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On-Farm Evaluation of Dry-Seeded Rice Cultivars and Cropping Systems in the Semi-Arid Region of India

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Improving and sustaining rice-based cropping systems in the semi-arid region are essential in persistent drought condition triggered by worsening effects of climate change and declining water availability. This on-farm study was conducted to evaluate and identify the most productive, resource-efficient and profitable direct dry-seeded rice (DDSR) cultivars, and DDSR-based cropping systems in the semi-arid region particularly in water-short irrigated rice areas. Farmer participatory field studies were conducted in Raichur District of Karnataka State, India to assess the performance of DDSR cultivars (*Samba Mahsuri, Gangavathi Sona* and *Prasanna*) seeded during the rainy season in rotation with dryland crops (chickpea, mustard and green gram) following rice. Among the three rice cultivars, Gangavathi Sona yielded 9% and 15% higher than Samba Mahsuri and Prasanna, respectively. Our study showed that productivity of rice can be improved by using drought resistant and high yielding cultivars with high harvest index, and stable canal water supply at the reproductive stage. Chickpea and green gram yielded better than mustard under minimal soil aeration conditions of zero-tilled and non-puddled fields which indicate that suitable post-rainy season crops for zero-tilled fields must be selected. The study revealed that sowing time, which depends on rainfall pattern and schedule of canal water supply, is among the major factors to be considered in selecting rice cultivars and dryland crops to achieve higher productivity, resource use efficiency and economic returns. Cropping system involving direct dry-seeding of Gangavathi Sona, followed by chickpea achieved higher production efficiency, land and water productivity, and economic returns compared to transplanted rice (TPR) system. Improving the productivity of chickpea and other suitable dryland crops that can be grown after rice in zero-tilled fields will contribute substantially to the evolving impacts of DDSR-based cropping systems in the semi-arid region.

Key words: cropping system, direct dry-seeded rice, dryland crops, productivity, profitability, resource use

INTRODUCTION

It is essential to produce around 60% more food, to meet the food demand of over nine billion people of the world in 2050, while sustaining the use of natural resources. Increasing food demand due to the growing population coupled with changes in diet and changing climate imparts a complex set of challenges to which agricultural practices must adapt (Bruinsma 2009). Food demands can be met by enhancing the productivity of scarce and costly natural resources such as water, land and labor, with minimal adverse impact on environment (Ladha et al. 2015). Crop diversification, the judicious use of land and water

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resources towards sustainable agricultural development and environmental improvement (Hegde et al. 2003), has been recognized as an effective strategy to contribute to food and nutrition security, income growth, poverty alleviation, and employment generation. Diversification of rice-wheat cropping system is recommended in India for sustainable production as higher productivity and more profit was obtained with rice-potato-mungbean, rice-clover, rice-rapeseed-mungbean and rice-wheat-mungbean cropping systems as compared to rice-wheat cropping system (Sharma & Sharma 2005). Fallow cropping of garlic after rice is thus considered as a good practice option that can both increase the ecological (e.g. improved soil quality) and socio-economic (e.g. source of additional income) resilience of farming households, especially in disaster-prone countries like the Philippines (FAO 2012).

Agriculture is the largest consumer of water, one of the major and important natural resources, which is withdrawn up to 70% from rivers and groundwater for irrigation (FAO 2003). It was projected that the arid and semi-arid regions, 54% of India's land area, are set to suffer further from water shortages in the future (Government of India 2004). The ever growing population and economic development are putting more pressure, resulting in reduced per capita availability of water by 29% between 1990 and 2010 in India (FAO 2014). While India is considered rich in terms of annual rainfall and total water resources, the uneven geographical distribution of rainfall will cause severe regional and temporal water shortages across the country's currently cultivable lands of 141 million ha. Rice is planted in around 43.4 million ha and 24 million ha of these lands are kept fallow in some cropping season due to limited canal water supply, insufficient rainfall and lack of farm resources such as agricultural machineries and irrigation facilities for cultivation.

The fallow eight million ha rice *(Oryza sativa*, L.*)* fields of India can be used for growing crops during the post-rainy season by utilizing residual soil moisture and improved nutrient management practices with minimum supplemental irrigation (Singh et al. 2014). Efficient management of natural resources such as residual soil moisture and nutrients, after harvest of the rice crop, would convert lowland rice farming into a profitable enterprise (Musa et al. 1998; Maclean et al. 2002). The overall cropping intensity of India's 141 million ha, based on net sown area was 134%, which is similar to the cropping intensity in irrigated areas. This is contrary to the expectation that multiple cropping would be more prevalent in irrigated areas where rice is considered as major crop especially during the rainy season.

Despite low rainfall, rice can be grown in the semi-arid region with supplemental irrigation through canals, tanks, tube wells and pressurized irrigation systems especially in black soils and low lying areas. Transplanted system of rice cultivation is common in rice producing countries of Asia, including India. However, this system is labor-water-energy-intensive and is becoming less profitable as these resources are continuously declining and expensive. Unstable water supply and its distribution in some irrigated rice areas are becoming worse as water demand for other uses are increasing, water quality is degrading and climate-weather scenarios are changing. Therefore, the farmers are increasingly shifting from transplanted rice (TPR) to direct dry-seeded rice (DDSR) system, especially in the tail-end of irrigation systems and favorable rainfed flat areas of several countries in Southeast Asia (Pandey & Velasco 2002; Rao et al. 2007; Kumar & Ladha 2011). DDSR can be defined as a system of cultivating rice in water-short areas such as those in favorable rainfed and tail-end of canal irrigated areas where seeds are directly sown in dry and non-puddled (aerobic) fields. 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. 2011), 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). Even in dry zones, DDSR is an emerging rice production system due to comparable yield, lesser cost of production and higher net returns compared to TPR system (Soriano et al. 2015).

