Philippine Journal of Science
147 (1): 165-174, March 2018
ISSN 0031 - 7683
Date Received: 16 May 2017

Comparative Evaluation of Direct Dry-Seeded and Transplanted Rice in the Dry Zone of Karnataka, India

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Sustaining yield and economic stability of direct dry-seeded rice needs to be considered before setting into large scale adoption of the emerging rice production system in the dry zone areas of Karnataka state, India. The study was aimed at comparing direct dry-seeded and transplanted systems of rice cultivation with the participation of farmers concerning rice growth, yield, water productivity, and economic returns. *Samba Mahsuri* (BPT 5204) rice cultivar was used in the two-year farmer participatory field study conducted at Raichur district of Karnataka. The rice grain yield, harvest index, 1,000-grain weight, and above-ground biomass did not differ among direct dry-seeded and transplanted rice systems. Results of this study indicated that higher grain yield with direct dry-seeded rice can be achieved by using rice cultivars that can produce more productive tillers plus longer panicles and not necessarily high biomass. Irrigation water use for direct dry-seeded rice is lesser by around 46% compared with transplanted rice due to dry cultivation during land preparation and flush irrigation at early crop growth stages. Grain yield of direct dry-seeded rice, which was comparable to that of transplanted rice and with higher water productivity, indicates that this system can be more attractive to rice farmers in the dry zones. Slight reduction in grain yield (5%) with direct dry-seeded rice compared to transplanted rice was compensated by 44-48% lower production cost, resulting in significantly higher net returns by US$ 230 ha^{-1} (23%) compared to transplanted rice. The benefit-cost ratio was significantly higher in direct dry-seeded rice by 69%. Considering usual drought and unstable water supply situations in the dry zones, it is anticipated that farmer adoption of direct dry-seeded rice system will be increased due to the benefits of greater profitability, better grain yield of improved cultivars, and higher water productivity.

Key words: direct dry-seeded rice, dry zone, economic returns, grain yield, transplanted rice, water productivity

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the major staple food crops of the world and is grown widely in all continents, especially in Asia. The global food demand is increasing with the continuous increase in population, which is expected to roughly double by 2050 (Godfray et al. 2001). The targeted 70% more food until 2050 requires an average annual increase in food production of 44 million metric tons, and this should be sustained for next 40 years (FAO 2009). However, 35% of rice growing

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areas globally are now suffering yield stagnation (Ray et al. 2012), which can have serious implications on the global food security if the productivity of rice will not improve. In addition, increased competition for land, water, energy, and rising negative impact of current food production on environment (Tilman et al. 2001) are necessitating the possibility of alternate systems of developing and implementing better rice production using limited resources with minimal impact on environment.

India is the second largest producer and consumer of rice in the world with cultivating area of around 37 million ha and produces 88 million tons annually (India.gov.in 2014). Around 1.51 million ha of India's rice cultivated area is situated in Karnataka state, which produced around 3.8 million tons annually. Karnataka has 10 agro-climatic zones, including dry zones covering around 9.15 million ha (Annual Season and Crop Report 2007-2008 of Directorate of Economics and Statistics) stretching across 14 districts and 106 *talukas* (Figure 1). About 20% of the Karnataka's total cropped area is irrigated (Lakshmikanthamma 1997). Of this irrigated areas, 9% is irrigated by canals, whereas the rest depends on tank and well irrigation which are directly dependent on rainfall. The average annual normal rainfall of the state is 1,200 mm and ranges from 450 mm to 3,932 mm across the districts. The state of Karnataka has two major perennial rivers, namely the Krishna and the Tungabhadra. A reservoir was constructed across the Tungabhadra River for irrigation services, where rice is one of the major and important crops grown in the command areas. However, tail-end farmers especially in Raichur district do not get sufficient water at right time and faced with unstable supply of water from the canal due to limited and declining water resource. Normally, rice farmers are getting water from the canal once in every 10-20 days only, thereby forcing them to complete transplanting within this period, but this is not possible at all times due to limited labor and machinery. With this, farmers are advised to go for early dry seeding by taking advantage of early rains received before the release of water from the canal.

