Productivity and Quality of Direct Seeded Rice under Different Types of Mulches and Planting Patterns: A Review

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Abstract: Rice (Oryza sativa L.) is the staple food of more than half of world population and is one of the leading cereal crops being grown in many regions of world. As this crop requires standing water from transplanting to harvesting, thus cultivation of this crop is facing problems due to water shortages, particularly in Asia. Aerobic rice technique involves by direct seeding of rice in the field by skipping the practice of nursery raising as in conventional flooded rice cultivation system, is gaining ground with passage of time. The technique of direct seeded rice not only saves water but labor as well. The yield of direct seeded rice can be increased to many folds by optimizing plating pattern which is the most important agronomic practice. Different types of mulches including organic and plastic are vital in increasing the growth and yield of aerobic rice as these mulches conserve water and reduce weeds infestation which is the most critical problem in the direct seeded rice fields.

Key words: Aerobic rice • Organic mulches • Paddy yield • Plastic mulch • Water conservation

INTRODUCTION

Rice (Oryza sativa L.) appears to have originated in the area of the foothills of the Himalayas, Oryza sativa var. indica on the Indian side and Oryza sativa var. japonica on the Chinese and Japanese side. It belongs to the genus Oryza of the sub tribe oryzineae in the family Gramineae. Rice genus Oryza consists of 25 conventional species, of which 2; Oryza glaberrima and Oryza sativa are cultivated and 22 are wild. All rice varieties of Europe, Asia and America belongs to the species Oryza sativa, whereas some of others rice cultivated varieties of West Africa belongs to the species Oryza glaberrima. It was considered that universal wild rice, Oryza rufipogon, was the wild ancestor of Asian rice [1, 2]. Rice is being grown in many regions of the world, mostly by conventional flooded rice cultivation system which provides 75% of the world rice supply [3]. Rice grown by this system consumes about 80% of total agricultural water available in Asia [4] and 75% of total available water resources in the world [5].

Rice in Indo-Pak Subcontinent: Different rice varieties are cultivated in more than 114 countries of the world and further fifty have an annual production of 100,000 tones, while India and China are producing almost half of the total production [6]. Approximately 90% of rice is grown on area of 153.25 m ha in South Asian countries with annual production of about 610 million tons that is extending from the Indo-Pakistan subcontinent to Japan [7]. In Indo-Pak subcontinent, about thirty-seven archeological sites have been showing traces of rice cultivation. These sites include Mohenjodaro in Pakistan, while Gujrat, Rangpur, Lohal and Uttar Pradesh in India [8-10]. Irrigation is the main user of water in the world. There is about 56 % of the total world irrigated area in Asia and in this area rice is the most important irrigated crop [11]. In Asia, it accounts for 40-46% of net irrigated area [12]. Production system of Asia is going to undergo adjustments in reaction to rising scarcity of land, water and labor; a major adjustment can be expected in the method of crop organization. Most vital determinants of farmer’s choice of crop establishment method are rainfall pattern, weed incidence, field elevation and capability of water supply. The major financial factors like accessibility of labor, wage rates and power for land preparation were considered for the choice of crop establishment technique [13].
Rice Transplanting: Most usual method of crop establishment for rice production in Asia is transplanting. It includes raising of rice nursery and transplanting into leveled fields after 15 to 30 days of sowing. In first two years rice yield was minimum in direct seeding (342 g m$^{-2}$) than transplanting (405 g m$^{-2}$), but interaction components with year, water conditions, varieties and weed management were statistically highly significant for direct seeding. Scarcity of water is a great hazard to agriculture because of less water resources [14]. Almost standard yield of direct seeding was similar to that of transplanting. In deep ooded and non-ooded conditions, dry weight and plant height of rice was reduced compared with shallow ooded condition while grain yield was the highest in shallow ooded condition. If efficient water usage is possible, the labor-intensive and costly technique of transplanting could be substituted with direct sowing [15]. Transplanting method is accepted for rice cultivation in most of countries like Pakistan. But transplanting method is difficult due to lack and high cost of labor, scarcity of water and reduced profit [16]. So there was a dire need to replace the transplanting culture with production culture, which solves problem of labor and water deficiency without sacrificing yield and productivity and hence secure future food needs. Conventional practice of transplanting was compared with wet and dry seeding techniques of rice establishment. Data indicated that yields differences were non-significant in almost all sowing techniques. In directly sown rice potential yield reduced due to greater weeds. It was observed that similar yield was obtained with dry direct sowing compared to rice [28, 29]. Bhushan [30] compared seven planting techniques with year, varieties, water conditions and plant height, filled grains per panicle, productive tillers per m$^2$, root length, 1000-grain weight and paddy yield were significant for water input of transplanted rice [19]. Rice transplanting requires high constant water supply and labor. The requirement of water for rice cultivation is more as compared to other cereal crops [20], as the water use efficiency of rice is fairly low. Generally, to control weeds and percolation losses, rice is grown under puddled conditions. However, the puddling process results in subsurface compaction besides consuming a considerable amount of irrigation water [21], which decrease the growth and yield of the succeeding wheat crop [22]. In Indo-Gangetic plains, different resource conservation technologies for rice are being used and developed to avoid puddling/transplanting. Apart from being cost-effective, direct seeding of rice is more water competent [23-25].

