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Research Paper

Yield and physiological response of newly released rice (*Oryza sativa*) varieties to crop establishment methods under temperate conditions of Kashmir

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ABSTRACT

A field experiment was undertaken during rainy (*kharif*) season of 2015 and 2016 to assess the effect of crop establishment methods, viz. system of rice intensification (SRI), direct seeded rice (DSR), recommended method (RM) and farmers' practice (FP) on the performance of 4 newly released high yielding rice (*Oryza sativa* L.) varieties, viz. 'SR-1', 'SR-2', 'SR-3' and 'Jhelum'. SRI method significantly improved growth parameters (plant height, tiller-number, leaf-area index, light interception, root dry weight and root volume), physiological parameters (photosynthetic rate and transpiration rate) and nutrient (NPK) uptake of all the varieties. The average increase in grain yield in SRI, DSR and RM was 22%, 14% and 6.0% over FP, respectively. Among the varieties, 'SR-1' and 'SR-2' produced 9.5% and 16.8% higher grain yield over 'Jhelum', which was at par with 'SR-3'. However, the highest net returns and benefit: cost ratio was recorded in DSR and 'SR-2' rice variety.

Key words : Crop-establishment methods, Direct seeded rice, Leaf-area index, Physiological parameters, System of rice intensification

Rice is a staple food of more than 60% of the world's population. In Kashmir valley, besides being a staple food, it is an integral part of rich cultural heritage. However, the average productivity (2.2 t/ha) is far below the potential yields of 6–7 t/ha for most of the newly released cultivars. Kashmir valley is characterised by temperate climate with abundant sunshine and nearly pest free environment during summer months. The varietal profile is of typical temperate rice varieties bred for cold tolerance, early maturity and high yield. Use of old varieties, high plant population, poor management of inputs such as nutrients and water and weed infestation and unscientific establishment methods leads to low yield.

The increasing scarcity of water is a major threat to rice production in many countries. Therefore, a key challenge before agronomists is to look for the alternative crop establishment methods for higher productivity and resource-use efficiency using high-yielding varieties. System of rice intensification (SRI) advocates the transplanting of seedlings at an age of 8–12 days, singly and at a spacing of 25 cm × 25 cm in square planting geometry. Nutrients are supplied preferably through organic sources such as FYM or compost combined with manual or mechanical weeding and application of relatively smaller quantities of water with provisions of intermittent drainage (WWF-ICRISAT, 2010). SRI has been shown to increase the productivity of rice and income of farmers, while reducing the need for water and other inputs (Hidayati *et al.,* 2016). Therefore, SRI evolved from Madagacar is being promoted worldwide for water and seed saving and higher yield. In view of escalating labour cost, development of suitable herbicide molecules and increasing water scarcity, direct seeded rice (DSR) is also gaining popularity world-wide. DSR method of rice cultivation locally called *watur* was in vogue in Kashmir valley some 40 years ago. However, because of the increasing scarcity of labour coupled with high cost involved in transplanting, there has been a renewed interest in DSR since the last two decades. Recommended management (RM) is the transplanting mode of rice cultivation where crop is supposed to be grown as per the recommendations of the university. Transplanting using recommended package of practices is seldom practiced by farmers and they follow random method of planting using over-aged seedlings at very high densities. Farmers' practice (FP) a random method of transplanting without any proper schedule regarding number of seedlings/ hill, spacing, irrigation, weed, nutrient management etc. Very little information is available regarding the compara-

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tive effect of these establishment methods on the performance of newly released high yielding rice varieties suitable for temperate conditions of Kashmir valley. We hypothesized that crop establishment methods will induce a significant differences in growth, physiology and yield of rice varieties. With this background, the current study was conducted to assess the growth, yield and physiological response of rice varieties to crop establishment systems.

MATERIALS AND METHODS

A field experiment was conducted for 2 years during rainy (*kharif*) season of 2015 and 2016 at Mountain Research Centre for Field Crops, SKUAST-K, Khudwani Anantnag. (34º N, 74'E and 1,560 m above the mean sea-level). The mean minimum and maximum temperature during the crop growing seasons ranged between 5.29 to 18.72°C and 15.29 to 31.57°C for 2015, respectively. The corresponding figures for the year 2016 were 4.43°C to 17.63°C and 17.79 and 32.64°C. The weather conditions during crop growth period in 2015 and 2016 are presented in figures 1 (a) and 1(b), respectively. The soil of the experimental field was silty clay loam in texture and neutral in *p*H (6.9). The soil was low in nitrogen (225 kg N/ha) and medium in phosphorus (20.8 kg P/ha) and potassium (270 kg K/ha). Treatments consisted of 4 crop establishment methods, viz. SRI, DSR, RM and farmers' practice (FP) in main plots and 4 newly released rice varieties ('SR-1', 'SR-2', 'SR-3' and 'Jhelum') in sub-plots, laid out in a split-plot design and replicated thrice. Plot size was 12 m^2. In SRI method 16 days-old seedlings with one seedling/hill was transplanted at a spacing of 25 cm × 25 cm. An alternate wetting and drying method of irrigation was practiced during vegetative phase and 2–3 cm of water depth was maintained during reproductive phase. Weeds were controlled by using a conoweeder at 15 and 30 days after transplanting (DAT). In DSR pre-germinated seeds were directly sown at a line spacing of 15 cm, using seed rate of 60 kg/ha. DSR plots were irrigated intermittently till the emergence of the seedlings. In RM, 3–4, 30 days-old seedlings/hill were planted at a spacing of 15 cm × 15 cm. In FP 35 days-old seedlings were planted randomly, 6–8 seedlings/hill and 35–40 hills/m^2. Fertilizer dose @ 120, 60 and 30 kg of N, P_2O_5 and K_2O/ha + 10 t FYM/ha as per the recommended schedule was followed in all the treatments. The fertilizers used were urea for N, diammonium phosphate (DAP) for P and muriate of potash (MOP) for K. In DSR, RM and FP, a water depth of 3–5 cm was maintained from transplanting to the grain filling stage of the crop. Herbicides pyrazosulfuron ethyl + pretilachlor (30 g + 0.45 kg a.i/ha) were applied 3-days after transplanting (DAT)/sowing in DSR, RM and FP. At full maturity, rice crop was harvested manually. Grain and straw yields were recorded from a net area of 4 m^2 from the centre of different treatment plots. Grain yield was adjusted to 12% moisture content and straw yield was weighed after field drying.