Raichur district is part of the dry zone areas of Karnataka state where transplanted rice (TPR) system is common in rice production areas. However, TPR is labor, water, and energy intensive, and is becoming less profitable as these resources are continuously becoming scarce. TPR also deteriorates the physical properties of soil, which adversely affects the performance of succeeding dryland crops, delays post-rainy season crops establishment, and contributes to methane emissions (Denman et al. 2007). Due to these disadvantages, a major shift on rice production system from

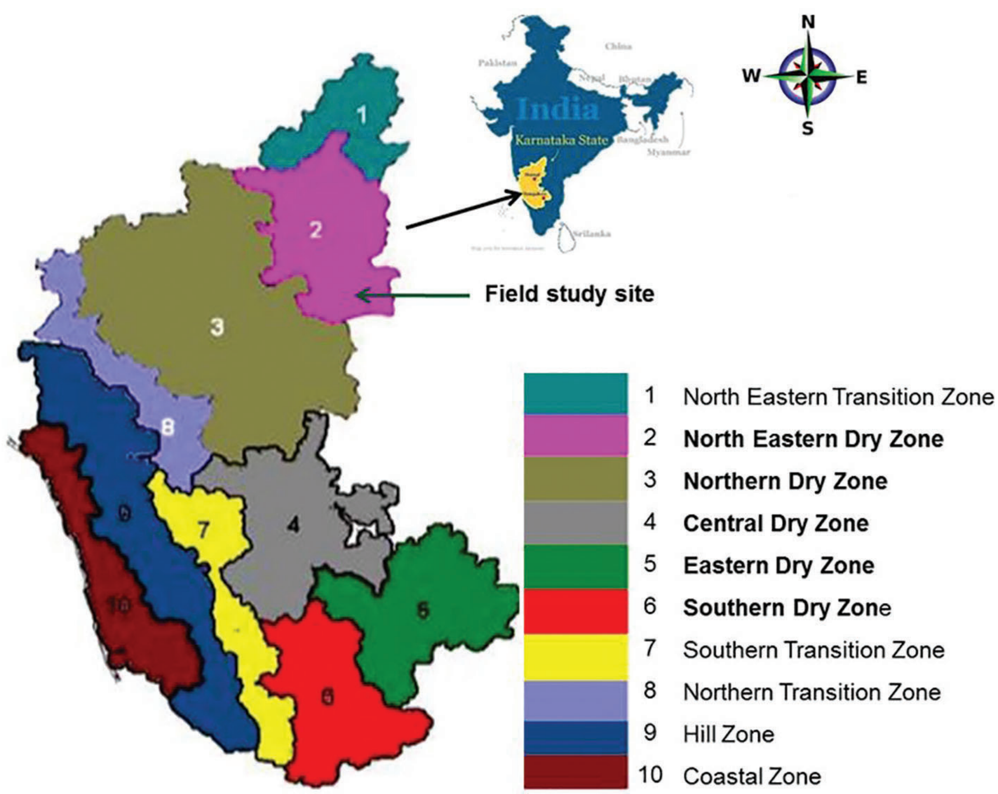

Figure 1. Map of Karnataka state, India showing its agro-climatic zones and location of the 12 farmers' field trials at Neermanvi village, Manvi taluka of Raichur district. Five out of ten agro-climatic zones of the state are classified as dry zones (numbered 2-6).

TPR to direct dry-seeded rice (DDSR) has occurred with wide adoption in several Asian countries including India (Pandey & Velasco 2005; Rao et al. 2007; Kumar & Ladha 2011). Compared to TPR, DDSR was reported to produce the same yield in several field experiments while saving irrigation water (Bouman & Tuong 2001; Yadav et al. 2011b), labor (Bhushan et al. 2007), cost of production with higher net returns (Lee et al. 2002; Singh et al. 2006), and less methane gas emissions (Wang et al. 1999; Singh et al. 2009). All proven advantages were obtained from different studies conducted at research stations. Farmer participatory evaluation of technology was often suggested for testing the advantages and popularizing the technology among farmers (Norman & Matlon 2000). This would enable farmers to judge the advantages by themselves and making appropriate decisions which are advantageous to them both economically and ecologically. However, such efforts are lacking in rice technological development, evaluation, and popularization particularly on emerging DDSR system in India. In addition, there is limited information on yield or yield penalty, response to water scarcity, and economic stability of DDSR as compared to TPR in the dry zones. Hence, an effort was made in canal irrigated rice areas of dry zones in Raichur district of Karnataka state, India to compare DDSR and TPR with the participation of farmers relative to rice growth, grain yield, water productivity, and economic returns.

