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Overview of research on establishment of rice varieties of varying duration in irrigated rice based cropping systems

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Abstract
Rice-Rice Cropping System is found in irrigated lands and coastal regions of Odisha, Tamil Nadu, Andhra Pradesh, Karnataka and Kerala. Due to Monocropping, this system has suffered from deterioration in soil health and micronutrient deficiency. Rice-rice system occupies the 2nd position with an of area 5.89 m ha after rice-wheat cropping system which occupies an area of 11 m ha in India. Rice-rice system is no longer productive in Southeast Asia. Transplanting after puddling has been a major traditional method of rice establishment. Repeated puddling adversely affects soil physical properties by dismantling soil aggregates, reducing permeability in subsurface layers, and forming hard-pans at shallow depths which make land preparation becomes difficult and requires more energy to achieve proper soil tilth for succeeding crops. Excessive pumping of water for puddling in peak summers also resulted in declining water table. Rice production with transplanting method has been limited by a number of factors such as water scarcity, high input costs, shortage of skilled labour, sub-optimal plant population. Rice seedlings are transplanted by hired skilled labour that resulted in skilled labour shortage throughout the transplanting period which results into low plant population and eventually low rice yield. To overcome this problem, direct seeding of rice and no-puddled transplanting seems to be viable alternatives in rescuing farmers. This technique reduces labour needs, input requirements, investment and save time by timely sowing of rice and shorten crop duration by 7–10 days than transplanted rice. Direct seeded rice, if managed properly, and provide grain yield comparable with that of transplanting and the system may be intensified by adjusting more crops in a year. Crop and varietal diversification of the rice based cropping systems may improve the productivity, profitability and resource use efficiency of the systems. Diversification is also a viable option to mitigate the risk of climate change. In this review article the effect of rice crop establishment methods with varying duration rice varieties on rice based cropping system are discussed.

Keywords: Establishment, rice varieties, irrigated rice

Introduction
Rice feeds about 50% of the world population and provides 19% of the global calories intake (IRRI, 2014). Rice is grown in 112 countries covering every continent and it is consumed by 2.5 billion people in developing countries, mostly in Asia (90%) and the rest (10%) in America, Africa, Australia and Europe. In India, rice was grown in an area of 43.95 million hectare with a production of 106.54 million tonnes and productivity of 2424 kg/ha during 2013-14 (MoA, GOI, 2015). however, FAO (2008) [25] reported that yield growth dropped to 0.60% per year from 1990 to 2006 due to continuous rice cropping. Doberman and Fairhurst (2000) [24] have evidently demonstrated decline in yield and depletion in soil nutrient status with intensified mono-cropping of rice for years by the long term experiments conducted in Asia. Repeated puddling adversely affects soil physical properties by dismantling soil aggregates, reducing permeability in subsurface layers, and forming hard-pans at shallow depths (Sharma *et al.*, 2003) [83], all of which can negatively affect the following non-rice upland crop in rotation (Tripathi *et al.*, 2005a) [99]. Pumping of water for puddling in peak summers in north west Indo-gangetic plains (IGP) causes problems of declining water table and poor quality water for irrigation on one hand, whereas, in eastern IGP, rice transplanting depends mainly on monsoon rains. The transplanted puddled rice (TPR), leads to higher losses of water through puddling, surface evaporation and percolation (Farooq *et al.*, 2011) [27]. Furthermore, need of ponded water for customary practice of puddling delays rice transplanting by one to three weeks (Ladha *et al.*, 2009) [55]. Huge water inputs, labour costs and labour requirements for TPR have reduced profit margins (Pandey and Velasco, 2005) [65].

