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RESEARCH ARTICLE

ADOPTION OF DIRECT SEEDED RICE (DSR) OVER PUDDLED-TRANSPLANTED RICE (TPR) FOR RESOURCE CONSERVATION AND INCREASING WHEAT YIELD

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ABSTRACT

Global rice production has revealed signs that it may no longer be stable in the future. Along with the increasing population, the resources for rice production are declining. Moreover, water needs labor force for transplanting rice has become insufficient because laborers are shifting from agriculture to industry, public works, and overseas job. In view of this, the Direct-seeded rice has been put forward as an appropriate substitute to traditional puddled-transplanted rice with efficiency to save water, reduced labor requirement, mitigation of green-house gas emission, and adaptability to climatic risks. It has potentiality to increase the productivity of the subsequent non-rice crop i.e. wheat particularly in Rice-Wheat cropping system, the dominant cropping system in South Asia. However, the DSR suffers from several constraints, particularly high weed infestation. The system has been proved farmers-friendly but requires more enhancements in technological approach to realize higher benefits. In recent years, strategies have been made in promoting the DSR technology by different organizations. Scientists are working in developing suitable varieties and agronomic packages for encouraging the DSR. This review describes the resource and environmental constraints of traditional puddled-transplanted rice cultivation, analyzes the advantages and constraints of DSR, and solutions to problems of DSR in Nepal.

KEYWORDS

advantage, constraints, rice-wheat cropping system, Nepal.

1. INTRODUCTION

As rice and wheat are major preeminent food for the majority of people in Nepal, Rice-Wheat cropping system is the pre-dominant cropping system adopted. The term 'rice is life' is most pertinent in Nepali ambience as this crop plays significant role in country's food security and is the buttress of sustenance for millions of rural households. The demand of rice and wheat to fulfill the food requirements of the burgeoning population is increasing. Contrarily, most indispensable inputs of agriculture, particularly, water and labor are depleting in the area. Farmers in Nepal have been practicing the transplanted rice cultivation in puddled field since antiquity. Rice transplantation depends on monsoon in Nepal. In past years, only 23% of the total rice growing area in Nepal was under irrigated condition (Adhikari and Khatiwada 1996/97). Yet, there seems not much progress in the statistics in these years too. Rice is usually planted by transplanting seedlings of 20 to 25 days on puddled soil. Because of late monsoon practice of puddling, it delays rice transplanting by one to three weeks (Ladha et al., 2009). This afterwards delays rice harvesting and ultimately wheat planting. Soil puddling in advance of transplanting of rice is usually considered expedient for achieving resource use efficiency, yield stability, and high productivity, chiefly by retaining water and nutrient resources while reducing weed pressure (DeDatta and Barker, 1978). The conventional system of rice production (conventional tilled-transplanted rice) in Nepal is intrinsically water, labor and energy intensive, adversely affecting the ecosystem. Rising water inadequacy, water-intensive nature of rice cultivation and

increasing labor costs drive the search for alternative management approaches to enhance water productivity in rice production. Direct seeded rice (DSR) has been more highlighted owing to its low-input demand.

Direct seeded rice (DSR) refers to the process of establishing rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery (Farooq et al., 2011). Three principle methods of establishing the direct seeded rice is commonly known; dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre germinated seeds on wet soil), and water seeding (seeds sown into standing water) (Joshi et al., 2013). After the germination and seedlings establishment are completed, the crop can then be sequentially flooded and water regimes maintained as for transplanted rice. Globally, 23% of rice cultivation is under direct seeded rice and 29 million hectares in Asia which is approximately 21% of the total rice area in the region (Rao et al., 2007; Pandey and Velasco, 2002). In Southeast Asia, DSR is mostly adopted in the dry season than in the wet season possibly because of better water management strategies. However, dry season rice accounts for less than one-quarter of rice production in this region (Farooq et al., 2011). Besides, direct seeded rice (DSR) has often lower yield than puddled-Transplanted rice (TPR), primarily owing to poor crop stand and high weed infestation (Singh et al., 2005). A group researcher reported that yield potential of direct seeded rice was equivalent to the transplanted rice under appropriate water management and weed control conditions (Awan et al., 1989). The average grain yield of dry direct seeded rice was about 9.6 t/ha (Yun et

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al., 1997; Kato et al., 2009). Also, some researchers reported that 5.33% higher grain yield and about 25-30% less water use in dry direct seeded rice than transplanted flooded rice (Zhao et al., 2007). The development of early-maturing varieties and improved nutrient management techniques along with increased availability of chemical weed control methods has encouraged many farmers in Nepal to switch from transplanted to DSR culture. This shift should substantially lessen crop water requirements, soil organic-matter turnover, nutrient relations, carbon sequestering, weed biota and greenhouse-gas emissions.

