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Resource conservation technology for enhancing the rice productivity in India: A review

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Abstract
Rice (*Oryza sativa* L.) is one of the most important staple food crops in the world. In India, rice occupies an area of 43.79 million ha with an average production of 112.91 million tones and productivity of 2.58 tonnes/ha (Anonymous, 2018). However, continuous use of traditional puddling method in rice crop has degraded the soil resource base and intensified soil degradation with concomitant decrease in crop production capacity. Further, escalating fuel, fertilizers and other input costs; necessitates the effective use of resources in agriculture. Demand for rice is growing every year and it is estimated that in 2025 AD, the requirement would be 140 million tonnes (Duttarganvi *et al.*, 2016). In order to achieve this target, the productivity of rice has to be brought to the level of 3.3 tonnes/ha (Anjani *et al.*, 2014). Food security depends on the ability to increase production with decreasing availability of resources to grow crops. The resource conservation technologies (RCTs) primarily focus on resource savings through minimal tillage, ensuring soil nutrients and moisture conservation through crop residues and growth of cover crops, and adoption of spatial and temporal crop sequencing. The resource conservation agriculture (RCT) technologies involving direct seeded rice (DSR), system of rice intensification (SRI), alternate wetting and drying (AWD), furrow irrigated raised bed planting systems (FIRB) and other inclusive technological practices have potential for improving productivity and soil quality, mainly by soil organic matter build-up. Resource conservation technologies in rice crop appear to be appealing options to achieve sustainable and intensive crop production under different agro-ecological environments because they use available resources efficiently and maintain soil fertility. However, there is a need for wider scale testing of these new technologies under diverse production systems, as the RCT's technologies are site specific and therefore appraisal of RCT's is important to have significant adoption.

Keywords: rice, food security, soil quality, resource conservation agriculture (RCT), productivity

1. Introduction

Rice is the staple food for more than half of the world's population and plays a pivotal role in food security of many countries. More than 90% of the global production and consumption of rice is in Asia (IRRI, 1997) [14]. In Asia, more than two billion people are getting 60-70 per cent of their energy requirement from rice and its derived products (Yogeswari and Porpavai, 2018) [35]. As for India, the country has witnessed a remarkable progress in rice production since independence. Presently, rice occupies an area of 43.79 million ha with an average production of 112.91 million tones and productivity of 2.58 tonnes/ha in India (Anonymous, 2018) [2]. Growth trends in cultivated area, irrigated area, production and productivity of rice in last five decades are given in Table 1.

Table 1: Scenario of cultivated area, area under irrigation, production and productivity of rice crop in India over past five decades

Year	Area (million-hectare)	Area under irrigation (%)	Production (million-tonne)	Productivity (kg/ha)
1974-75	37.89	38.81	39.58	1045
1984-85	41.16	43.72	58.34	1417
1994-95	42.81	49.87	81.81	1911
2004-05	41.91	55.23	83.13	1984
2014-15	44.11	60.09	105.48	2391

Anonymous (2018) [2]

Based on the increasing population growth at the rate of 1.4% (Duttarganvi *et al.*, 2016) [7] is creating burden on land and other natural resources base of the country, which damage the ecological base of agriculture system. More water requirement in rice crop is because of low water use efficiency. The increased rice cultivation over the years has accelerated the removal of soil nutrient four times during the last four decades exerted fourfold pressure on soil resources. Further more denitrification, volatilization losses and nutrients leaching was reported than earlier grown rice ecosystem. This leads to lower nutrient use efficiency and more nutrient loss. The cost of cultivation is high for rice production due to excessive use of inputs and increasing the energy demand needed of tillage operation, fertilizers requirement, number of irrigation needed for rice production. These problems can be addressed through adoption of resource conservation technologies.

2. Traditional method of rice cultivation: Puddled Transplanted rice (TPR)

In India, rice is the staple food and a source of livelihood for about 120-150 million rural households (Nivrutti, 2014) [25]. Irrigated rice occupies 50 % area and contributes nearly 70% to total rice production of the country with an average yield of 3.1 t/ha. It is estimated that to produce 1 kg of grain, farmers have to supply 3-5 times more water in rice fields than other cereals (Kumar *et al*., 2013) [20-21]. Transplanted rice is predominantly cultivated in the North-Western Indo-Gangetic Plains (IGP). Transplanting requires at least 25 ha-cm of water for puddling operation, which creates a dense clay layer in the sub-soil to prevent seepage losses. Generally, about 40% of all irrigation water goes to paddy cultivation in the region. In traditional rice cultivation, rice is sprouted in a nursery; sprouted seedlings are then transplanted into standing water. The reported amount of irrigation water required for puddling varies from 100 mm (Sudhir-Yadav *et al*., 2011) [32] to 544 mm. Singh *et al*., (2014) established that preparation of land for transplanting paddy (puddling) consumes about 20-40 % of the total water required for growing of crop and subsequently poses difficulties in seed bed preparation for succeeding wheat crop in rotation. It also promotes the formation of hard pan which effects rooting depth of next crop. It, therefore, becomes imperative to identify alternative establishment method to puddling especially in those regions where water is becoming scarce, and an upland crop is grown after rice.

