direct seeded rice because rice roots can aerate rhizosphere by releasing oxygen (O_2), and this activity promotes the process of nitrification, that is, the conversion of ammonium to nitrate. So there is a need to evaluate the difference in NUE among different rice cultivars, by determining nitrate uptake efficiency and the activities of key enzymes supporting the N-assimilation pattern. There is a need to determine the physiological basis of variability in N-efficient and N-inefficient cultivars.

Compared to other graminaceous plants, rice secretes a very low amount of deoxymugineic acids as a phytosiderophore even under Fe deficiency, which is the main cause for the high sensitivity of rice to Fe deficiency (Mori et al., 1991). Sometimes severe chlorosis in rice due to Fe-deficiency has led to complete failure of the rice crop (Katyal and Sharma, 1980). This problem is aggravated in DSR, because Fe from the soil is not available in reduced form. So, strong agronomic and breeding efforts are needed to overcome this issue.

Most reports claim lower emission of methane gas under DSR compared to traditional practices of puddled transplanted rice (Corton et al., 2000; Harada et al., 2007). Although DSR can reduce CH_4 emissions, relatively more soil aerobic condition can also increase N_2O emissions. Nitrous oxide production increases at redox potentials above 250 mV (Hou et al., 2000). So, there is need to deploy strategies to reduce N_2O emissions from DSR for minimizing adverse impacts on the environment. This trade-off between CH_4 and N_2O emission is a major hurdle in addressing global warming risks. So, strategies must be devised to reduce emissions of both CH_4 and N_2O simultaneously in DSR.

This project will focus on developing agronomic and water management practices in such a way that soil redox potential can be kept at intermediate range (-100 to +200 mV) to minimize emissions of both CH_4 and N_2O in DSR.

However, there is a paucity of experimental data to support many of these gaps. Therefore, it is essential to fill this information gap through research in order to develop optimal management practices for DSR to be adapted according to local needs and conditions on long term basis. This will provide sound scientific basis to conduct research for developing effective and sustainable agronomic practices for DSR in NW-IGP, and establish appropriate information systems to support better decision making. There is demonstrated need for research at both strategic and applied levels involving a holistic approach to arrest these issues.

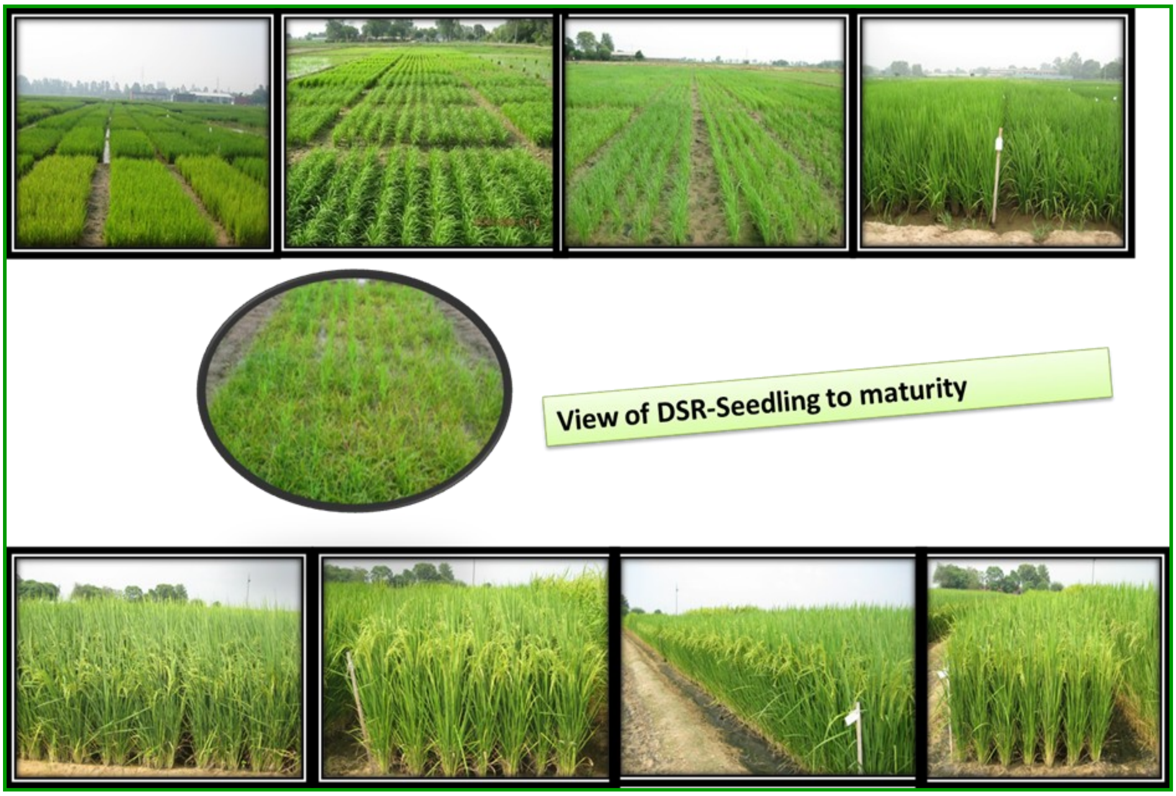

Glimpses of DSR survey in Punjab

Conclusions

Dry seeding of rice is an emerging production system in Pun-jab and other parts of N-W IGP. The looming water crisis and growing shortage of labor dictate the need for the following changes in DSR. Large-scale adoption of DSR is possible; however, prioritizing resources and public–private partnership are the keys to success. The success of DSR depends primarily on precise land leveling using laser levelers, good-quality drills fitted with improved seed-metering systems, and trained tractor and pesticide operators. The manipulation of seeding depth is important and it varies according to soil types and moisture levels.