Here, a basic question may arise – “Though DSR has lower yield, poor crop stand, and higher weed infestation than TPR, why to adopt direct seeded rice in rice-wheat cropping system?” Though, DSR has weak crop stand and severe weed problems, the crop in DSR matures earlier than in TPR with less resource demand and sequentially it allows the wheat crop planting on time thus increasing overall productivity of the cropping system than the rice crop alone. In short, the advantage of DSR can be derived in wheat crop. DSR too has many constraints; weed infestations being the prime one. Several management practices, strategies, and approaches have been made from the part of agricultural institutions and government to tackle the weed problem (Rao et al., 2007). This study completely delves into the comprehensive overview of the advantage of adopting DSR over TPR, resources conservations, and the influence of wheat productivity with DSR in rice-wheat cropping system. The main objective of the study was to understand how the resources can be conserved with Direct seeded rice instead of using conventional puddled rice transplantation.

2. MATERIALS AND METHODS

Secondary method of data collection was used to collect the related information. This paper is based on the review of different publications. Pieces of Literatures were collected from several Journal articles, Government institutes, and other relevant reports and the major findings were evaluated and summarized. The agricultural reports from various institutes have also been considered.

3. DISCUSSION

3.1 Trend of Rice and Wheat productivity in Nepal

According to the Ministry of Agriculture and Livestock Development (MoALD), this year paddy production plunged by 1.05 percent compared to last years (SpotlightNepal, 2020). Due to untimely rainfall, plotting of arable land, inundation in the Terai, paucity of sufficient irrigation facilities and youth population deserting from agricultural activities, it caused the drop in rice production. Yield (hg/ha) of rice in Nepal has increased from 20161 hg/ha in 1985 to 35058 hg/ha in 2018. Rice and wheat are the two major cereal crops of Nepal which are grown subsequently after each crop. The yield (hg/ha) of wheat crop in Nepal is in increasing trend since few years. It has increased from 11811 hg/ha in 1985 to 27573 hg/ha in 2018. The area under rice cultivation was 1391040 ha in 1985 which increased and reached 1469545 ha in 2018. Similarly, wheat cultivation area increased from 451890 ha in 1985 to 706843 ha in 2018. Graph 1 and graph 2 shows the trend of rice and wheat yield and the area under cultivation respectively.

Figure 1: Rice and wheat yield (hg/ha) from 1985-2018 (Source: FAOSTAT, (1985-2019))

Figure 2: Acreage (ha) under Rice and Wheat from 1985-2018 Source: FAOSTAT, (1985-2019)

3.2 Rice-wheat cropping system (RWSC) in Nepal

The rice wheat cropping system covers nearly 13.5 million hectares in South Asia (10 million in India, 2.2 million in Pakistan, 0.8 million in Bangladesh and 0.5 million in Nepal), extending across the Indo-Gangetic floodplain into the Himalayan foothills (Ladha et al., 2000). Furthermore, rice-wheat cultivation exists outside the Indo-Gangetic plain in China (10.5 million hectare). Rice-wheat cropping system holds nearly 32% of the total rice area and 42% of the total wheat area in these four nations; India, Pakistan, Bangladesh and Nepal (Anonymous, 2007). Particularly, this system contributes 37% of the rice and 85% of the wheat area in Nepal in 2002 and from that period, this system began to get popularity (Tripathi et al., 2002). It accounts 65.8% and 72% of the total area and total production of cereal crops in the country in 2012 and is now in increasing trend (Khanal et al., 2012).

Rice-wheat rotation plays a crucial role in maintaining food safety in the country. Nevertheless, some somber issues are emerging during agricultural production. One is that long-term conservation tillage results in shallow and stringent ploughing layers. The other is that hefty quantity of straws is difficult to successfully manage in the limited rotation gaps between both crops. Yields in this rotation have enhanced over time, but report shows that factor productivity may be declining. Rice-wheat cropping system is known for high cropping intensity. Green fodder is conveniently available in rice-wheat cropping system and this in turn works to support large livestock population. This way, the Rice-Wheat cropping pattern has been the mainstay of Nepal's food security and is most widely prevalent in not only Nepal but in entire South Asia. However, production of rice and wheat over a prolonged period has brought about the degradation of natural resources (groundwater, soil) to a great extent. Hence, the sustainability of rice-wheat system is affected due to over milling of essential nutrients from soil; declining groundwater levels; diseases / pest emergence due to prolonged system adoption; disturbance in soil due to rice puddling etc. The government has been constantly encouraging the alternate crops in order to lessen the wheat and paddy crop rotation.

