Review on scope and challenges of direct seeded rice in Nepal

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Abstract

Rice is an important staple food crop of more than half of the population in the world to provide food security and livelihoods. Imminent water crisis due to climate change, water demanding nature of traditionally cultivated rice, increasing scarcity of labor and escalating labor costs drive the search for alternative management methods to increase water productivity, system sustainability and profitability in rice cultivation. Direct seeded rice (DSR) technique has received much attention and popularity nowadays because of its low-input demanding nature that can mitigate emission of green-house gases and adaption to climatic risks. DSR involves sowing of dry seed into a prepared seedbed, pre-germinated seed into a puddled soil surface and standing water. The development of early maturing varieties and use of efficient nutrient management practices along with increased adoption of integrated weed management techniques have encouraged many farmers to switch from transplanted to DSR culture. DSR technology is highly mechanized in some developed countries like USA, Australia, Japan, China, Korea etc. This shift from traditional rice to DSR will substantially reduce crop water requirements, soil organic-matter turnover, enhanced nutrient management, carbon sequestration, weed management, greenhouse-gas emissions and enhance crop intensification. However, weed and nematode infestation, blast, panicle sterility, lack of suitable varieties for DSR and lodging are major challenges. Based on existing evidences, this paper reviews the integrated package of technologies for DSR, potential advantages and challenges associated with it.

Keywords: Food security, green-house gases, priming, tillage

Introduction

Rice is the world's most important cereal crop and a major staple food for more than half (>3.5 billion) of the world's population (CGIAR, 2016) and covered about 11% of the world's cultivated land area (Kumar and Batra, 2017). Rice provides 20% of the world's dietary energy supply, while wheat and maize supplies 19% and 5 %, respectively (Alexandratos and Bruinsma, 2012). Rice cultivated area is decreasing annually and there is no possibility of increasing the area, whereas the world population is increasing very speedily.The major reasons of declining global land area under rice cultivation are urbanization, industrialization, crop diversification and environmental degradation (Mishra *et al.*, 2017). Asia is the center of the global food security, where a total of 90% of the global rice is produced and consumed (Bandumula, 2017). More than half of the world's population with one-thirds of global hungry and poor are living in Asia (Monika, 2013). To meet the global rice demand, it is estimated that about 114 million tons of extra milled rice is needed by 2035, which is equivalent to an overall increase of 26% in the next 25 years (Kumar and Ladha, 2011). The rice production is only possible by increasing rice productivity per unit area and per unit time. Global warming due to increasing greenhouse gases (GHGs) like methane, carbon dioxide, carbon monoxide, sulphur dioxide is threatening the sustainability and productivity of transplanted rice. Farooq *et al.*, (2011) reported that, as compared with other cereal crops like maize and wheat, the conventional transplanted rice (CT-TPR) consumes 2-3 times more amount of water. The high consumption is due to high losses of water through puddling, surface evaporation and percolation. The water scarcity for rice cultivation has been serious matter and is widespread these days. Approximately 18 million ha of irrigated rice in Asia is being projected to suffer from water scarcity by 2025 (Tuong *et al.*, 2002). The adoption of CT-TPR has deleterious effects on soil environment and for the succeeding wheat and other upland crops (Dhakal *et al.*, 2013). It is a widespread concern issue of the population growth and the agricultural production needed to sustain agriculture without environmental degradation (Maskey, 2001).

Rice is a major staple crop of Nepal in terms of area, production and livelihood which fulfills more than 50% of the calorie requirement of the people (Adhikari *et al.,* 2013). The total cultivated area was 1.48 million hectares with 5.43 million tons of production during year 2018 (FAOSTAT, 2019). Rice contributes about 20% to the Agricultural Gross Domestic Product (AGDP) and more than 7% to the total GDP (Joshi and Upadhya, 2020). The productivity growth rate of rice in the last 54 years was only 1.5% in Nepal which has not kept up with the population growth rate of 2.3% and the per capita rice consumption is 137.5 kg which is the highest figure in the world. The reduction of rice area may be due to developmental works like road, buildings, land plotting for buildings etc. The low average yields indicate that there is a considerable yield gap between attainable yields and actual mean yields in farmers' fields in many production situations (Adhikari and Haefele, 2014). Devkota and Phuyal (2017) reported that several factors including high population growth, lack of marketing network, human induced deforestation and desertification have already threatened food security in Nepal. Before 1975, Nepal was once a food exporting country which has become a net food importer because of decline in food production that leads to more malnutrition particularly for children (Adhikari, 2015). Based on the above mentioned evidences, the present paper reviews DSR as an alternative integrated package of technologies with potential scopes, advantages and disadvantages in Nepalese situation.

