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**Review Article**

# Direct Seeded Rice: A New Technology for Enhanced Resource-Use Efficiency

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## Abstract

Rice (*Oryza sativa* L.) is a major staple food crop that feeds around 60% of the world's population. It is a major food crop in terms of production, economy and is grown in all ecological zones of Nepal. In Nepal, traditional method of rice cultivation is widely accepted in which 20-25 days old seedlings are transplanted in the puddled field. Looming water scarcity, water-intensive traditional method of rice cultivation, escalating labour costs pressurize the development of alternative which is highly sustainable and profitable. Direct-seeded rice (DSR) offers a very good opportunity that can cope up the global need and reduces the water use to 50%, labour cost to 60% and increases productivity by 5-10%. It involves sowing of pre-germinated seeds into wet soil surface (wet seeding), dry soil surface (dry seeding) and standing water (water seeding). Weeds are the major constraint in direct-seeded rice (DSR) reducing the crop yield upto 90% and sometimes even crop failure. Enhanced nutrient use efficiency and integrated weed management can produce comparable yields to that of transplanted rice (TPR) encouraging many farmers to switch to DSR. Methane gas emission is significantly lower in DSR than in conventionally tilled puddled transplanted rice mitigating the world's threat of global warming. Blast disease and root-knot nematode (RKN) are other important problems associated with DSR. Based on the evidences collected, the article reviews integrated package of cultivation technologies associated with DSR, advantages, constraints and likeliness of DSR to be the future of rice cultivation in Nepal.

**Keywords:** DSR; TPR; nutrient management; weeds

## Introduction

Rice (*Oryza sativa* L.) is one of the leading staple food crop that feeds around 60% of the world's population. It belongs to family poaceae. Around 20 species of genus *Oryza* has been identified and among them *Oryza sativa* L. is cultivated worldwide. It is grown from $50^0$ N latitude and $40^0$ S latitude from the geographic equator. Rice has a wide range of adaptation and can be grown from sea level (Indonesia) up to 3050m (Jumla, Nepal). The actual origin of rice has not been identified yet but there is general consensus that it had originated independently in china, India and Indonesia. Rice is cultivated in more than 95 countries. Looking at the global scenario, rice production was 501.2 million ton (milled basis) in 2016 (FAO, 2017). Rice provides 30–75% of the total calories to more than 3 billion Asians (Khush, 2004). Around 90% of rice is produced in Asia. China is the highest producer of rice contributing more than 28% of the global production, followed by India and Indonesia. Brazil, Japan, Bangladesh,

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Vietnam, Thailand, Philippines are the other leading countries in rice production. Rice covers around 11% of the world's arable land.

In Nepal, rice is cultivated widely in large belts of terai to some scant in mountain region. Being particular, rice cultivation occupies 71% area in terai, 25% in hills and 4% in mountains. Agriculture is a major occupation of Nepalese people, it occupies 29 % share in Gross domestic product (GDP) and rice contributes 21% to agriculture gross domestic product (GDP).In Nepal, the area under rice cultivation is 1,362,908 ha with an average production of 4,299,079 metric ton (MOAD, 2016). Productivity of rice have recorded to be as low as 1 ton/ha to as high as 10 ton/ha. The average productivity of rice is 3.154 ton/ha in Nepal. The general scenario of rice cultivation in Nepal can be depicted as a lowland field, conventionally tilled using tractors or bullocks. Then, the fields are puddled and water depth of 5-10 cm is maintained followed by transplantation of 20-25 days old seedlings. This method of rice cultivation has detrimental effect in soil, environment and successive crops like wheat, potato e.t.c. Similarly, it incurs intensive water and labour use and reduces the cost efficiency of the crop. Hence, a Nationwide question is arising for an alternative to this system of rice cultivation.

## Direct-seeded rice (DSR): Present situation

Direct seeding of rice is the process of growing rice crop in the field by sowing of seeds in the field rather than by transplanting seedlings from the nursery. Once germination and seedling establishment are complete, the crop can then be sequentially flooded and water regimes maintained as for transplanted rice. Alternatively, the crop can remain rainfed, the upper surface soil layers fluctuating from aerobic to non-aerobic conditions. Unlike conventionally tilled transplanted rice; puddling, transplanting and standing water are outside the realm of direct seeded rice. DSR has been successfully practiced across different countries around the globe like U.S.A., Sri lanka, India, Malaysia, Phillippines, Brazil, China, Cambodia, Bangladesh e.t.c. (Kumar and Ladha, 2011). At present, 23% of rice is under direct-seeding practice globally (Rao *et al*., 2007). Rice cropping system varies from country to country and along regions. Rice crop is planted by dry-seeding or water-seeding in U.S.A., Europe and Australia (Gianessi *et al*., 2003; Pratley *et al*., 2004). In Australia, more than 90% of rice is aerially sown into water (Pratley *et al*., 2004); meanwhile in Asia 21-22% of rice was noted to be dry- or wet-seeded (Pandey and Velasco, 2002). Similarly, direct-seeding in saturated soil has been adopted widely in southern Brazil, Chile, Venezuela, Cuba, some Caribbean countries, and in certain areas of Colombia (Fischer and Antigua, 1996).

Basically, there are three principal methods of establishing direct seeded rice (DSR): dry-seeding (sowing dry seeds in dry soil), wet-seeding (sowing pre-germinated seeds on wet soils) and water seeding (seeds sown in standing water); as presented in (Table 1). Recent statistics on rice suggests the shifts from TPR to DSR; water scarcity and higher costs for labour being the major drivers of the shift. Direct seeded rice is expected to reduce the water use by 30% as it lacks raising of seedling, puddling and maintenance of standing water. As a matter of fact, the global reduction in the availability of water for agriculture purpose is one of the greatest threat to rice producers. Hence, DSR can be a mitigation strategy to meet up the increasing water demand of the rice crop due to climate change i.e. research reports have revealed that for each 1ºC rise in temperature water requirement of rice crop increases by 2-3%. Similarly, lower availability of labour and higher costs of rice drudgery can be a limiting factor for rice cultivation if the similar pattern follows on for long run. Since, DSR reduces the labour use during nursery preparation, puddling and transplanting; It can be a better alternative compensating the future needs. DSR reduced the labour use upto 60% lower and reduced the cost of production by US$ 9-125 $ha^{-1}$ (Kumar and Ladha, 2011). Puddling operation in CT-TPR is a major limiting factor that completely dismantles the soil aggregates, reducing permeability in subsurface layers, and forming hard-pans at shallow depths (Sharma *et al*., 2003) but direct seeding of rice surpasses this operation hence offers a better soil physical conditions for the preceeding crops particularly wheat and other winter crops. Weeds in DSR are a major yield declining factor and if managed well can help to increase yields by substantial level. Furthermore, DSR avoids the transplanting shock hence attains the physiological maturity earlier than transplanted rice and reduces the vulnerability to late-season drought. Yield in DSR is expected to be often lower than TPR principally due to poor crop stand, high percentage of panicle sterility, higher weed and root-knot nematode infestation. But, higher yield, root dry matter, benefit cost ratio and infiltration rate was recorded in DSR than TPR while comparing productivity and economics of various planting techniques in rice-based cropping systems in the Indo-Gangetic Plains (Gangwar *et al*., 2008). It is reported that productivity of DSR is 5-10% more than the yield of transplanted rice. Some reports have suggested similar or even higher yields of DSR than TPR as presented in (Table 2). Hence, DSR is gaining momentum because of being more productive, profitable and sustainable in long run and DSR can be a major opportunity to those farmers in water scarce areas with higher efficiency in cost of production and labour use.