Direct Seeding of Rice: Seeds sowing on dry unsaturated soils are called direct seeding. Seeds can be broadcast, dilled, drilled. In the direct-seeded method about 30% less water was needed at land preparation compared to the transplanted technique of crop establishment [26]. From all the treatments of direct-seeded rice, yield was considerably higher (0.6 t ha$^{-1}$) than transplanted one. At the vegetative and reproductive stages of the crop, yield losses in direct-seeded rice were 20% and 31%, respectively. But in transplanting yield losses were 27% and 43% [27]. Thus it was recorded that direct-seeded was more water stress tolerant as compared to transplanted rice [28, 29]. Bhushan et al. [30] compared seven planting techniques of rice with traditional method of transplanting. Three transplanting techniques (parachute transplanting, farmer method of random transplanting and line transplanting) and five direct seeding techniques (drilling of soaked seed in water soil, drilling of soaked seed in zero-tilled soil, broadcasting of soaked seed in water soil, broadcasting of sprouted seed in puddled soil, drilling of soaked seed on raised beds 2 rows on each bed) were integrated for comparison. Results showed that plant height, filled grains per panicle, productive tillers per m$^2$, root length, 1000-grain weight and paddy yield were notably high in line transplanting and minimum in drill sowing of soaked seed in zero-tilled soil. Infertility of rice (12.53%) in conventional method of transplanting (13.07%) was low in line transplanting but high (16.05%) in drilling of soaked seed in zero-tillage and broadcasting of soaked seed in water soil (15.38%). About 29% less water was required in the direct-seeded method than
transplanted method. Highest yield was considered (6 t ha\(^{-1}\)) in all the treatments of direct-seeded rice than transplanted one using 20% less quantity of water. Yield losses in direct-seeded rice were 20% and 30% at the vegetative and reproductive stages of the crop. But in transplanted rice yield losses were 28% and 43% [31, 32, 33]. In the Philippines, Peng et al. [34] observed that aerobic rice yields up to 6 t ha\(^{-1}\). Aerobic rice can maintain a high yield because of minimum water use by as much 50% compared with lowland rice. There are also some disadvantages of direct seeded rice as under field conditions like lower yield of direct seeded rice, uneven and poor crop establishment. The major reason for its poor performance is inappropriate methods of weed control [35]. Good seedling establishments, correct weed management and prevention from lodging, are considered for good yield. The success of direct seeding is almost totally depend on effective weed control, so weed control is the key factor in direct seeded rice. Due to changes in crop physiology and increased weed invasion, the degree of flooding in rice may lead to reduced yields [36]. If weeds are managed, then direct sowing culture can evenly be successful as compared to transplanting method. This could be accomplished by using varieties with crop management technologies and early seedling vigor. Direct-seeding mulch-based cropping systems involving various crops are currently adopted in large areas throughout the world, mostly in countries such as the United States, Canada, Australia, Brazil, Paraguay and Argentina to obtain a sustainable production of grain and increase agronomic and environmental efficiency (water saving in soil) [37]. This method enhances water use efficiency and grain yield [38]. In non-flooded mulching cultivation, plastic film mulching cultivation has been practiced in lot of areas in China and considered as a modern water-saving system [39]. On organic farms, weeds are major agronomic problems as weed control can only be accomplished without herbicides. Therefore, it is dire need to develop alternative methods of weed control in organic agriculture [40]. Germination of weed seed is influenced by temperature and soil moisture, mulch not only maintains soil moisture at higher levels compared with un-mulched soil but also suppresses weeds [41]. Normally, crop residues on soil surfaces lower soil temperature in the hot season and maintain it in autumn [42]. In certain stages of growth, phytotoxicity of wheat residues was better and decreased in later stages as observed by Narwal et al. [43]. Rice straw decreased (16.9%) of broad leaf weed population but did not decreased grassy weeds. But wheat straw condensed both types of weeds. After sowing, this suppression increased up to 120 days and reduced afterwards. 16.8% reduction of broad leaf weeds and grassy weeds were caused by wheat straw. For this purpose, wheat straw is inexpensive source of mulching material and can be efficiently utilized. By applying different wheat straw management practices (straw burned, incorporated, rolled and baled/removed), grain yield of rice crop was better where straw was retained, i.e., incorporated and rolled as described by Eagle et al. [44].