Methodology

Review was made based on the secondary information from different sources of publications through national and international journals, proceedings, books and internet browsing etc.

Rice growing environment in Nepal

Rice is grown in three agro-ecological regions from terai and inner terai (60m to 900m); mid hills (1000m to 1500m) and high hills (1500m to 3050m) under two water regimes (Irrigated and rainfed) and in two topographic conditions (lowland and upland) (Gadal *et al.,* 2019). The tropical climate is found in terai and inner terai region where as sub-tropical and warm temperate is found in mid hills and mountain areas, respectively (Table 1). Rice is classified based on agro-ecological domains (terai, mid hills and mountain), planting season (spring, summer, rainy and winter), species *(indica, japonica* and *javanica*) in Nepal. The Terai region is plane and fertile which is considered as the granary of the country. Terai accounts for about 73% of the country's rice output; the hills produce 24%, and the mountain about 3 % (Adhikari *et al.,* 2013). In general, the monsoon starts in June from eastern part of Nepal and move to central and western part. The success or failure of rice production in Nepal depends on rainfall. About 65% of the rice in Nepal is cultivated under rainfed conditions. Of the total rainfall more than 80% is in between June to September. The year receiving higher rainfall produces more rice and vice versa in the year with less rainfall (Adhikari *et al.,* 2013). There is more rice cultivation and production in eastern parts of Nepal than western. In a very limited area, farmers in the eastern part of Terai produce three rice crops in a year (spring, main season and boro/winter) in few districts (Jhapa, Morang and Sunsari). In the mid hills and valleys (warm sub-tropical climate) with year-round assured irrigation facilities, rice farmers grow spring rice (Chaite Dhan) in addition to main season rice (Adhikari and Haefele, 2014). However, majority of the rice in the mid hills are produced as a single crop in the pond terraces. In the high hills upto 3,050 m irrigated cold tolerance rice is grown once in a year due to its longer growing period and low temperature. Basnet (2008) reported that in Nepal, the rice production area and productivity is decreasing from east to west, which might be due to variation in rainfall and socio-economic conditions of the regions. Rice-wheat and rice-maize are the predominant cropping patterns adopted in Terai and the mid hills in Khet land (irrigated and rainfed lowland) respectively. The rice is commonly grown in Nepal by transplanting seedlings into puddled field which is called CT-TPR. It involves growing seedlings in a nursery bed and later transplanted. The main fields are puddled, leveled and water depth of 5-10 cm is maintained followed by transplantation of 20-25 days old seedlings from nursery (Bista, 2018). The puddled field can reduce water percolation, control weeds, facilitate fast and easy seedling establishment, and create anaerobic conditions to enhance nutrient availability to plants (Sanchez, 1973).

Why DSR ?

Conventional transplanting of rice is more water demanding, laborious, more time consuming, tedious during transplanting due to drudgery and requires a lot of expenditure on raising nursery, uprooting, and transplanting of seedlings (Pathak *et al.,* 2011). Among cereal crops, rice is a two to three times more user of freshwater (Toung *et al.,* 2005). Due to increasing population, lowering of the water table, uncertain supply of irrigation water, declining of water quality, inefficient system of irrigation, competition with non-agricultural sectors, the share of water for agriculture is declining very fast (Kaur and Singh, 2017). It is estimated that only 50-55% of water will be available for agriculture by 2025 as against 66-68% in 1993 (Sivannapan, 2009). The International Water Management Institute estimates that one-third of the Asian population will face water shortages by the year 2020 (Mishra *et al.,* 2017). Pathak *et al.,* (2011) reported that CT-TPR rice cultivation needs 3000 to 5000 litres of water to produce 1 kg rice. It is reported that at global level 70-80% of fresh water is used in agriculture and rice accounts for 85% of this water. In CT-TPR practices, due to heavy use of pesticides and fertilizers caused increased pollution (water, air, soil) in many rice growing areas, which results in human and animal health problems like cancer, reduce fertility, varied metabolic disorder and high infant mortality etc. The CT-TPR practice increases the cost of cultivation during field preparation and water management (Giri, 1996) with potential loss of farm income (Tripathi *et al.*, 2004). The labour requirement for transplanted rice including nursery bed management and transplanting is approximately 50 person days/ha in comparison to 3-7 person days/ha for seed drilled or wet seeded rice (Mann *et al*., 2007). Labor involved in rice transplanting has become scarce and costly these days because laborers are shifting from agriculture to industry, public works, and overseas employment (Devkota *et al.*, 2013). Therefore, for the sustainable rice production, we must focus on alternative crop establishment methods which can reduce water and labor use and can increase rice productivity.