Short-duration cultivars, hybrids, and basmati rice perform better under dry seeding but tailoring cultivars for dry seeding is needed for further productivity gains in DSR. Almost all farmers emphasized that weeds were the number-one problem in DSR. Pre- and postemergence herbicide applications are a must for effective weed management; however, the choice of herbicides depends upon dominant weed flora. To delay herbicide resistance in weeds, there is a need to integrate different weed management strategies to effectively and sustainably man-age weeds in DSR. Effective weed management in DSR depends on the timing and method of land preparation, effectiveness of herbi-cides relative to the dominant weed species and soil conditions at the time of application, and the effect of weather on weeds.

Weed surveillance in different zones may also prove beneficial in selecting suitable

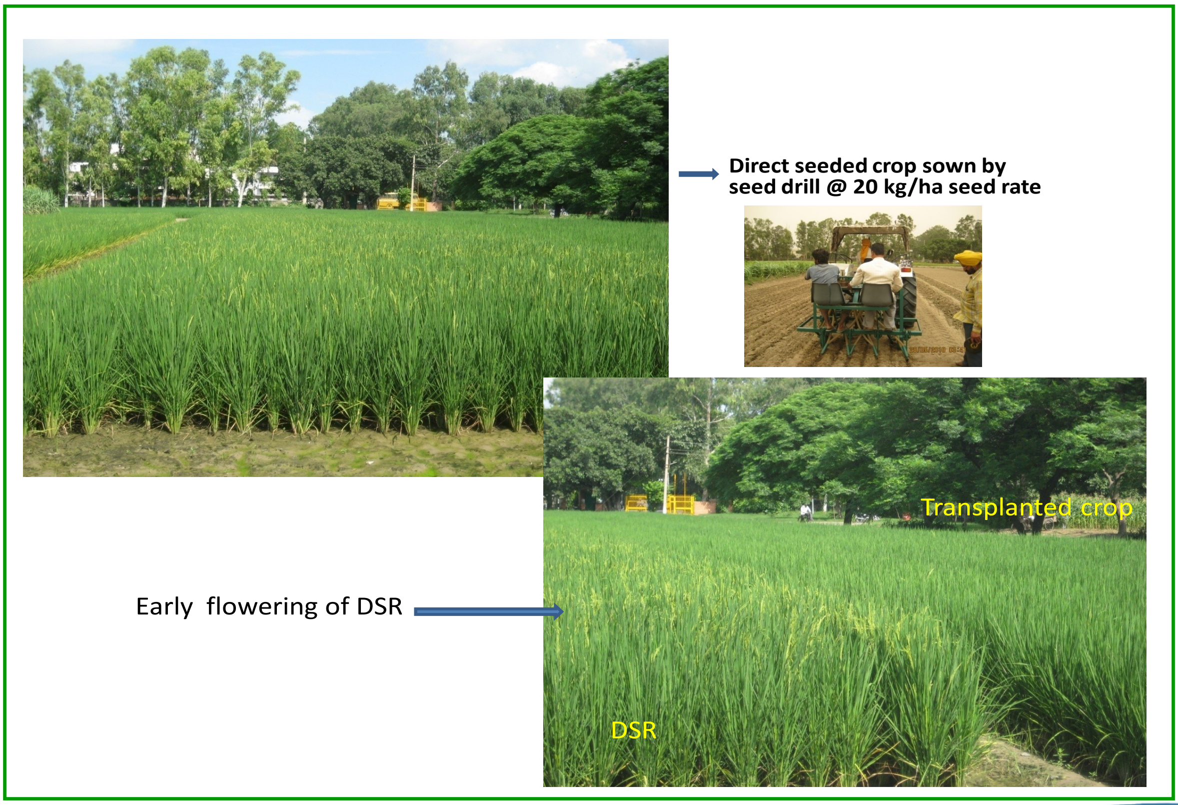


herbicides and weed management strategies in a region. The incidence of foot rot and false smut was less in DSR; however, the occurrence of brown leaf spot and sheath blight was common in many farmers' fields. In DSR-based cropping systems, there may be positive effects on the yields of succeeding crops (e.g., wheat or corn) due to the absence of a hard pan. Since DSR does not suffer from transplanting shock and takes 7–10 days less to maturity than a transplanted crop, it is easy to incorporate DSR in different cropping systems and this may help in recharging the groundwater table. Water savings in DSR vary across management practices, soil types, etc., but optimization of water savings needs to be evaluated in a way so as to avoid any yield penalty from water stress. The appearance of vol-unteer rice seedlings and poor crop emergence where rain occurs immediately after sowing are the main obstacles to the promotion of DSR.