Past studies and current development in DDSR have focused on improving or developing cultivars, developing specific crop management options and comparing rice production systems. Limited research is done on evaluating the feasibility of cultivating dryland crops, especially legumes, after DDSR using the residual soil moisture and fertility of the same fields as DDSR adoption picked up only during recent years. Growing of dryland crops during the post-rainy season as a relay crop has a special relevance for efficient utilization of irrigation water, labor and other inputs to attain higher productivity, profitability and food security (Satyasai & Viswanathan 1996). Relay cropping system can also fetch other benefits such as usage of residual moisture from previous crop and reduced production cost (Saleem et al. 2000; Malik et al. 2002; Jabbar et al. 2005). Dryland crops such as chickpea (*Cicer arietinum* L.), mustard (*Brassica juncea* L.) and green gram or mung bean (*Vigna radiata* L.) are important multi-purpose crops as they are source of high-value food, essential nutrients and livelihood of smallholder farmers as well as forage and feed for livestock in the semi-arid regions of India (ICRISAT 2013). Likewise, commercially available drilling machines, suitable for zero-tilled fields, help DDSR farmers to grow dryland crops after rice. Currently, improving the production of food crops to meet the increasing demand, enhancing resource use efficiency and farm income, and sustaining better rice-based cropping systems are major challenges in the semi-arid region that must be addressed extensively. This study, therefore, was conducted to evaluate and identify the most productive, resource-efficient and profitable rice cultivar and DDSR-based cropping system in the semi-arid region of India.

MATERIALS AND METHODS

Research Site Description

The on-farm study, in a farmer participatory manner, was conducted at Kasbe Camp village (16°10′N, 77°15′E), Raichur *Taluka* situated in the north-eastern part of Raichur District, Karnataka State, India. The research site is located in the northern Maidan region, particularly between the two major rivers namely the Krishna and the Tungabhadra, which form the northern and southern boundary of the district, respectively. A reservoir was constructed across the Tungabhadra River for irrigation services of around 60,000 ha. The major main crops grown in irrigation command areas are rice (40%), cotton (15%), groundnut (15%), sugarcane (10%) and sorghum (10%). The total cropped area of Raichur is 668,110 ha but Tungabhadra command area can only serve 207,371 ha, about 31% of the area. Only 10% of the total cropped area is normally planted more than once in each of the year (ICRISAT 2013) despite normal annual rainfall of 621 mm and a good size water reservoir. The annual rainy days were about 49 days where 65% of the rain is received during the southwest monsoon period (June-September). The northeast monsoon (October-December) contributes about 30% and 5% occurs during the pre-monsoon and summer period (January-May). Progressive farmers and farmer leaders were selected as co-operators to represent the entire farming community with common soil conditions, source of water for irrigation and other farm resources needed for rice and dryland crops cultivation.

Field Experiments

During rainy season of 2013 and 2014, a farmer participatory dry-seeded rice cultivar evaluation was conducted as a part of DDSR-based cropping systems. Samba Mahsuri (BPT 5204), Gangavathi Sona and Prasanna (IET 7564) rice cultivars, with high yield potential and farmers' acceptable grain quality and marketability, were evaluated in the paddy field of 15 randomly selected farmers. One cultivar was randomly assigned to each farmer and this was grown in a half ha rice field. The five farmers assigned to a cultivar represent the number of replications for such cultivar. Seeding was completed within three days by sowing each of the rice cultivar in five farmers' fields on the same day. Summer ploughing followed by two criss-cross harrowing and one levelling was done to maintain the field crumbly before sowing rice. Seeding was done during the 1st week of June in 2013 and 3rd week of June in 2014 rainy seasons. Dry rice seeds at the rate of 20 kg ha^{-1} were sown immediately after receiving favorable rain in moist but aerobic and non-puddled soil, using mechanical seeder (National Seed cum Fertilizer Drill Model or NSFD) at a spacing of 20x10 cm (Simerjeet & Surjit 2014). Nutrients were added at 120 kg nitrogen (N), 60 kg phosphorus (P_2O_5), 40 kg potassium (K_2O) and 25 kg zinc (Zn) per ha in all experimental fields. Basal fertilizer was applied with the seeds in the rows and top dressing of fertilizer was done manually. Relative to TPR system, a higher dose of N (higher by 30 kg ha^{-1}) was applied in DDSR system to compensate the higher losses and lower availability of N from soil mineralization at early stage as well as longer duration of the crop (Kumar & Ladha 2011). One third of N and full dose of P_2O_5, K_2O and Zn were applied along with the seeds at the depth of 2.5 cm (Blanche et al. 2009). The remaining 2/3 N was equally divided and applied at 50 and 80 days after germination (DAG), except for Prasanna rice cultivar for which the remaining 2/3 N was applied two weeks earlier. Existing weeds in the fields were controlled by spraying of glyphosate three days before sowing (Gopal et al. 2010). Flush irrigation was done immediately after sowing using canal water in 2014 to allow good germination while sufficient soil moisture was maintained within two weeks from sowing due to frequent rainfall in 2013. Pendimethalin herbicide was applied at 1 kg a.i. ha^{-1} two days after sowing followed by another herbicide, bispyribac sodium, at 25 g a.i. ha^{-1} after 25 DAG. Spot hand weeding was done as and when needed to keep the fields weed-free. Subsequent irrigations were applied when hair-line cracks appeared in the soil surface and this coincided with 25 to 35 kPa at 15 cm depth as suggested by Bhushan et al. (2007). Floodwater was maintained in all fields at reproductive stage during both years due to subsequent irrigation using canal water and occurrence of rainfall. This situation has favored the establishment of dryland crops after rice due to the availability of sufficient soil moisture in the fields. After collecting plant samples for biomass, rice crop in the field was harvested and threshed using mechanical harvester and thresher. Samba Mahsuri, Gangavathi Sona and Prasanna were harvested 137, 132 and 116 DAG in 2013 rainy season, and 135, 130 and 118 DAG in 2014 rainy season, respectively. Harvested rice grains were sun-dried for 2 days and placed in gunny bags.

For TPR, pre-germinated rice seeds were sown in nursery at a seeding rate of 80 kg ha^{-1} during the 2nd week of June in 2013 and 1st week of July in 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 20x15 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. One third of N and full dose of P_2O_5, K_2O and Zn fertilizers were applied at the final puddling. The remaining 2/3 N was applied at 20 and 50 days after transplanting (DAT) in two equal splits, except for Prasanna rice cultivar for which the remaining 2/3 N was applied one week earlier. Application of pre-emergence herbicide using anilophos (400 g a.i. ha^{-1}) was done at three DAT. Floodwater was maintained in TPR fields 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.