DSR production technology

DSR is the process of establishing a rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery. Commonly three principal methods of DSR are followed by the farmers in different countries are: dry seeding (sowing dry seeds into dry soil called Dry DSR), pre-germinated seeds are sown on wet puddled soils (Wet DSR) and water seeding (sowing seeds into standing water) (Farooq *et al.*, 2011) (Table 2). DSR technology is developed as a resource conserving technology and as a viable alternative to transplanted rice (Tripathi *et al.,* 2004). DSR practice can be readily adopted by small farmers as well as large farmers in Nepal where the required machinery are also locally available through custom hire (Devkota *et al.*, 2013). The dry seeding is practiced in upland and rainfed lowland, while wet seeding is in irrigated areas (Balasubramanian and Hill, 2002). In DSR, seeds are drilled or dribbled or broadcast on unpuddled soil either after dry tillage or zero tillage or on a raised bed as an agronomic management and technological innovation into dry or moist soils (Chauhan *et al.*, 2015). The principle methods of DSR are:

1. Dry direct seeding (Dry DSR)

The different seeding practices are followed in different countries in Dry DSR. Some of used important practices are: broadcasting of dry seeds on unpuddled soil after either zero tillage or minimum tillage and conventional tillage, dibbled method in a well prepared puddled field, drilling of seeds after conventional tillage, reduced tillage using a power operated seeder, a seed-cum fertilizer drill after land preparation is completed (Kumar and Ladha, 2011). The dry seeding method is traditionally practiced in rainfed upland, lowland, and flood prone areas of Asia (Rao *et al.,* 2007).

Rao *et al.,* (2007) reported that DSR practice was most common before 1950s but was gradually replaced by CT-TPR method. After sowing of seeds using DSR, precise water management during seed emergence (first 7-15 DAS) is of great importance (Kumar *et al.*, 2009). After seed germination, the field does not get saturated during root formation. Field can be saturated at three-leaf stage to ensure proper rooting and seedling establishment as well as germination of weed seeds (Kamboj *et al.,* 2012). Proper repairing and management of bunds also assists in maintaining the uniform water depth and reduce the water losses through seepage and percolation (Humphreys *et al.,* 2010). Water stresses during tillering, panicle initiation and grain filling stages causes heavy losses of grain yield by delay in anthesis and higher grain sterility (Kumar *et al.,* 2017).

2. Wet direct seeding

Wet direct seeding involves the sowing of pre-germinated seeds with a radicle having 1-3mm on or into the puddled soil. In Wet-DSR if seeds are sown into the puddled soil, the seed environment becomes anaerobic, which is called anaerobic Wet-DSR. The aerobic wet seeding practice is increasing in irrigated and rainfed lowland areas (Balasubramanian and Hill, 2002). The rice farmers in developing countries followed wet seeding due to labor shortage because of migration of farm labor from farm job to non-farm jobs (Smith and Shaw, 1966). To prepare pre germinated seeds, the dry seeds are soaked in water for 24 hours followed by incubation for 24 hours in the jute bag (loose pack and sprinkle water 3-4 times within a day), results pre sprouted seeds, which are broadcasted manually (Deo *et al.,* 2019) or sown in line using a drum seeder (Khan *et al.*, 2009). At this period the seedling root will emerge 2−3 mm in length. The seed rate may vary from 80-100 kg/ha (targeted plant population 100−150 plants/m^2) and it would be better if an extra 10-20% seed is added when seed is not pre-germinated. After germination of seed, seedling desiccation may take place due to water stress which should be avoided by intermittent wetting and drying of field. However, there are some disadvantages of wet DSR. More seed damage by birds, snails, rats etc, desiccation of seeds if exposed to direct sunlight for long time, damage by floods (Bhuiyan *et al.,* 1995), increase lodging at maturity due to poor root anchorage on the soil surface (Yamauchi *et al.,* 1995), more weed infestation, higher pest and disease incidence if seed rate is used high (Sittisuang, 1995).