Rice and wheat are now cultivated in sequence on the same land in the same year in Nepal and many other countries to meet the food demand of an expeditiously expanding human population. This rice-wheat (R-W) system generates conflicting and complementary practices. Much of the system operates at low yield due to insufficient nutrients and inappropriate water management techniques. The repeated transitions from anaerobic-aerobic-anaerobic growing conditions deteriorate soil structure, nutrient relations, the growth of the component crops and their associated pests and diseases. Regardless of the expanding populations, production of rice and wheat has kept pace with demand in South Asian countries, and in Nepal too. However, the system is depicting signs of fatigue and evidence indicates that natural resource degradation may be reducing productivity in Nepal's rice-wheat systems. This has grievous implications for millions of producers who rely on this system for their livelihoods, and for meeting the ever-increasing food demand due to population growth.

3.3 Traditional puddled-transplanted rice (TPR)

Contributing almost 28% of the Total Gross Domestic, agriculture has been predominant occupation, having more than 66% of people directly engaged in agriculture, employing two-thirds of the country's labor force (Khanal and Shrestha, 2019). Here, rice is grown widely in large belts of plain terai to some scant in mountain region. Transplanting after repeated puddling is the traditional method of rice production which is not merely water intensive but also tedious and laborious. In the traditional puddled

transplanting system (PTR), high quantity of irrigation water is used for puddling which destructs capillary pores; breaks soil aggregates, and results in formation of hard pan, creating problems for the establishment and growth of succeeding crops. Several impediments like declining water table, shortage of labor during peak periods, deteriorating soil health, etc. demands some alternative establishment method to sustain productivity of rice as well as natural resources. Moreover, to enhance transplanting, puddling serves various functions including weed control and reduction in deep percolation losses of water. Currently, the transplanting system of rice is most practiced in the irrigated areas whereas dry-seeding is extensively common in rainfed lowlands, uplands and flood-prone areas in Nepal.

3.3.1 Constraints of TPR

Transplanted method of rice cultivation is high water demanding, laborious, cumbersome, time consuming and incurred a lot of expenditure on raising nursery, uprooting, and transplanting. Shortage of labor during peak period of transplanting, erratic supply of monsoon rain, decrease of underground water and rising production cost necessitate the search for an alternative to the conventional puddled transplanting of rice. Some of the prime problems associated with puddled transplanted rice are discussed below:

3.3.1.1 Declining water resource base

Rice consumes about two times as much water as wheat or maize. In some regions, water application in rice is about 5–6 times that of wheat. The decreasing availability and quality of water, increased competition from domestic and industrial sectors, and rising costs are already affecting the sustainability of irrigated rice production systems in many parts of the country. Water consumption in rice cultivation, hence, needs to be reduced by enhancing water-use efficiency through reduced losses caused by seepage, percolation and evaporation; laser land leveling; crack plowing to reduce bypass flow; and bund maintenance. The direct seeded rice (DSR) has got potential to increase the water use efficiency.

3.3.1.2 Effect on subsequent crop

Puddling changes the physical structure of soil which can be favorable for rice. However, it can be very harmful to the cultivation of subsequent non-rice crops such as wheat by causing temporary water logging, poor crop emergence and restricted root development because of a dense zone of compaction i.e., plough pan below 30 cm soil depth.

3.3.1.3 Pollution due to pesticides and fertilizers

The application of pesticides and fertilizers is a part of modern rice cultivation and their application greatly enhanced agricultural production. But, the non-judicious application of pesticides has caused concerning issues of air, water, and soil pollution in many rice-growing regions. Fertilizer, particularly, nitrogen fertilizer, is most applied in excess of the crop requirement and at unsuitable times in many intensively irrigated rice systems, which increases the risk of poor fertilizer recovery by the rice crop. Below 35% of applied nitrogen (N) is absorbed by rice and the remaining 65% is lost from soil-plant systems into the surrounding through volatilization, denitrification, leaching, and runoff, thus creating pollution problems (Ladha et al., 2005). It leaves negative impacts in the environment.

3.3.1.4 Burning or rice residues

Straw and husk of rice are usually not disposed in an ecological manner. Tons of rice residues are burned annually in Nepal. The burning of rice straw is environmentally toxic as it leads to release of smoke, causing human health problems such as asthma or other respiratory problems, emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, causing global warming, and loss of plant nutrients such as N, P, K, and S. Almost the whole amounts of C and N, 25% of P, 50% of S, and 20% of K present in straw are lost due to burning.