3. Resource Conservation Technologies in rice

Resource Conservation Technologies are any practices or technology, which improves input or resource use efficiency. Resource Conservation Technologies RCTs protect top soil, improve water holding capacity and productivity of rice. However, for rice production water is one of the essential inputs as it affects plant development by influencing its vital physiological processes. Fresh water for agriculture is becoming increasingly scarce. In Asia, with relatively more suitable growing conditions for rice, production has declined due to increasing water stress (Tao *et al*., 2004). Groundwater tables have dropped, on average by 0.5–0.7 m/year in the Indian states of Punjab, Haryana, Rajasthan, Maharashtra, Karnataka and Northern Gujarat and by about 1 m/year in Tamil Nadu. There are various nutrient losses in rice crop through leaching, volatilization and dentrification, which reduces the productivity per unit area. Thus in order to meet the increasing pressure of biotic and abiotic stresses in response to soil degradation, crop productivity and farmers' profits have shown a downward trend. Current efforts have endeavoured to develop and carry resource conservation technologies (RCTs) with effective and environmentally friendly tillage/crop establishment and water use as compared to the conventional practices of farmers.

Various novel resource conservation technologies that would make rice production more water-efficient with integrative use of crop improvement and management tools are alternate wetting and drying (AWD), ground-cover systems, system of rice intensification (SRI), Direct seeded rice, aerobic rice, furrow irrigated raised beds, irrigation scheduling, etc. Effect of different resource conservation technologies on grain yield and water productivity of paddy with respect to methods of crop establishment and irrigation regimes and nutrient management have been presented in Table 3, 4 and 5. Any approach that would lessen the amount of water use without compromising the rice yield would certainly be a novel resource conservation technology

3.1 Alternate wetting and drying (AWD)

AWD has been commonly used as a water-saving practice in many parts of the world for more than a decade. In this system, the soil is allowed to dry for a few days within irrigation events depending on plant developmental stages. Savings in irrigation water in the AWD treatments were 53–87 mm (13–16%) compared with the continuously submerged regime. Water productivity was significantly higher in the AWD regime than in the continuously submerged regime (Belder *et al*., 2004) [4]. Yield penalty was commonly observed under AWD compared with continuously flood-irrigated (CF) rice (Bouman and Tuong, 2001) [6]. However, the water consumption is still high in AWD since the soils need to be submerged at least during the irrigation period.

3.2 Direct seeded rice (DSR)

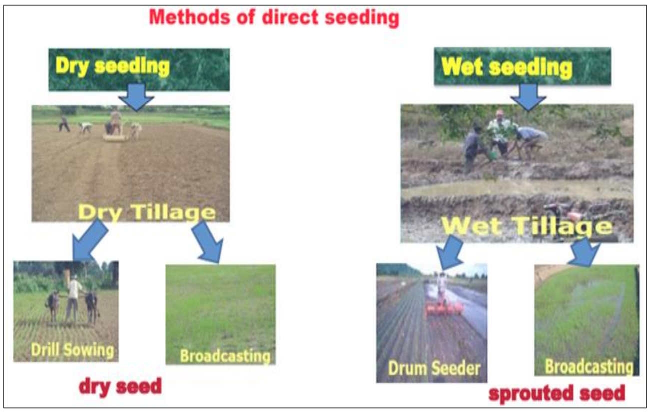

Fig 1: Direct seeded rice

In direct seeded rice (DSR) cultivation, raising of nursery for transplantation is excluded. DSR gives the farmer flexibility to take up direct sowing of paddy in case of water shortage or delayed monsoon. Direct sowing can be practiced for cultivating both coarse rice and basmati rice wherever feasible in the North-West IGP region. In DSR, crop established after applying presowing irrigation, first irrigation can be applied 7-10 days after sowing depending on the soil type. During active tillering phase i.e. 30-45 days after sowing (DAS) and reproductive phase (panicle emergence to grain filling stage) optimum moisture (irrigation at 2-3 days interval) is required to be maintained to harvest optimum yields from DSR crop. In a 6-year study conducted in Modipuram on sandy-loam soil, it was observed that dry DSR can be irrigated safely at the appearance of soil hairline cracks (Gathala *et al*., 2011) [8]. The direct seeded rice (DSR) on raised beds decreased water use by 12-60 per cent, and increased yield by 10 per cent as compared to puddle transplanted rice, in trials at both experimental stations and on-farm (Gupta *et al*., 2002) [11].