Problems arising due to rice – rice double cropping system
Agriculture in India is largely rice-based. The spread and extent of rice-based cropping systems across the country and more precisely in eastern India is predominant (Mahapatra *et al*., 2012) [58]. Imbalanced uses of fertilizer, injudicious water management and monoculture of rice have resulted in rapid degradation of rice ecology. Continuous rice–rice cropping system causes declining soil health by increasing bulk density, development of hard pans due to puddling, deterioration of soil structure, micronutrient (Zn, S and B) deficiency, non-synchronous utilization of nutrients from different soil layers, decline in soil microbial activity and increasing iron toxicity. It also causes increased weed, insect and pest menace, methane (CH_4) gas emission, low water productivity and resource use efficiency, low system productivity leading to low income generation. In this context, inclusion and management of remunerative crops like non rice cereals, pulses, oilseeds, vegetables and other crops of low water requirement in various rice ecologies through system perspective can improve the input use efficiencies of land, water, energy and nutrients, besides maintaining the soil health.

Effect of Crop establishment methods (PTR, NPTR and DSR) on growth parameters of rice
Hugar *et al*. (2009) [45] noticed significantly taller plants with normal transplanting than direct sown rice which was followed by SRI. In contrast, Prabhakar (1996) [69] reported more plant height with direct sown rice than transplanted rice. This may be due to the transplanting shock which may take about one week for establishment in transplanted rice. Singh *et al*. (1997) [91] reported higher plant height with transplanted rice.
Sudhir-Yadav *et al.* (2011) conducted an experiment on research farm of Punjab Agricultural University on clay loam soil to compare the performance of dry direct seeded rice (DSR) and puddled transplanted rice (PTR). They have concluded that the tillers m^{-2}, leaf area index (LAI) and dry matter accumulation was better in DSR than PTR because of higher plant density in DSR. Similar result was presented by Kumar and Ladha (2011) [54]. The maximum tillers m^{-2} was observed in DSR as compared to PTR because of initial higher growth rate at Bangladesh. But after maximum tillering, the tiller mortality was higher in DSR which may be because of competition for light, nutrients and water (Hasanuzzaman *et al*., 2009) [43]. The plant height of rice was significantly greater when rice was established by transplanting as compared to direct seeded (Singh *et al*., 2004). The DSR showed greater plant height, better dry matter accumulation and LAI than transplanted rice (Sarkar *et al*., 2003 and Tuong *et al.*, 2000) [79, 100].
Chander and Pandey (2001) [19] and Gill *et al*. (2006) [34, 36] recorded the maximum dry matter accumulation in transplanted rice, which was significantly more than direct seeded rice. In contrast to above findings, Halder *et al.* (2009) observed significantly higher dry matter accumulation in direct seeded rice under puddle condition compared to regular transplanting method.
Peng *et al*. (2006) [66] stated that transplanting of rice seedling registered higher number of tillers on sandy loam soils during wet season. The maximum number of panicles in conventionally transplanted crop was due to production of maximum number of tillers per unit area on account of higher availability of nutrients (Aslam *et al*., 2008) [5]. These findings were supported by Prasad *et al.* (2001) [73] who reported that transplanting technique increased all the growth and yield attributes of rice significantly over seeding and puddle sowing of sprouted seeds, where as dry seed drill produced the minimum number of panicles per unit area.

Effect of Crop establishment methods (PTR, NPTR and DSR) on yield attributes and yield
Awan *et al*. (2007) [6] reported higher productive tillers m^{-2} (336) in direct seeded rice than manual transplanted crop (229 tillers m^{-2}). Haque *et al.* (2017) [40] in Durgapur and Godagri, Bangladesh evaluated three establishment methods *viz.* tranplanting on dry strip (transplanting was done manually on dry land prior to irrigation); transplanting on wet strip (transplanting was done on irrigated field for 18 to 24 hours) and conventional transplanting. The grain yield in transplanting on wet strip was higher than conventional. Chauhan *et al.* (2015) [21] reported that the yield of NPTR was greater than DSR in clay loam soil at IRRI, Philippines. The grain yield and harvest index of dry season was greater than wet season. Similar results were reported by Sudhir-Yadav *et al.* (2014) [94].
Sharma *et al*. (2016) [86] reported higher grain yield and production efficiency (kg/ha/day) in direct seeding after conventional tillage than conventional transplanting after puddling. Saharawat *et al*. (2010) [75] conducted a field experiment in Haryana on clay loam soil including transplanting and direct seeding of rice after reduced and no tillage. They reported similar grain yield between non-puddled transplanting and puddled transplanting. Similarly, a two year trial was conducted in Indo-Gang etic plains to evaluate different establishment systems. It was observed that the yield of rice under PTR and DSR on non-puddled flatbed systems was similar (Bhushan *et al*., 2007) [13].
Bari (2004) [9] reported that the yield attributing characters were significantly affected by establishment methods. The grain and straw yield from direct wet seeded line sowing method was significantly higher than transplanting. Balasubramanian *et al.* (2003) [7] found that DSR on flat land gave similar or higher yield than PTR.