Dryland crops grown in the 2013-14 and 2014-15 post-rainy seasons were chickpea (cultivar: JAKI 9218), mustard (cultivar: Pusa Mustard 22) and green gram (cultivar: BG 256), which were planted after harvest of the rice crop during the 4th week of October (three to four days after harvest of Samba Mahsuri) in 2013, and 2nd week of November in 2014 (two to three days after harvest of Samba Mahsuri). Chickpea was planted in five farmers' fields on the same day, followed by planting of green gram and mustard in ten farmers' fields on the next day. Each dryland crop was planted in half ha field planted with rice during the rainy season. Line sowing of chickpea and green gram spaced at 30 cm using mechanical seeder following zero-tillage system (Jat et al. 2010), and broadcast seeding of mustard was completed within two days. Chickpea and green gram seeds were sown in zero-tilled soils at around 2 cm depth and with an intra-row spacing of 10 cm. Seeding rate used for chickpea, mustard and green gram was 60, 2.5 and 7.5 kg ha^{-1}, respectively. Seed treatment was done using *Trichoderma viride* at 4 gm kg^{-1} seed to prevent wilt that may occur at early growth stage of chickpea. P_2O_5 fertilizer at 20 kg ha^{-1} was applied along with the seeds, except in the case of mustard where P_2O_5 along with sulphur (S) and K_2O at the rate of 20 kg ha^{-1} were applied a day before seeding. N fertilizer was applied at the rate of 10 kg ha^{-1} within the rows of chickpea and green gram at 45 and 40 DAG, respectively. Same rate of N fertilizer was broadcasted in the field planted with mustard at 35 DAG. Endosulfan at 350 g a.i. ha^{-1} was sprayed at 30 and 50 DAG to control insect pests of all crops. Fields were kept weed-free by regular spot hand weeding. Chickpea, mustard and green gram were harvested 95, 90 and 85 DAG in 2013-14 cropping season, and 93, 92 and 80 DAG in 2014-15 cropping season, respectively. Chickpea was harvested by cutting the whole plant from the ground when leaves started to senesce and shedding, pods turned yellow, plants were dried, and seeds were hard and rattled within the pod. Harvested chickpea plants were sun-dried for two days and threshed using threshing machine. Matured pods of green gram were harvested thrice by hand picking. Handpicked pods of green gram were sun-dried for a day and threshed manually with pliable bamboo stick. Combine machine was used to harvest mustard. All seeds collected after threshing were sun-dried for one day and placed in gunny bags.

Data Gathered

Yield of rice and dryland crops was determined after sun drying with the help of the farmer cooperators. The gunny bags with dried grains were weighed and then the bag weight was subtracted from the total weight to get the total crop yield in kg dry weight. Yield in kg dry weight and its moisture content, and area of the experimental field (ha) were used to calculate the yield (t ha^{-1}) of all the crops at 12% moisture content. To determine the above-ground biomass (t ha^{-1}), plant samples were collected randomly before harvest of the entire crops by cutting the plants from its base in a one square meter plot within the experimental fields. Grains of the plant samples were threshed manually and sun-dried separately for five days. Total dry weight of the plant samples including the grains in kg was determined and used to calculate the total above-ground biomass at 0% moisture content. Harvest index (%) was calculated by dividing the crop yield by the total above-ground biomass and multiplied by one hundred.

Rice cultivars and dryland crops used in the experiments have different maturities and cultural management practices, thereby, labor and water requirements, and the quantity of other production inputs varied accordingly. For all the crops, the growing period was determined from the date of sowing up to harvest. Land use (day) was assessed using the recorded number of growing period of all the crops within the cropping season starting from sowing date. Volume of irrigation water applied to DDSR system was calculated by multiplying the measured depth of floodwater after irrigation and area of experimental fields. Field water lost by percolation, evapotranspiration and seepage was not accounted and included in the computation of the total water use. Irrigation frequency and duration was also recorded by the farmers. Rainfall data was recorded using the installed automatic rain gauge near the selected farmer's field. Total volume of water use (m^3) (irrigation + rainfall) was computed from land preparation up to harvest during both cropping seasons and years. Labor use (day) was recorded for all field operations including the use of machinery *viz*., land preparation, seeding, irrigation, fertilizer and pesticide application, weeding, harvesting, transporting, threshing and drying. Eight-hour manual labor is equivalent to one man-day. Locally prevailing rate was used in computing the cost of hiring manual labor and machines for different field operations. Likewise, cost of farm inputs *viz*., seed, fertilizers, herbicides and pesticides used in all crops grown during both seasons for two years was recorded based on the prevailing local market rates. Gross income (US$) from sales of produce was based on the average local market price of paddy, chickpea, mustard and green gram during the last three years. Total cost of production (US$) was also computed by combining the cost of labor and farm inputs including land rental and taxes.

DDSR-Based Cropping Systems Evaluation

Mean yield of Gangavathi Sona and dryland crops, rice equivalent yield, production efficiency, profitability, productivity and economic efficiency were considered to evaluate the DDSR-based cropping systems based on the results of the two farmer participatory field experiments during both cropping seasons and years. The evaluated DDSR-based cropping systems of this study were: DDSR-chickpea, DDS-mustard and DDSR-green gram, and they were compared with transplanted rice (TPR) system. The rice equivalent yield (REY) (t ha^{-1}) per year was determined by combining the mean yield of the crops grown in the experimental fields. Computed REY of the four cropping or production systems was based on the mean grain yield and market price of paddy and dryland crops. The production efficiency (PE) was computed using the following formula, PE (%) = [(RD-GT)/ GT] x 100 (Singh et al. 2008), where RD is REY of DDSR-based cropping system and GT is average grain yield of TPR system in representative farmers' fields. Land productivity (US$ ha^{-1}) was computed as average equivalent value of the produce of all crops per year (FAO 2000). Water productivity (WP) (US$ m^{-3} of water ha^{-1}) was defined as the economic value of the produce of all crops in terms of REY per unit volume of water used (irrigation + rainfall) in the field per year (Burt 2002). Equivalent value of the farm labor in growing crops per year was computed to determine the labor productivity (US$ ha^{-1}) (IRRI 1994). The net returns (US$ ha^{-1}) per year was computed by subtracting all gross returns or sales of produce and total cost of production. The ratio of the net returns or benefits and total production cost (B:C) was also computed and expressed as benefits per unit cost in US dollar. The economic efficiency (EE) was computed using the formula, EE (%) = [(NRD-NRT)/ NRT)] x 100 (Singh et al. 2008), where NRD is net returns of DDSR-based cropping system and NRT is net returns of TPR system.