MATERIALS AND METHODS

The farmer participatory field study was conducted in Neermanvi *village*, Manvi *taluka*, Raichur *district* of Karnataka state, India (16°02′N, 77°05′E) during the 2013 and 2014 rainy seasons (May-Nov). Farmers' fields were selected randomly and the criterion used was that the farmers should be following TPR as system of rice cultivation several years ago. The identified 12 farmers' fields were considered as replications and the soil textures were clay loam. The two systems of rice cultivation *viz., TPR*: transplanted rice, and *DDSR*: direct dry-seeded rice, were established side by side in one acre paddy field each of every selected farmer. Paddy dikes surrounding the experimental fields were fixed firmly to reduce seepage and avoid unwanted outflows to or from adjacent fields. The researchers used indica rice cultivar, *Samba Mahsuri* (BPT 5204) with 140-150 days growth duration. *Samba Mahsuri* is popular among rice farmers of Raichur district and is widely grown because of its good quality and marketability (Reddi et al. 1979).

For TPR, pre-germinated rice seeds were sown in nursery at a seeding rate of 80 kg ha^{-1} during the second week of June 2013 and first week of July 2014 rainy seasons. Puddling operation was done two times in saturated field with standing floodwater using mechanical rotavator. Manual transplanting was done in puddled soil using rice seedlings with 30 days of age at 20 cm x 15 cm spacing. Nutrients were added at 90 kg N, 60 kg P_2O_5, 40 kg K_2O, and 25 kg Zn per hectare both in TPR and DDSR fields. A third of N and full dose of P_2O_5, K_2O, and Zn fertilizers were applied at the final puddling, and the remaining 2/3 N was applied at 21 and 45 days after transplanting (DAT) in two equal splits. Application of pre-emergence herbicide using anilophos (400 g a.i. ha^{-1}) was done at 3 DAT. Floodwater depth was maintained in TPR fields at 3-10 cm throughout the growing period due to available canal water and frequent rainfall in 2013, while intermittent irrigation was introduced at early part of the growing season in 2014 due to unstable supply of canal water and insufficient rainfall. Volume of irrigation water was computed based on the changes of floodwater depth in the paddy field after applying canal water and rainfall occurence.

In all DDSR fields, summer ploughing followed by two criss-cross harrowing and one leveling was done to maintain the fields crumbly before sowing. Dry rice seeds were sown immediately after receiving favorable rain in moist but unsaturated soil at the rate of 20 kg ha^{-1} at 20x10 cm spacing (Simerjeet & Surjit 2014) during the first week of June 2013 and third week of June 2014 rainy seasons. A third of N and full dose of P_2O_5, K_2O, and Zn were applied along with the seeds using mechanical seeder at the depth of 2.5 cm (Blanche et al. 2009). The remaining 2/3 N was applied at 45 and 80 days after germination in two equal splits. Existing weeds were controlled by spraying of glyphosate three days before sowing (Gopal et al. 2010). Pendimethalin was applied at 1 kg a.i. ha^{-1} just after first irrigation, and it was followed by bispyribac sodium at 25 g a.i. ha^{-1} after 25 days of rice germination. Spot hand weeding was done as and when needed to keep the fields weed-free. Flush irrigation was done immediately after seeding using canal water and soil saturation was maintained due to frequent rainfall in 2013, while irrigation was introduced within two weeks from sowing in 2014. Subsequent irrigations in DDSR were applied when hair line cracks appeared in the soil surface and this coincided with 25-35 kPa at 15 cm depth of floodwater as prescribed by Bhushan and co-authors (2007). Volume of applied water in DDSR fields was computed based on 15 cm floodwater depth after irrigation. Floodwater both in DDSR and TPR fields at later part of the growing season in both years was maintained at 3-10 cm depth due to favorable canal water supply and rainfall. DDSR fields were flooded at reproductive stage until ripening stage. Saved canal water in DDSR fields is due to dryland preparation practice and flush irrigation or lower floodwater depth during irrigation period. Rainfall data were recorded using the installed automatic rain gauge near the selected farmer's field.