**Table 1**: Major methods of direct seeding of rice in different ecologies/environments.

| S.N. | Direct-seeding method | Brief description | Depth of seeding | Seeding method/pattern | Rice ecology/environment |
|---|---|---|---|---|---|
| A. | Dry seeding (Dry-DSR) | | | | |
| 1 | Conventionally tilled (dry) broadcast rice (CT-dry-BCR) | Land is ploughed, harrowed but not puddle, leveled, and then dry seeds are broadcast manually before the onset of monsoon to use rainfall more effectively. In some cases, seeds are covered with soil by shallow tillage or planking. | Surface or 0-3 cm | Broadcasting/random | Mostly rainfed upland and flood-prone; some rainfed lowland |
| 2 | Conventionally tilled (dry) dibbled rice | Land preparation is same as in CT-dry-BCR but seeds are sown by dibbling methods, placing five to six seeds manually at desired spacing. This is useful in identifying weedy rice | 1-3 cm | Dibbling/rows | Mostly rainfed upland and flood-prone; some rainfed lowland |
| 3 | Conventionally tilled (dry) drill-seeded rice | Land preparation is<br>same as in CT-dry-BCR. But, dry seeds are drilled in rows (20-cm apart)<br>in a well-prepared soil (dry or moist)<br>and leveled, followed by one light irrigation | 2-3 cm | Drilling/rows | Irrigated and favorable rainfed lowland |
| 4 | Reduced-tillage (dry) drill-seeded rice with a power-tiller-operated seeder (PTOS) | In this, PTOS tills the soil at shallow depth (4-5 cm) and drills rice seed at the same time in rows at adjustable distance (20 cm row spacing) in a single operation | 2-3 cm | Drilling/rows | Irrigated and favorable rainfed lowland |
| 5 | Zero-till dry broadcast rice | Fields are flush-irrigated to moisten the soil and allow weeds to germinate. After about 2 weeks, glyphosate/paraquat is applied to kill weeds. Then, rice seeds (pregerminated) are broadcast in moist soil, followed by a light irrigation, if needed | surface | Broadcasting/random | Irrigated and favorable rainfed lowland |
| 6 | Zero-till dry drill-seeded rice | Fields are flush-irrigated to moisten the soil and allow weeds to germinate. After about 2 weeks, glyphosate/paraquat is applied to kill weeds. Then, a zero-till drill seeder is used to seed rice in rows (20 cm apart) in moist or dry soil, followed by a light irrigation, if needed. | 2-3 cm | Drilling/rows | Irrigated and favorable rainfed lowland |
| 7 | Raised-bed dry-drill seeded rice | A bed former-cum-zero-till drill is used to form 37 cm wide raised beds and 30 cm wide furrows in a well prepared and pulverized soil and rice seeds are sown in rows on both sides of the beds (moist/dry). Frequent light irrigations are applied for quick and uniform germination | 2-3 cm | Drilling/rows | Irrigated and favorable rainfed lowland |

| | | | | | |
|---|---|---|---|---|---|
| B | Wet-seeding (Wet-DSR) | | | | |
| 8 | Conventionally tilled (wet) broadcast rice on surface of puddled soil (CT-wet-BCR) | Land is ploughed, puddled, and leveled; pre-germinated seeds are sown by broadcasting manually (24 hr soaking and 24 hr incubation) or by motorized blower (with 24 hr soaking and 12 hr incubation) 1-2 days after puddling on the surface of puddled (wet) soil after drainage | surface | Broadcasting/random | Irrigated and favorable rainfed lowland |
| 9 | Conventionally tilled (wet) drum-sown rice on surface of puddled soil | Land preparation is same as in CT-wet-BCR but pre-germinated seeds (with 24 hr soaking and 24 hr incubation) are sown in rows (18-20 cm apart) on the surface of wet soil by using a drum seeder | surface | Line sowing | Irrigated and favorable rainfed lowland |
| 10 | Conventionally tilled (wet) subsurface broadcast rice | Land is ploughed, puddled, and leveled; pre-germinated seeds (with 24 hr soaking and 24 hr incubation) are sown by broadcasting (manually or by using a motorized blower) on wet soil immediately after puddling and suspended mud is allowed to settle down and form a protective cover over the seeds sown | 0.5-1 cm | Broadcasting/random | Irrigated and favorable rainfed lowland |
| 11 | Conventionally tilled (wet) drill-seeded rice using anaerobic seeder | Land is ploughed, puddled, and leveled; pre-germinated seeds (with 24 hr soaking and 24 hr incubation) are drilled in rows 1-2 days after puddling by using an anaerobic seeder fitted with furrow opener and closer | 0.5-1 cm | Drilling/rows | Irrigated and favorable rainfed lowland |
| C | Water seeding | | | | |
| 12 | Water seeding after dry tillage | Land is dry ploughed, disked harrowed, leveled but not puddled, and the seedbed is rougher (large clods) than dry seeding. Alternatively, a smooth seedbed is firmed with a grooving implement, which results in a grooved seedbed (2.5 cm depth) on 17.5-25 cm spacing. Pre-germinated seeds (24 hr soaking and 24 hr incubation) are then broadcast either manually or using a motorized blower or by a tractor-mounted broadcast seeder with the aircraft in the standing water of 10-15 cm depth | Standing water of 15 cm | Broadcasting/random | Irrigated lowland |
| 13 | Water seeding after wet tillage | Land is ploughed, puddled, and leveled as in CT-wet-DSR. Then, pre-germinated seeds as explained in dry-water seeding are broadcast in standing water | Standing water of 5-10 cm | Broadcasting/random | Irrigated lowland |

(Source: Ladha *et al*., 2009)