Effect of Crop establishment methods (PTR, NPTR and DSR) on soil properties
Sudhalakhsmi *et al*, 2007 had reported higher redox potential of soil in dry seeding as compare to the conventional transplanting method due to enhanced root oxidising power in drained field conditions.
Singh *et al*. (2002) [93] studied the effect of different crop establishment methods and wheat tillage on soil bulk density. They found that bulk density was significantly lower in puddled plots (1.31 Mg m^{-3}) compared with direct seeding without puddling (1.42 Mg m^{-3}) in surface soil (0-7 cm) at 20 days after transplanting. Later at harvest, these differences narrowed. In subsurface soil (12-19 cm), differences in bulk density in direct seeding without puddling and transplanted plots were not significant.
Dhiman *et al.* (1998) [23] reported that bulk density (g cc^{-1}) was higher under transplanted rice compared with dry seeding of rice and this might be due the puddling effect under transplanting method. Available water content was higher in dry seeding of rice because with decrease in bulk density there was increase in available water content which was due to increased porosity with decrease in bulk density.
Gangwar *et al.* (2008) reported that the higher infiltration was recorded under direct seeded rice which revealed the quality of seed bed prepared which allowed greater amount of water

to penetrate into the field and favoured vigorous growth of subsequent crops. Higher value of bulk density was recorded under puddled conditions because puddling resulted in destruction of soil aggregates and dispersion of soil particles to form a compact layer with reduced porosity. Direct seeded rice had higher yield and accumulation of N following a post-rice legume than following fallow, but transplanted rice derived no such benefit from the legume (Sharma *et al.,* 2005) [81].

Soil organic carbon content in the 15–30 cm soil layer after 4 years of cropping remained almost unchanged in both conventional and zero tillage (Bhattacharyya *et al*., 2008) [12]. The study by Gosai *et al*., (2009) [37] revealed higher concentration of soil organic matter in the no-till and shallow tilled plots compared to other conventionally tilled plots.

Singh *et al*., (2002) [93] reported that tillage had no significant effect on organic carbon, alkaline permanganate hydrolysable N, exchangeable K content and soil pH. However, they observed sodium bicarbonate extractable P was significantly more under zero tillage than conventional tillage.

Chander and Pandey (1997) [18] observed that uptake of N (112.8 kg ha^{-1}), P (17.0 kg ha ha^{-1}) and K (172.3 kg ha^{-1}) by rice was significantly higher under transplanting than direct seeded rice under puddle condition. Similarly, Anbumani *et al*. (2004) [3] found that line transplanted rice registered significantly higher nutrient uptake than direct seeded rice. The N requirement was higher in DSR than for TPR (Mahajan *et al.,* 2011a).

Effect of Crop establishment methods (PTR, NPTR and DSR) on water requirement and water use efficiency

The review paper by Joshi *et al.,* (2013) [48] reveals that direct seeded rice (DSR) technique is becoming popular because of its low-input demanding nature. It offers a very exciting opportunity to improve water and environmental sustainability. Dry seeding increases water use efficiency (WUE) and productivity, if appropriate leveling of lands is done. Early crop vigour, short stature and short duration may also improve WUE.

Dry seeded rice (DSR) provides a gateway for advancing crop establishment to make better use of early season rainfall, and facilitates an increase in crop intensification in rice based systems (Tuong *et al*. 2000) [100]. However, DSR needs to be sown earlier, so the field is exposed to higher evaporative demand for a much longer period than a puddled transplanted field. However, Bouman (2001) [14, 16] claimed the potential water savings at the field level in upland rice due to less evaporation since there is no permanent ponded water layer, and the amount of water used for puddling is eliminated altogether.