Tips for improving the productivity direct seeded rice

- Grow DSR in heavy to medium textured soil
- Do laser levelling in the field
- For high quality and crop water productivity in DSR, non basmati cultivars should be sown in the fortnight of June and basmati cultivars should be sown in the second fortnight of June.
- Crop should be sown with direct seeded rice drill having seed metering device/ inclined plates planter
- In medium textured soil, do the sowing in dry condition, and irrigate the field immediately. In such soil, *vattar* conditions came 3 days after sowing (DAS) and apply pre-emergence herbicide with in 3 DAS.
- In heavy soil, prefer to sow the crop in *vattar* condition. In heavy soil, *vattar* condition does not come within 3 DAS if irrigation immediately followed after dry seeding, so in such soil, it is advisable to sow the crop in *vattar* condition and apply pre-emergence herbicide immediately after sowing in order to utilize the available moisture for increasing the efficacy of pre-emergence herbicide.
- Optimum seed rate for DSR is 15-30 kg ha^{-1}.
- Seeds should be primed with water for 10-12 h before sowing.
- Seeding depth should be approximately 2-3 cm.
- Row spacing for DSR is about 20 cm.
- Sequential spray of pre-emergence application of pendimethalin (Stomp) 30 EC (1000 ml/acre) 3 days after sowing followed by bispyribac (Nominee gold) 10 SC (100 ml/acre) at 20-30 days after sowing are recommended for effective control of weeds in DSR. Bispyribac is not effective against *Leptochloa*, but pendimethalin effectively controlled *Leptochloa*.

- For more effective control of *Leptochloa*, Pyrasufuron ethyl 10 WP (60 g/acre) can also be used as an alternative of Pendimethalin.
- If there is severe problem of *Cyperys rotundus* and broad leaf weeds in the field, then prefer to use Azimsulfuron 50 DF (16g/acre) as an alternative of Bispyribac.
- Herbicide spray should be done with flat fan nozzle. Selection of wrong nozzle may give the poor results of weed control. Do not spray the herbicide in a "swinging" way.
- Use 200 litre water/acre and for post- emergence application of herbicide and use 150 litre water/acre for making spray solution.
- Adequate and timely application of fertilizer is a prerequisite for higher yield of direct seeded rice. For medium duration cultivar (140 d), N should be applied in 4-splits (15, 30, 45, 60 days after sowing). Fertilizers should be applied on soil test basis.
- First irrigation in heavy textured soil and second irrigation in medium textured soil should be applied at 5-6 DAS, afterwards next irrigation should be given at a 15 DAS and thereafter crop should be irrigated at 4-5 days interval depending upon the soil and climatic conditions.



References

Blanche B, Harrell D, Saichuk J (2009) General Agronomic Guidelines. In "Louisiana rice production handbook 2009" (J. Saichuk, eEd.), pp. 3–15, Pub. 2321 (3M) 6/09 Rev

Gopal R, Jat RK, Malik RK, Kumar V, Alam MM, Jat ML, Mazid MA, Saharawat YS, McDonald A, Gupta R (2010) Direct Dry Seeded Rice Production Technology and Weed Management in Rice Based Systems. Technical Bulletin. International Maize and Wheat Improvement Center, New Delhi, India, 28pp

Kamboj BR, Kumar A, Bishnoi DK, Singla K, Kumar V, Jat ML, Chaudhary N, Jat HS, Gosain DK, Khippal A, Garg R, Lathwal OP, Goyal SP, Goyal NK, Yadav A, Malik DS, Mishra A, Bhatia R (2012) Direct Seeded Rice Technology in WesternIndo-Gangetic Plains of India : CSISA Experiences. CSISA, IRRI and CIMMYT. 16 pp.

Basra SMA, Farooq M, Tabassum R, Ahmad N (2005) Physiological and biochemical aspects of seed vigor enhancement treatments in fine rice. Seed Sci. Technol. 33:623–628

Farooq M, Basra SMA, Afzal I, Khaliq A (2006c) Optimization of hydro-priming techniques for rice seed invigoration. Seed Sci. Technol. 34:507–512

Harris D, Joshi A, Khan PA, Gothkar P, Sodhi PS (1999) On-farm seed priming in semi-arid agriculture: development and evaluation in maize (*Zea mays* L.), rice (*Oryza sativa*) and chickpea (*Cicer arietinum*) in India using participatory methods. Exp. Agric. 35:15–29

Farooq M, Basra SMA, Wahid A (2006a) Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. Plant Growth Regul. 49:285–294

Farooq M, Basra SMA, Tabassum R, Afzal I, (2006b) Enhancing the performance of direct seeded fine rice by seed priming. Plant Prod. Sci. 9:446–456

Farooq M, Basra SMA, Hafeez K (2006d) Seed invigoration by osmo-hardening in coarse and fine rice. Seed Sci. Technol. 34:181–187

Farooq M, Basra SMA, Karim HA, Afzal I (2004) Optimization of seed hardening techniques for rice seed invigoration. Emirates J. Agric. Sci. 16:48–57

Gupta RK, Ladha JK, Singh S, Singh RJ, Jat ML, Saharawat Y, Singh VP, Singh SS, Sah G, Gill MS, Alam M, Mujeeb H, Singh UP, Mann R, Pathak H, Singh BS, Bhattacharya P, Malik RK (2006) Production technology for direct seeded rice. In: Rice Wheat Consortium Technical Bulletin 8, New Delhi, India.