3.3.1.5 Methane gas emission

Rice cultivation leads to global climate change through release of methane and nitrous oxide. Methane is emitted in soil due to the metabolic reactions of a small but highly specific bacterial group called methanogens. Their activity activates in submerged, anaerobic condition produced in wetland rice fields, which inhibit the transport of oxygen into the soil, and the microbial activities render the water-saturated soil practically lacking of oxygen. The upland, aerobic soil does not emit methane gas. So, water management plays a determining role in methane production. Altering water management practices, especially mid-season aeration by short-term drainage as well as alternate wetting and drying can highly control

methane emission in rice cultivation. Bettering organic matter management by promoting aerobic degradation through composting or incorporating into soil during off-season drain period is another effective technique.

3.3.1.6 Adverse effects of puddling on soil properties

Puddling during traditional rice cultivation is the responsible drawbacks of rice-wheat cropping system which is decreasing the productivity of the cropping system (Bajpai and Tripathi, 2000; Mohanty et al., 2006). A number of studies have reported the adverse impact of puddling on soil physical properties which are proved to have been destructive for the performance of subsequent wheat crops (Sharma and DeDatta, 1985; Meelu et al., 1979). The physical manipulation of soil during puddling causes disruptions of clay fraction from the compacted layer which eventually increases bulk density in the compacted layer forming tillage pan (Sharma and DeDatta, 1985; Aggarwal et al., 1995; Bhatgat et al., 1999; Koenings et al., 1950; Hobbs et al., 1995).

3.4 DSR: shift from TPR

Transplanted rice has pernicious impacts on the soil environment for the succeeding wheat and other upland crops. DSR, which removes puddling and drudgery of transplanting, the young rice seedlings, provides an option to deal with the edaphic conflict and embellish the sustainability of rice-wheat cropping system. Puddling high volume of scarce water at a time when there is insufficient water in the reservoirs and damages soil structure and unfavorably declines soil productivity. DSR solves the problem of seasonality in labor requirement for rice nursery raising and transplanting operations. Insufficiency of ground water in kharif, late beginning of monsoon and drudgery of operations often delays rice transplanting which results in late vacation of fields, compelling farmers to plant wheat after the optimum sowing time. DSR promotes timely establishment of rice and succeeding winter crops. Unlike puddled fields, DSR fields do not crack and thus help save irrigation water. Substitute of puddled transplanted rice (PTR) by dry seeded rice (DSR) can conceivably lower utilization of resources and reduction in emissions of greenhouse gases like methane while maintaining grain yields.

This review was performed to better understand the problems and opportunities for replacing TPR with DSR in Nepal. With appropriate water management, grain yield of DSR is about to or higher than yield of TPR while increasing irrigation water productivity and nitrogen use efficiency (NUE), lessening greenhouse gas emissions and decreasing labor requirement. Nonetheless, bottlenecks that include lodging, weak root development, weed and weedy rice infestations and poor crop establishment under drought, waterlogging, or chilling stresses might limit large-scale adoption of DSR in Nepal. Hence, substitute of the puddled transplanted rice (PTR) production system with a non-puddled system has many potential advantages. Farmers have adopted puddling and transplanting over time and are reluctant to try alternatives. However, economics play a determining role in the decision making of farmers. Trials conducted by researchers over the globe precisely reveal the benefits in DSR over puddled transplanting.

There are two major rice establishment methods which remove puddling and manual transplanting: dry seeding and mechanical transplanting. Dry seeding may take place on raised beds or on the flat. Rice can be directly seeded either through dry or wet (pre-germinated) seeding. Dry seeding of rice can be done by drilling the seed into a fine seedbed at a depth of 2–3 cm. Wet seeding needs leveled fields to be harrowed and then flooded (puddling). The field is left for one day after puddling, then germinated seeds (2–3 days) are sown using a drum seeder. Seed can be broadcasted for either dry or wet seeding, but manual weeding is more cumbersome.

3.5 Looming Scenario

3.5.1 Declining underground water table

Nepal, instead of being a high consumer of water, agricultural sector has been appearing to lose its share as water allocated for irrigation is probably to decrease in the coming years. Since few years, per capita water availability is diminishing in the major rice growing countries of the Asia. Irrigation is the primary need for the agriculture sector but its injudicious application results in huge consumption of water needed for the rice and wheat cultivation. Since antiquity, rivers that originate from the high mountains directly goes into the sea without much infiltrating much into the ground. The table below shows the declining underground water in different countries of the South Asia. In Nepal, 21263 cubic meters of water was available in 1950 which is 4820 cubic meters now in 2020. Also, it is estimated to be 3467 m³ in 2050. Puddled-transplanted rice needs more volume of water than DSR. So, in order to conserve the water for future use, DSR seems to be a better alternative for the farmers.