Dry seeding of rice with subsequent aerobic soil conditions eliminates the need for ponding water, thus reducing the overall water demand and providing opportunities for water and labor savings (Bouman and Tuong, 2001; Sharma *et al.,* 2002) [15, 82]. High water-use efficiency (WUE) and water productivity have been reported for DSR, whose yield penalty is relatively small compared with the savings in water use (Bouman *et al.,* 2005; Mahajan *et al.,* 2011b) [14, 16, 57].

Direct seeding helps in reducing water consumption by about 30 percent (2.25 million liters ha^{-1}), as it eliminates raising of seedlings in a nursery, puddling, transplanting under puddled soil and maintaining 4-5 inches of water at the base of the transplanted seedlings. The farmer saves about Rs 3500 ha^{-1} in cultivation cost. Direct seeding, on the other hand, avoids nursery raising, seedling uprooting, puddling and transplanting, and thus reduces the labour requirement (Pepsico International, 2011) [67]. In addition to labour savings, the demand for labour is spread out over a longer period in DSR than in transplanted rice (Kumar and Ladha, 2011) [54].

Effect of crop duration (early, medium and late) on growth, yield attributes and yield of rice

Lal *et al.* (2017) [56] reported that long duration rice cultivar (Gayatri) produced the highest number of effective tillers, spikelets per panicle, panicle weight and the maximum rice yield followed by medium duration rice cultivar (Swarna) and short duration rice cultivar (Naveen), but, rice equivalent yield (REY) of dry-season crops was higher after Naveen as compare to Swarna and Gayatri.

Direct seeding of rice allows early establishment of the succeeding crop and higher profit in areas with assured water supply by utilizing short duration modern varieties and cost efficient herbicides (Balasubramanian and Hill, 2002) [8].

Gill *et al.* (2014) [33] reported that rice seedlings are transplanted by hired skilled labour that results in shortage of skilled labour throughout the transplanting period leading to low plant population and eventually low rice yield. To overcome this problem, direct seeding of rice seems only viable alternatives in rescuing farmers. Simultaneously, the availability of high-yielding, short-duration varieties, and chemical weed control methods made such a switch technically viable. This technique reduces labour needs, input requirements, investment and save time by timely sowing of rice and shorten crop duration by 7–10 days than transplanted rice. Direct seeded rice, if managed properly, provides grain yield comparable with that of transplanting.

Effect of crop duration (early, medium and late) in rice on growth parameters, yield attributes and yield of succeeding crops

The development of short duration rice varieties coupled with high yielding maize hybrids provided an opportunity for increasing the area under R–M cropping in south asian countries (Timsina *et al*., 2010; Buresh and Haefele, 2010) [96, 97, 98, 17].

Rice varieties differ greatly in the time required from sowing until harvest. These periods often are strongly influenced by planting date and maturation in five months or more after seeding is common in the tropics. Obviously, a short duration crop would have several advantages over a long duration crop, even with equal total grain yields. A short duration crop would require less water per crop; would be less exposed to hazards such as insects, pathogenic organisms, droughts and typhoons: and would increase the time that the land would be available for subsequent plantings of rice or other crops.

Vergara (1966) [102], by taking data from the wet season planting, suggested that a short growth duration rice is preferable to a long one. Although grain yield is more or less the same in crops with growth duration of 100 to 200 days, short growth duration crops, would be more efficient in grain production per unit of time.

