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Experiences, Challenges and Opportunities of Direct Seeded Rice in Bhandara District of Maharashtra

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Abstract—*Rice is the most important food crops in the world, and staple for more than half of the global population. Increasing water crisis, water-intensive nature of rice cultivation and labour costs have made to do the search for alternative management methods to increase water productivity in rice cultivation. Direct seeded rice (DSR) has received much more attention because of its low-input demand. It involves sowing pre-germinated seed into a puddled soil surface (wet seeding), standing water (water seeding) or dry seeding into a prepared seedbed (dry seeding). 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 India to switch from transplanted to DSR culture. This shift should substantially reduce crop water requirements, soil organic-matter turnover, nutrient relations, carbon sequestering, weed biota and greenhouse-gas emissions. Still, weed infestation can cause large yield losses in DSR. In addition, recent incidences of blast disease, crop lodging, impaired kernel quality and stagnant yields across the years are major challenges in this regard. In this review, we discuss the experiences, potential advantages and problems associated with DSR, and suggest likely future patterns of changes in rice cultivation.*

1. INTRODUCTION

Direct seeding of rice refers to the process of establishing a rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery. There are three principal methods of direct seeding of rice (DSR): dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre-germinated seeds on wet puddled soils) and water seeding (seeds sown into standing water). Dry seeding has been the principal method of rice establishment since the 1950s in developing countries [1]. In the traditional transplanting system (TPR), puddling creates a hard pan below the plough-zone and reduces soil permeability. It leads to high losses of water through puddling, surface evaporation and percolation. Water resources, both surface and underground, are shrinking and water has become a limiting factor in rice production. Huge water inputs, labour costs and labour requirements for TPR have reduced profit margins [2]. In recent years, there has been a shift from TPR to DSR cultivation in several countries of Southeast Asia [3]. This shift was principally brought about by the expensive labour component for transplanting due to an acute farm labour shortage, which also delayed rice sowing. Low wages and adequate water favour transplanting, whereas high wages and low water availability suit DSR. TPR has high labour demands for uprooting nursery seedlings, puddling fields and transplanting seedlings into fields. The adoption of a direct-seeded method for lowland rice culture would significantly decrease costs of rice production. To date, no specific varieties have been developed for this purpose. Existing varieties used for TPR do not appear to be well-adapted for seedling growth in an initially oxygen depleted microenvironment. As a result, farmers often resort to the costly practice of increasing the seeding rate for DSR by 2–3 times. New varieties suitable for DSR must be able to emerge and grow from a non-flooded soil. DSR is a major opportunity to change production practices to attain optimal plant density and high water productivity in water-scarce areas. Traditionally, rice is grown by transplanting one-month-old seedlings into puddled and continuously flooded soil. The advantages of the traditional system include increased nutrient availability (e.g. iron, zinc, phosphorus) and weed suppression [4]. With respect to yield, both direct seeding (viz. wet, dry or water seeding) and transplanting had similar results [5]. DSR has been practiced for some time, but has not gained popularity; even though many research studies suggest its benefits over TPR [6]. This review sums up the most recent experiences, potential advantages, associated problems and likely patterns of changes in DSR.

2. EXPERIENCES

Direct seeding of rice was the major method of stand establishment for about six decades. It was replaced with transplanting during the 1970s in most parts of the world [1]. As a result of water scarcity and labour issues, farmers are again considering direct-seeding systems in rice production. Yield benefits, resource conservation, varietal development and weed management of DSR are summarized below.

2.1. Role of direct seeding

Direct-seeding methods have several advantages over transplanting. In addition to higher economic returns, DSR crops are faster and easier to plant, less labour intensive and consume less water are conducive to mechanisation, generally flower earlier leading to shorter crop duration and mature 7–10 days earlier and have less methane emissions than TPR. Typically, DSR is established earlier than TPR without growth delays from transplant injury; which hastens physiological maturity and reduces vulnerability to late-season drought. Dry-seeding on flat land or raised beds with successive saturated soil conditions reduces the amount of water needed for land preparation and thus overall water demand. Direct seeding also offers the option to resolve edaphic conflicts (between rice and the subsequent non-rice crop) and enhance sustainability of both the rice–wheat cropping system and succeeding winter crops, particularly early sown wheat.

