Rice Production Systems

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Abstract

The rice is the third most grown crop in the world among maize (corn) and sugarcane crops. Rice cultivation started in China thousands of years ago and then went throughout Asia to the rest of the world. Today the 9 out of 10 top rice producing countries belong to the Asian continent. There are more than 115 countries cultivating rice around the world in varying agro-ecological zones. Rice production systems have been classified over many years differently depending on different factors. In this chapter, the rice production systems have been classified based on cultivation methods, and some other factors influencing the efficacy of these methods. Some other factors, like resources used, total crop production, emerging challenges, and research areas to be studied, have been summarized. There are two well-established rice growing systems in the world: (1) transplanted rice (TPR) producing system and (2) direct-seeded rice (DSR) producing system. The DSR can further be categorized as (a) dry-seeded rice producing system, (b) wet-seeded rice producing system, and (c) water-seeded rice producing system. The System of Rice Intensification (SRI) is another intervention. Both systems have similar productivity depending on how you overcome the challenges. There is a wild shift in adopting DSR producing system in developing countries due to water scarcity and climate change. Due to the unavailability of labor, transplanting has been shifted from manual to mechanical trans-planters. Some new horizons of research in rice cultivation systems have emerged to improve the productivity of rice.

Keywords: Information technology; Modern farming; Rice; Satellite technology; GIS; Remote sensing

Introduction

Rice (*Oryza sativa* L.) is an vital staple feeding the billions in the world and accounts for 20-70% of the calorie intake [1]. About 58.6% of rice produced in Asia is irrigated and uses more than 50% of the agriculture water supplies. Growing water scarcity is threatening the irrigated rice production in this area, and global rice demand is still in the rise [2]. In Pakistan, rice is an important cash crop and exportable commodity and accounts for approximately 13.5% of the total cultivated area. Total rice production in the country remained 6883 thousand tones with an average yield of 2387 kg ha^{-1} during last season [3].

In Pakistan, mostly rice is cultivated by transplanting of nursery nurtured seedlings into the puddled field which is kept flooded throughout the growing season. Poor drainage and low water table are usually responsible for this continuous flooding and believed for maximizing rice yield. However, decreasing water availability and lower water tables are not sufficient to meet the projected rice demand of growing population in the country [4] and irrigated rice in Pakistan may experience physical water shortage by 15-20% [5]. Also, the high labor cost required for also transplanting constraints the economic feasibility of conventional rice production [6].

To reduce the water inputs and improve water productivity in rice, several water-saving technologies, i.e. alternate wetting and drying (AWD) and aerobic rice, are being practiced. Decreased water inputs in these rice systems have been achieved by reducing the unproductive seepage and percolation flow at field level [7], to some or less extent through weed management, and avoiding non-beneficial transpiration and reduced evaporation at plant level [8]. The AWD system reduces water inputs by 5-35% without sacrificing yield even maintained or high rice yield. Under certain conditions, reduced water inputs of 50% with some yield penalty in loamy and sandy soils with lowered groundwater tables are also reported [9]. Nonetheless, the system has high adaptability and is being successfully adapted and practiced in China, India, and the Philippines. Likely decreased water inputs of 50%, higher water productivity (60%) and lower labor use (55%) than flooded rice have been reported [10] in aerobic rice systems. This harvest in water use is also accompanied by 20–30% lower yield in aerobic rice than flooded with a higher yield. However, switching from saturated to aerobic or alternate wetting-drying soil three conditions may affect the processes determining nutrient availability, mode of their uptake, and associated losses [11]. This review sums up the most recent experiences, potential advantages, associated problems, and likely patterns of the different rice production system.

Constraints to Rice Production

Rice ranks second staple after wheat, important cash crop and also an important export item of the country. This contributes 6.4% of the total value added in agriculture and 1.4% in GDP. The total area under the crop grown during 2008-09 and 2009-10 has been declined 17.1 and 8.4% with similar proportion to percent change in yield by 21.7 and 1.3% respectively [3].

Drawbacks of Rice Transplanting System

In the traditional transplanting system (TPR), puddling creates a hard pan below the plow-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 [12]. Massive water inputs, labor costs, and labor requirements for TPR have reduced profit margins. In recent years, there has been a shift from TPR to DSR cultivation in several countries of Southeast Asia [13]. This shift was principally brought about by the expensive labor component for transplanting due to an acute farm labor shortage, which also delayed rice sowing [14]. Low wages and adequate water favor transplanting, whereas high wages and low water availability suit DSR [15]. TPR has high labor demands for uprooting nursery seedlings, puddling fields and transplanting seedlings into fields.