A quadrat of 0.5 m^2 (0.5 m × 1 m) was laid randomly in the field and from the quadrat, ten plant samples were collected from each of the DDSR and TPR fields. Height (cm) of rice plant was measured at harvest by measuring its length from the base to the tip of the longest panicle of the plant. The number of tillers (number m^{-2}) was counted within the quadrat. Plant samples taken from the quadrat were dried in an oven at 70°C in 72 h and weighed, and expressed as above-ground biomass (t ha^{-1}). Other yield attributing parameters i.e., panicle (number m^{-2}) and 1,000-grain weight (g), were also recorded at harvest using the collected rice plant samples. After plant samples collection, the standing rice crop in the fields were harvested and threshed using harvesters and threshers. Total grain yield of each of the selected farmer's field was recorded after threshing. The harvested rice seeds were placed in gunny bags and weighed separately. The gunny bag weight was subtracted from total weight of rice seeds and the rice grain yield (t ha^{-1}) was computed at 12% moisture content. Harvest index (%) was calculated by dividing the weight of grain yield by the total above-ground biomass and multiplied by 100.

The volume of irrigation water (m^3) – applied during land preparation in rice established by TPR and during the crop growth period of both TPR and DSR – was calculated based on the measured depth of floodwater after irrigation and area of each of the farmer's field. Percolation, surface evaporation, and seepage were not accounted and included in the computation of the total water used in both systems. Water use (m^3) [irrigation (I) + rainfall (R)] was computed from land preparation up to harvest (May-Nov), as shown in Figure 2. Water productivity or WP_{I+R} (kg grain m^{-3} water) was calculated as grain yield divided by total water use.

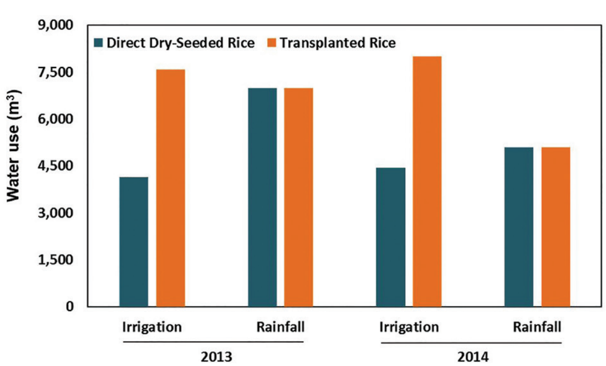

Figure 2. Computed water use (m^3) from land preparation up to harvest under DDSR and TPR systems of rice cultivation in farmers' fields during 2013 and 2014 rainy seasons in the dry zone areas of Raichur district.

Human labor was recorded for every system of rice cultivation in each of the field operation *viz*., land preparation, seeding, irrigation, fertilizer and pesticide application, weeding, harvesting, transporting, threshing, and drying. Eight hours human labor work was treated as one man-day. Farm inputs *viz*., seed, fertilizers, herbicides, and pesticides used in both the systems of rice cultivation were recorded and the cost was estimated based on the prevailing local market rates. Local rate was used in computing the cost of hiring human labor and machines for different field operations. The net returns (US$ ha^{-1}) was computed by subtracting the gross returns or sales of produce based on the average local market price of paddy in the last three years and total cost of production. The ratio of the net returns or benefits and total cost of production was also computed and expressed as benefits per unit cost in US dollar.

Data were analyzed following analysis of variance (SAS 2012) and means with significant effects were compared based on the least significant difference (LSD) test at 0.05 probability level. The difference between DDSR and TPR was calculated as 100 x [(DDSR-TPR) (mean of DDSR and TPR)$^{-1}$].