Rice yield of 'Samba Mahsuri' (long duration *i.e.* 150 days) increased by 10.4 and 24.7 per cent over 'Early Samba' (medium duration *i.e.* 135 days) and 'Tellahamsa' (short duration *i.e.* 120 days), respectively (Mukundam *et al.,* 2012) [63]. Long duration nature of the variety was favourable to assimilate and translocate the maximum amount of photosynthates from source to sink resulting in higher percentage of filled spikelets compared to medium and short duration varieties. Such varieties have greater vigour with superior growth and yield attributing characteristics and higher yields of grain and straw. Hence, yield of grain and straw of 'Samba Mahsuri' was superior to 'Early Samba' which was in turn superior to 'Tellahamsa'. On the other hand, there was no significant effect of previous rice varieties on growth, development and yield of maize, even though dates of harvest of rice varieties and subsequent sowing times of maize were different as they fell within the recommended time of sowing of maize in Telangana region of Andhra Pradesh. Hence, maize grain and stover yield following different varieties did not vary much leading to carry over effect of high *kharif* rice yields to higher rice equivalent yields with 'Samba Mahsuri' followed by 'Early Samba' and 'Tellahamsa' sequence. Consequently the net returns and B: C ratio followed the same trend. Mahapatra and Behera (2004) [59] also reported similar results in rice–wheat cropping system.

The cultivation of short duration aman rice can create an opportunity to intensify the cropping intensity from double cropping to triple cropping (Rashid *et al.*, 2012) [73].

Kachroo *et al.* (2014) [48] concluded that rice variety 'PC 19' (medium duration) and 'IET 1410' (short duration) were more suitable in terms of productivity and profitability under rice–garlic–cowpea, rice–potato–onion and rice–marigold–french bean cropping system, respectively. While rice–berseem, rice–potato–maize + green gram were identified as sustainable sequences which contributed to appreciable buildup of soil organic carbon and NPK in the soil. Intensification/diversification of crops after rice by vegetable like potato, garlic, onion, cabbage and legumes may enhance profitability, sustainability and employment to the maximum extent.

Effects of cropping systems (Rice-rice, Rice – maize and Rice-rice-pulse/legume) on system performance

Singh *et al.* (2012) [88] reported that the cropping intensity of the Eastern Region of India is as low as 140% in an irrigated ecosystem, which can be enhanced to 300% by adopting developed diversified cropping systems.

Crop diversification has been recognized as an effective strategy for achieving the objectives of food security, nutrition security, income growth, poverty alleviation, employment generation and the judicious use of land and water resources, sustainable agriculture development and environmental improvement (Singh, 2010) [90].

The recent development of short-duration rice varieties and maize hybrids with improved drought tolerance is also providing opportunities for the expansion of R-M systems into areas of South Asia with insufficient irrigation or rain for continuous rice cultivation. Rabi planting of maize after rice in October and November would provide high yield potential (low temperature during grain filling, long growth duration, and large receipts of solar radiation) and would help in successful intensification and diversification of the rice-based systems. (Timsina *et al.* 2010) [96, 97, 98].

Rice-maize systems are practiced in an acreage of more than 0.5 mha in India, where this system is rapidly increasing under resource-conserving technologies, mostly zero tillage (Jat *et al*. 2009) [46].

Legumes increased the supply of inorganic soil N, which was mostly present as nitrate, for the following rice crop. Transplanted rice did not benefit from this soil N, because the nitrate was lost by denitrification or leaching during soil flooding and puddling before transplanting. Direct-seeded rice apparently used only a relatively small fraction of the accumulated nitrate. The results indicated that the N demand of young direct-seeded rice was not sufficiently great to take up the nitrate before it was lost. Yields and N accumulation of direct-seeded rice, but not transplanted rice, were greater in cropping system included with legumes (Sharma *et al.*, 2005) [82].

Gangwar and Ram (2005) [28] reported that inclusion of legumes and other crops using intensification and interruptive approaches, as per resource availability, led to considerable improvement in productivity and profitability, on the one hand, and soil fertility, on the other hand.

Pulses remain the most preferred option for diversification of conventional cereal-based rotations due to various inherent qualities like biological N-fixation, short duration, deep root, easy to accommodate under diverse agro-ecosystems and more importantly complementary with cereals. The scope for exploiting direct and residual fertility due to legumes becomes increasingly apparent in a country like India that has very low level of average plant nutrients consumption from chemical fertilizers on national basis (Ghosh *et al.* 2006) [32]. The implications of including pulses in cereal-based system were explored by various researchers in particular concerning soil quality, system productivity and sustainability (Ghosh *et al.* 2006) [32]. Introducing pulses in cereal based system may alter the nutrient input–output balance over cereal–cereal system.