Data were statistically analyzed using SAS 9.4 software for windows (SAS 2013) and they are presented per cropping season to separately compare three rice cultivars and dryland crops using one-way analysis of variance (ANOVA). Least square means were compared based on the least significant difference (LSD) test at 0.05 probability level. Combined ANOVA across two cropping seasons was also performed using mixed model analysis by modelling individual season's residual variances. Average of different TPR system across years was calculated and their significant differences were analyzed using *t*-test. *T*-test results depicting overall differences were compared with the performance of DDSR-based cropping systems.

RESULTS AND DISCUSSION

Yield, Biomass and Harvest Index

Yield and above-ground biomass was significantly affected by rice cultivar and dryland crop during both years (Figure 1i). Yield of Gangavathi Sona was higher by 9 and 15% compared with Samba Mahsuri and Prasanna, respectively. Frequent rainfall in 2013 rainy season influenced early rice crop establishment and prevented water stress at reproductive stage, which resulted in higher yield of all the three rice cultivars in 2013 than in 2014 rainy season. Lower yield of rice in 2014 rainy season can be attributed to lesser rainfall and unstable canal water supply especially at the grain filling stage of the crop. Water stress at vegetative stage of the rice crops may result to early flowering. The most sensitive growth stage to water deficit, which is an indicator of drought susceptibility, is flowering. Water stress at flowering will result to poor grain filling (Pantuwan et al. 2002). Our study indicates that rice productivity in DDSR system can be increased using suitable rice cultivars and stable canal water supply especially at the reproductive stage.

As expected, chickpea produced significantly higher yield in both cropping seasons compared to mustard and green gram (Figure 1ii). However, the yield of chickpea and green gram recorded in this study was comparable to Indian national level productivity (1.01 and 0.40 t ha^{-1}, respectively) of these crops which are normally grown during post-rainy season. The yield of mustard was much lower (62%) compared to national yield level of 0.76 t ha^{-1} (Anonymous 2009). The early sowing (October 1st week) of chickpea in Karnataka, India was reported to be advantageous (Patil 2010) as it avoided the end of season soil moisture deficiency and heat stress, and helped in proper germination, plant stand and better crop establishment as well as to harvest good crop. Lower yield of mustard can be attributed to high temperature during the vegetative stage and poor soil aeration. In India, sowing mustard at optimum time gave higher yields due to suitable environment that prevails at all growth stages, though different cultivars have different response to date of sowing (Kapila Shekhawat et al. 2012). Mustard sown between 2nd and 3rd week of October took significantly