2.2. Seed priming

In seed priming, a pre-sowing hydration technique, seeds are partially hydrated such that germination processes begin, but radical emergence does not occur [8]. This technique allows some metabolic processes to occur without actual [9]. Seed priming techniques are a promising solution to poor stand establishment in DSR [10]. Seed priming techniques, such as hydro-priming on-farm priming hardening and priming with growth promoters like growth regulators and vitamins have been successfully employed in rice to hasten and synchronise emergence, achieve uniform stands, and improve yield and quality.

2.3. Yield benefits

DSR is both cost- and labour-saving, although grain yield in DSR is comparatively less than TPR. Some reports claim similar or even higher yields of DSR with good management practices. For instance, substantially higher grain yield was recorded in DSR (3 t ha 1) than TPR (2 t ha 1), which was attributed to increased panicle number, higher 1000 kernel weight and lower sterility percentage. Among semi-dwarf rice cultivars (IR-56, IR-58, IR-64 and IR-29732-143-3-2-1), IR-58 had superior yield when seeds were directly broadcasted rather than nursery transplanted [11]. The DSR in moistened soil produced taller plants, more dry matter, lower chlorophyll contents and specific leaf weights, and more panicles and sterile spikelets than transplanted rice [12]. Farmer and researcher trials in the Indo-Gangetic Plain reported irrigation water savings of 12–60% for DSR on beds, with similar or lower yields for transplanted compared with puddle-flooded transplanted rice (Gupta et al., 2003), and usually slightly lower yields with DSR in flat fields. A study evaluating the effect of different seeding techniques, cultivars, seed rates and soil types on basmati rice found 44% and 30% higher grain yield in direct-drilled compacted and puddled plots, respectively than un-compacted/un-puddled plots [14]. On-farm studies in India revealed comparable rice yields in some DSR and TPR systems when weed control was adequate. While comparing productivity and economics of various planting techniques in rice-based cropping systems in the Indo-Gangetic Plain, Gangwar et al. (2008) recorded higher yield, root dry matter, net cost benefit ratio and infiltration rate for a DSR-based cropping system using hybrid rice than TPR. Higher values of bulk density, soil organic carbon, available P and K were recorded under mechanical transplanting. Similarly, higher total nutrient uptake was recorded in a rice–wheat sequence under mechanical transplanting than manually transplanted rice under puddle conditions. Gupta et al. (2003) reported 10% higher yields in DSR than flooded TPR.

2.4. Resource conservation

Rice farming is ongoing but subject to rapid change. The DSR is a resource conservation technology as it uses less water with high efficiency, incurs low labour expenses and is conducive to mechanisation. DSR reduces the labour requirement for establishment by transferring field activities to periods when labour costs are comparatively lower (Pandey and Velasco, 1999). Substantial water savings are possible from DSR [17]. For example, experiments in Northwest India using DSR into non-puddled soils found 35–57% water [18],[19]. In these trials, soils were kept near saturation or field capacity unlike the flooded conditions used in puddle-transplanted systems. In small plot DSR trials, the irrigation requirement decreased by 20% [13]. DSR on raised beds decreased water use by 12–60%, and increased yield by 10%, in trials at both experimental stations and on-farm, compared with TPR.

2.6. Weed management

Weeds are the major constraint towards the success of DSR. Estimated losses from weeds in rice are around 10% of total production grain yield; however, such losses can be much higher (Rao et al., 2007). In wet-seeded and dry-seeded rice, weed growth reduced grain yield by up to 53 and 74%, respectively [21], and up to 68–100% for direct-seeded Aus rice. More than 50 weed species cause yield losses in DSR [22]. The DSR fields are more species-rich with greater diversity in weed flora than TPR (Tomita et al., 2003). In large-scale farmer participatory trials in India, [24] had success with DSR by using the stale-seed bed technique combined with a pre-emergence herbicide, pendimethalin, applied within 2 days after seeding (DAS).