**Planting Pattern:** Szwedo et al. [45] recorded the highest number of panicle bearing tillers per hill (16) in case of 30 cm spaced single row which was at par with that of planted in the patterns of 60 cm spaced triple row strips. The next best treatment appeared to be 45 cm apart double row strips, with corresponding value of 14.45 panicle bearing tillers per hill. However, the lowest number of tillers per hill (13.61) was recorded in 20 x 20 cm hills which was attributed to narrow inter row spacing as compared to rest of the planting patterns. So the highest number of panicle bearing tillers per hill is seen in 30 cm spaced single rows. The results exposed that sowing of aerobic rice at a spacing of 45 cm x 20 cm has recorded considerably higher number of leaves per plant (187.4), leaf area per plant (4583 cm\(^2\)), number of tillers per plant (41.2), total dry matter production (79.5 g/plant), panicle length (22.1 cm), number of grains per panicle (195.9) and grain yield (57.4 q ha\(^{-1}\)) compared to other spacing. Hussain et al. [46] reported that the maximum maize grain yield was obtained in hybrid varieties using plant spacing of 25 x 75cm, while the lowest yield was obtained in the local maize kind with plant spacing of 100 x 100 cm. Joshi et al. [47] reported that historically, 7.0- to 7.5- inches. Row spacing has been utilized when the rice is drill-seeded. However, during the past 15 years, a number of producers utilizing 10-inches drills have increased considerably. The highest grain yields were obtained with 7-inches row spacing. They concluded that net returns from 7-inches row spacing ranged from $14.50 to $50.00/acre greater than net returns from 10-inches row spacing. So it was recommended that direct-seeded rice should be drill-seeded on 7.0 to 7.5-inches row spacing. Lin et al. [48] evaluated the effects of amount and timing of fertilizer nitrogen (N) application and row spacing on the yield of aerobic rice under rainfed situation in the 2004 and 2005 wet seasons in 3 and 2 locations, respectively, in Central Luzon, Philippines. Yields were similar for row
spacing ranging from 25 to 35 cm. Although the number of panicles per square meter was significantly higher at 25-cm spacing than at 35-cm spacing, this difference was compensated for more spikelets per panicle at 35-cm spacing, while spikelet fertility and grain weight were similar for all row spacing. Basavaraja et al. [49] concluded that a rice-fish culture field experiment was conducted to study the special effects of alternate wide and narrow row spacing on yield components and paddy yields. In 1986 yields (6.09 t/ha) were highest in alternate rows 35 and 15 cm apart, followed by 5.71 t in rows 30 and 20 cm apart and 5.51 t in rows 25 cm apart.