Total productivity

Cropping systems having maize as a component crop expressed higher production efficiency (Rs 124 to 128/ha/day), water-use efficiency (Rs 203 to 213/ha-cm) and energy intensiveness (11.23 to 12.56 MJ/Re) in economic terms (Bastia *et al.* 2008) [10].

Kumar *et al.* (2008) [49] reported the maximum REY of 18.1 t/ha/year with rice–potato–greengram sequence, which was 54, 61, 107 and 84% higher than rice (medium duration)–wheat (normal sown), rice–berseem, rice–oat and rice (long duration) –wheat (late sown) sequences, respectively at Faizabad. Bastia *et al*. (2008) [10] from Bhubaneswar reported that system yield of rice–maize–cowpea was the maximum (15.98 t REY/ha), which was at par with that of rice–maize–greengram (15.30 t REY/ha).

However, Mukundam *et al*. (2012) [63] reported that rice–maize cropping system recorded 77.5 and 86.9% higher system productivity over rice–blackgram and rice–greengram system, respectively.

Rice equivalent yield and system productivity was more in rice-maize cropping systems as compared to rice-rice cropping system, which was due to higher production potential of maize (Shridhara *et al.*, 2015) [87].

Rice – maize cropping system recorded 77.5 and 86.9 percent higher productivity over rice-blackgram and rice-greengram systems. Maize 'Kargil Super 900 M' being a single cross hybrid and C4 in nature exploited well, the natural and applied resources over greengram or blackgram resulting in higher grain and stover yield. Greater yield and higher demand of the maize produce in summer fetched higher price. Consequently, the rice equivalent yields from rice - maize sequence were higher Mukundam *et al.* (2012) [63]. On an average, the net income and benefit: cost ratio were Rs.37,673 and 1.03 and Rs 39,802 and 1.13 higher over rice-blackgram and rice- greengram sequence, respectively. The results are in conformity with the findings of Sarkar *et al*. (2000) [80], Gangwar *et al*. (2006) [29] and Prasad and Urkurkar (2010) [71] also reported superiority of rice – maize system over rice-pulse system.

Sharma *et al.* (2005) [82] reported that the cropping system with pulse crop significantly increases the grain yield in direct seeded rice as compared to transplanting method carried out for the rice crop.

Progressive increase in the grain yield of *kharif* crops preceded by pulses was recorded in rice-rice-black gram and rice-rice-green gram cropping systems in the second, third and fourth year (Porpavai *et al.*, 2011) [68]. They also observed a reduction in the yield of rice grown after sesame and maize. The grain yield of *kharif* season crops decreased in rice-rice-sesame, rice-rice-okra, lab lab-rice-maize, okra-rice-radish and maize-rice-sesame cropping systems. Kumar *et al.* (1993) [51] reported similar result, pointing out the superiority of leguminous crops in increasing the yield of the succeeding crops of rice, thus legumes were potentially important to diversify cereal based mono cropping into cereal-legume sequences which had nutrient cycling advantages.

Kumar *et al* (2012) reported that hybrid rice was more remunerative and productive than inbred rice in *kharif* season. Replacement of wheat with mustard or potato was better option for higher profitability and energy production in *rabi* season and the inclusion of pulse crops (grain/fodder) or green manuring of *Sesbania* during summer season improved soil fertility besides intensifying the system for higher productivity and sustainability.

Sharma *et al*. (2014) [85] reported that the higher rice-equivalent yield was owing to replacement of wheat with high-volume and high-priced vegetable crops like potato and onion instead of wheat and found that the increased productivity of rice crop can be attributed to the cumulative effect of fixed nitrogen from legume crops. Mishra *et al.* (2007) [60] also reported higher productivity and profitability with the inclusion of vegetables and pulses in rice-based cropping system.

Water productivity

In the era of shrinking resource base of land, water and energy, resource use efficiency is an important aspect for considering the suitability of a cropping system (Yadav, 2002) [104]. Hence, selection of component crops needs to be suitably planned to harvest the synergism among them towards efficient utilization of resource base and to increase overall productivity (Anderson, 2005) [4].

The water productivity of the system (crop yield per unit water) could be increased by over 65% when maize or green gram extent was increased.