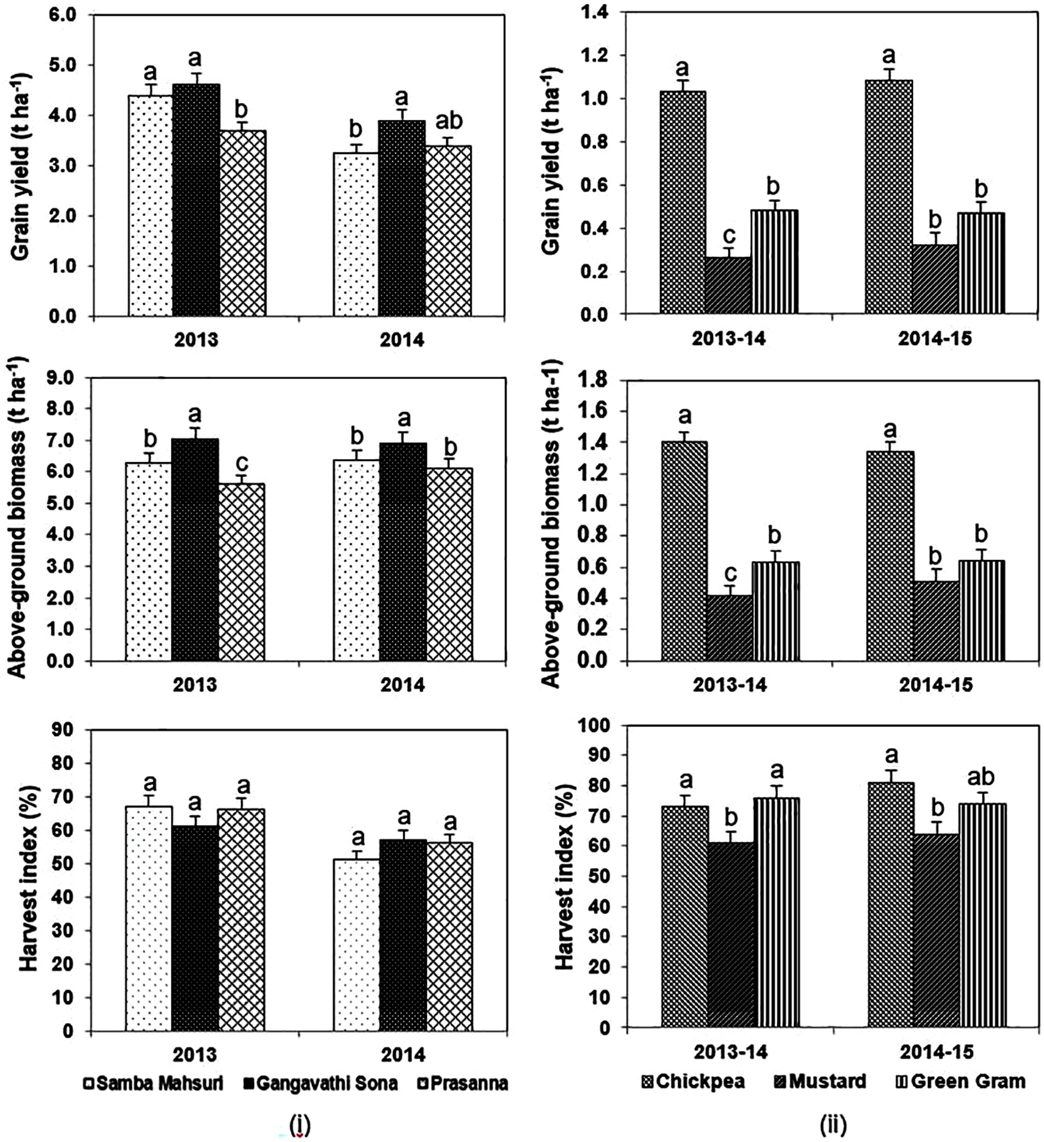

Figure 1. Grain yield, above-ground biomass and harvest index of (i) three rice cultivars and (ii) dryland crops grown in the semi-arid region of Raichur District, Karnataka State, India. Bars with different letters above are significantly different based on Fisher's protected LSD (P=0.05) within the year.

more days to 50% flowering and maturity compared to 1st week of October planting. Delayed sowing of mustard (2nd to 4th week of November) resulted in poor growth, low yield, and low oil content, while normal sowing (1st week of November) reduces the risk of mustard aphid incidence. Two weeks delay in planting of dryland crops during the 2014-15 cropping season did not result in greater yield difference between the two cropping seasons, indicating that sowing of chickpea and green gram in zero-tilled soils after rice can be done from 4th week of October up to 2nd week of November without much difference on grain yield, while sowing of mustard must be done from 4th week of October to 1st week of November. Accordingly, rice can be sown using medium maturing cultivars (with 120-130 maturity days) until 4th week of June during the rainy season as per general crop recommendation. It was observed that chickpea and green gram had good growth and yield response even though the soil aeration was minimal in non-puddled (rainy season) and zero-tilled (post-rainy season) fields. Generally, poor growth and lower yield of post-rainy season crops like chickpea is expected in paddy fields. The impaired soil structure, poor aeration, excess moisture retention for extended period in the plough-soil layer due to puddling and continuous submergence of rice was found to cause low crop stand, restricted root growth and poor nodulation, resulting to lower yield (Prasadini et al. 1993). Our results suggest that suitable post-rainy crops, for zero-tilled soils, must be selected through further research for cultivation in DDSR fields where soils are non-puddled during the rainy season.

Above-ground biomass of Gangavathi Sona rice cultivar was higher by 10 and 19% compared with Samba Mahsuri and Prasanna, respectively. Chickpea produced more biomass at harvest than mustard and green gram during both years. Results on above-ground biomass of dryland crops showed similar trend with that of yield (Fig.1ii). It was observed that sowing date among the two cropping seasons did not result to greater difference on biomass of the three rice cultivars and dryland crops. Harvest index (HI) of the three rice cultivars did not vary significantly unlike the HI of dryland crops which varied significantly during both years. However, HI of chickpea and green gram did not differ significantly during both years. It can be concluded that the observed yield difference between the three rice cultivars may be attributed more to the difference in above ground biomass produced than to HI. Conversely, yield difference among dryland crops was influenced by both biomass production and HI. Results of this study indicate that rice cultivars and dryland crops with higher harvest index may contribute to higher productivity of DDSR-based cropping systems in the semi-arid region. As suggested by Soriano et al. (2015), higher HI and yield of DDSR can be achieved using rice cultivars that produce more productive tillers, longer panicles and not necessarily producing high biomass.

Resource Use

Land Use - Growing period from sowing to harvest of the three rice cultivars and dryland crops was the major factor that affects land use within a year. Land use in this study was affected significantly by the three rice cultivars and dryland crops during both years (Figure 2). Obviously, late maturing crops had longer land use per hectare within the cropping season. It was revealed that timely sowing of rice during the rainy season will ensure additional crops that can be grown during the post-rainy season, thereby improving land use of the semi-arid region particularly in water-short irrigated and rainfed areas. Our results support the findings of Saleh et al. (2000) that DDSR system matures one to two weeks earlier than transplanted rice due to early sowing, thus reducing the risk of terminal drought and allowing earlier planting of non-rice crop during the post-rainy season. Sharma et al. (2004) also reported that intensification through inclusion of vegetables and leguminous crops increased the production and land use efficiency. Likewise, the productivity and water use efficiency of the second crop in lowland rice area can be improved by practicing timely sowing of post-rainy season crops (Singh et al. 2014). Use of early maturing rice cultivars like Prasanna grown under DDSR system had lower land use by 12% during both years. Land use of dryland crops decreased with the order from chickpea, mustard and green gram during both cropping seasons which may be attributed to the respective crop adoptability to clay loam soil texture and other discussed factors. To ensure cultivation of dryland crops during the post-rainy season that improve land use and rice yield, medium maturing rice cultivars must be used if sowing can be done within the month of June, while early maturing rice cultivars (with maturity lower than 120 days) are recommended if sowing can be done between 1st and 2nd week of July. Thus, late planted rice during the rainy season should be followed by an early maturing dryland crops.

Water Use - Similar to land use, water use was affected significantly by rice cultivar (Figure 2i). Volume of irrigation water used in Samba Mahsuri was higher by 10% due to longer maturity that requires more irrigation cycles. Only rain water was utilized during the post-rainy season, thereby, water use was the same among the three dryland crops in both cropping seasons (Figure 2ii). Our results indicated that irrigation water can be reduced by cultivating early maturing rice cultivars (120 days or less) during the rainy season. However, the selection of rice cultivars during the rainy season for DDSR, as previously discussed, must be based on sowing time which depends on rainfall pattern, to ensure the cultivation of post-rainy season crops. This finding confirms rainfall pattern as more efficient basis for scheduling sowing time for DDSR system especially in the tail-end portion of irrigated areas than the schedule of canal water distribution, which is also unstable within a cropping season and year. Therefore, irrigation water use of rice production in the semi-arid region can be reduced not only by way of using short duration and drought resistant rice cultivars through DDSR system but also proper time of sowing during the rainy season. However, canal water supplied and rainfall during the mid and end season of rice production are helpful to increase residual soil moisture which are favorable to post-rainy season crop production.