**Table 2**: Comparision of grain yield (ton/ha) in Direct-seeding (DSR) and Transplanted rice (TPR).

| DSR | TPR | Rice ecology | Country | Reference |
|---|---|---|---|---|
| 5.50 | 5.40 | Shallow wetland-irrigated | Japan | (Harada *et al*., 2007) |
| 3.83 | 3.63 | Rainfed lowlands | Thailand and Cambodia | (Mitchell *et al*., 2004) |
| 2.93 | 3.95 | Irrigated | Pakistan | (Farooq *et al*., 2006a; Farooq *et al*., 2009) |
| 5.40 | 5.30 | Favourable irrigated | India and Nepal | (Hobbs *et al*., 2002) |
| 5.59 | 5.22 | Favourable irrigated | India | (Sharma *et al*., 2004) |
| 5.38 | 5.32 | Irrigated | South korea | (Ko and Kang, 2000) |
| 3.15 | 2.99 | Unfavourable rainfed lowland | India | (Sarkar *et al*., 2003) |
| 4.64 | 4.17 | Rainfall lowland-hill | India | (Rath *et al*., 2000) |
| 6.09 | 6.35 | Rainfall lowland-hill | India | (Tripathi *et al*., 2005) |
| 2.56 | 3.34 | Irrigated | Pakistan | (Farooq *et al*., 2006b); Farooq *et al*., 2007) |
| 6.6 | 6.8 | Rainfed lowland-hill | India | (Singh *et al*., 2009) |

Table 3: Comparison of methane emissions (kg $CH_4$/ha) under Direct-seeded and Transplanted rice.

| S.N. | Location/country | Year/season | Tillage and crop establishment method | Water management | Seasonal total emission (kg $CH_4$ $ha^{-1}$) | % change from TPR or puddling | Yield (t $ha^{-1}$) | References |
|---|---|---|---|---|---|---|---|---|
| 1 | Beijing, China | 1991 | CT-TPR | Intermittent irrigation | 299 | 0 | 4.5 | (Wang *et al*., 1999) |
| | | | CT-dry-seeding | Intermittent irrigation | 74 | -75 | 3.6 | |
| 2 | Akasaka, Japan | 1992-1994 | CT-TPR | Continuous flooding | 159 | 0 | - | (Ishibashi *et al*., 2001) |
| | | | ZT-dry-seeding | Continuous flooding | 34 | -79 | - | |
| | Suimon, Japan | 1994-1997 | CT-TPR | Continuous flooding | 271 | 0 | - | |
| | | | ZT-dry-seeding | Continuous flooding | 129 | -52 | - | |
| 3 | Jakenan, Indonesia | 1993 WS | CT-TPR | Continuous flooding | 229 | 0 | 4.7 | (Setyanto *et al*., 2000) |
| | | | CT-wet-seeding | Continuous flooding | 256 | 12 | 7.1 | |

Table 3: Comparison of methane emissions (kg $CH_4$/ha) under Direct-seeded and Transplanted rice.

| S.N. | Location/country | Year/season | Tillage and crop establishment method | Water management | Seasonal total emission (kg $CH_4$ $ha^{-1}$) | % change from TPR or puddling | Yield (t $ha^{-1}$) | References |
|---|---|---|---|---|---|---|---|---|
| | | | CT-TPR | Rainfed | 59 | 0 | 4.9 | |
| | | | CT-dry-seeding | Rainfed | 26 | -56 | 4.4 | |
| 4 | Southeastern korea | 1996 | CT-TPR (30 day old seedling) | Continuous flooding | 403 | 0 | 5.3 | (Ko ad Kang, 2000) |
| | | | CT-TPR (8 day old seedling) | Continuous flooding | 424 | 5 | 5.4 | |
| | | | CT-wet-seeding | Continuous flooding | 371 | -8 | 5.4 | |
| | | | CT-dry-seeding | Continuous flooding | 269 | -33 | 5.3 | |
| 5 | Maligaya, Philippines | 1997 DS | CT-TPR | Continuous flooding | 89 | 0 | 7.9 | (Corton *et al*., 2000) |
| | | | CT-wet-DSR | Continuous flooding | 75 | -16 | 6.7 | |
| | | | CT-TPR | Midseason drainage | 51 | 0 | 7.7 | |
| | | | CT-wet-DSR | Midseason drainage | 48 | -6 | 6.4 | |
| | | 1997 WS | CT-TPR | Continuous flooding | 348 | 0 | 5.4 | |
| | | | CT-wet-DSR | Continuous flooding | 272 | -22 | 3.5 | |
| | | | CT-TPR | Midseason drainage | 323 | 0 | 5.5 | |
| | | | CT-wet-DSR | Midseason drainage | 150 | -54 | 3.4 | |
| 6 | Milyang, Korea | 1998-2000 | CT-TPR | Continuous flooding | 402 | 0 | - | (Ko *et al*., 2002) |
| | | | CT-dry-seeding | Continuous flooding | 241 | -40 | - | |
| | | | ZT-dry-TPR | Continuous flooding | 295 | -27 | | |
| | | | ZT-dry-seeding | Continuous flooding | 258 | -36 | | |
| 7 | Sanyoh, Japan | 1992-2000 | TPR | Continuous flooding | 330 | 0 | - | (Tsuruta, 2002) |
| | | | ZT-dry-DSR | Continuous flooding | 252 | -24 | - | |
| 8 | Pantnagar, India | 2004 | CT-TPR | - | 315 | 0 | 6.8 | (Singh *et al*., 2009) |
| | | | CT-dry-DSR | - | 220 | -30 | 6.6 | |

## Greenhouse Gases ($GHG_s$) Emission Under Different Crop Establishment Methods

Rice-based cropping are one of the major contributors of $GHG_s$ ($CH_4$, $N_2O$, $CO_2$) emission and holds a high potential for global warming. $CH_4$ emissions vary considerably between different crop establishment techniques, which could be due to individual or combined effects of different soil characteristics, climatic conditions, and management such as soil pH, redox potential, soil texture, soil salinity, temperature, rainfall, and water management (Aulakh *et al*., 2001; Harada *et al*., 2007). Flooded rice culture with puddling and transplanting are the major sources of $CH_4$ emissions in the rice fields attributed anaerobic soil condition due to prolonged flooding. This accounts 10-20% (50-100 Tg year$^{-1}$) of the total annual $CH_4$ emissions globally (Reiner and Aulakh, 2000). Prolonged flooding leads to anaerobic conditions in soil and creating a favourable environment for methanogenic bacteria and stimulates $CH_4$ production. Methane emission starts at redox potential of soil below -150 mV and is stimulated at less than -200mV (Jugsujinda *et al*., 1996; Masscheleyn *et al*., 1993; Wang *et al*., 1993). Studies comparing $CH_4$ emissions in different tillage and CE methods under similar water management management (continuous flooding/mid-season drainage/intermittent irrigation) in rice suggested lower $CH_4$ emissions in DSR than in TPR (Table 3), except a data obtained in Jakenan, Indonesia (Setyanto *et al*., 2000). Direct seeding has an immense potential to reduce $CH_4$ emission by various management practices such as reducing the number of irrigations, multiple drainage system during the crop cycle, alternate wetting and drying, *Azolla* application, semi-dry cultivation, arbuscular mycorrhiza and methanotrophs application (Zhao *et al*., 2006; Tsuruta, 2002). Water-saving technologies like dry-DSR are expected to reduce $CH_4$ emissions but at the same time aerobic soil state favours $N_2O$ emissions. Nitrous oxide production is increased at the redox potential >250mV (Hou *et al*., 2000). Aerobic environment and high moisture content under zero tilled direct seeded rice (ZT-DSR) results in nitrogen losses as N2O gas and contribute to global warming. In a study conducted in India, $N_2O$ emissions from CT-TPR compared with different dry-DSR practices (CT-dry-DSR, Bed-dry-DSR, ZT-dry-DSR), it was found that $N_2O$ emissions were 0.31-0.39 kg N/ha in CT-TPR, which increased to 0.90-1.1 kg N/ha in CT-dry-DSR and Bed-dry-DSR and 1.3-2.2 kg N/ha in ZT-dry-DSR (Kumar and Ladha, 2011). Similar results were reported in western Japan, higher emissions of N2O under ZT-dry-DSR was observed than in CT-TPR (Ishibashi *et al*., 2007). Looking at these results in both DSR and TPR, it has been observed that measures to reduce one source of GHG emission lead to increase in emission of another GHG and this trade-off between CH4 and N2O is becoming a great challenge in devising an effective GHG mitigation strategy for rice (Wassmann *et al*., 2004). Very few work have been done for comparing different rice production systems in terms of relative effect on GWP. ZT-dry-DSR was found to be 20% more efficient in reducing GWP than CT-TPR (Ishibashi *et al*., 2009). Just by changing puddling to zero tillage, GWP declined by 42% in Japan (Harada *et al*., 2007).