Kreye C, Bouman BAM, Reversat G, Fernandez L, Vera Cruz C, Elazegui F, Faronilo JE, Llorca L (2009b) Biotic and abiotic causes of yield failure in tropical aerobic rice. Field Crops Res. 112:97–106

Farooq M, Siddique KHM, Rehman H, Aziz T, Dong-Jin Lee, Wahid A (2011) Rice direct seeding: Experiences, challenges and opportunities. Soil & Tillage Research 111: 87 –98

Mohanasarida K, Mathew J (2005a) Seed priming effect on crop establishment and seedling vigor in semi-dry rice (Oryza sativa L.). Res. Crops 6:23–25

WARDA (2002) In: Jones MP, WopereisPura M, Bouake Cote d'Ivoire (Eds.), Participatory Varietal Selection: Beyond the Flame. West Africa Rice Development Association WARDA)

Kim CK (1987) Disease dispersal gradients of rice blast from point source. Korean. J. Plant Prot. 3:131–136

Sah DN, Bonman JM (2008) Effects of seedbed management on blast development in susceptible and partially resistant rice cultivars. J. Phytopathol. 136:73–81

Bonman JM (1992) Durable resistance to rice blast disease-environmental influences. Euphytica 63:115–123

Oyediran IO, Heinrichs EA (2001) Arthropod populations and rice yields in direct seeded and transplanted lowland rice in West Africa. Int. J. Pest Manage. 47:195–200

Pongprasert S (1995) Insect and disease control in wet-seeded rice in Thailand. In: Moody K (eEd.), Constraints, Opportunities, and Innovations for Wet-seeded Rice, Discussion Paper Series No. 10. International Rice Research Institute, Los Bano˜s, Philippines, pp. 118–132

Savary S, Castilla NP, Elazegui FA, Teng PS (2005) Multiple effects of two drivers of agricultural change, labour shortage and water scarcity, on rice pest profiles in tropical Asia. Field Crops Res. 91:263–271

Prabhu AS, Filippi MC, Araujo LG, Faria JC (2002) Genetic and phenotypic characterization of isolates of *Pyricularia grisea* from the rice cultivars Epagri 108 and 109 in the State of Tocantins. Fitopatologia Brasileira 27:566–573

Padgham JL, Duxbury JM, Mazid AM, Abawi GS, Hossain M (2004) Yield losses by *Meloidogyne graminicola* on lowland rainfed rice in Bangladesh. J. Nematol. 36:42–48

Soriano IR, Reversat G (2003) Management of *Meloidogynaegraminocola* and yield of upland rice in South-Luzon, Philippines. Nematology 5:879–884

Kukal SS, Aggarwal GC (2002) Percolation losses of water in relation to puddling intensity and depth in a sandy loam rice (*Oryza sativa*) field. Agric. Water Manag. 57:49–59

Nie L, Peng S, Bouman BAM, Huang J, Cui K, Visperas RM, Park HK (2007). Alleviating soil sickness caused by aerobic mono-cropping: Response of aerobic rice to soil over-heating. Plant Soil 300:185–195

Pankaj, Ganguly AK, Kumar Harender (2012) Root knot Nematode, *Meloidogyne graminicola*: A key nematode pest of rice. Technical bulletin (TB ICN: 90/2012) IARI, New Delhi, pp16

Kreye C, Bouman BAM, Reversat G, Fernandez L, Vera Cruz C, Elazegui F, Faronilo JE, Llorca L (2009b) Biotic and abiotic causes of yield failure in tropical aerobic rice. Field Crops Res. 112:97–106

Khush, G. S. (2004). Harnessing science and technology for sustainable rice-based production systems. Proceedings of FAO Rice Conference “Rice is life”. Int. Rice Comm. Newsl. 53, 17–23.

Rodell, M., Velicogna, I., and Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. Nature 460, 999–1002.

UC Irvine (University of California—Irvine (2009). Satellites unlock secret to northern India's vanishing water. Science Daily, www.sciencedaily.com/releases/2009/08/ 090812143938.htm(accessed 13 October 2009).

GOI (Government of India) (2011). The Mahatma Gandhi National Rural Employment Guarantee Act 2005. Ministry of Rural Development, Government of India. Online available at: http://nrega.nic.in/netnrega/home.aspx (Accessed on 28 March 2011).

Balasubramanian, V., and Hill, J. E. (2002). Direct seeding of rice in Asia: Emerging issues and strategic research needs for the 21st century. In "Direct Seeding: Research Strategies and Opportunities" (S. Pandey, M. Mortimer, L. Wade, T. P. Tuong, K. Lopez, and B. Hardy, Eds.), pp. 15–39. International Rice Research Institute, Los Ban˜ os, Philippines.

Dawe, D. (2005). Increasing water productivity in rice-based systems in Asia—Past trends, current problems, and future prospects. Plant Prod. Sci. 8, 221–230.

Jat, M. L., Chandna, P., Gupta, R., Sharma, S. K., and Gill, M. A. (2006). Laser land leveling: A precursor technology for resource conservation. In "Rice-Wheat Consortium Technical Bulletin 7. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India," 48 p.

Jat, M. L., Gathala, M. K., Ladha, J. K., Saharawat, Y. S., Jat, A. S., Vipin, Kumar, Sharma, S. K., Kumar, V., and Gupta, R. K. (2009). Evaluation of precision land leveling and double zero-till systems in the rice-wheat rotation: Water use, productivity, profitability and soil physical properties. Soil Till. Res. 105, 112–121.