RESULTS AND DISCUSSION

Rice Growth and Development

Plant height, which indicated the health and vigor of the rice plants, was higher if rice was established by TPR system during both the rainy seasons (Table 1). The difference in plant height between DDSR and TPR was greater in 2014 cropping season, which can be attributed to more favorable growing conditions due to more frequent rainfall (data not shown) and irrigation interval. These results are in conformity with the findings of Maqsood (1998) and Ramzan and Rehman (2006), who reported similar trends in their field studies that transplanted rice grew taller than in direct seeding on flat soil. Significantly higher number of tillers per square meter was recorded in DDSR system and produced 46% more tillers than TPR, probably due to closer planting distance and alternate wet and dry condition of the soil at vegetative stage. More tillers in DDSR were produced when the rice was sown with seeding rate of 20-30 kg ha^{-1} and spaced at narrower row spacing of 15-20 cm (Simerjeet & Surjit 2014). However, it was observed that number of productive tillers did not differ significantly. This indicates that even though the DDSR system can produce more tillers at vegetative stage, almost half of the produced tillers remain unproductive at maturity and thus provide little contribution to the grain yield. Similar observation was made by Lampayan and colleagues (2010) with aerobic rice, where soils are kept aerobic for a few

Table 1. Growth, biomass and yield components of *Samba Mashuri* (BPT 5204) rice cultivar under DDSR and TPR systems of rice cultivation in farmers' fields during 2013 and 2014 rainy seasons in the dry zone areas of Raichur district.

Parameters	2013		2014		Difference (%)	
	DDSR	TPR	DDSR	TPR	2013	2014
Plant height (cm)	98.9 a[a]	102.5 b	99.3 a	109.7 b	-4	-10
Tiller number (number m^{-2})	900 a	633 b	850 a	533 b	35	46
1,000-Grain weight (g)	21.5 a	20.8 a	20.2 a	19.5 a	3	4
Panicle length (cm)	22.1 a	23.3 b	21.5 a	23.0 b	-5	-7
Above-ground biomass (t ha^{-1})	6.62 a	6.92 a	6.58 a	6.77 a	-4	-4

[a]Within a row by year, means followed by different letters are significantly different at 0.05 probability level according to least significant difference (LSD) test. Percent decreased on DDSR against TPR reflects negative percent difference. DDSR - direct dry-seeded rice, TPR - transplanted rice.

days at vegetative stage. These differences in rice yield and associated parameters are also linked to overall soil fertility and availability of plant nutrients under flooded and non-flooded condition; the latter condition creates unfavorable nutrient regime for several plant nutrients (Sahrawat 2012).

There were no significant differences in 1,000-grain weight and above-ground biomass between DDSR and TPR. Direct-seeding of rice in the dry soils produced heavier grain weight by 3-4%, but it did not reflect in grain yield at maturity. Percent decreased on panicle length and produced biomass in DDSR fields might be due to greater planting distance in TPR, which resulted in greater sunlight and soil nutrient availability to rice plants. This, in turn, resulted to greater panicle length and biomass compared to rice established by direct-seeding. The higher weed densities and frequent weeding activities in DDSR fields during normal growing period may delay the development of panicle and production of biomass, as reported by Bouman & Tuong (2001) and Lampayan and colleagues (2010) with aerobic rice system.