Higher emissions of $N_2O$ was observed in dry-DSR and substantially higher emissions of $CH_4$ was observed in CT-TPR but looking at the GWP dry-DSR tend to contribute lower than CT-TPR. So, DSR can be a relatively better eco-friendly practice for rice cultivation. However, more systematic studies need to be done to come up with appropriate $GHG_s$ emission strategies that involves ecologically sound crop management practices, enhanced nutrient use efficiency and maintains higher yield (Cassman, 1999). Developing water management practices in such a way that soil redox potential can be kept at an intermediate range (-100 to +200 mV) to minimize emissions of both CH4 and N2O (Hou *et al*., 2000).

## Seed Treatment

### *Seed Priming*

One of the short term and the most pragmatic approaches to overcome the drought stress effects is seed priming (Farooq *et al*., 2006a). Since DSR crop is sown at the shallow depth (<2 cm) prior to the monsoon rain occurs, insufficient soil moisture can be a major constraint to rapid and better crop establishment. Seed priming is a pre-sowing hydration technique in which seeds are allowed to be partially hydrated to the point where germination enhancing metabolic activities are accelerated, but seeds do not reach the irreversible point of radical emergence (Basra *et al*., 2005; Bradford, 1986). Seed priming can improve the traits associated with weed competitiveness of rice i.e. growth rate, early crop biomass and early vigour. Primed seeds often exhibits increased germination rate, uniform and faster seedlings growth, greater germination uniformity, greater growth, dry matter accumulation, yield, harvest index and sometimes greater total germination percentage (Farooq *et al*., 2006b; Kaya *et al*., 2006). Seed priming techniques, such as hydro-priming (Farooq *et al*., 2006c); on-farm priming (Harris *et al*., 1999); osmo-hardening (Farooq *et al*., 2006a, b, d); hardening (Farooq *et al*., 2004); and priming with growth promoters like growth regulators and vitamins have been successfully employed in DSR in order to hasten and synchronise emergence, uniform crop stand and improve yield and quality (Basra *et al*., 2005; Farooq *et al*., 2006a, b). Priming the rice seeds with imidachloprid resulted in increased plant height, root weight, dry matter production, root length, increased yield by 2.1 ton ha$^{-1}$ compared to control, which was attributed to higher panicle numbers and more filled grains per panicle (Farooq *et al*., 2011). *Azospirillum* treatment resulted in maximum no. of tillers and highest shoot: root ratio during early vegetative growth. Seed priming assists in reducing the higher seeding rates in DSR to some extent. Furthermore, faster and uniform seedling emergence from primed seeds was attributed to improved alpha-amylase activity and increased level of soluble sugars. The physiological changes produced by osmo-hardening (KCl or $CaCl_2$) enhance starch hydrolysis, making more sugars available for embryo growth, kernel yield and quality attributes at maturity (Farooq *et al*., 2006a). In direct seeded medium grain rice, osmo-hardening with KCl led to higher kernel yield (3.23 ton $ha^{-1}$), straw yield (9.03 ton $ha^{-1}$) and harvest index (26.34%) than untreated control which results were kernel yield (2.71 ton $ha^{-1}$), straw yield (8.12 ton $ha^{-1}$) and harvest index (24.02%).

***Seed Treatment with Fungicides and Insecticides***

Seed treatment with appropriate fungicides is recommended to manage diseases such as loose smut, false smut, root rot, collar rot and stem rot where seed-borne diseases are a concern. For this, a weighted quantity of seed is soaked in water + fungicide (tebuconazole-Razil Easy @ 1 ml/kg seed, or carbendazim-Bavistin @ 2g/kg seed) for 24 hrs. Volume of water used for soaking is equivalent to volume of seed (Kamboj *et al*., 2012). After 24 hrs of soaking, the seeds are removed from fungicide solution and dried in shade for 1-2 hrs before sowing into the field. Similarly, routine observation of insect pests in the field is also equally important. Areas where soil-borne insect pests (e.g., termites) are a serious problem, seed treatment with insecticide (imidacloprid-Gaucho 350 FS @ 3 ml/kg alone or in combination with tebuconazole-Razil Easy @ 0.3 ml/kg seed) is desirable. The combination treatment is generally preferred to protect the seed from both soil-borne fungi and insects.

## Varietal Characteristics

Conventional way of rice cultivation is facing several problems regarding labour and water supply. DSR is anticipated to reduce these problems but is itself facing several issues in crop establishment, growth and development and most importantly lower yields. Almost no varietal selection and breeding efforts have been done for developing rice cultivars suitable for alternate tillage and establishment methods i.e. DSR. Hence, looking forth the future, several research activities are to be carried out on genetic and agronomic basis. There is no hard and fast rule that a different variety is to be developed for DSR. The same variety used for transplanted rice can be used for DSR as per the ecological requirement. Wide range of characters are to be taken into account before starting any research activities. Scientists keep yield as their first priority for their research activities as easily accepted by farmers. But, high emphasis should be given on the factors like eating quality, crop duration and yield stability. The proper exploitation of molecular biology and genomics platform helps in developing the need based cultivars. Quantitative trait loci (QTLs) can directly access the required genetic characteristics in the plants adaptive response (Kirgwi et al., 2007). Several approaches have been made to develop varieties with higher nutrient use efficiency (NUE) and nodulation activity (Ladha and Reddy, 2000). Several research activities are ongoing to alter the photosynthesis pathway from C3 to C4 which is expected to increase rice yield by 30-35%. Anaerobic germination, early vigor, drought resistance, submergence tolerance, tolerance against adverse soil conditions, pest resistance, herbicide tolerance and grain quality are the major parameters to be considered in the breeding approach of DSR (Jennings et al., 1979). Several organizations like International Rice Research Institute (IRRI), Nepal Agriculture research council (NARC), land Grant colleges etc. are active in the varietal improvement of rice primarily focusing on the yield traits. Some varieties of DSR suitable in Nepal conditions are presented in (Table 4). Similarly, inbreds like Sarju-52, Makarkaddu, Samba-Sub-1, Sona Mansuli are also very popular and suitable cultivars of terai and inner terai but are not released officially (Yadav, 2015).