Kahlown, M. A., Raoof, A., Zubair, M., and Kemper, W. D. (2007). Water use efficiency and economic feasibility of growing rice and wheat with sprinkler irrigation in the Indus Basin of Pakistan. Agric. Water Manage. 87, 292–298.

Rickman, J. F. (2002). Manual for Laser Land Leveling. Rice–Wheat Consortium Technical Bulletin Series 5. In "Rice–Wheat Consortium for the Indo-Gangetic Plains," New Delhi, India, 24 p.

Bouman, B. A. M., and Tuong, T. P. (2001). Field water management to save water and increase its productivity in irrigated rice. Agric. Water Manage. 49, 11–30.

Humphreys, E., Kukal, S. S., Christen, E. W., Hira, G. S., Balwinder-Singh, Sudhir-Yadav, and Sharma, R. K. (2010). Halting the groundwater decline in north-west India—Which crop technologies will be winners? Adv. Agron. 109, 155–217.

Bouman, B. A. M., Peng, S., Castan˜eda, A. R., and Visperas, R. M. (2005). Yield and water use of irrigated tropical aerobic rice systems. Agric. Water Manage. 74, 87–105.

Ismail, A. M., Ella, E. S., Vergara, G. V., and Mackill, D. J. (2009). Mechanisms associated with tolerance to flooding during germination and early seedling growth in rice (Oryza sativa). Ann. Bot. 103, 197–209.

Redon˜ a, E. D., and Mackill, D. J. (1996). Mapping quantitative trait loci for seedling vigor in rice using RFLPs. Theor. Appl. Genet. 92, 395–402.

Dilday, R. H., Mgonja, M. A., Amonsilpa, S. A., Collins, F. C., and Well, B. R. (1990). Plant height vs. mesocotyl and coleoptile elongation in rice: Linkage or pleiotropism? Crop Sci. 30, 815–818.

Fukai, S. (2002). Rice cultivar requirement for direct-seeding in rainfed lowlands. In “Direct seeding: Research strategies and opportunities”. (S. Pandey, M. Mortimer, L. Wade, T. P. Tuong, K. Lopez, and B. Hardy, Eds.), Proceedings of the International Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities, 25–28, January 2000, pp. 15–39.

Turner, F. T., Chen, C. C., and Bollich, C. N. (1982). Coleoptile and mesocotyl length in semi-dwarf rice seedlings. Crop Sci. 22, 43–46.

Cousens, R. D. (1996). Comparative growth of wheat, barley, and annual ryegrass (Lolium rigidum) in monoculture and mixture. Aust. J. Agric. Res. 47, 449–464.

Dingkuhn, M., Johnson, D. E., Sow, A., and Audebert, A. Y. (1999). Relationships between upland rice canopy characteristics and weed competitiveness. Field Crops Res. 61, 79–95.

Caton, B. P., Cope, A. E., and Mortimer, M. (2003). Growth traits of diverse rice cultivars under severe competition: Implications for screening for competitiveness. Field Crops Res. 83, 157–172.

Chavez, R. S. C. (1989). Cultivar competitiveness and weed control in upland rice. M.Sc. Thesis. University of Philippines, Los Ban˜ os, College, Laguna, Philippines.

Fischer, A. J., Ramirez, H. V., Gibson, K. D., and Pinheiro, B. D. S. (2001). Competitiveness of semidwarf upland rice cultivars against palisadegrass (Brachiaria brizantha) and signalgrass (B. decumbens). Agron. J. 93, 967–973.

Garrity, D. P., Movillon, M., and Moody, K. (1992). Differential weed suppression ability in upland rice cultivars. Agron. J. 84, 586–591.

Haefele, S. M., Johnson, D. E., M'bodj, D. M., Wopereis, M. C. S., and Miezan, K. M. (2004). Field screening of diverse rice genotypes for weed competitiveness in irrigated lowland ecosystems. Field Crops Res. 88, 39–56.

Quintero, S. H. (1986). Competitive ability of different upland rice cultivars against weeds. M.S. thesis. University of the Philippines, Los Ban˜ os, College, Laguna, Philippines.

Jannink, J. L., Orf, J. H., Jordan, N. R., and Shaw, R. G. (2000). Index selection for weed-suppressive ability in soybean. Crop Sci. 40, 1087–1094.

Zhao, D. L., Atlin, G. N., Bastiaans, L., and Spiertz, J. H. J. (2006). Cultivar weed competitiveness in aerobic rice: Heritability, correlated traits, and the potential for indirect selection in weed-free environment. Crop Sci. 46, 372–380.

Jordan, N. (1993). Prospects for weed control through interference. Ecol. Appl. 3, 84–91.

Pal, S., Datta, S. P., Rattan, R. K., and Singh, A. K. (2008). Diagnosis and amelioration of iron deficiency under aerobic rice. J. Plant Nutr. 31, 919–940.

Castin, E. M., and Moody, K. (1989). Effect of different seeding rates, moisture regimes, and weed control treatments on weed growth and yield of wet-seeded rice. In "Proceedings of the 12th Asian-Pacific Weed Science Society Conference, Seoul, Korea", pp. 337–343.