Table 1: Declining underground water table of different Asian countries

Country	1950	1995	2000	2005	2010a	2015a	2020a	2025a	2050a
	(m ³)								
China	5047	2295	2210	2134	2068	2006	1956	1927	1976
India	5831	2244	2000	1844	1717	1611	1525	1457	1292
Japan	6541	4374	4314	4292	4307	4348	4423	4528	5381
Indonesia	31,809	12,813	12,325	11,541	10,881	10,361	9952	9609	8781
Nepal	21,623	7923	6958	6245	5695	5230	4820	4470	3467
Pakistan	11,844	3435	3159	2822	2533	2277	2069	1900	1396
Philippines	15,390	4761	4158	3778	3450	3175	2945	2754	2210
Sri Lanka	5626	2410	2302	2212	2117	2041	1990	1961	1990
South Korea	3247	1472	1424	1390	1363	1345	1336	1336	1500
Thailand	8946	3073	2871	2714	2627	2559	2505	2465	2440

(Bhatt et al., 2016)

3.5.2 Labor-shortage to involve in farming

In 1999, the youth unemployment rate was 2.93% whereas in 2019, it fell to 2.14%. The unemployment rate is fluctuating since few years. This causes great impact on the labor availability to work or to involve in agricultural production. Labor shortage is one of the major reasons to be shifted from TPR to DSR as practices in DSR are less labor intensive.

Figure 3: Nepal: Youth unemployment rate 1999 – 2019 (Statistica, 2020)

3.6 DSR: an alternative to TPR

Direct seeded rice (DSR) is an alternative to TPR in many regards. It helps to cope with the problems of water and labor inadequacy associated with conventionally flooded rice (Weerakoon et al., 2011). In addition, direct seeded rice avoids transplanting shock, therefore attains the physiological maturity earlier than transplanted rice and decreases the vulnerability to late season drought (Tuong et al., 2008). Besides resources conservation and potential benefits to subsequent wheat crop, direct seeded rice technology is popular to have less emission of greenhouse gas (GHG) as compared to puddled-transplanted rice. Flooded rice culture with puddling and transplanting are the main cause for methane gas emission in the rice fields characterized to anaerobic soil condition due to prolonged flooding. This contributes to 10 to 20% (50-100 Tg/year) of the total annual CH₄ emission worldwide (Reiner and Aulakh, 2000). ZT-dry-DSR showed 20% more efficiency in reducing GWP than CT-TPR (Ishibashi et al., 2009). The reason for low methane gas emission from dry-DSR is aerobic conditions, usually during early growth stage (Kumar and Ladha et al., 2011).

Presently, several countries of south Asia have shifted from puddled-transplanted rice to direct seeded rice cultivation (Pandey and Velasco, 2002). Water inadequacy and labor shortage or increasing labor wages are the major reason for choosing direct seeding whereas crop intensification and recent development in DSR production technologies, detrimental impacts of puddling on soil physical properties and the succeeding wheat crop are the other drivers for shift from puddled transplanting to direct seeded rice (Kumar and Ladha, 2011). The attributes that are probably to be the most helpful for direct seeding include tolerance of early submergence for quick cation exchange, high seedling vigor with faster leaf area development during the early vegetative stage for weed suppression, erect leaves with few specific leaf area and increased chlorophyll content for effective crop growth during the reproductive phase along with high remobilization ability for higher spikelet fertility, a strong, thick and sturdy culm with long and heavy panicles positioned at lower height for lodging resistance, and high genetic yield potential with high input use efficiency under direct seeded rice (Kumar and Ladha, 2011). Direct seeded rice under no/reduced tillage is an effective resource conserving technology (RCT) claiming good promise in coming days because of the following advantages over transplanting of rice:

- Labor requirement for nursery raising, uprooting and transplanting of seedlings are saved to the extent of nearly 40% and the work cost is low.
- Mitigation in emission of methane gas and reduced the perils to global warming potential.
- Enhanced the production of the subsequent crops; non-rice crops, especially, wheat.
- Water consumption saving up to 60% as nursery raising, puddling, seepage and percolation are no longer needed as like in TPR.
- Fertilizer use efficiency is enhanced due to application of fertilizers in the root zone and hence causes less environmental pollution.
- Soil structure is not damaged in direct seeded rice as like in puddled transplanted system.
- Cost of cultivation is reduced to some extent.
- Yield develops 7-10 days sooner than the transplanted-puddled rice.
- Reduction in burning of rice straw that is environmentally toxic as it results in the release of soot particles and smoke causing human health problems.