Labor Use - Human labor for agriculture is becoming scarce in the semi-arid region due to large forced migration to urban areas of farm laborers searching for better livelihood opportunities. Labor use varied significantly among rice cultivars and dryland crops (Fig. 2). Samba Mahsuri had higher manual labor usage compared to Gangavathi Sona and Prasanna with 3 and 12%, respectively. Significantly higher labor use of rice was attributed primarily by maturity while maturity and required farming activities of dryland crops affects labor use. Longer duration of rice cultivar requires additional manual labor for irrigation and weeding. Labor requirements for rice crop establishment decreased by more than 75% with direct-seeding compared with

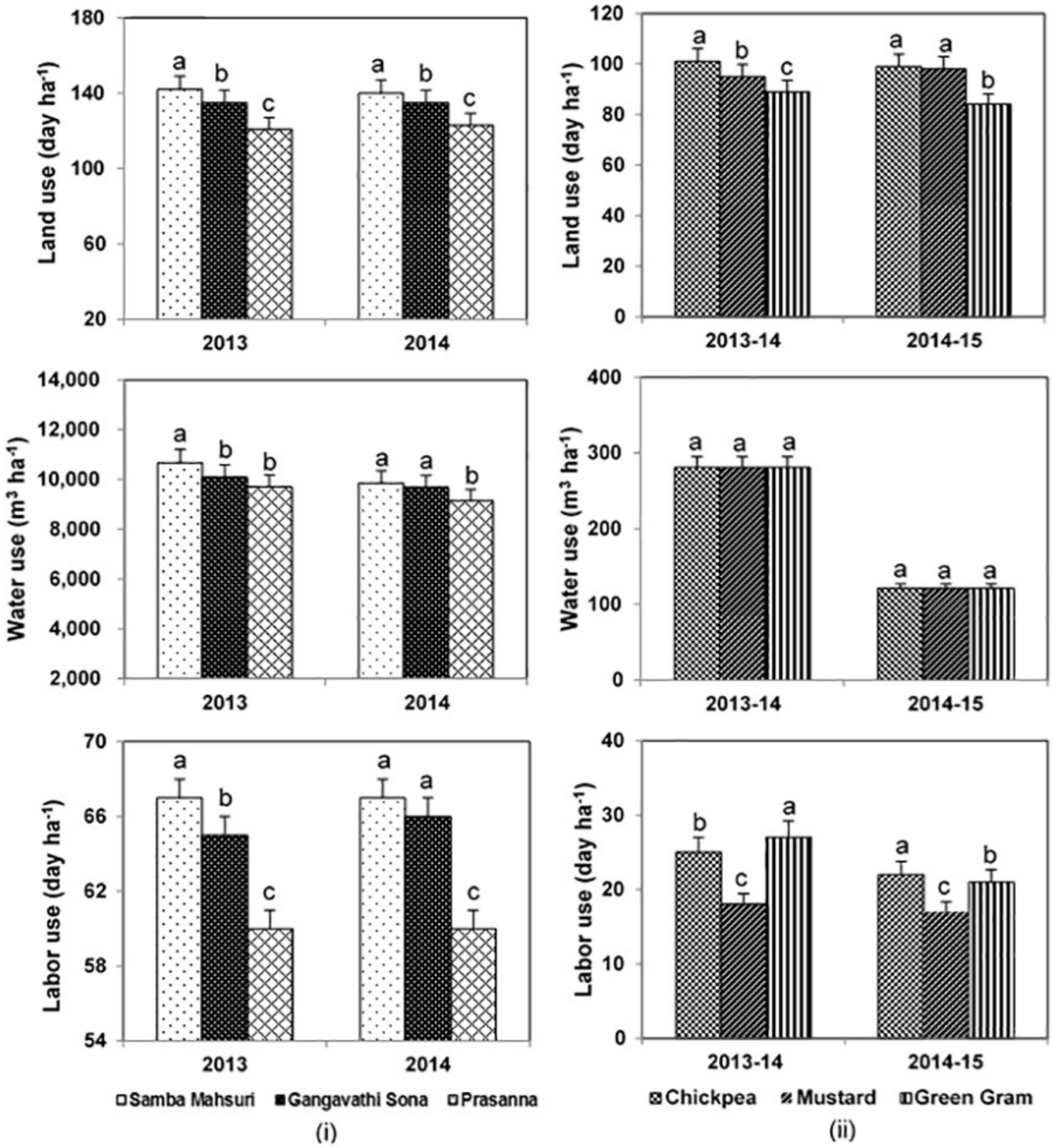

Figure 2. Land, water and labor resources used during the cultivation of (i) three rice cultivars and (ii) dryland crops in the semi-arid region of Raichur District, Karnataka State, India. Bars with different letters above are significantly different based on Fisher's protected LSD (P=0.05) within the year.

transplanting (Pandey & Velasco 2002). Direct dry-seeding of rice avoids farming activities such as nursery raising, seedling uprooting, puddling and transplanting, and thus reduces the labor requirements (Kumar & Ladha 2011). Our results indicated that mechanization will play an important and critical role in reducing human labor required for cultivation of DDSR and dryland crops as well as mitigation of the decreasing number of farm laborers. Commercially available machines for direct sowing of rice and dryland crops may propel farmers to adopt DDSR system during the rainy season and grow dryland crops after rice. Currently, the DDSR system and the additional crops that can be grown in the same field during the post-rainy season can generate jobs which are spread out within the year unlike TPR system where labor requirements are needed mostly during crop establishment. Kumar & Ladha (2011) documented that the demand for labor was spread out over a longer period in DDSR than in TPR system, thus helping farmers by making full use of family labor and having less dependency on hired labor.