Table 2: Effect of different crop establishment methods on grain yield of paddy

Establishment method	Grain yield (t/ha)	Location	Source
Direct Seeded Rice	4.60	IGKV, Chhattisgarh	Hemlata *et al.* (2018) [12]
System of Rice intensification	6.10	ICAR-IIRR, Hyderabad	Duttarganvi, *et al.* (2016) [7]
Normal transplanted rice	4.00	ICAR-IIRR, Hyderabad	Duttarganvi *et al.* (2016) [7]
Furrow irrigated raised bed	3.04	ANGRAU, Hyderabad	Balamani *et al.* (2012) [3]

3.3 Aerobic rice

Aerobic rice is a new way of production system in which specially developed, input-response rice varieties with aerobic adaptation are grown in well-drained, non-puddled, and non-saturated soils without ponded water. It is a fundamental approach to reduce water inputs in rice is growing like an irrigated upland crop, such as wheat or maize. Main driving force behind aerobic rice is the economic water use. Kadiyala *et al*., (2012) [18] reported that the total amount of water applied (including rainfall) in the aerobic plots was 967 and 645 mm compared to 1546 and 1181 mm in flooded rice system, during 2009 and 2010, respectively. This resulted in 37 to 45% water savings with the aerobic method. Jinsy *et al*., (2015) [17] found that compared to conventional flooded rice, the average water productivity of aerobic rice (0.68 kg/m^3) was 60.7 per cent higher. Reddy *et al*., (2010) [27] reported that water productivity was higher under aerobic (0.20 to 0.60 kg/m^3 of water) than that under transplanted (0.14 to 0.43 kg/m^3 of water) condition.

Fig 2: Aerobic rice

Nevertheless, decline in yield was observed when aerobic rice when continuously grown and the decline was greater in the dry than in the wet season (Peng *et al*., 2006) [26]. In crux, aerobic rice is an attractive option to the traditional rice production system. Yield penalty and yield stability of aerobic rice have to be considered before promoting this water-saving technology.

3.4 Furrow irrigated raised beds

Transplanting of rice on beds omits puddling and hence avoids the detrimental effects of puddling. In this case rice is grown on raised beds and irrigation is applied in furrows between the beds. Naresh *et al*., (2014) [23] revealed that among different crop establishment techniques, wide raised beds saved about 15%–24% water and grain yield decrease of about 8%. Sandhu *et al*. (2012) [28] revealed that transplanting of rice seedlings on slopes of freshly constructed beds resulted in 15% saving of irrigation water as compared to puddled plots (conventional method used by farmers) without any significant reduction in grain yield of rice. Singh *et al*., (2001) [30] evaluated the yield and water use of rice established by transplanting, wet and dry seeding with subsequent aerobic soil conditions on flatland and on raised beds. Compared with transplanted rice, dry-seeded rice on flatland and on raised beds reduced total water input during crop growth by 35–42% when the soil was kept near saturation and by 47% and 51% when the soil dried out to 20 and 40 kPa moisture tension in the root zone, respectively. Gathala *et al*., (2013) [9] reported that irrigation water productivity (IWP) was significantly higher in beds to the tune of 13.9% and 13.16% than flat puddled planting.

3.5 System of rice intensification

SRI that evolved in the 1980s and 1990s in Madagascar permits resource limited farmers to realize paddy yields of up to 15 t/ha even on infertile soils, with greatly reduced rates of irrigation and without external additional inputs (Stoop *et al*., 2002) [11]. The main features of this system are transplanting young seedlings singly in a square pattern with wide spacing, using organic fertilizers and hand weeding, and keeping the paddy soil moist during the vegetative growth phase. Significant phenotypic changes occur in plant structure and function and in yield and yield components under SRI cultivation. SRI increased yields substantially (50–100% or more), while requiring only about half as much water as conventional (Uphoff *et al*., 2010) [34], whilst not needing the purchase of additional external inputs.