3. Water seeding

This method of water seeding is popular in those areas where red rice or weedy rice is becoming a severe problem (Azmi and Johnson, 2009). This practice is popular in Australia, European countries, USA (Southern Louisiana, Texas, California and Arkansas) and Malaysia to suppress weedy rice or red rice, reduced labor cost and production inputs. The incubated and pre-germinated seeds are sown in standing water on puddled or un-puddled field. Because of heavy weight of seeds, the sown seeds will sink in standing water, allowing good anchorage. The rice varieties that are used under this situation have good tolerance to a low level of dissolved oxygen, low light and other stress environments (Balasubramanian and Hill, 2002). In addition to irrigated areas, water seeding is practiced in areas where early flooding occurs and water cannot be drained from the fields easily.

Advantages of DSR over transplanting

a. Increase water productivity

Both Dry and Wet-DSR are more water efficient technologies and have advantage over CT-TPR (Dawe, 2005). With increasing shortage of water in the world, D-DSR with zero or minimal tillage has potential for saving of water especially for irrigated areas of Asia (Humphreys *et al.*, 2005). Kumar and Ladha (2011) reported that about 12–33% (139–474 mm) lower irrigation water use was found in DSR compared to flooded CT-TPR. Due to these reasons, the total water required amount and crop duration from seed to seed is reduced. (Kumar and Ladha, 2011). Le Xu *et al.,* (2019) reported that among water management practices, the DSR performed best under mild water stress conditions, matching with TPR yield.

b. Minimize the production of greenhouse gases (GHGs)

Rice-based cropping systems are major contributors of GHGs emission (CH_4, N_2O, CO_2) and holds a high potential for global warming. Under anaerobic condition during prolonged flooded condition in the rice field, CH_4 emissions takes place which is varies considerably under different conditions. CH_4 production is directly related to the characteristics of soil (soil chemical and physical properties), climatic conditions (temperature, rainfall) and crop management practices (Harada *et al.*, 2007). The amount of methane production from the rice field accounts to 10-20% (50-100 Tg per year) of the total annual CH_4 emission (Reiner and Aulakh, 2000). Pathak (2010) reported that continued flooded rice field showed highest emission of methane (34%) followed by rainfed flood prone rice (21%), respectively.

c. Good performance of succeeding crops

Sharma *et al*., (2003) reported that repeated puddling in CT-TPR adversely affects the physical properties of soil by dismantling soil aggregates, forming hard-pans at shallow depths by reducing permeability in subsurface layers. This situation can negatively affect the following non-rice upland crop like wheat, barley, mustards etc. This can be corrected by using DSR method instead of CT-TPR.

d. DSR saves the labor requirement

CT-TPR method is highly labor intensive which require more number of labors during nursery establishment, seedling uprooting, land preparation (puddling and labeling) and in transplanting. Rapid economic development in Asia has increased the demand for labor in non-agricultural sectors, resulting in reduced labor availability for agricultural use (Dawe, 2005) and limited number of available labors is more costly for agricultural works. Kumar and Ladha (2011) reported that labor forces in agriculture are declining at 0.1-0.4%, with an average of 0.2% per year in Asia. DSR practices can overcome the crisis of mechanization for land preparation and transplanting practices and help in drudgery reduction (Din *et al.*, 2013). Pandey and Velasco (2002) reported that depending on the nature of the production system, direct seeding can reduce the labor requirement by as much as 50% (Table 1).