Production Cost and Gross Income

High cost of TPR system of rice cultivation is one of the major constraints in the semi-arid region. Hence, DDSR was considered as a good cost-reducing system of rice cultivation in the semi-arid region where farmers are experiencing difficulties in sourcing capital before the cropping season (Soriano et al. 2015). In this study, cost of production among the three rice cultivars did not vary significantly during both years (Figure 3i). Gangavathi Sona had the highest production cost of US$ 496 ha^{-1}, which was comparable with other rice cultivars. Slightly higher (5%) cost of production observed in 2014 cropping season was due to higher labor cost on land preparation and irrigation. Our result indicates that variation on resource use among the three rice cultivars did not affect significantly the cost of production, indicating that longer maturity of rice which resulted to higher water and labor use did not cause higher cost of production. The cost of producing dryland crops has varied significantly during both years (Figure 3ii). Growing chickpea during post-rainy season was more expensive compared to green gram (29%) and mustard (70%). Direct-seeding of dryland crops using machines, which eliminated land preparation, has reduced remarkably the cost of production.

Additional income from alternative rice production systems and cultivars was given more importance by the farmers other than associated risks in rice producing areas. The gross income among the three rice cultivars and dryland crops varied significantly during both cropping seasons and years (Figure 3). Higher yields of Gangavathi Sona and chickpea have resulted to higher gross income in both years. Gangavathi Sona had significantly higher gross income of 10 and 15% compared with Samba Mahsuri and Prasanna, respectively. Similarly, chickpea produced more income (30 and 158%, respectively) than green gram and mustard. These results indicate that growing of Gangavathi Sona rice cultivar in rainy season through DDSR system and chickpea after rice can be more attractive to rice farmers in the semi-arid region due to higher grain yield, biomass and income.

Performance of Three DDSR-Based Cropping and TPR Systems

Combined effects of Gangavathi Sona and dryland crops were analyzed based on the results of the field experiments to compare DDSR-based cropping systems with TPR system. Mean grain yield of Gangavathi Sona, chickpea, mustard, green gram and TPR from a two-year field experiments was 4.08, 1.06, 0.28, 0.48 and 4.43 t ha^{-1}, respectively (Table 1). DDSR-chickpea had the highest REY of 5.28 t ha^{-1} followed by DDSR-green gram with

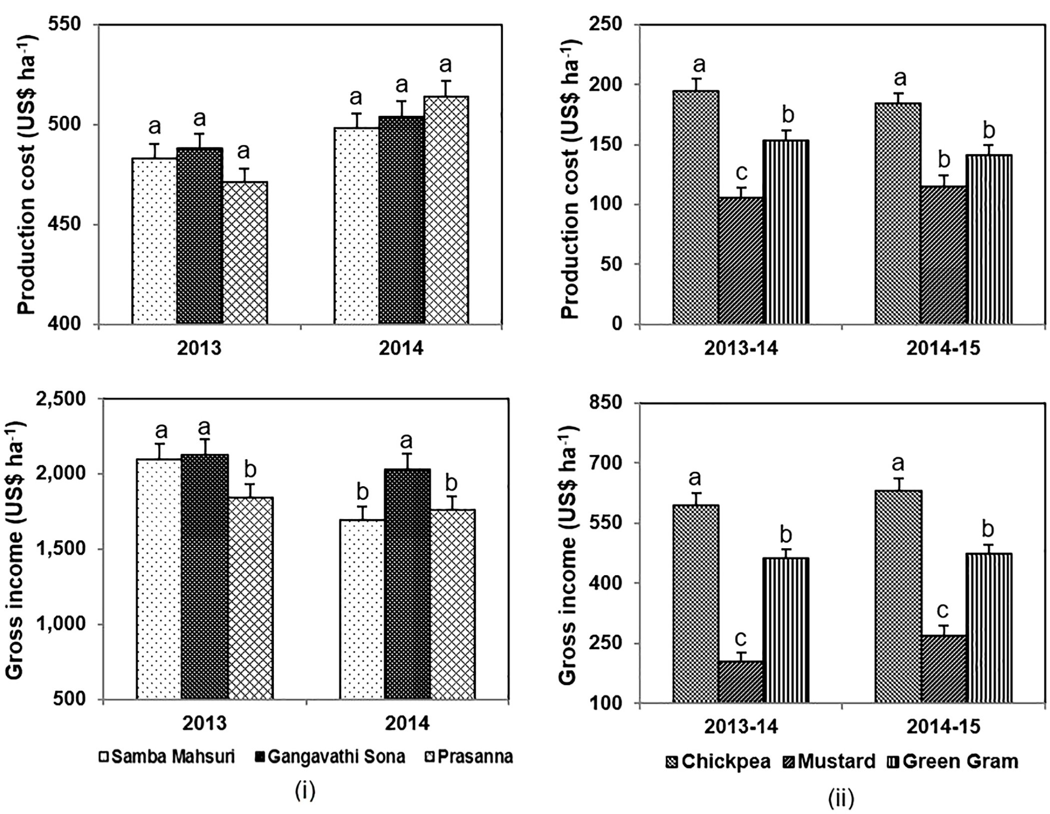

Figure 3. Gross income and production cost during the cultivation of (i) three rice cultivars and (ii) dryland crops in the semi-arid region of Raichur District, Karnataka State, India. Bars with different letters above are significantly different based on Fisher's protected LSD (P=0.05) within the year.

Table 1. Performance of DDSR-based cropping systems compared to TPR system relative to mean grain yield, rice equivalent yield, production efficiency, productivity, profitability and economic efficiency in the semi-arid region of Raichur District, Karnataka State, India.