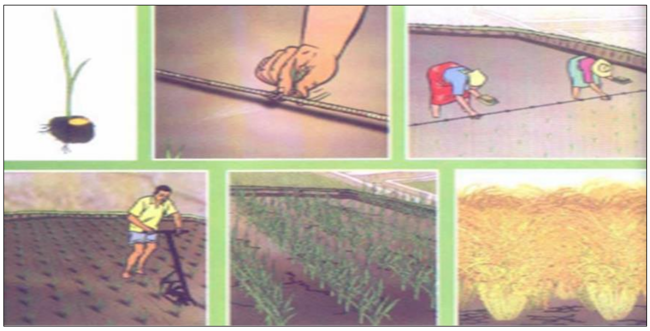

Fig 3: System of rice intensification

A survey was conducted by Moser and Barett (2003) [22] on farmers in Madagascar to investigate farmer implementation of AWD as part of SRI and showed that farmers have adapted AWD practices to fit the soil type, availability of water and labor. They suggested that combination of AWD with SRI, farmers can increase grain yields and also reduced irrigation water requirement of rice crop. In another experiment conducted by Thiyagarajan *et al*. (2003) [33] reported that there was savings in irrigation water of 56% and 50% using conventional and young seedlings, respectively, without a significant effect on grain yield under SRI system. Krupnik *et al.* (2012) [19] confirmed that substantial water savings and increases in water productivity can be obtained with SRI, although significant yield increases compared to recommended management practices should not be expected. Further work should be conducted to investigate the mechanisms underlying these results, and to compare SRI's yield and water productivity performance to other water-saving rice management systems.

Table 3: Effect of different systems of rice cultivation on grain yield and water productivity of rice

System of rice cultivation	Grain Yield (kg/ha)	Water productivity (kg/m^3)
Transplanted rice	6262	0.37
Alternate wetting drying	5796	0.42
System of rice intensification	6682	0.47
Direct wet seeded rice	5500	0.35
Aerobic rice	3933	0.42

Geethalakshmi *et al.* (2011) [10]

3.6 Site specific nutrient management (SSNM)

Real time N Management is key to improve N use efficiency between the crop by management of N demand and the available N supply. Since crop N requirement are closely related to yield levels, which turn are sensitive to climate, particularly solar radiation and the supply of nutrients and crop management practices, dynamics N adjustment of real time has prime significance. We easily find which crop needs nitrogen application by using SPAD meter, green seeker (GS) and leaf colour chart (LCC). These technologies provide instantaneous results and have been demonstrated as effective tool to schedule N fertilization to crops like rice.

3.6.1 Leaf color chart (LCC)

A LCC developed in Japan, is used to measure green color intensity of rice leaves to assess the nitrogen requirements by non-destructive method (Nachimuthu *et al.*, 2007) [24], and is being standardized with chlorophyll meter. In hybrid as well as inbred rice, N management through LCC proved superior to locally recommended N application in three splits. It was found possible to curtail 20-30 kg of fertilizer N/ha without sacrificing rice yield, when N is applied as per LCC values. N application at LCC<3 in Basmati and at LCC<4 in coarse and hybrid rice was found optimum. Moreover, in LCC-based N management, basal application of N can be skipped without any disadvantage in terms of grain yield, and agronomic, physiological or recovery efficiency of fertilizer N. The studies indicate that nitrogen can be saved from 10 to 15 percent using the LCC (Sharma *et al*. 2008) [29].

3.7 Laser land leveler

Laser leveling is a process of smoothening the land surface (± 2 cm) from its average elevation using laser equipped drag buckets to achieve precision in land leveling. Precision land leveling involves altering the fields in such a way as to create a constant slope of 0 to 0.2%. This practice makes use of large horsepower tractors and soil movers that are equipped with global postioning systems (GPS) and/or laser-guided instrumentation so that the soil can be moved either by cutting or filling to create the desired slope/level. (Walker *et al.* 2003). A review of various studies suggested that laser land leveling in Pakistan resulted in about 25% reduction in irrigation water application and an increase of about 30% in wheat yield as compared to conventional practices (non-laser leveled fields; Humphreys *et al.*, 2010) [13]. Similar increased yield and reduced irrigation water application in the case of zero tillage wheat and laser land leveling were reported in India and China (Jat *et al*., 2009; Humphreys *et al*., 2010) [15, 13]. For instance, Jat *et al*. (2009) [15] showed that the use of RCTs, including zero tillage, laser leveling, reduced irrigation water applications between 23 and 45% while increasing yield.

4. Conclusion

Rice being the staple food crop in South Asia has contributed immensely to fill the increasing empty stomachs but has consequently led to many sustainability issues *viz*. declining water resources, degrading soil health and environment degradation which is further responsible for stagnating/ decreased land and water productivity. Hence, alternate tillage and establishment methods must be invented, tested and recommended for the sustainable establishment of rice as a whole including the intervening period so that land and water productivity, soil health and environment must be improved for overall lifting of the livelihoods of the farmers of South-Asia. Performance of these technologies is however, site-specific and changed depending upon the soil textural classes and agro- climatic conditions. This suggests that farmers must pick them up from the many as per their soil texture and agro-climatic conditions. Conventional indigenous age-old practices are responsible for all the earlier discussed un-sustainability issues which must be replaced with more advanced and sustainable resource conservation technologies (RCTs). Adoption of these technologies can substantially conserve resources at the field level while increasing productivity at the same time. Therefore, the role of these RCTs to achieve sustainable food production with minimal impact on the soil, underground water and the atmosphere and in improving the declining land and water productivity become more important now than ever for a sustainable food future.

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