**Table 4**: Rice varieties suitable for Direect-seeding in Nepal.

| Regions | Genotypes suitable for DSR |
|---|---|
| Terai and inner-terai | Inbreds (Hardinath-1, Tarahara-1, Radha-4, Sukha-1, Sukha-2, Sukha-3, Ramdhan, Sabitri) Hybrids (Gorakhnath, Arize 6444, Bioseed 786, RH 245, Loknath-505, Raja ) (Yadav, 2015) |
| Mid-hills | Khumal-4, Khumal-8, Khumal-10 (Yadav, 2015) |
| High-hills | Chhomorong (Shah and Bhurer, 2005) |

## Water Management

Indiscriminate use of surface and ground water for various industrial, domestic and agricultural purposes are reducing the global available water. It is predicted that only 50-55% of water will be available for agriculture by 2025 as against 66-68% in 1993 (Sivannapan, 2009). Global scarcity for water and high cost incurred for pumping out ground water is deviating scientists in developing a adaptive rice cultivation technology. Rice is one of the major crop consuming substantial amount of water because of its traditional practice of cultivation in flooded fields. DSR has been arising as a very good alternative for water saving in rice cultivation. After sowing of seeds in field, precise water management during crop emergence (first 7-15 days after sowing) is of great importance in DSR (Balasubramanian and Hill 2002; Kumar *et al*., 2009). It is to be ensured that the field does not get saturated to avoid rotting of seed. Saturating the field at three-leaf stage can be done to ensure proper rooting and seedling establishment as well as germination of weed seeds (Kamboj *et al*., 2012). Fewer reports, apart from thse of china suggested that 20-90% of input water savings and weed suppression occurred with plastic and straw mulches in combination with DSR with continuously flooded TPR (Lin *et al*., 2003). Bund management also assists in maintaining the uniform water depth and reducing the water losses through seepage and leakage (Lantican *et al*., 1999; Humphreys *et al*., 2010). Reports have suggested that water stresses during vegetative and reproductive phases has incurred economic losses by 34% and 50% respectively. Hence, it is highly recommended to maintain optimum moisture level in the field at following stages: tillering, panicle initiation, and grain filling. Water stresses during these stages bombards heavy losses by delay in anthesis and higher panicle sterility (Kumar *et al.* 2017; De Datta *et al*. 1975). The development of new cultivars of short to medium duration adapted to water limitations also helps to reduce irrigation water use (Humphreys *et al*., 2010). 33-53% irrigation water can be saved in Dry-DSR with AWD (alternate wetting and drying) as compared with conventional tilled-transplanted puddled rice (CT-TPR) without compromising grain yield (Yadav *et al*., 2007).

## Nutrient Management

Several research activities have been done for enhanced fertilizer use efficiency in CT-TPR but limited researches have been conducted for DSR. Land preparation and water management are the principal factors for governing the nutrient dynamics in both DSR and TPR systems (Farooq *et al*., 2011). Land is often prepared in dry soil and it remains aerobic throughout the crop season in DSR and has different nutrient dynamics than TPR (farooq *et al*., 2011). In DSR, the availability of several nutrients N, P, S and micronutrients such as Fe and Zn are reduced, likely to be constraint (Ponnamperuma, 1972). In addition, losses of N due to denitrification, volatilization, and leaching is likely to be higher in dry-DSR than in TPR (Davidson, 1991). Micronutrient deficiency are of great concern in DSR because imbalances of such nutrients (e.g. Zn, Fe, Mn, S and N) results from improper and imbalanced N fertilizer application (Gao *et al*., 2006). The general recommendation for NPK fertilizers are similar in both DSR and TPR but slightly higher dose of N (22.5-30 kg $ha^{-1}$) is recommended in DSR (Dingkuhn *et al*., 1991a; Gathala *et al*., 2011). This is done to compensate the higher losses and lower availability of N at the early stage of rice due to volatilization and mineralization as well as longer duration of rice crop in DSR field. One-third N and full dose of P and K is applied as basal dose at the time of seed sowing in DSR using a seed-cum-fertilizer drill/planter. This facilitates the placement of fertilizer just below the seeds enhancing the fertilizer efficiency and improving germination percentage and crop establishment. The remaining two-third dose of N is top-dressed in equal splits at active tillering and panicle initiation stages (Kamboj *et al*., 2012). Split applications of N are necessary to maximize grain yield and to reduce N losses. The nitrogen dose for conventionally tilled direct seeded rice can be reduced by 25% by green manuring, i.e., growing *Sesbania* (dhaincha) and incorporating it 2-3 days prior to sowing DSR using a knock down herbicide (glyphosate) and then seeding into the *Sesbania* mulched field using Turbo Happy Seeder (Yadav, 2015). In addition, nitrogenous can be managed in two approaches using Leaf color chart (LCC) (IRRI, 2010). In fixed time approach, after basal application of N, remaining N is applied at preset timing of active tillering and panicle initiation. Dose is adjusted besed upon LCC reading. In real time approach, after basal application of N color of rice leaves is monitored in regular interval of 7-10 days from active tillering and N is applied wherever the leaf color falls below critical threshold level (IRRI, 2010). For hybrids and high yielding coarse rice varieties N application should be based on critical LCC value of 4, whereas, for basmati types N should be applied at critical LCC value of 3 (Gopal *et al*., 2010; Kamboj *et al*., 2012). Since, losses are higher and availability is lower in dry-DSR, more N is to be applied for dry-DSR. In order to mitigate this constraint efficient measures for N management are to be developed and introduced into farmers field practice. Slow-release fertilizers (SRF) or controlled-release N fertilizers (CRF) reduce N losses because of their delayed release pattern and offers “one-shot dose” of N, which matches better to the N demand of crop at different periods (Shoji *et al*., 2001). In addition, one-shot application of N will reduce the labour cost required for top dressing of split dose. Fashola *et al*., (2002) reported the superiority of CRF over untreated urea in Nitrogen use efficiency and yields obtained. Japanese farmers are using CRF with polymer-coated urea in ZT-dry-DSR and are getting highly benefited by it (Saigusa, 2005; Ando *et al*., 2000). Despite the benefits offered by CRF, its use is limited to research plots only. The higher costs associated with CRF is a mojor reason behind its limited use in the farmers level. Shaviv and Mikkelsen (1993) reported the price of CRF to be higher than conventional fertilizers by four to eight times. In addition, published results on the performance of SRFs/CRFs compared with conventional fertilizers are not consistent (Kumar and Ladha 2011). Saigusa (2005) reported higher N recovery of co-situs (placement of both fertilizer and seeds or roots at the same site) application of CRF with polyolefin-coated ureas of 100-day type (POCU-100) than conventional ammonium sulfate fertilizer applied as basal and topdressed in zero-till direct-seeded rice in Japan. In contrast, Wilson *et al*. (1990), Wells and Norman (1992), and Golden *et al*. (2009) reported inferior performance of SRF or CRF compared with conventional urea top-dressed immediately before permanent flood establishment.