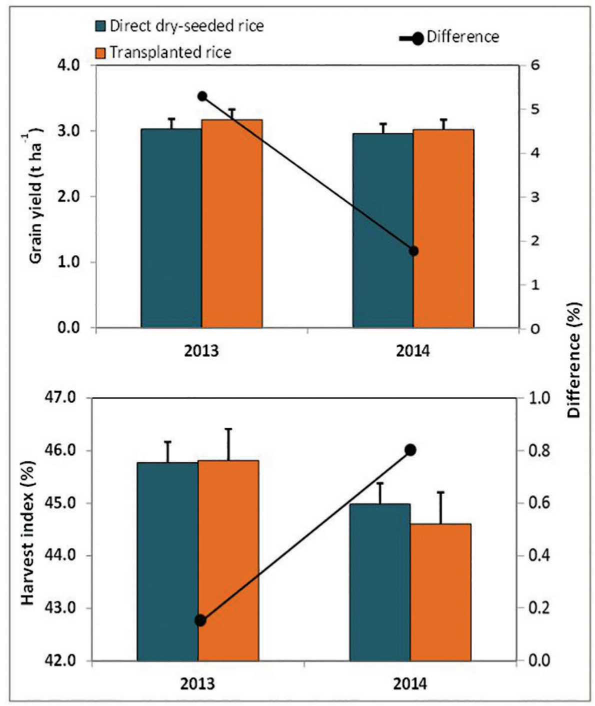

Figure 3. Grain yield and harvest index of *Samba Mashuri* (BPT 5204) rice cultivar under DDSR and TPR systems of rice cultivation in farmers' fields during 2013 and 2014 rainy seasons in the dry zone areas of Raichur district. Error bars denote the standard error of the mean. Sloping line denotes the difference on grain yield and harvest index within the year.

Grain Yield and Harvest Index

The grain yield and harvest index of rice established by DDSR and TPR did not differ significantly (Figure 3). Rice yield in DDSR fields was consistently lower by 5% and 2% during 2013 and 2014 rainy season, respectively. Yield reduction did not hinder farmers in Raichur who opted to adopt DDSR system, because this can be compensated with lower production cost (personal communication by DDSR farmers). Some factors associated with reduction in rice yield under direct-seeding as reported by Kumar & Ladha (2011) include reducing availability of soil nutrients such as nitrogen, iron, and zinc, plus more soil carbon loss due to frequent wetting and drying. Simerjeet & Surjit (2014) suggested that direct-seeded rice can be drilled with lower seeding rate without any yield loss under weed-free conditions and it saves the cost of seed as vital input. Other factors attributed to lower grain yield of DDSR are: (1) uneven or poor crop establishment (Rickman et al. 2001); (2) inadequate weed control (Johnson & Mortimer 2005; Kumar et al. 2008; Rao et al. 2007); (3) higher spikelet sterility (Bhushan et al. 2007; Choudhury et al. 2007); (4) higher crop lodging (Fukai 2002; Ho & Romli 2002; Rickman et al. 2001; Yoshinaga 2005); and (5) insufficient knowledge on water and nutrient management (Choudhury et al. 2007; Humphreys et al. 2010; Sharma et al. 2002; Singh et al. 2002; Yadvinder-Singh et al. 2008; Yadav et al. 2011a,b).

Slightly higher (0.1-0.8%) harvest index was observed with DDSR compared with TPR. The harvest index of rice established by both the systems was lower in 2014 than in 2013 as the biomass was higher in 2014, while the grain yield was similar in both systems. It was observed that insignificant yield difference of DDSR and TPR, despite of significant difference on water used, is due to adequate and available water at reproductive stages where both systems are flooded until ripening stage. It indicates that dryland cultivation during land preparation and flush irrigation at early rice growth stages in DDSR did not affect grain yield at harvest. It shows that ensuring canal water delivery to maintain flood water in DDSR fields from panicle initiation until ripening stage is vital to attain comparable yield with TPR. The depth of water maintained at TPR fields was 3-10 cm. Saved canal water in DDSR fields is due to dryland preparation practice and flush irrigation or lower floodwater depth during irrigation period (up to 5 cm). DDSR fields were flooded at reproductive stage until ripening stage. It can be noted that schedule of seeding or planting, either DDSR or TPR system, must coincide with the plan of canal water delivery schedule and rainfall pattern. In relation to rice growth and development, result shows that the yield difference of DDSR and TPR was attributed more to harvest index than to biomass production. The study suggests that higher harvest index can be achieved in DDSR system with taller plant height, longer panicles, and more productive tillers.