3. CHALLENGES

Several challenges confront the wide-scale adoption of DSR by farmers, such as weed infestation, stagnant yield, availability of purposely developed varieties, panicle sterility, nutrient availability, pests and diseases and water management. An account of each is given below.

3.1. Weeds

High weed infestation is the major bottleneck in DSR especially in dry field conditions [25],[20]. TPR seedlings have a competitive advantage over newly emerged weeds compared with emerging DSR seedlings. In addition, early weeds in TPR are controlled by flooding, unlike in DSR [20]. More than 50 weed species infest direct-seeded rice, causing major losses to rice production worldwide [20],[23]. When farmers change from TPR to DSR the weed flora changes dramatically. DSR is subjected to more severe weed infestations than TPR because, in dry-seeded rice, weeds germinate simultaneously with rice, and there is no water layer to suppress weed growth. In DSR, weedy rice becomes another major weed to control.

3.2. Diseases and insect pests

Sometimes the attack of arthropod insect pests is reduced in DSR compared with TPR, but a higher frequency of ragged stunt virus, yellow orange leaf virus, sheath blight and dirty panicle have been observed in DSR. The soil-borne pathogenic fungus Gaeumannomyces graminis var. graminis has been observed in dry-seeded rice without supplemental irrigation [26]. Root-knot nematodes have also been observed when switching from flooded to water conservation rice production systems.

3.6. Nutrient dynamics

Puddling in continuously flooded rice limits percolation losses in the field and retains a saturated soil profile, which inhibits establishment and growth of many weeds [27], and has positive consequences for nutrient availability (Wade et al., 1998). Reduced oxygen in the rhizosphere for long periods prevents oxidation of NH4+ and retains this form of N against leaching [29]. High pH favours NH3 volatilisation, and increase stocks of plant available K, Ca, Si and Fe in soil for rice growth [4]. Some evidence suggests that chemical changes in flooded soils increase P availability. Continuous removal of nutrients by the crop results in decreased availability of NH4, P, K, Ca, Mg, Mn, Zn and Cu. However, there is a small increase in Fe availability in soil with increased periods of submergence and crop growth. Land preparation and water management are the principal factors governing the nutrient dynamics in both DSR and TPR systems. As most often in DSR, land is prepared in dry and soil remains aerobic throughout the season, nutrient dynamics are altogether different than the TPR, where land is prepared in standing water and soil is kept flooded during most of the season

3.7. Lodging

Lodging, the permanent vertical displacement of the stem of a free-standing crop plant, has been observed more often in DSR than TPR fields in recent years. Lodging results in substantial yield reductions due to decreased photosynthesis by self-shading, and hampered grain quality due to increased colouring and decreased taste. In addition, mechanical harvesting of a lodged crop is extremely cumbersome. In this regard, intermediate plant heights, large stem diameters, thick stem walls and high lignin contents are lodging resistant characteristics.

4. OPPORTUNITIES

Despite several challenges confronting DSR, many opportunities exist to tackle these issues; some of which are discussed below.

4.1. Management options

Management options start from the selection of a good genotype, site selection, seedbed preparation, sowing time, plant protection, nutrient management, through to crop harvesting. In DSR systems, soil type, weed management and land levelling are of primary importance. Early canopy closure helps to reduce evaporation after crop establishment.