Split application of K has also been proved to be advantageous for direct seeded rice in medium-textured soil (PhilRice, 2002). K can be split as 50% basal and 50% at panicle initiation stage in these types of soil (Kumar and Ladha, 2011). Deficiency of Zn and Fe is often pronounced in aerobic/non-flooded rice systems than in flooded systems (Sharma *et al*., 2002; Pal *et al*., 2008). Low redox potential, high carbonate content and high pH are supposed to be the major reasons behind Zn deficiency in DSR fields (Mandal *et al*., 2000). Zn deficiency in the rice grown in calcareous soil occurs due to the presence of bicarbonates (Forno *et al*., 1975); possibly due to which inhibition and immobilization occurs in the roots, which restricts its translocation to shoots. In aerobic soils, Fe oxidation occurs by the oxygen released by the roots which reduces the rhizosphere soil pH and limits the release of Zn from highly insoluble fractions for availability to the rice plant (Kirk and Bajita, 1995). 25-50 kg $ha^{-1}$ zinc sulphate is recommended to avoid Zn deficiency in direct seeding. Basal application of zinc is often preferred ad found to give best results. However, if a basal application is missed, the deficiency can be corrected by topdressing upto 45 days (Anonymous, 2010). Zinc can be applied as a foliar spray (0.5% zinc sulfate and 1.0% urea) 30 days after sowing (DAS) and at panicle initiation (PI), which occurs approximately 3–4 weeks prior to heading. pH below neutral in the rhizosphere increased solubility of P and Zn and hence their availability (Kirk and Bajita, 1995). The timing and source of Zn application may influence Zn uptake in DSR (Giordano and Mortvedt, 1972). Therefore, a shift from TPR to DSR may also affect Zn bioavailability in rice (Gao *et al*., 2006). Dry seeded rice often suffers from iron deficiency when grown on lighter soils (sandy loams and loams). In aerobic conditions, the available ferrous form of Fe gets oxidized to unavailable ferric form leading to Fe deficiency for DSR crop. The general symptoms of Fe deficiency is observed during early vegetative stage in the form of yellowing, stunted plants, and seedling death. Quite promising results were obtained by drilling 0.5 kg liberal Fe in the soil at sowing time to overcome Fe deficiency. However, foliar application was observed to be superior to soil application since foliar-applied Fe is easily translocated acropetally and even retranslocated basipetally. A total of 9 kg Fe ha-1 in three splits (40, 60, and 75 DAS) as foliar application (3% of FeSO4.7H2O solution) has been found to be effective (Pal *et al*., 2008). Furthermore, seed treatment with iron sulphates could be quite beneficial in improving the health of young rice plants and if iron chlorosis persists, foliar application of iron is recommended (Gopal *et al*., 2010). Appearance of iron deficiency symptoms at later stages of crop growth may be due to cereal cyst nematodes. Hence, the roots are to be checked for the presence of galls, if galls are present the field should be avoided for DSR in future (Yadav, 2015). To overcome sulphur deficiency, ground application of 2 kg acre-1 of librel sulphur needs to be done.

## Effective and Efficient Management of Weeds: A Major Constraint

Weeds are no doubt a major constraint to the successful DSR crop. High weed infestation is a major bottleneck in DSR; especially in dry soil conditions (Rao *et al*., 2007). Substitution of CT-TPR by DSR results in the heavy weed infestation and prevalence of hardy grassy weeds and sedges (Azmi *et al*., 2005). Reports have suggested that around 50 species of weed flora are found to invade DSR plots (Caton *et al*., 2003; Rao *et al*., 2007). Some of the major weeds present in DSR fields are presented in (Table 5). In traditional method of rice cultivation, the farming practice of maintaining standing water itself reduces large amount of weeds hence 2-3 manual weeding can also be economic and feasible. Whereas, weeds in DSR emerges along with the rice, increasing the cost of production and reducing the economic yields upto 90% by competing with main crop for nutrients, moisture, space, light (Bista and Dahal, 2018; Rao *et al*., 2007). Weedy rice (*Oryza sativa* f. *spontanea*), also known as red rice, has emerged as a serious threat in the areas where TPR is replaced by DSR. Severe losses in yield was recorded ranging from 15-100% attributed high competitive nature of weedy rice. Weedy rice is difficult to control because of its genetic, morphological, and phenological similarities with rice. Selective control of weedy rice was never achieved at a satisfactory level with herbicides (Noldin *et al*., 1999a, b). Hence, weed management in DSR has emerged as a great challenge for the scientists for the successful establishment of DSR as a alternative to CT-TPR. Several approaches used for weed management are discussed below;

### *Mechanical*

Mechanical weeding involves the weeding by hands (manual weeding) or by use of sophisticated tools like mechanized cono-weeders. Manual weeding involves the pulling out the weeds from the soil. For this, weeds should be sufficiently large enough to be pulled out so it is done after 25-40 days after sowing (DAS) leading to losses in yields. Mechanical method of weeding is a universally practiced operation possible only when rice is sown in proper rows. This is economically and practically not feasible in the commercial scale because of the lower efficiency in controlling the weeds and decreasing pattern in the availability of labourers and increased wages.

**Table 5**: Common weeds of DSR in Nepal.

| Scientific Name | Common Name | Vernacular Name |
|---|---|---|
| **Grassy weed** | | |
| *Echinochloa colona* | Junglerice | Banso |
| *Echinochloa crus-galli* | Barnyardgrass | Sama |
| *Paspalum distichum* | Knot-grass | Ghode dubo |
| *Eragrostis pilosa* | Indian love grass | Charako dana |
| *Leptochloa chinensis* | Chinese sprangletop | |
| *Eleusine indica* | Goosegrass | Khode jhar |
| *Panicumm dichotomiflorum* | False panygrass | Banso |
| *Digitaria spp* | | Banso |
| *Cynadon dactylon* | Bermuda grass | Dubo |
| **Broad leaf weed** | | |
| *Ageratum conyzoides* | Goat grass | Gandhe |
| *Alternanthera philoxeroides* | Alligator weed | Patpate, maobade jhar |
| *Amaranthus spinosus* | Spiny pig weed | Kande jhar |
| *Caesulia axillaris* | Pink node flower | Thuk jhar |
| *Commelina benghalensis* | Tropical spider wort | Kane |
| *Commelina diffusa* | Day flower | Kane |
| *Cyanotis spp* | | |
| *Eclipta prostrata* | False daisy | bhingharaj |
| *Galinsoga ciliata* | Hairy galinsoga | chitlange |
| *Ludwigia hyssopifolia* | | |
| **Sedges** | | |
| *Cyperus difformis* | Small flower umbrella plant | Mothe |
| *Cyperus iria* | Rice flatsedge | Chatre |
| *Cyperus rotundus* | Purple nutsedge | Mothe |
| *Fimbristylis littoralis* | Globe fringerush | Jhiruwa |

***Cultural***

Stale seedbed technique: In this technique of weed management weeds are encouraged to emerge by a light irrigation; a month prior to rice sowing. After the weeds germinate they are killed by use of non-selective herbicide (paraquat or glyphosate) or by tillage. This method is assumed to suppress the weeds upto 53%. This technique not only reduces weed emergence but also reduces the number of weed seeds in the soil seedbank (Rao *et al*., 2007).