Chandrapala *et al.* (2010) [20] suggested that replacement of rice with maize (*Zea mays* L.) in dry season is increasing to save water and for maximum system production. However, from the view point of water economy, soil-health and maximum production potential, it became necessary and inevitable to rotate rice with an upland crop such as maize under irrigated dry conditions.

Pulse plants extracted about 4 mm of water from the top 30 cm layer and extracted little to non below 30 cm soil depth (Wang *et al.*, 2009) [103].

Haefele *et al.* (2013) [39] noticed R–M systems offered several advantages for farmers in the Philippines. Even with water-saving technologies for rice cultivation, the water requirements for rice remained higher than for other cereal crops, especially in the dry season with very little rainfall and high evaporation losses. Thus, expensive and/or limited supplies of irrigation water together with opportunities for income from non-rice crops served as drivers for diversification from a rice monoculture with soil submergence to a rotation of rice with other crops such as maize grown on well-drained aerobic soils.

Land use efficiency

The higher land-use efficiency indicates longer duration of crops in a calendar year. Sharma *et al.* (2014) [85] reported that the land-use efficiency (LUE) was the highest in rice (LD)–chickpea + coriander–maize (Grain) + cowpea incorporation, followed by rice (LD)–wheat (ZT)–mungbean (ZT) and rice (LD)–maize (ZT)–clusterbean (Fodder) systems, as these systems occupied the land for longer period. Though, the rice is a common crop in all the systems evaluated, but due to long-duration rice in the rainy season and growing of maize/mungbean for grain purpose in summer occupied the field for a maximum of about 340–355 days and hence the LUE of these systems increased. The results are in conformity with the findings of Prasad *et al.* (2013) [72]. The land-use efficiency was the lowest in existing rice–wheat system, as the land remained fallow for more than two months in a year. The rice (LD)–wheat (ZT)–mungbean (ZT) cropping system recorded LUE 94.4%.This indicates that the existing rice–wheat system has a scope to include one more crop like mungbean. The variation in land-use efficiency among different cropping system was mainly due to the variation in duration of crops in the cropping systems. Sharma *et al.* (2004) [84] also reported that crop intensification through the inclusion of vegetables and leguminous crops increased the production and land-use efficiencies. Sharma *et al.* (2014) [84] also reported that the higher benefit: cost ratio was found in rice (LD)–wheat (ZT)–mungbean (ZT) cropping system.

Economic indicators

Sarangi *et al*. (2017) [78] reported that the net returns and benefit: cost ratio of DSR was higher than NPTR. But there was no significant effect of establishment methods on gross returns. Haque *et al*. (2016) [41] stated that the gross return of rice under non-puddled condition i.e. under strip tillage and bed formed was higher compared to transplanting under puddle condition. Similar result was obtained by Younas *et al*. (2016) and Singh *et al*. (2017) [2]. Mechanized transplanting into non-puddled soil is another labour- and cost-saving option worth investigation following initial evaluation by Hossain *et al*. (2017).

The study by Alam *et al.* (2017) [1] has shown that the wheat-mungbean-aman rice systems were superior to the rice-rice system in terms of economics and labor and irrigation water requirements. The triple cropping systems with direct seeded aman rice were superior to the system with puddle transplanted both season rice in terms of labor and irrigation requirements. Thus diversifying from the double puddle transplanted rice system to more diverse triple cropping systems such as the rice-wheat-mungbean system should be promoted for the maximum wheat and mungbean productivity and reduced irrigation requirement.

Effects of cropping systems (Rice-rice, Rice-maize and Rice-rice-pulse/legume) on Soil properties

Dawe *et al.* (2000) [22] reported soil properties was adversely affected by prolonged soil wetness and soil nutrient depletion due to intensive rice monocropping.