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

DSR	TPR	Rice ecology	Country	Reference
6.6	6.8	Rainfed lowland-hill	India	(Singh et al., 2009)
2.56	3.34	Irrigated	Pakistan	(Farooq et al., 2006b); Farooq et al., 2007)
5.5	5.4	Shallow wetland-irrigated	Japan	(Harada et al., 2007)
3.83	3.63	Rainfed lowlands	Thailand and Cambodia	(Mitchell et al., 2004)
6.09	6.35	Rainfed lowland-hill	India	(Tripathi et al., 2005)
4.64	4.17	Rainfed lowland-hill	India	(Rath et al., 2000)
2.93	3.95	Irrigated	Pakistan	(Farooq et al., 2006a; Farooq et al., 2009)
5.4	5.3	Favorable irrigated	India and Nepal	(Hobbs et al., 2002)
3.15	2.99	Unfavorable rainfed lowland	India	(Sarkar et al., 2003)
5.38	5.32	Irrigated	South Korea	(Ko and Kang, 2000)
5.59	5.22	Favourable irrigated	India	(Sharma et al., 2004)

3.7 DSR as an aid to wheat productivity

Puddling leaves detrimental impacts on wheat production mainly in two ways: firstly, it damages soil structure and secondly it defers planting of subsequent wheat crop (Hobbs et al., 1994; Sharma et al., 1985). Kumar

and Ladha reported 8-9% decline in wheat yield when wheat was sown after puddled-Transplanted Rice (TPR) than after dry-direct seeded rice (DDSR) (Kumar and Ladha, 2011). Rice and wheat crops have dissimilar edaphic requirements. The contrasting seedbed requirements for rice and wheat cause problems in tillage, timeliness of wheat seeding, maintenance of soil structure and management of irrigation. Ploughing of puddled soil after rice results in the formation of large clod, showing more breaking strength which restricts the effectiveness and increases the cost of tillage for seedbed preparation (So and Woodland, 1987; Sharma and Bhagat, 1993). Sub-surface compaction can intensify drought probability for wheat crop by inhibiting root development at depth (Sur et al., 1981; Aggarwal et al., 1995). A study reported that puddling decreases the root length density of wheat crop by 28% (Bajpai and Tripathi, 2000). Low root growth limits water uptake which results water stress to the wheat. A research performed in India reveals that the number of wheat seedling emerged was higher in P₀ (No puddling, that is direct seeding), followed by P₁ (puddling by four passes of 5 hp power tiller at a depth of 10.9cm) and P₂ (puddling by eight passes of 5 hp power tiller at a depth of 14.5cm) (Mohanty et al., 2006). This depicts that puddling reduced the emergence of seedling in subsequent wheat crop. Delayed planting is the principle limitation to wheat productivity in many countries of South Asia (Hobbs et al., 1994; Gan et al., 1992). Late sowing of wheat remarkable decreased the germination percentage (Hussain, 2007). Some researchers noted that sowing of wheat after 15th November reduced the number of fertile fillers and grain yield considerably (Akhtar et al., 2002). Direct seeding of rice also favors early establishment of wheat crop as direct seeded rice matures 7 to 10 days earlier than transplanted rice because there is no transplanting shock in direct seeded rice (Balasubramanian and Hill, 2002). Thus, because of transplanting shock and more turn-around period between rice and wheat in puddled-transplanted rice cultivation, it delays wheat planting and leads to yield losses of 35 (north western IGP) to 60 kg per day per hectare (eastern TGP) (Pathak et al., 2003).

3.8 DSR varieties suitable for Nepal

Selection of cultivars plays a crucial role to attain the desirable yield. The choice of varieties is determined as per the availability of irrigation water and soil types. Inbreds like Sarju-52, Makarkaddu, Samba-Sub-1, and Sona Mansuli are also very common and suitable cultivars of Terai and inner Terai but are not released officially (Yadav, 2015). Varieties suitable for DSR in Nepal are listed below:

Table 3: Rice varieties suitable for Direct-seeding in Nepal	
Regions	DSR varieties used in Nepal
Terai and Inner Terai	Inbreds (Hardinath-1, Tarahara-1, Radha-4, Sukha-1, Sukha-2, Sukha3, 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)