Residue mulch and cover crops: Crops residue on the surface of soil suppresses the weed population by reducing the recruitment of seedlings and early growth. This technique is based on the principle that the residues mulch act as a physical barrier for the emerging weeds and the residues secrete allelochemical which posseses inhibitory effect on the early growth and development of weeds. A study in India found out that wheat residue when used as mulch @ 4 ton/ha reduced the emergence of grass weeds by 44-47% and broadleaf weeds by 56-72% in dry-drill-seeded rice (Singh *et al*., 2007).

*Sesbania* co-culture (Brown Manuring): In this method the seeds of *Sesbania* are sown along with rice. After 25-30 days *Sesbania* are killed with 2, 4-D ester @ 0.50 kg $ha^{-1}$. *Sesbania* reduces the weed population by competing with weeds during emergence and by mulching action. *Sesbania* co-culture is expected to reduce the weed population by 50% without any adverse effect in yield. The effectiveness of this technique is further enhanced by the application of pendimethalin, a pre-emergence herbicide. Pendimethalin controls the grasses which would be a great problem after the knockdown of *Sesbania* . Besides reducing the weed population *Sesbania* also mop up the soil nitrogen by atmospheric nitrogen fixation and furthermore assists in crop emergence in the areas where crust formation is a problem.

***Chemical***

Chemical method of weed management is the most effective method of weed reduction within short period of time. It necessarily does not mean that herbicides are the best alternatives to weed management but if integrated with other options of weed management gives best result in the yield and quality. Despite the fact that herbicides are a serious threat to environment; herbicides are considered to be the best method of weed management in DSR (De Datta, 1981). Herbicides are categorized as pre-plant (Applied to destroy the vegetation prior to sowing), pre-emergence (Applied 1-3 days after sowing before emergence) and post emergence (After the emergence of the seed). Judicious selection of herbicide at right time, right dose and right method helps to effectively manage weeds and increase the crop yield. Some of the commonly used knockdown, pre-emergence ad post emergence herbicides along with their appropriate dose and time is presented in (Table 6). A single herbicide can never be a complete for the weed management in DSR, because of complex weed flora in DSR. Hence, two or more combination of herbicides can be the most effective and integrated approach in controlling the complex weed flora. Extensive researches have been done by researchers in the earlier days to draw out the conclusion of appropriate dose, time, method of application of herbicides in rice fields.

## Diseases and Pest Management

Research reports from past suggests that DSR is infested by similar kinds of disease pests as in CT-TPR. Rice is highly susceptible to blast and its efficacy increases under water limited conditions (Bonman, 1992; Mackill and Bonman, 1992). Kim (1987) opined that the level of water supply influences several processes like spore liberation, germination and infection in rice blast epidemics. Poor water management practices result in moist and dry soils for rice cultivation favouring dew deposition. Dew deposition can be a severe issue in DSR as it affects the lifecycle of the pathogen (Sah and Bonman, 2008), and indirectly affects crop physiology and modifies the crop microclimate susceptible for host and blast development (Bonman, 1992). Two major rainfed wetland rice insects, whorl maggot and caseworm can be controlled under dry-seeded conditions as dry-seeded rice starts as a dryland crop and is not attractive to whorl maggot and caseworm. Golden apple snails and rats are also a major problem to rice establishment in wet-seeded rice. Sometimes the attack of arthropod insect pests is reduced in DSR compared with TPR (Oyediran and Heinrichs, 2001), but a higher frequency of ragged stunt virus, yellow orange leaf virus, sheath blight and dirty panicle have been observed in DSR (Pongprasert, 1995). *Meloidogyne graminicola* (MG) a root-knot nematode (RKN) is the most infectious soil-borne pathogen for aerobic rice (Padgham *et al*., 2004; Soriano and Reversat, 2003). *Meloidogyne graminicola* (MG) cannot enter the rice roots under flooded conditions but can survive for prolonged period of time and can attack rice roots once aerobic conditions meet up. A study in Philippines suggested $RKN_s$ to be most damaging pathogen for aerobic rice crop (Kreye *et al*., 2009). Rice yield in untreated plots was 0.2-0.3 t/ha in 2006 and nil in 2007 but in the plots treated with nematicide dazomet rice yield was 2.2 t/ha in 2006 and 2.4 t/ha in 2007. Heating soil at 1200 C for 4 hr is also reported to control soil pathogens (Nie *et al*., 2007). Poor farmers of Asian countries have been using plant derived bio-pesticides for disease and pest management. A suitable example of such bio-pesticide is Neem (*Azadirachta indica*) which is reported to have antiviral, fungicidal, insecticidal and nematicidal properties. It is cheaper, readily available, eco-friendly and does not require skilled manpower as it is easier to prepare and use. Furthermore, the pathogen cannot develop resistance against neem products since they have more than one molecule exhibiting the biocidal activity. Recent advancements in IPM (Integrated pest management) have introduced the concept for pest management using the indigenously available materials to be mixed in appropriate ratios. Fumigating the rats burrows in the rice fields with dung cakes and cow dung balls well soaked in kerosene all over the field helps in controlling the rats and other burrowing animals in the rice fields. Similarly, growing of disease resistant cultivars and summer plouging can be another strategy for efficient management of viral diseases and several pests. Use of nitrogen and potassium in proper ratios also credits in pest management. Soil application of bio agents such as *Trichoderma harzianum* @ 4 g ha-1 and *T. virens* @ 8 g ha-1 after one week of nematode infestation results in better nematode control and optimum yield of DSR crop (Pankaj *et al*., 2012)

**Table 6**: Major knockdown, pre-emergence and post emergence herbicides used in DSR with appropriate dose, time, mode of action, strength and weaknesses.