Water Productivity

The system of rice cultivation had a significant effect on water productivity (Figure 4). During both years, significantly higher water productivity was observed

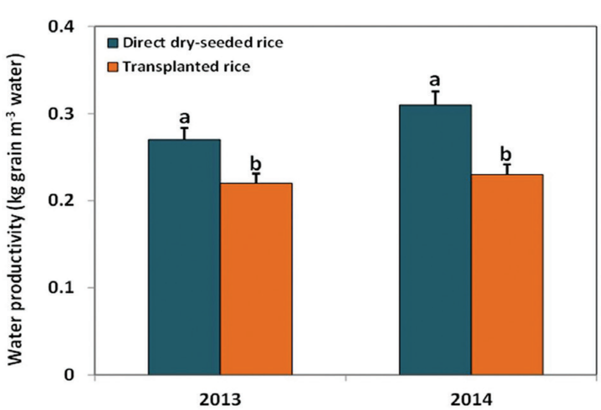

Figure 4. Water productivity as affected by total grain yield of *Samba Mashuri* (BPT 5204) rice cultivar and water use under DDSR and TPR systems of rice cultivation in farmers' fields during 2013 and 2014 rainy seasons in the dry zone areas of Raichur district. Error bars denote the standard error of the mean. Bars with different letters above are significantly different based on Fisher's protected LSD (p=0.05) within the year.

with DDSR due to significantly lower (46%) irrigation water use compared with TPR. Thus, saved canal water can be used in irrigating other fields which may result for improved farm productivity and economic value of irrigation system in the dry zones. Under water-shortage areas such as in dry zones, it has been argued that water productivity (i.e., the amount of harvested product per unit water use) becomes more important than yield or 'land productivity' (Guerra et al. 1998; Tuong & Bouman 2003).

Higher water use in TPR fields is due to additional irrigation water required for puddling and to meet natural field losses such as seepage and deep percolation. These observations are consistent with the findings of Cabangon and co-authors (2004), who compared the water inputs of transplanted and direct-seeded rice. Rainfall (May-Nov) contributes around 50% on the total water use both in DDSR and TPR during the whole cropping seasons. However, more rainfall was lost in TPR than in DDSR fields due to longer period of land preparation and waiting period while seedlings are still growing in the nursery. This situation motivates more rice farmers to adopt DDSR system where sowing can be done as soon as favorable rainfall is started (personal communication by farmers).

The overall water productivity of DDSR ranged 0.27-0.31 kg grain m^{-3}, which was 20-30% higher than that of TPR. Tuong (1999) reported water productivity of around 0.5 kg grain m^{-3} water of best performing aerobic rice experiments. Soriano (2008) reported that aerobic rice system has lower water inputs by 54% with corresponding higher water productivity up to 49% as compared with transplanted rice. Recorded higher water productivity in DDSR indicates that this system can be more attractive to farmers in the dry zones. DDSR system, as popularly promoted especially in Asia for more than 15 years now, was not appealing to majority of the farmers especially in irrigated areas because of the lower yield and lack of consideration to its higher water productivity. With more pronounced drought and limited water supply especially in the dry zones, the benefits of higher water productivity and better yield of improved rice cultivars intended for DDSR will be more advantageous.

Economic Returns

Rice farmers have traditionally adopted puddling and transplanting over time and are reluctant to try alternative production system because they are thinking about possible crop failures, and possibly, higher farm and labor inputs. Currently, economic returns of alternative production system have given more important consideration of the farmers than other associated risks in producing rice, especially in the dry zone areas. The gross return of DDSR and TPR were not significantly different in both years due to lower yield difference (Table 2). The lower

Table 2. Economic returns of DDSR and TPR systems of rice cultivation in farmers' fields during 2013 and 2014 rainy seasons in the dry zone areas of Raichur district.

Parameters	2013		2014		Difference (%)	
	DDSR	TPR	DDSR	TPR	2013	2014
Gross return (US$)	1,606 a[a]	1,680 a	1,569 a	1,601 a	-5	-2
Cost of production (US$)	479 a	783 b	463 a	724 b	-48	-44
Net returns (US$)	1,127 a	897 b	1,106 a	876 b	23	23
Benefit-cost ratio	2.35 a	1.15 b	2.39 a	1.21 b	69	66

[a]Within a row by year, means followed by different letters are significantly different at 0.05 probability level according to least significant difference (LSD) test. Percent decreased on DDSR against TPR reflects negative percent difference. 1 US$ = 65 Indian rupees. 1 kg paddy = 0.53 US$.

Table 3. Average cost that vary between DDSR and TPR systems of rice cultivation in farmers' fields during two rainy seasons in the dry zone areas of Raichur district.