Increasing Water Scarcity

Rice is grown as wet season crop in Pakistan from April to November and depends on irrigation supplies from Indus River melts of Himalayan glaciers. Traditional cultivation system with continuous flooding is followed in major rice-growing areas of the country. This requires higher water and labor inputs, particularly at critical crop stages, increasing higher energy and production costs [16]. Puddling in rice is usually done to create standing water conditions and reduce deep percolation and water inflows. This facilitates in ease of transplanting, reduce weeds pressure, and considered advantageous in terms of yield stability due to better rice growth and increased availability of some nutrients [17]. Ground and surface water are the primary source to meet the rice crop demand. But over drafting, falling water tables, low quality of groundwater supply, water logging and salinity, increased competition from industrial and urban usage, non-availability of irrigation water at critical crop stages, inefficient irrigation techniques and least development in water storage reservoirs are reasons for depleting groundwater resources [18]. Reduced water availability has been the major constraint affecting rice production in the country and fresh irrigation water supply to produce irrigated rice is further to be reduced due to physical water shortage [5]. Per capita, water availability has been reported to decrease from 1066 to 858 m3 and is to be aggravated by 15-54% by 2025. Pakistan has been declared as water-stressed country, and global climate change has significant impact on rice production [19]. Although the area under rice cultivation has increased and total production in 2009-2010 was 6.883 m. Tones and country rank 14th for rice production and 6th for export in the world. Efforts have also been made for better infrastructure of groundwater resources, favorable environmental conditions, and increased support price to farmers.

However, since the last decade, extreme weather conditions, acute water shortage, and onset of drought conditions due to variability in rainfall occurrence greatly affected the rice production from 2000 to onwards [20]. Change in temperature and rainfall has potential impacts on glaciers melts, drought and flood events and change in rainfall pattern and rice production is most vulnerable to these effects in the country [21]. Thus under escalating water crisis, growing rice under submergence conditions is not a viable option and necessitates making efficient use of available irrigation resources by alternative methods of rice production [22]. And development and assessment of water-saving rice can increase crop water productivity.

Water saving Rice Production

Rice production in Asia is in the transition towards water saving cultivation, and several water saving technologies are being successfully practiced to reduce water inputs and improve rice water productivity [23, 10]. These technologies include raised beds, a system of rice intensification [24], alternate wetting and drying (AWD) [25] and direct seeding under aerobic culture [26]. Water savings in these rice systems mainly have been achieved by reduced unproductive water losses of seepage and percolation, non-beneficial transpiration, and to some extent by evaporation [8].

Direct- Seeded Rice (DSR)

Rice can be established by three principal methods: Dry-DSR, Wet DSR, and water seeding. These methods differ from others either in land preparation (tillage) or CE method or in both. Dry-, wet-, and water-seeding, in which seeds are sown directly in the main field instead of transplanting rice seedlings, are commonly referred to as direct seeding. Direct seeding is the oldest method of rice establishment. Before the 1950s, direct seeding was most common but was gradually replaced by puddled transplanting [27]. As it often happens, essential prototype technologies, when introduced to farmers' fields, undergo various modifications to suit local needs and also to optimize the benefits [29]. There is now much confusion in the terminology used for various versions of direct-seeding practices. Therefore, standard terminology is essential to communicate better among different groups of stakeholders.

Dry direct seeding

In Dry-DSR, rice is established using several different methods, including (1) broadcasting of dry seeds on unpuddled soil after either zero tillage (ZTdry-BCR) or conventional tillage (CT-dry-BCR), (2) dibbled method in a well-prepared field (CT-dry-dibbled R), and (3) drilling of seeds in rows after conventional tillage (CT-dry-DSR), reduced tillage using a power tiller-operated seeder (PTOS) [RT (PTOS)-dry-DSR], zero tillage (ZTdry-DSR), or raised beds (Bed-dry-DSR). For CT-dry-DSR and ZT-dry-DSR, a seed-cum-fertilizer drill is used, which, after land preparation or in zero-till conditions, places the fertilizer and drills the seeds. The PTOS is a tiller with an attached seeder and a soil-firming roller. It tills the soil at shallow depth (4–5 cm), sows the seeds in rows at adjustable row spacing, and covers them with soil and lightly presses the soil for better seed to soil contact, all in a single pass [30]. For Bed-dry-DSR, a bed-planting machine is used, which, after land preparation, forms a bed (37-cm wide raised bed and 30-cm wide furrows), places fertilizer and drills the seed on both sides of the bed in a single operation [6]. The seedbed condition is drying (unpuddled), and the seed environment is mostly aerobic; thus, this method is known as Dry-DSR. This method is traditionally practiced in rainfed upland, lowland, and flood-prone areas of Asia [27]. However, recently, this method has been gaining importance in irrigated areas where water is becoming scarce. Drill seeding is preferred over broadcasting in irrigated or favorable rainfed areas in both developed and developing countries as it allows line sowing and facilitates weed control between rows saves seeds and time and provides better CE. In Dry-DSR, land preparation is done before the onset of monsoon, and seeds are sown before the start of the wet season to take advantage of pre-monsoon rainfall for CE and early crop growth.