Wells, B. R., and Faw, W. F. (1978). Short-statured rice response to seeding and N rates. Agron. J. 70, 477–480.

Jones, D. B., and Snyder, G. H. (1987). Seeding rate and row spacing effects on yield and yield components of drill-seeded rice. Agron. J. 79, 623–626.

Gravois, K. A., and Helms, R. S. (1992). Path analysis of rice yield and yield components as affected by seeding rate. Agron. J. 84, 1–4.

Gopal, R., Jat, R. K., Malik, R. K., Kumar, V., Alam, M. M., Jat, M. L., Mazid, M. A., Saharawat, Y. S., McDonald, A., and Gupta, R. (2010). Direct Dry Seeded Rice Production Technology and Weed Management in Rice Based Systems. Technical Bulletin. International Maize and Wheat Improvement Center, New Delhi, India, 28pp.

Gupta, R. K., Ladha, J. K., Singh, S., Singh, R., Jat, M. L., Saharawat, Y., Singh, V. P., Singh, S. S., Singh, G., Sah, G., Gathala, M., Sharma, R. K., et al. (2006). Production Technology for Direct Seeded Rice. Technical Bulletin Series 8. In "Rice–Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India," 14pp.

Sudhir-Yadav, Gill, M. S., and Kukal, S. S. (2007). Performance of direct-seeded basmati rice in loamy sand in semi-arid sub-tropical India. Soil Till. Res. 97, 229–238.

Wu, Y., Xin He, P., ChangHui, Ge, Xun, S. Jian, Liang, S., andWan Gen, K. (2008). A study on suitable sowing date and sowing rate of a new late japonica hybrid rice combination Bayou 52 in no-tillage and direct seeding cultivation. Hybrid Rice 23, 48–50.

Johnson, D. E., White, J. L., and Mortimer, M. (2003). Development of sustainable weed management systems in direct seeded, irrigated rice Final technical report, the United Kingdom Department for International Development (DFID): Crop Protection Program-Project-R7377/ZA0299. Natural Resources Institute, University of Greenwich, Chatham, Kent. 55pp.

Xie, G. H., Yu, J., Wang, H., and Bouman, B. A. M. (2008). Progress and yield bottleneck of aerobic rice for the North China Plains: A case study of varieties Handao 297 and Handao 502. Agric. Sci. China 7, 641–646.

Farooq, M., Basra, S. M. A., and Wahid, A. (2006a). Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. Plant Growth Regul. 49, 285–294.

Farooq, M., Basra, S. M. A., Tabassum, R., and Afzal, I. (2006b). Enhancing the performance of direct seeded fine rice by seed priming. Plant Prod. Sci. 9, 446–456.

Gupta, R. K., Ladha, J. K., Singh, S., Singh, R., Jat, M. L., Saharawat, Y., Singh, V. P., Singh, S. S., Singh, G., Sah, G., Gathala, M., Sharma, R. K., et al. (2006). Production Technology for Direct Seeded Rice. Technical Bulletin Series 8. In "Rice–Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India," 14pp.

De Datta, S. K. (1981). Principles and Practices of Rice Production. John Wiley and Sons, New York, 618pp.

Prasad, R. (2005). Rice–wheat cropping systems. Adv. Agron. 86, 255–339.

Xie, G. H., Yu, J., Wang, H., and Bouman, B. A. M. (2008). Progress and yield bottleneck of aerobic rice for the North China Plains: A case study of varieties Handao 297 and Handao 502. Agric. Sci. China 7, 641–646.

Bouman, B. A. M., Lampayan, R. M., and Tuong, T. P. (2007). Water Management in Irrigated Rice: Coping with Water Scarcity. International Rice Research Institute, Los Ban˜ os, Philippines, 54p.

Bhushan, Lav, Ladha, J. K., Gupta, R. K., Singh, S., Tirol-Padre, A., Saharawat, Y. S., Gathala, M., and Pathak, H. (2007). Saving of water and labor in rice-wheat systems with no-tillage and direct seeding technologies. Agron. J. 99, 1288–1296.

Gathala, M. K., Ladha, J. K., Kumar, V., Saharawat, Y. S., Kumar V., Sharma, P. K., Sharma, S., and Pathak, H. (2011). Tillage and crop establishment affects sustainability of South Asian rice-wheat system. Agron. J. (In press).

Sudhir-Yadav, Gurjeet, Gill, Humphreys, E., Kukal, S. S., and Walia, U. S. (2011a). Effect of water management on dry seeded and puddled transplanted rice. Part 1. Crop performance. Field Crops Res. 120, 112–122.

Sudhir-Yadav, Humphreys, E., Kukal, S. S., Gurjeet, Gill, and Rangarajan, R. (2011b). Effect of water management on dry seeded and puddled transplanted rice. Part 2. Water balance and water productivity. Field Crops Res. 120, 123–132.

Jalota, S. K., and Arora, V. K. (2002). Model-based assessment of water balance components under different cropping systems in north-west India. Agric. Water Manage. 57, 75 –87.

Spanu, A. G., Andria, P. R., Lavini, A., and Chiranda, F. Q. (1996). Yield response of rice to increasing sprinkler irrigation. J. Int. Commun. Drain. 45, 56–66.

Sharma, S. K. (1984). Principles and Practices of Irrigation. Oxford and IBH Publication Co., New York.