Labor & Material Inputs	DDSR, USD (%)	TPR, USD (%)
Nursery raising	0 (0%)	107.82 (14.3%)
Seedling uprooting	0 (0%)	46 (6.1%)
Irrigation	77.71 (16.5%)	100.29 (13.3%)
Land preparation	156.19 (33.16%)	261.73 (34.71%)
Weeding	50 (10.61%)	15 (2%)
Transplanting or seeding	69.24 (14.7%)	92 (12.2%)
Cost of seeds	23.08 (4.9%)	49.01 (6.5%)
Other cost*	94.78 (20.12%)	81.43 (10.8%)
Total production cost (USD)**	471	754

*Cost that vary under this item is only herbicide; **Average cost of 2 years.

yield in 2014 with both systems might be due to lower rainfall and unstable supply of irrigation water from the canal. Higher gross return was observed with DDSR in 2013 than in 2014.

DDSR system avoids labor in different field activities such as nursery raising, seedling uprooting, puddling land preparation, and transplanting, thus limiting labor inputs (Table 3). It also reduced the quantity and cost of seeds. Reduction on labor inputs and cost of seeds in DDSR fields has reached up to 48% compared to TPR. Reduced production cost in DDSR were attributed more on nursery raising, land preparation, mechanical seed sowing, and seeding rate. This reduction has resulted in significantly higher net returns by US$ 230 ha^{-1} (23%) compared to TPR (Table 2). Kamboj and co-authors (2012) reported that grain yield of DDSR in comparison to puddled transplanted rice was either similar or higher with US$ 128-137 ha^{-1} net returns. Since land preparation is mostly mechanized, more savings was obtained with machine labor than with human labor. Short- to medium-term on-station studies reported 34-46% savings with machine labor used in zero tillage-dry-direct seeded rice (ZT-dry-DSR) compared to puddled transplanted rice (Awan et al. 2007).

DDSR is a good cost-reducing method of producing rice in the dry zones where farmers are experiencing difficulties in sourcing capital before the cropping season. Farmers always prefer to get greater economic benefits per unit of land as well as cost of investment. The benefit-cost ratio (B:C) was significantly higher in DDSR by 69% compared to TPR. This study shows that farmers can earn US$ 2.39 for every US$ investment with DDSR. Percent increased on B:C between DDSR and TPR was attributed greatly to reduced cost of production than to increased gross return.

CONCLUSION

The increasing scarcity of water and labor are the major constraints to transplanting system of rice cultivation, and direct seeding is one of the promising options to realize higher net returns, B:C, and water productivity in the dry zones. The insignificant yield difference of DDSR and TPR is mainly due to adequate and available water at reproductive stages, where both systems are flooded until ripening stage. It was revealed that dryland cultivation during land preparation and flush irrigation at early rice growth stages in DDSR did not affect grain yield at harvest. Yield difference of DDSR and TPR was attributed more to harvest index than to biomass production as relates to plant growth and development. Results of this study indicated that higher grain yield under DDSR system can be achieved by using rice cultivars that produce more productive tillers plus longer panicles and not necessarily high biomass. Attaining grain yield comparable with transplanted rice coupled with higher water productivity indicate that DDSR system can be more attractive to rice farmers of the dry zones. DDSR consumed around 46% less irrigation water compared with TPR, thereby enabling saved water to be used for irrigating other fields to improve farm productivity. DDSR is a good cost-reducing rice production system for the dry zones, where farmers are experiencing difficulties in sourcing capital before the cropping season. Emerging DDSR system with comparable grain yield of improved rice cultivars, higher water productivity, and attractive economic returns will be more advantageous to majority of resource-poor rice farmers in the dry zones, where usual drought and unstable water supply situations are occurring often.

ACKNOWLEDGMENTS

This work was supported by the Government of Karnataka through the *Bhoo-Samrudhi* project coordinated by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) through the efforts of ICRISAT Development Center (IDC) with the support of International Rice Research Institute (IRRI)-South Asia Hub at ICRISAT campus, Joint Director of Agriculture (JDA) of Raichur District, and University of Agricultural Sciences-Raichur (UAS-R), Karnataka state, India.

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