3.9 Constraints in adoption of DSR

The main constraints in the adoption of DSR are severe weed infestation; poor germination and uneven crop stand (Du and Tuong, 2002; Rao et al., 2007; Singh et al., 2009). It is observed that more than 50 weed species attack direct seeded rice (Rao et al., 2007; Caton et al., 2003). Weed grows faster in DSR as compared to TPR (Karim et al., 2004; Begum et al., 2006). Ramzan in his study, reported yield decline by 48, 53, and 74% in transplanted, direct seeded in flooded condition and direct seeded in dry soils respectively (Ramzan, 2003). Furthermore, evolution of weedy rice (*O. sativa f. spontanea*), also known as red rice, has become a serious problem in DSR (Diarra et al., 1985). He recorded yield reduction up to 82% at a density of 215 weeds/m². According to a study, the major weeds observed in DSR plots are *Cyperus rotundus*, *Cyperus difformis*, *Cyperus iria*, *Sphenoclea zeylancia*, *Echinochloa colona* and *Echinochloa crusgalli* (Hussain et al., 2008). Besides this, decreased availability of soil nutrients such as Nitrogen, Iron and Zinc especially in case of dry-DSR, increased incidence of new soil borne diseases and pests are also the other constraints in the adoption of DSR (Kumar and Ladha, 2011). A group researcher revealed increased attack of brown spot disease and plant hoppers in DSR compared with TPR (Savary et al., 2005). *Meloidogyne graminicola* (MG), a root knot nematode is the most infectious soil borne pathogen for anaerobic rice (Padgham et al., 2004).

Table 4: Weed commonly observed in Direct Seeded Rice.	
Weed group	Weed species
Grassy	<i>Echinochloa colona</i> (Junglerice), <i>Echinochloa crus-galli</i> (Barnyard grass), <i>Paspalum distichum</i> (Knot-grass), <i>Leptochloa chinensis</i> (Chinese sprangletop), <i>Cynodon dactylon</i> (Bermuda grass), <i>Panicum dichotomiflorum</i> (False panygrass), <i>Eleusine indica</i> (Goosegras), <i>Digitaria sanguinalis</i> , <i>Ischaemum rugosum</i>
Broad-leaved	<i>Ludwigia hyssopifolia</i> , <i>Galinsoga ciliata</i> (Hairy galinsoga), <i>Eclipta prostrata</i> (False daisy), <i>Cyanotis spp</i> , <i>Ageratum conyzoides</i> (Goat grass), <i>Alternanthera philoxeroides</i> (Alligator weed), <i>Commelina benghalensis</i> (Tropical spider wort), <i>Trianthema monogyna</i>
Sedges	<i>Fimbristylis littoralis</i> (Globe fringerush), <i>Cyperus rotundus</i> (Purple nutsedge), <i>Cyperus iria</i> (Rice flatsedge), <i>Cyperus difformis</i> , <i>Scirpus juncoideus</i>

3.10 Solutions

Convenient weed management techniques should be adopted for persuasive weed controls which include identification of new herbicide that is efficient against a broad spectrum of weeds (FAO, 1999). Integrated weed management (IWM) techniques are appropriate for ecological and sustainable weed control. Cultural method of weed control includes mulching, proper land preparation, brown manuring etc. Rickman noted correct land levelling mitigated the weed population upto 40% (Rickman, 2002). Mulching by using crop residues also proved to suppress weed population (Mohler et al., 1996; Teosdale et al., 1991). Co-culture of *Sesbania* (brown manuring) can decrease the weed population to about half without any negative impacts on rice yield (Kamboj et al., 2012). *Sesbania* inhibits weed growth and after about a month it should be killed by spraying 2, 4-D. Likewise, physical method of weed management includes manual weeding or by employing advanced tools like mechanized cono-weeders. A group researcher recorded twice hand weeding resulted in few weed densities compared to weedicides and untreated control (Rekha et al., 2002). In a like manner, reported that 98.18% of weed can be controlled by hand weeding followed by weedicide Nominee 100 SC which was 90% (Hussain et al., 2008). Manual weeding is appropriate if the area of cultivation is less. However, for the big area of cultivation chemical method is effective and convenient to apply. Sharma and DeDatta considered in spite of the fact that herbicides pose threat to environment; herbicides are the effective way of weed control in DSR (Sharma and DeDatta, 1985). Herbicides should be used in early stage of weed emergence as it is tedious to control weed when it spread in large extent (Bastiaans et al., 2008). For pre-plant application Glyphosate (1kg a.i./ha), Paraquat (0.5kg a.i./ha) are recommended (Gupta et al., 2006). Pendimethalin (1kg a.i./ha), Pyrazosulfuron (0.02 kg a.i./ha) are suggested as pre-emergence herbicides (Gupta et al., 2006; Rao and Nagaman, 2007). Pendimethalin (1kg a.i. /ha), Oxadiargyl (90g a.i./ha), Pyrazosulfuron (20g a.i./ha) are recommended as post emergence herbicides (Kumar and Ladha, 2011). For nutrient management the application of fertilizer is same as puddled TPR but a little of higher Nitrogen (22.5 - 30kg/ha) is suggested in DSR to compensate higher losses and lower availability of Nitrogen.