Kato, Y., Okami, M., and Katsura, K. (2009). Yield potential and water use efficiency of aerobic rice (Oryza sativa L.) in Japan. Field Crops Res. 113, 328–334.

Hira, G.S., 2009. Water management in northern states and the food security of India. J. Crop Improv. 23, 136–157.

Mahajan, G., Timsina, J., Singh, K., 2011c. Performance and water use efficiency of rice relative to establishment methods in northwestern Indo-Gangetic Plains. J. Crop Improv. 25, 597–617.

Zhang, L., S. Lin, B.A.M. Bouman, C. Xue, F. Wei, H. Tao, X. Yang, H. Wang, D. Zhao, and K. Dittert. 2009. Response of aerobic rice growth and grain yield to N fertilizer at two contrasting sites near Beijing, China. Field Crops Res. 114:45–53.

Atlin, G.N., H.R. Lafitte, D. Tao, M. Laza, M. Amante, and B. Courtois. 2006. Developing rice cultivars for high fertility upland systems in the Asian tropics. *Field Crops Res.* 97:43–52.

Mahajan, G., T.S. Bharaj, and J. Timsina 2009. Yield and water productivity of rice as affected by time of transplanting in Punjab, India. *Agric. Water Manage.* 96:525–533.

Mahajan, G., Chauhan, B.S., Gill, M.S., 2011a. Optimal nitrogen fertilization timing and rate in dry-seeded rice in northwest India. Agron. J. 103, 1676–1682.

Römheld V, Marschner H. 1990. Genotypical differences among graminaceous speci e s in release of phytosiderophores and uptake of iron phytosiderophores . *Plant and Soil*, **123**, 147-153.

Mori S, Nishizawa N, Hayashi H, Chino M, Yoshimur E, Ishihara J. 1991. Why are young rice plants highly susceptible to iron deficiency? *Plant and Soil*, **130**, 143-156.

Peng, S., Bouman, B. A. M., Visperas, R. M., Castan˜eda, A., Nie, L., and Park, H.-K. (2006). Comparison between aerobic and flooded rice in the tropics: Agronomic performance in an eight-season experiment. Field Crops Res. 96, 252–259.

Mori, S., Nishizawa, N., Hyashi, H., Chino, M., Yoshimura, E., and Ishihara, I. (1991). Why are young rice plants highly susceptible to iron deficiency. Plant Soil 130, 143–156.

Synder, G. H., and Jones, D. B. (1991). Post-emergence treatment of iron-related rice seedling chlorosis. Plant Soil 138, 313–317.

Singh, K., Sharma, H. C., Sarangi, S. K., and Sudhakar, P. C. (2003). Iron nutrition in rice. Fertil. News 48(2), 21–39.

Pal, S., Datta, S. P., Rattan, R. K., and Singh, A. K. (2008). Diagnosis and amelioration of iron deficiency under aerobic rice. J. Plant Nutr. 31, 919–940.

Katyal, J. C., and Sharma, B. D. (1980). A new technique of plant analysis to resolve iron chlorosis. Plant Soil 130, 143–156.

Naidu, B. S., Mahadevappa, M., Inamdar, S. S., Mahapatra, K., and Jayaram (1981). Performance of IR36 in Karnataka, India. Int. Rice Res. Newsl. 6(4), 4.

Romyen, P., S. Khunthasuvon, and S. Fukai. 2002. Managing direct seeding for rainfed lowland rice with particular attention to weed control. In Direct seeding: Research strategies and opportunities, ed. S. Pandey, M. Mortimer, L. Wade, T. P. Tuong, K. Lopez, and B. Hardy, 369–80. Los Banos, Philippines: International Rice Research Institute.

Gibson, K. D., J. E. Hill, T. C. Foin, B. P. Caton, and A. J. Fischer. 2001. Water seeded rice cultivars differ in ability to interfere with watergrass. *Agron J* 93:326–32.

De-Datta, S.K. 1981. Principles and practices of rice production. Int. Rice Res. Inst., Los Baños, Philippines.

Bouman, B.A.M., A.R. Castañeda, and S.I. Bhuiyan. 2002. Nitrate and pesticide contamination of ground-water under rice-based cropping systems: Evidence from the Philippines. Agric. Ecosyst. Environ. 92:185–199. doi:10.1016/S0167-8809(01)00297-3

Prasad, R. 2011. Aerobic rice systems. Adv. Agron. 111:207–246. doi:10.1016/B978-0-12-387689-8.00003-5

Zhang, Q.C., and G.H. Wang. 2002. Optimal nitrogen application for direct seeding early rice. Chin. J. Rice Sci. 16:346–350.

Malvolta, E. (1983). Potassium status of tropical and sub-tropical soils. In "Potassium in Agriculture" (R. D. Munson, Ed.), pp. 163–200. Am. Soc. Agron. Madison, WI, USA.

Fageria, N.K. 2010. Optimal nitrogen fertilization timing for upland rice. p. 176–179. *In* 19th World Con-gress of Soil Science, Soil Solution for a Changing World, Brisbane, Australia. 1–6 Aug. 2010.