Wet direct seeding

In contrast to Dry-DSR, Wet-DSR involves sowing of pre-germinated seeds with a radicle varying in size from 1 to 3 mm on or into puddled soil. When pre-germinated seeds are sown on the surface of puddled soil, the seed environment is mostly aerobic, and this is known as aerobic Wet-DSR. When pre-germinated seeds are sown/drilled into puddled soil, the seed environment is mostly anaerobic, and this is known as anaerobic Wet-DSR. In both aerobic and anaerobic Wet-DSR, seeds are either broadcast [CT-wet-BCR (surface)] or sown in-line using a drum seeder [CT-wet DrumR (surface)] [31] or an anaerobic seeder [CT-wet-DSR (subsurface)] with a furrow opener and closer [32]. In CT-wet-DSR (subsurface), seed coating with calcium peroxide to improve oxygenation around germinating seeds can be used. When manual broadcasting is done, seeds are soaked in water for 24 h followed by incubation for 24 h. However, when motorized broadcasting is done, the pre-germination period is shortened (24-h soaking and 12-h incubation) to limit root growth for ease of handling (easy flow of sprouted seeds) and to minimize damage, as is the case when a drum seeder is used for row seeding [32]. A drum seeder is a simple manually operated implement for sowing rice seed on puddled soil. It consists of six drums, each 25 cm long and 55 cm in diameter, connected one after the other on an iron rod having two wheels at the two ends [30]. For the motorized blower, a 3.5-hp mist blower/duster is used, attached with either a 1-m-long blowpipe or a 20- to 30-m-long shower blowpipe.

Water seeding

Water seeding has gained popularity in areas where red rice or weedy rice is becoming a severe problem [33]. Aerial water seeding is the most common seeding method used in California (United States), Australia, and European countries to suppress difficult-to-control weeds, including weedy rice. This method is also becoming popular in Malaysia. In this method, pre-germinated seeds (24-h soaking and 24-h incubation) are broadcast in standing water on puddled (Wet-water seeding) or unpuddled soil (Dry water seeding). Usually, seeds, because of their relatively heavy weight, sink in standing water, allowing good anchorage. The rice varieties that are used possess good tolerance of a low level of dissolved oxygen, low light, and other stress environments [32]. In addition to irrigated areas, water seeding is practiced in areas where early flooding occurs, and water cannot be drained from the fields.

Alternate wetting and drying (AWD)

Alternate wetting and drying involve transplanting of 2-3 weeks old nursery seedlings into puddle field and kept flooded for 10 d with water enough for 3-5 d. After which field is allowed to dry for 2-4 d before re-flooding and the number of days without 15 ponded water varies with soil type, climatic conditions, and groundwater depth. At panicle initiation and flowering, the field is kept flooded, and AWD cycles are continued until harvest [34]. Water inputs can be further reduced, and water productivity values are increased if soil drying periods are prolonged and slight drought stress is imposed, but this substantially occurs at yield penalties [7]. For practicing AWD as a safe guide, irrigation can be applied when soil water potential of -20 kPa is achieved at 10 cm depth [35]. Reduced water inputs of 5-35 and 50% have been found when AWD is practiced in loamy and sandy loam soils with water tables deeper in India, China and Philippines respectively. Although increased yields with AWD are also reported [36] but with recent studies yield reductions by 20% or in some cases maintained or even increased yields as compared to flooded rice are also found [9]. AWD is a mature technology and widely practiced in China, Philippines, and India and can be commonly practiced in lowland rice in any country of the world [37]. However, further quantification studies in AWD are needed with water outflows, i.e., evaporation, seepage, and percolation. Recent studies suggest that AWD reduced seepage and percolation with some effects on evaporation [38] and reduced water evaporation losses by 2-33% compared with flooded conditions are reported. Very little research has been done to quantify the impact of AWD on the different water outflows: evaporation, seepage, and percolation. The little work done so far suggests that AWD mostly reduces seepage and percolation flows and has only a small effect on evaporation flows. Cabangon et al. (2004) calculated that evaporation losses were reduced by 2-33% compared with fully flooded conditions.