The organic carbon status of the soil increased after all the crop sequences tested at the end of each year. The maximum organic carbon build up was observed with the inclusion of leguminous crops. Among the ten cropping systems tested, rice – rice – black gram, onion – rice –black gram, groundnut – rice – black gram and rice – rice– green gram cropping sequences recorded higher organic carbon content. (Porpavai *et al.*, 2011) [68]. These cropping systems contributed to an increase of 0.04% organic carbon content at the end of the fourth year. This increase in organic carbon content was found to be superior than the other cropping systems with no inclusion of leguminous crops. Such an increase in the organic carbon content is attributed to the accumulation of root residues and shedding of leaves by the leguminous crops (Thakur and Sharma, 1988) [95]. Kumar *et al.* (2001) [50] also reported that, inclusion of leguminous crops in the system increased the organic carbon and available nitrogen, phosphorus, potassium and sulphur content of the soil. This may be due to the addition of nutrients by biological N fixation of these crops.

Porpavai *et al.* (2011) [68] reported that the soil available N status was depleted in maize -rice - sesame (20 kg/ha) and rice–rice-sesame (19 kg/ha) due to the exhaustive nature of maize and sesame, however, rice–rice– black gram, onion-rice -black gram, groundnut-rice-black gram and rice-rice - green gram cropping systems significantly improved the soil available nitrogen status. Increase in available nitrogen, phosphorus, potassium and sulphur content in cropping sequences involving vegetable, pea, green gram were reported by Gangwar and Ram (2005) [28]. Cultivation of legume crop is viewed more as a soil fertility improver than as independent crops grown for their grain output. This is because legume crops are self-sufficient in N supply (Kanwarkamla, 2000). Samui *et al*. (2004) [77] reported that inclusion of a legume increases soil fertility.

Venkatesh *et al*. (2013) [101] also reported below ground biomass of pulses significantly contributed towards enrichment of labile fractions of SOC. Highly intensive rice-wheat-mungbean system eliminated the summer fallow and higher above and below ground crop residues resulted in improvement in SOC under the system. Pulses helped in solubilizing insoluble P in soil, improving the soil physical environment, increasing soil microbial activity and restoring organic matter (Ghosh *et al*. 2006) [32]. Legume/pulse acts as a catalyst to augment availability of native and fixed P, therefore, increased availability of P under pulse inclusive systems.

Mukundam *et al*. (2012) [63] reported that among the rice varieties, 'Tellahamsa', being a short duration variety, got lesser time to assimilate the applied nutrients and thus left behind higher soil available N, P and K after its harvest. On the other hand, 'Samba Mahsuri' a long duration variety had enough time to absorb and assimilate nutrients and hence left the soil with lower fertility status. These results corroborate with Kumar and Prasad (2004) [52]. They also reported that among cropping sequences, rice – maize system showed lower fertility status of the soil after harvest, compared to rice – pulse sequence, which was due to pulses with characteristic promotion of free living microorganisms (*Rhizobium sps*), solubulization of insoluble Al-P and Fe- P fractions through exudation of organic substances through their nodules (Palaniappan and Sivaraman, 1994) [64] and release of K by mineralization (Saha and Moharana, 2007) [74] are known to enrich the soil. Budgeting of the nutrients added as fertilizer and of those removed by crops showed lower status of the nutrients of N, P and K in rice– maize system compared to rice–pulse cropping sequence.

Hazra *et al.*, (2014) [44] reported that among the different cropping systems evaluated, continuous cultivation of rice-wheat-mungbean significantly increased available N, P and K, whereas long-term cultivation of rice-wheat rotation significantly depleted SOC, available N, P, and K compared to the pulse inclusive rice based rotations.

Sharma *et al.* (2005) [82] reported that there was a significant interactive effect of rice establishment method and cropping system on soil ammonium and nitrate. Topsoil ammonium and nitrate were higher after legumes with direct seeded than transplanted rice.

Conclusion

Continuous puddling of soil for transplanted rice can damage soil structure and thereby adversely affect germination, growth, and yield of succeeding crops. Profitability and resource use efficiency in DSR establishment method is better than NPTR and PTR and if managed properly they can give comparable yield with PTR. The rice cultivar having shorter duration helps the system by intensifying more crop to increase the system productivity rather than occupied by a long duration cultivar. Irrespective of crop establishment method, maize grown after rice crop gives higher productivity, profitability and resource use efficiency than rice-rice system.

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