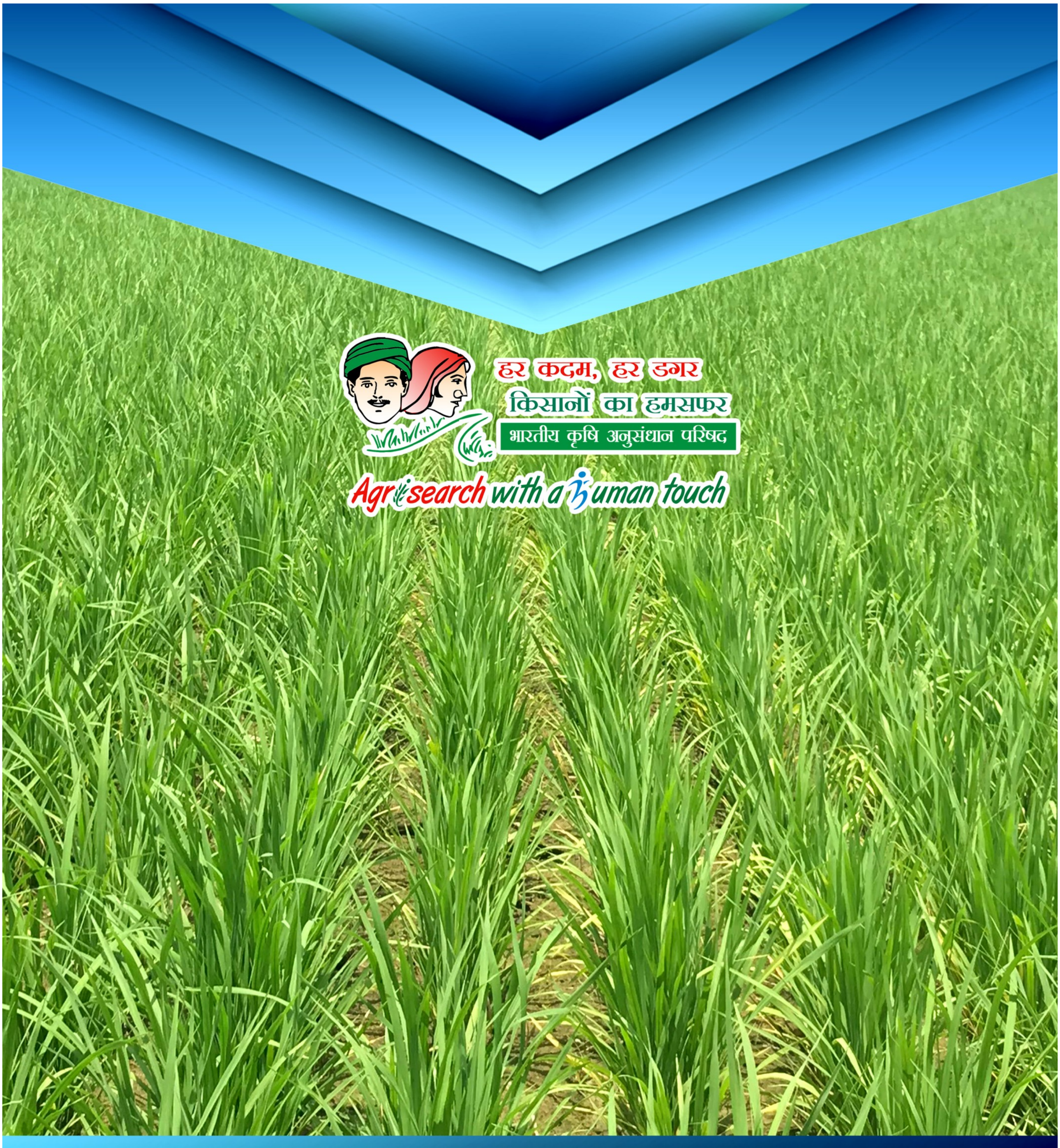
Lampayan, R.M., B.A.M. Bouman, J.L. de Dios, A.J. Espiritu, J.B. Soriano, A.T. Lactaoen, J.E. Faronilo, and K.M. Thant. 2010. Yield of aerobic rice in rainfed lowlands of the Philippines as affected by nitrogen management and row spacing. Field Crops Res. 116:165–174. doi:10.1016/j.fcr.2009.12.007

Belder, P., Bouman, B. A. M., Spiertz, J. H. J., Peng, S., Castaneda, A. R., and Visperas, R. M. (2005). Crop performance, nitrogen and water use in flooded and aerobic rice. Plant Soil 273, 167–182.

Cassman, K.G., Dobermann, A., Walters, D.T., 2002. Agroecosytems, nitrogen use efficiency and nitrogen management. AMBIO. J. Human Environ. 31, 132–140.

Bijay-Singh, Sekhon, G.S., 1997. Nitrate pollution of groundwater from farm use of nitrogen fertilisers—a review. Agric. Environ. 4, 207–225.

Bijay-Singh, Yadvinder-Singh, Sekhon, G.S., 1995. Fertiliser-N use efficiency and nitrate pollution of groundwater in developing countries. J. Contam. Hydrol. 20, 167–184.



ICAR-Agricultural Technology Application Research Institute
Zone-1, PAU Campus, Ludhiana - 141 004

Tel.: 0161-2401018, Fax: 0161-2412719
Email: zcu1ldh@gmail.com, atari.ludhiana@icar.gov.in   Website: http://atari1icar.res.in