Production or Cropping System (Rice-Dryland Crops)	Mean Grain Yield (t ha^{-1})		Rice Equivalent Yield (t ha^{-1} yr^{-1})	Production Efficiency (%)	Productivity			Cost of Production (US$ ha^{-1} yr^{-1})	Net Returns (US$ ha^{-1} yr^{-1})	B: C Ratio	Economic Efficiency (%)
	Rice (Rainy Season)	Dryland Crops (Post-Rainy Season)			Land (US$ ha^{-1})	Water (US$ m^{-3} water ha^{-1})	Labor (US$ ha^{-1})				
DDSR[a] - Chickpea	4.08	1.06	5.28 *[c]	19	2,693 **	0.26 **	432 ns	680 *	2,013 **	2.9:1	34
DDSR - Mustard	4.08	0.28	4.54 ns	2	2,317 **	0.23 **	415 ns	607 **	1,710 ns	2.8:1	14
DDSR - Green Gram	4.08	0.48	5.00 *	13	2,548 **	0.25 **	460 ns	640 *	1,907 **	2.9:1	27
Transplanted Rice[b]	4.43	-	4.43	-	2,194	0.16	424	753	1,504	2.0:1	-

[a] Mean grain yield of Gangavathi Sona; [b] Mean results of transplanted rice (TPR) system from 15 rice farmers within the experimental site; [c] Significance levels compared to transplanted rice: ns P>0.05, * P<0.05, ** P<0.01; 1 man-day = 325 Indian rupees or 5 US$ and 1 US$ = 65 Indian rupees; Local market price: Paddy = US$ 0.51 kg^{-1}, Mustard = US$ 0.81 kg^{-1}, Chickpea = US$ 0.58 kg^{-1}, Green Gram = US$ 0.98 kg^{-1}.

REY of 5.00 t ha^{-1}. Thus, rice farmers in the semi-arid region may produce an additional REY of 0.85 t ha^{-1} year^{-1} by growing chickpea during the post-rainy season after rice. Added REY in DDSR-chickpea, DDSR-green gram and DDSR-mustard systems increased PE by 19, 13 and 2%, respectively against TPR system.

DDSR-based cropping systems had significantly higher land and water productivity compared with TPR system (Table 1). Land productivity of TPR was lower by 19, 5 and 14% compared with DDSR-chickpea, DDSR-mustard and DDSR-green gram, respectively. Higher land productivity in DDSR-chickpea was attributed mainly to higher grain yield and gross income of Gangavathi Sona and chickpea. DDSR-chickpea system had higher (63%) water productivity compared to TPR system, indicating that DDSR-chickpea cropping system can almost double the value of water (irrigation + rainfall) used in the semi-arid region. There was no significant difference on labor productivity of DDSR-based cropping systems compared to TPR system (Table 1). Labor productivity of TPR system was lower than DDSR-chickpea and DDSR-green gram systems, but higher in DDSR-mustard system. Hence, DDSR-based cropping systems can be more beneficial to farm laborers who are mostly landless because labor requirements and job opportunities were spread out within the year, unlike TPR system where bulk of manual labor requirements is extremely needed during crop establishment.

Combined production cost of DDSR-based cropping systems was significantly lower by 10 to 19% than TPR system. DDSR-chickpea was the most expensive cropping system with an average cost of US$ 680 ha^{-1} year^{-1} followed by DDSR-green gram (US$ 640 ha^{-1} year^{-1}). Specifically, labor productivity or cost among the DDSR-based cropping systems was 64 to 72% of the total cost of production, which was higher than percentage of labor productivity or cost (56%) of TPR system. Thus, ways must be sought to further reduce the labor cost of DDSR-based cropping systems to earn higher net returns. However, in general, DDSR-based cropping systems can generate more jobs or income for farm laborers compared to TPR system. Lower cost of production of DDSR-chickpea and DDSR-green gram cropping systems has resulted to significantly higher net returns (US$ 509 and 403 ha^{-1} yr^{-1}, respectively) compared to TPR system. Kamboj et al. (2012) reported that grain yield of DDSR system alone in comparison to TPR during the rainy season was either similar or higher with US$ 128 to 137 ha^{-1} net returns. Growing chickpea and green gram during the post-rainy season in the same fields after DDSR system of rice cultivation can produce an additional net income of around US$ 458 and 351 ha^{-1} (data not shown), respectively. Greater economic benefits per unit of land as well as cost of investment were always the major factors in adopting new agricultural systems. The benefit-cost ratio (B: C) in DDSR-based cropping systems was significantly higher by around 50% compared to TPR system. Nageswara et al. (2011) reported that crop yield, total productivity and economic returns were greater with double cropped sequential systems compared to post-rainy season single cropped traditional rotations, and these systems can easily be adopted by dryland small holder farmers. Rice farmers in the semi-arid region can earn a net return of around US$ 3.0 for every US$ investment in DDSR-based cropping systems. Higher

B: C in DDSR-based cropping systems when compared with TPR system was attributed to higher REY and added net returns. Sharma et al. (2007) reported that inclusion of crops like oilseeds, pulses, vegetables and fodder crops will improve the economic condition of small and marginal farmers owing to higher price and volume of by-products. Overall, DDSR-chickpea system had higher EE (34%) followed by DDSR-green gram (27%).

CONCLUSIONS

Stable canal water supply and rainfall during the later part of rainy season, which resulted to sufficient residual soil moisture, may propel the farmers to grow additional crops after rice during the post-rainy season in the semi-arid region particularly in water-short irrigated rice areas. DDSR system using high yielding rice such as Gangavathi Sona and chickpea had more grain yield, biomass and income when grown during the rainy season and post-rainy season, respectively. The yield difference between the three rice cultivars was attributed more to difference in biomass production than to harvest index. Likewise, the yield difference among dryland crops was attributed to both biomass production and harvest index. Irrigation water use in DDSR system can be reduced by both using short duration and drought resistant rice cultivars, and following proper time of sowing during the rainy season, which depends on rainfall pattern and canal water supply. To ensure the cultivation of dryland crops during the post-rainy season, medium maturing rice cultivars (with 120-130 maturity days) must be used, if sowing time can be done within the month of June, while early maturing rice cultivars (with maturity lower than 120 days) are recommended if sowing time can be done between 1st and 2nd week of July. Sowing of chickpea and green gram in zero-tilled soils after rice can be done from 4th week of October up to 2nd week of November without much difference on grain yield, while sowing of mustard must be adjusted from 4th week of October until 1st week of November. DDSR-chickpea system is the most promising alternative rice-based cropping system in the semi-arid region particularly in water-short irrigated rice areas due to its higher production efficiency, land and water productivity and economic efficiency.

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