**Water Saving by Organic and Plastic Mulches:** Li et al. [50, 51] examined the effect of constant plastic film mulching on water use efficiency, soil properties and yield of rice fields under non-flooding condition. Plastic film mulching under non flooding condition increased soil temperature, root growth and accelerated decomposition of organic carbon. By plastic film mulching, irrigation water use efficiency increased by 273.7–519.5% and water use efficiency by 69.7–107.0%. In contrast with conventional flooding, plastic film mulching increased soil organic matter content by 8.3–24.6% over the soil surface. Plastic mulching rather than an irrigation system is a production technology. To lock in moisture between the ground and the sheeting, this describes numerous specific techniques that involve the use of plastic film [52]. Plastic sheeting is used to cover the soil during or before the crop growing period. For example, one use of plastic sheeting is as a part of an agronomic system called soil cover rice production system [53]. In addition, farmers via ground cover rice production system increases soil temperature allowing prior planting and harvesting. Plastic sheeting under experimental field conditions also enhance soil temperatures [54]. Li et al. [55] reported the integration of ridge and furrow system of rainfall harvesting with mulching for crop production under semiarid condition. Various experimental result showed that grain yield in plastic covered ridge and furrow rainfall harvesting system with mulches was higher than the control with an increase of 4010-5299 kg ha⁻¹ (108-144%) and this technique can raise corn yield 60-96% in drought, 20-30% in very wet years and 70-90% in wet years. Xie et al. [56] studied the evapotranspiration, growth, yield and water use efficiency of plastic-mulched spring wheat. They conducted lot of experiments to retain smallest amount soil water content to different levels: 85%, 70%, 60%, 50% and 40% of field capacity in rooting depth. Experiment results showed that over non-mulch, there were increases of 0.9-30.9% in evapotranspiration and 4.0-110.2% in yield for all plastic-mulched treatment. Plastic mulch showed maximum (2-60%) water use efficiency than non-mulch. While, Fisher et al. [57] stated that semi-permanent plastic mulching was most appropriate for regions where the shortage and irregularity of rainfall are the greatest constraints to increasing yields and yield was extensively higher in plastic mulch treatment than the control (no-mulch) treatment. It was also reported that by managing the seeding time and by using a proper mixture of deep tillage, mulch and irrigation, higher corn yields on coarse-textured soils may be achieved [58]. Zhang et al. [59, 60] evaluated the yield, grain quality of rice and water use efficiency in non-flooded mulching farming. They concluded that both straw mulch and plastic mulch could extensively increase water use efficiency, while the straw mulch could maintain a high grain yield and also improve quality of rice. Mahajan et al. [61] reported that plastic mulch increased corn yield (18.9% and 77.6%) over rice straw and un-mulched treatment respectively. Soil temperatures are increased in plastic sheeting under experimental field conditions Cheng et al. [62] observed that the plants under polythene film, in comparison with the plants under conventionally flooded cultivation had considerably lower K and P concentrations at heading and maturity stages and superior N concentration at booting stage. Polythene sheet is more efficient to reduce water loss but it is an expensive option. Photo-Biodegradable polyethylene mulching are better able to enhance temperature, preserve moisture and raise probable yield than common polyethylene as Moitra et al. [63] observed the effects of four mulch types: (no mulch; soil dust mulch; green mulch at 20 Mg ha⁻¹ and rice straw mulch at 5 Mg ha⁻¹) and three tillage treatment (two, four and six ploughings to 100 mm depth) on water conservation, grain yield and water use efficiency of rainfed yellow sarson (Brassica rapa L. varglauca). They found that grain yield was improved by 47%, 43% and 16%, respectively under green, straw and soil dust mulching as compared with no mulch condition. The major features of the direct seeding of rice are that compared with conservative traditional flooding, it requires less water. It is reported by the scientists that less labor are required for direct seeded rice as compared with transplanting method [64]. To achieve the dual goal of saving water and increasing food production, non-flooded mulching cultivation has been adopted as a new rice production system in recent years [65-69].
Weed Control by Mulches: Employing straw mulches or polythene sheet can control weeds up to a positive level. Use of soil cover has a major role in the conservation of soil moisture and in weed control without use of herbicides [70]. Without any demand of herbicides, plastic mulch enhanced plant height, reduced temperature of soil, accelerated early growth, fruiting of plants and gave satisfactory weed control [71]. Weed suppressing was found efficient by plastic film mulching and rice straw. It increased the soil temperature by about 6 °C at 5 cm depth and by 4 °C at 10 cm depth. Groundnut plants in polythene and straw mulched plots were normally tall, vigorous and showed early flowering [72, 73]. Rodriguez [74] reported the effect of rice bran mulching on growth and yield of cherry tomato. Results exposed that the highest (3.4 kg plant⁻¹) total fruit production was obtained with the rice straw and bran treatment, followed by the other two treatments, with about 2.5 kg plant⁻¹ in cherry tomato. The results also indicated that weed control can be managed by the using the rice bran. It was also reported that application of wheat residue mulch @4tha⁻¹ was equally useful in controlling weeds in direct-seeded rice [75]. Crop residues (straw mulch and plastic film mulch) should be part of integrated weed management in an agro-ecosystem which may selectively give weed control through their physical presence on the soil surface and prevents nutrient loss, particularly nitrogen loss as volatilization and more availability of nitrogen increases vegetative growth [76-80].

CONCLUSION AND FUTURE RESEARCH TREND

It has been established that relatively close planting pattern in direct seeded rice results in better growth and productivity due to the better utilization of environmental as well as soil resource base. This close planting pattern also suppresses the weed infestation which is the most notorious factor for reducing the quality and yield of aerobic rice. However there can be more research to explore the possibility of intercropping some other crops with direct seeded rice. Moreover it has been concluded that plastic mulch is much better in increasing aerobic rice productivity as well as yield than other organic mulches as wheat straw. However due to economic constraints of small farmers and keeping in view the problem of using plastic mulch on large scale, there is dire need to explore other organic mulching materials that are easily available and having no allopathic effects. There is also need to assess the allelopathic effect of wheat straw mulch on aerobic rice. So these can be the lines and points for future research as well as a challenge to Agronomists and other researchers.

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REFERENCES