System of Rice Intensification (SRI)

Intensification of irrigated double- and triple-crop rice systems in Asia since the mid-1960s involved an increase in the number of crops grown per year and greater yield per crop cycle. Higher yields resulted from the combination of increased yield potential of modern varieties, improved crop nutrition made possible by fertilizer application, and improved host-plant resistance and pest management. Growth rates of yield and total irrigated rice production have, however, slowed down in recent years due to lower rice prices and a slowdown in demand growth, but the concern was also raised about resource degradation [39]. In many large irrigated rice production domains, where farmers were early adopters of modern technologies, yields have stagnated since the mid1980s [40]. At issue is how rice yield growth in Asia can potentially be re-energized. In several recent publications, Uphoff (2001) [41], Stoop et al. (2002), and Uphoff et al. (2002) [42] described the system of rice intensification (SRI), which mainly evolved through participatory on-farm experimentation conducted in Madagascar during the 1980s and 1990s. They suggested that SRI represents an integrated and agro-ecologically sound approach to irrigated rice cultivation, which may offer new opportunities for location-specific production systems of small farmers. They also proposed that such approaches could unlock currently untapped production potentials of rice, allowing farmers to realize yields of up to 15 Mg ha-1 or more with reduced irrigation and mineral fertilizer inputs [43]. Many development-oriented organizations have, therefore begun to evaluate the SRI system or some of its components in other regions, including major rice-growing areas of south and southeast Asia [44]. However, although most published and unpublished reports on SRI tend to be optimistic, they are incomplete in their coverage of the existing scientific literature, and there is a general lack of detailed field research following high scientific standards. Both Uphoff (2001) and Stoop et al. (2002), for example, do not report research data that would allow a thorough examination.

Key elements of SRI

Stoop et al. (2002) and Uphoff et al. (2002) provide a detailed overview of the rationale and critical components of SRI, and they also discuss its scope for adoption. Therefore, only a summary will be given here. SRI is understood as a set of principles and a set of mostly biophysical mechanisms. It originated in the humid highlands of Madagascar with rainfall mostly ranging from 1000 to >2000 mm [45], mostly on poor soils with low pH, low CEC, low available P, and high concentrations of soluble Fe and Al. Major SRI principles include (1) raising seedlings in carefully managed nurseries, (2) careful transplanting of single, young (8–15 days old) seedlings at wide plant spacing (starting at 2525 cm, but going up to 5050 cm), (3) intermittent irrigation to avoid permanent flooding during the vegetative growth phase, (4) addition of nutrients to the soil, preferably inorganic forms such as compost instead of chemical fertilizer, and (5) intensive manual or mechanical weed control without herbicide use.

It should be noted, however, that SRI is not a ‘‘standard package’’ of specific practices, but rather represents empirical practices that may vary to reflect local conditions [24]. Variants of SRI have also been tested in which only some of the basic components were practiced. The key physiological principle behind the principal SRI measures is to provide optimal growing conditions to individual rice plants so that tillering is maximized and phyllochrons are shortened, which is believed to accelerate growth rates [46]. It was also observed that tiller mortality is reduced. Furthermore, intermittent irrigation is believed to improve oxygen supply to rice roots, thereby decreasing aerenchyma formation and causing a stronger, healthier root system with potential advantages for nutrient uptake [41].

Conclusion

On the face of global water scarcity and escalating labor 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 to breed of particular rice varieties and developing appropriate management strategies. Because of the water-, labor-, and energy-intensive nature of this system, and rising interest in CA, dry-seeded rice (Dry-DSR) with zero or reduced tillage (ZT–RT) and SRI has emerged as a viable alternative for the rice production a system. Projections and trends seem to suggest that Dry-DSR will likely be a significant rice culture in many countries in the future.

Future aspects

A successful change from the traditional flooded to aerobic rice production requires the breeding of unique aerobic rice varieties and the development of appropriate water and crop management practices. Therefore, to combine novel regulatory systems for the targeted expression with useful genes, more effective and rational engineering strategies must be provided for the improvement of rice for higher water productivity. Different strategies need to be tested experimentally to genetically improve the water-use efficiency and drought stress tolerance in rice. Different strategies need to be integrated, and the genes representing distinctive approaches be combined with increasing rice water productivity substantially. Extensive hybridization using hardy wild rice species is another area to be emphasized. Moreover, combining the transgenic with traditional breeding methods may be a practical approach to develop abiotic stress tolerant rice cultivar.

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