Seed priming tools have the power to enhance emergence and stand establishment under a broad range of field conditions (Phill, 1995). Seed priming is a pre sowing hydration method in which seeds are allowed to be partially hydrated to the point where germination increasing metabolic activities are accelerated, but seeds do not reach the irreversible point of radical emergence (Bradford, 1986). Primed seeds usually show enhanced germination rate, uniform and faster seedlings growth, greater germination uniformity, greater growth, dry matter accumulation, yield, harvest index and often higher germination percentage (Farooq et al., 2006a). Likewise, for pest management, neem products can be employed which have been proved to have fungicidal, insecticidal, nematocidal and antiviral properties (Prasad, 2007). Heating soil at 1200 degree Celsius for 4 hours is also proved to control soil borne pathogens (Nie et al., 2007). Soil application of biological control such as *Trichoderma harzianum* @ 4g/ha and *T. virens* @ 8g/ha after one week of nematode infestation leads to effective nematode management (Pankaj et al., 2012). Fumigating the rat borrows with cow dung cake keeping the cow dung balls soaked in the kerosene oil over the field results in economic control of rats and other burrowing animals (Joshi et al., 2013). In addition, for effective yield in DSR, recommended seed rate is 20 to 25 kg/ha, with a spacing of 20cm between rows and 5cm within rows in Indo-gangnetic plains (Gupta et al., 2006; Sudhir et al., 2007).

3.11 Future Research Work

The DSR holds promising potential and is an alternative to TPR in current context of water and labor shortage along with increasing global warming. It is gaining more popular among rice producer as it is economical than transplanting. The yields are also more than transplanted rice if crop is properly handled. Moreover, the system productivity also is high in case of DSR. The system has been observed cost-effective and eco-friendly but requires further betterment in technological approaches to realize higher benefits. Following points are suggested for the consideration:

- Further study and research subject should be emphasized to develop high-yielding rice varieties suitable for DSR under different agro-climatic conditions which possess the desirable attributes such as vigorous growth, weed suppressing ability, germinating ability under moisture stress, tolerant to micronutrient deficiency.
- Improve the yield of DSR which is declining because of paucity of nutrient inputs, inefficient water management techniques, and problem associated with weed management.
- Irrigation water supply must be provided at the sowing time as DSR crop establishment in correct time during mid-May to mid-June is determining factor for the success of the crop.
- Agri-inputs should be made accessible to the farmers whenever they required at the time from sowing to marketing.
- Importance should be given to the low-cost integrated weed management strategies involving stale seed bed technique, desirable aerobic genotypes, cultural, physical, and mechanical and use of low doses of herbicides for various ecosystems in the different regions.
- Frequent trainings to the rice growers is required to teach them for calibration of sprayers, preparation of herbicidal spray, importance of flat fan/flood jet nozzles, way of herbicidal application.

4. CONCLUSION

Conventional practices of puddled-transplanted rice (TPR) requires large amount of water and labor. In Nepal, dependency on monsoon for traditional rice cultivation and migration of youth for foreign employment result in the problems of late planting and labor shortage respectively. Puddled TPR has been proved to cause detrimental effects on soil properties either it is physical or chemical. This lengthens turnaround period and creates problems in germination of wheat crop. Hence, we are not able to gain potential yield of both crops in rice-wheat cropping system. In this regard, DSR can be the viable, sustainable and feasible alternative to TPR. Direct seeding can be as productive as conventional TPR under good agronomic management practices. It has also been proved cost and time effective. Benefit-cost ratio is higher in DSR as compared to TPR. DSR has now become attractive to farmers owing its economic advantage over TPR. However, higher weed infestation or the evolution of weedy rice and poor crop stand are the major hindrances in the adoption of DSR. But these problems can be solved by the application of Integrated Weed Management (IWM) practices and seed priming respectively. Focuses should be given on IWM rather than direct use of herbicide, taking consideration of environmental health and also to prevent the evolution of herbicide-resistance weed. At present situation, when the world community is facing water and labor scarcity and inclining towards conservation agriculture (CA); it is very high time for the adoption of DSR. However, research on DSR production technologies has not yet become satisfactory to achieve potential yield. There is immense need for research regarding site specific production technologies and biotechnological and genetic or varietal advancement in DSR. Identification of broad-spectrum herbicide is the emergent need for effective weed control. In addition to research, extension activities also need to be extended among farmers emphasizing its advantages on resources conservation and increasing wheat productivity for its adoption. The authors recommend that future research endeavors should include comprehensive studies on searching for alternative way to traditional puddled rice such as DSR, which is economical, eco-friendly, and is sustainable. The conducted research can be applied to enhance conservation of the scarce resources during the farming of rice. Future research should be focused on developing new and the most effective methods of weed management, resource management, and yield improvement. It is hoped that the findings of this review present clear insights into efforts that will encourage rice growers to adopt DSR.

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