Table 1. Pre harvest labour use (man days per ha) in different countries in direct seeding and transplanting

Country / Province	Dry seeding	Transplanting	Reference
1. Philippines			
• Lloilo	40	53	Pandey and Valasco (1998)
• Pangasinan	22	49	Pandey *et al.*, (1995)
2. India			
• Utter Pradesh	72	112	Pandey *et al.*, (1998)
• Bihar	75	152	Singh *et al.*, (1994)
• Orissa	141	152	Fujisaka *et al.*, (1993)
3. Myanmar	19	60	
4. Vietnam			
• Longan	38	68	Farm survey data
5. Thailand	15	29	Isvilanonda (1990).

Challenges of DSR

a. Lack of suitable varieties for DSR

Most of varieties in different countries have been developed for TPR condition. No specific rice varieties have been developed for this purpose till now. The existing varieties for TPR do not appear to be well-adapted initially under oxygen-depleted micro environment. In Nepalese context, those inbred and hybrid varieties which are practiced in DSR under rainfed condition were especially released for TPR. The development of short to medium duration and drought tolerant varieties can grow under water limited condition (Humphreys *et al.*, 2010) and varieties suitable for conservation tillage practices, especially in zero or minimum tillage conditions (Fukai, 2002).

b. Weed management problem

High infestation of weed is a major problem of DSR especially in dry soil conditions (uplands) or in rainfed lowland (Rao *et al.,* 2007). Weeds are more problematic in DSR than in CT-TPR due to DSR seedlings are less competitive with weeds. The initial flush of weeds is not controlled in Wet and Dry-DSR (Kumar *et al.,* 2008a). Xu *et al.,* (2019) reported that weed management was identified as the most important factor limiting the productivity of DSR, and the variation in DSR relative yield exceeded 30% under different weed control levels. In CT-TPR methods, the practice of maintaining standing water itself reduces large amount of weeds and about 2-3 manual weeding can also be economic and feasible (Bista, 2018). Mechanical weeding practice is economically and practically not feasible in commercial farming because of the lower efficiency in weed control and decreasing the pattern of labor availability with increased wages (Bista, 2018).

c. High grain sterility and low yield

DSR can produce comparable yields to CT-TPR but this practice is more prone to yield losses due to inappropriate management practices, unsuitable soil properties and climatic stresses (Xu *et al.,* 2019). As compare to other cereal crops, rice is more drought-sensitive crop during flowering (Liu and Bennett, 2010). Dry seeding is the most common method of crop growing in DSR in which rice grows on marginal soil moisture compared with TPR. Any short period of drought, in particular during the reproductive phase, may be more critical in DSR compared with TPR. Time to anthesis reduces when panicle water potential decreases, resulting in large scale panicle sterility. Panicle transpiration resistance increased rice spikelet fertility during flowering when water stressed.

d. Poor establishment of plant population

Less germination of seeds and poor crop stand establishment are major problems of DSR due to which the final yield of crop can be reduced. The use of poor quality seed, lack of moisture in the field at the time of seeding, infestation of termites for root damage, blast and root knot diseases are major reasons for poor crop establishment.

Conclusion

DSR is a viable and sustainable alternative practice to produce slightly lower or comparable or even higher yield as that of CT-TPR with greater water use efficiency. It appears to be a viable alternative to solve the problems of labor and water shortage. Adoption of DSR practices can meet up the increasing demand of water for rice and reduce drudgery problem. For a successful transition of rice cultivation from CT-TPR to DSR culture, the demand of breeding special rice varieties with improved package of practices is very important issue. The use of DSR practices may change the mineral nutrients dynamics in soil (the availability of most micro elements is reduced in DSR). The water use efficiency (WUE) and water productivity may increase if appropriate land leveling is done in DSR field. Better seed germination, early crop vigour, semi dwarf and earliness may improve WUE and intensive farming. DSR can be a major opportunity for all farmers in water scarce areas with higher efficiency in cost of production and labour use. Poor establishment of plant population is a hindrance in the wide-scale adoption of DSR. However, we should also comprehensively consider the threats from weeds, the lodging problem, insect pests (root knot nematode) and disease (blast), varietal problem, N_2O emission, when we advocate direct-seeded rice in the country.

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