4.1.1. Integrated weed management

Weeds pose a serious threat to DSR by competing for nutrients, light, space and moisture throughout the growing season. Tillage may help to control weeds temporarily by burying unterminated weed seeds at a depth that stops germination; but it may allow other, once deeply buried, seeds to germinate. An integrated approach involving cultural practices, crop rotation, stale seedbed practices, selection of suitable competitive varieties, and use of herbicide mixtures is essential in response to changes in weed community structure in DSR

4.1.2. Nutrient management

Productivity in DSR systems approaches TPR systems when N-fertiliser is supplied at high rates. Nutrient management practices such as deep placement and use of controlled-release fertilisers performed well under rainfed conditions. For efficient use of N in flooded rice production, it is important for N to be quickly converted into NH_4+ which plants should assimilate as early as possible. With improved management, farmers should be able to double their present average recovery of N fertiliser to 50%. One method of maintaining soil N as NH_4+ is to add nitrification inhibitors along with the fertilisers, which also increase NUE and crop yield. Greater fertiliser N efficiency in rice can be achieved by using N efficient varieties, improving timing and application methods and better incorporation of basal N fertiliser application without standing water. Split application of N has been reported as the best method to improve N fertiliser use efficiency, reduce denitrification losses, synchronize with plant demand, and improve N uptake, straw and grain yield, and harvest index in DSR.

4.1.3. Water use and water use efficiency

New water cannot be created; thus, we have to conserve and make judicious use of every drop. Two possible options are to minimize water losses through better management thus ensuring more water for crop production, and improve water use efficiency, i.e. increase in production per unit of water. Soil type influences the need for irrigation water, e.g. coarse-textured soils have higher percolation losses. Land levelling also facilitates uniform water application in less time and helps in weed control.

4.1.6. Greenhouse gas (GHG) emission

In wetland rice systems (both water seeding and transplanting in flooded soils), large quantities of CH_4 are emitted, which account for 8.7–28% of total anthropogenic emissions. Emission of GHG from rice fields is very sensitive to management practices, so rice is an important target in this regard. Direct seeding has the potential to decrease CH_4 emission Wassmann et al. (2004) proposed that CH_4 emissions may be suppressed by up to 50% if DSR fields are drained mid-season. The net effect of direct seeding on GHG emissions also depends on N_2O emissions, which increase under aerobic conditions.

4.2. Genetic and biotechnological approaches

The use of molecular markers and genomics platforms offer unique opportunities to develop early maturing and high-yielding rice varieties with resistance to lodging. Dissecting quantitative traits into single genetic components, so-called QTLs, is a more direct method for accessing valuable genetic diversity of physiological processes that regulate a plant's adaptive response. Genomics-assisted improvement of rice genotypes to direct-seeding environments increasingly relies on the QTL approach. Improvement of genetic resistance to biotic stress is another important and effective breeding approach to water-saving cultivation of rice. Rice blast disease, a destructive disease of rice under water-limited conditions, is a major problem. Likewise, production of transgenic herbicide-resistant rice is a pragmatic approach to popularise DSR culture. Although there are research efforts to develop herbicide-resistant rice transgens, so far there has been little success. Approaches to improve NUE are also being investigated to incorporate the nitrogenase enzyme into the rice plant chloroplast and to engineer plants to nodulate with N-fixation bacteria.

5. CONCLUSIONS

On the face of global water scarcity and escalating labour rates, when the future of rice production is under threat, direct seeded rice (DSR) offers an attractive alternative. A successful transition of rice cultivation from transplanting system (TPR) to DSR culture demands breeding of special rice varieties and developing appropriate management strategies. Despite controversies, if properly managed, comparable yield may be obtained from DSR compared with TPR. As the extent and nature of weed flora changes as a result of this transition, sustainable integrated weed management tools must be identified. This shift also changes the dynamics of mineral nutrients; the availability of most microelements is reduced in DSR. If not managed, weeds may cause partial to complete failure of DSR crops. In DSR culture, WUE and productivity may increase if appropriate soil types from levelled land are selected. Methane emissions are substantially reduced in DSR, NO_2 emissions increase; methods to reduce its emission for a safer environment are needed. Lodging and blast attack are threats in DSR that need attention; biotechnological and genetic approaches may help resolve these issues.

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