| **Herbicide (active ingredient, a.i.)** | **Product (trade) name*** | **Rate (g a.i./ha)** | **Product dose (g/ha or ml/ha)** | **Application time (DAS)** | **Mode of action** | **Strengths** | **Weaknesses** |
|---|---|---|---|---|---|---|---|
| Knockdown/non-selective | | | | | | | |
| Glyphosate | Roundup | 1000 | 2500 ml | | EPSP synthase inhibitor | Good control of most grasses, some broadleaves and annual sedges | Weak on *Ipomea tribola* and *Commelina* species |
| Paraquat | Gramoxone inteon | 500 | 2000ml | | Photosystem I electron diverter | Good control of most grasses, some broadleaves and annual sedges | |
| Pre-emergence | | | | | | | |
| Pendimethalin | Stomp/stompxtra | 1000 | 3330 ml 2580 ml | 1-3 | Microtubule assembly inhibitor | Good control of most grasses, some broadleaves and annual sedges. Has residual control. | Sufficient moisture is needed for its activity |
| Oxadiargyl | Topstar | 90 | 112.5 g | 1-3 | Protoporphyrinogen oxidase inhiibitor | Broad-spectrum weed control of grasses, broadleaves, and annual sedges. Has residual control. | Sufficient moisture is needed for its activity |
| Pyrazosulfuron (post-emergence also) | | 20 | | 1-3 or 15-20 DAS | ALS inhibitor | Broad-spectrum weed control of grasses, broadleaves, and annual sedgesincluding *C. rotundus* . Has residual control. | Poor on grasses including *L. chinensis* and *Dactyloctenium aegyptium*. |
| Post-emergence | | | | | | | |
| Bispyribac-sodium | Nominee Gold/Adora | 25 | 250 ml | 15-25 | ALS inhibitor | Broad-spectrum weed control of grasses, broadleaves and annual sedges. Excellent control of *Echinochloa* species | Poor on grasses other than *Echinochloa species*, including *L. chinensis, Dactyloctenium aegyptium, Elusine indica, Ergrostis species.* No residual control |
| Penoxsulam | Granite | 22.5 | 93.75 ml | 15-20 | ALS inhibitor | Broad-spectrum weed control of grasses, broadleaves and annual sedges. | Poor control of grasses other than *Echinochloa species*, including *L. chinensis, Dactyloctenium aegyptium, Elusine indica, Ergrostis species.* |
| Fenoxaprop-ethyl | | 60 | | 25 | ACCase inhibitor | Excellent control of annual grassy weeds | Does not control broadleaves and sedges. Not safe on rice if applied at early stage (before 25 DAS). |

**Table 6**: Major knockdown, pre-emergence and post emergence herbicides used in DSR with appropriate dose, time, mode of action, strength and weaknesses.

| **Herbicide (active ingredient, a.i.)** | **Product (trade) name*** | **Rate (g a.i./ha)** | **Product dose (g/ha or ml/ha)** | **Application time (DAS)** | **Mode of action** | **Strengths** | **Weaknesses** |
|---|---|---|---|---|---|---|---|
| Fenoxaprop-ethyl + safner | Rice star | 60-90 | 870-1300 ml | 15-20 | ACCase inhibitor | Excellent control of annual grassy weeds, safe on rice at early stage | Does not control broadleaves and sedges |
| Cyhalofop-butyl | | 120 | | 15-20 | ACCase inhibitor | Excellent control of annual grassy weeds | Does not control broadleaves and sedges |
| Propanil | | 4000 | | 15-25 | Photosynthesis at photosystem-II inhibitor | Broad-spectrum weed control, can be tank mixed with many herbicides | No residual control. Need sequential application for effective control or need some residual herbicide with it as tank mix |
| Azimsulfuron | Segment | 17.5-35 | 35-70 g | 15-20 | ALS inhibitor | Broad-spectrum control of grasses, broadleaves and sedges. Excellent control of sedges, including *Cyerus rotundus*. | Poor on *echinochloa* species. |
| Ethoxysulfuron | Sunrice | 18 | 120 g | 15-20 | ALS inhibitor | Effective on broadleaves and annual sedges | Does not control grasses and poor on perennial sedges such as *C. rotundus*. |
| Triclopyr | | 500 | | 15-20 | Synthetic auxins | Effective on broadleaf weeds | Does not control grasses |
| 2,4-D ethyl ester | | 500 | 1250 ml | 15-25 | Synthetic auxins | Effective on broadleaves and annual sedges. Very economical | Has no residual control |
| Carfentrazone | Affinity | 20 | 50 g | 15-20 | | Effective on broadleaf weeds | Does not control grasses. Has no residual control. |
| Chlorimuron + metasulfuron | almix | 4(2+2) | 20 g | 15-25 | ALS inhibitor | Effective on broadleaves and annual sedges | No control of grassy weeds and poor on *C. rotundus* |
| Bispyribac + azmisulfuron | | 25+17.5 | 250 ml + 35 g | 15-25 | ALS inhibitor | Broad-spectrum weed control of grasses, broadleaves and sedges, including *C. rotundus* | Poor on grasses ther than *Echinochloa* species |
| Fenoxaprop + ethoxysulfuron | | 56+18 | 645 ml + 250 g | 15-25 | ACCase and ALS | Broad-spectrum control of grasses, broadleaves and sedges. Excellent control of all major grasses, including *L. chinensis* and *D. aegyptium* | Poor on perennial sedges such as *C. rotundus* |
| Propanil + pendimethalin | | 4000+1000 | | 10-12 | Photosynthesis and microtubule assembly inhibitor | Broad-spectrum weed control with residual effects | Poor on sedges such as *C. rotundus* |
| Propanil + triclopyr | | 3000+500 | | 15-25 | Photosynthesis and synthetic auxins | Broad-spectrum control of grasses, broadleaves and sedges | Poor control on perennial sedges such as *C. rotundus*. No residual control |

(Source : Kumar and Ladha, 2011)

## Conclusion

At this point of time, where globe is facing water scarcity, escalated labour and climate change when rice production is under severe threat, no doubt questions for its alternative are arising. Direct-seeded rice (DSR) with appropriate conservation measures and variety has proved to offer similar and comparable yields as that of TPR. Weeds are the major constraint in DSR fields contributing higher yield losses and sometimes complete crop failure. So integrated weed management options are to be discussed and conclusions should be drawn for successful DSR cultivation. There is immense need for researches in soil ecology of rice fields and weed management of DSR. Selection of appropriate variety and seed priming helps early growth and development of DSR without fungal attack and keeps crop away from soil borne pathogens. Varieties capable of synthesizing osmoprotectants and capable of synthesizing stress proteins may be introduced. Different site specific production technologies should be developed to cope up with the similar rice ecologies. Methane production was significantly reduced in DSR fields but $N_2O$ emission became an issue. To combat the $N_2O$ production in DSR plots and start up a sustainable way of farming several strategies are to be developed to reduce N losses via $N_2O$ emissions. Effective crop management, enhanced biotechnological and genetic approach, effective weed management, increased NUE and better understanding of disease-pest dynamics will assist in optimizing the DSR yields and stand itself high as a better alternative to TPR.

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