Among the growth and yield parameters; plant height, tillers/m^2, leaf-area index, panicles/m^2, filled grains/panicle and 1,000-grain weight were recorded using standard procedures. Light interception was measured using lux meter Apogee Model MQ-200. Roots were recovered from the top 20 cm soil depth using a quadrant (0.25 m^2) by sieving the soil at flowering stage of the crop. Root volume was measured using water displacement-Archimedes method. Plant samples collected at harvest were dried in a hot air oven at 60 °C for 24 hours after sun drying. The oven dried samples of plants and air dried samples of grains having moisture content (12%) were ground to pass through 40 mesh sieve in a Macro-wiley mill. From each replication, 0.5 g samples were taken for chemical analysis to determine the N, P and K concentration. N, P and K uptake in grain and straw was calculated by multiplying N P and K concentration of rice grain and rice straw with their respective yields. Chlorophyll content at flowering stage in flag leaf as per Arnon method (1949), using spectrophotometer (Electronic Corporation of India Limited, model: AAS-4141). Photosynthetic rate (Pn; µmol $CO_2/m^2/s$) and transpiration rate (TR; m mol H_2O/

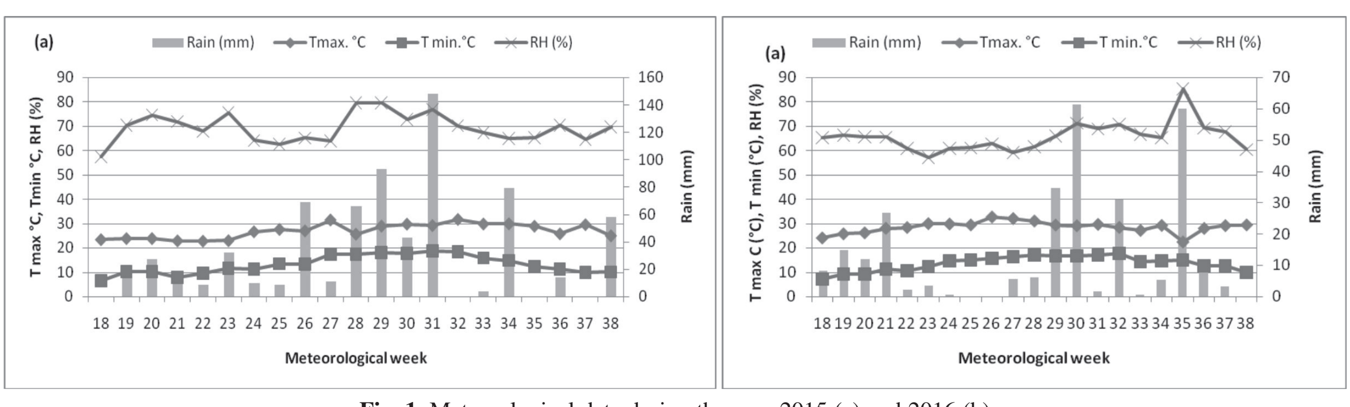

Fig. 1. Meteorological data during the year 2015 (a) and 2016 (b)

m^2/s) were measured in flag leaf at flowering stage using portable photosynthesis system (Model PP Systems, TPS-2).

The data pertaining to the growth, physiology and yield was subjected to analysis of variance using R software (version 3.2.0; Developer: R Core Team, University of Auckland, New Zealand).

RESULTS AND DISCUSSION

Plant growth parameters

Plant height was significantly higher under SRI method followed by DSR. Minimum plant height was found in FP (Table 1). Plant height in RM was medium and at par with both DSR and FP. Variety 'SR-2' registered maximum plant height followed by 'SR-1'. Number of tillers/m^2 registered significant differences ($P \leq 0.05$) among the establishment methods and the values were in the order of SRI>DSR>RM>FP. Among the varieties same trend in number of tillers/m^2 was observed as that of plant height. The superiority of SRI could be attributed to the transplanting of single seedling/hill at wider spacing which reduces competition for light, water, nutrients and space. Further transplantating of young seedlings leads to full expression of the innate genetic potential, maximum tillering and rooting potential of rice plants and can easily overcome transplanting shock. Consequently plant height and tillers/hill were significantly higher in SRI method. Leaf-area index (LAI) under SRI conditions was significantly higher than the other 3 establishment methods, which were at par with each other. The effect of varieties on LAI was non-significant. Interception of photosynthetically active radiation (PAR) in SRI and DSR was similar and significantly ($P \geq 0.05$) higher than RM and FP. PAR interception in 'SR-2' was significantly ($P \geq 0.05$) higher than other 3 test varieties (Table 1). The favourable environmental conditions in SRI method resulted in larger leaf size. SRI plants had a wider canopy and more erect leaves. This, along with higher LAI resulted in significantly higher interception of photosynthetically active radiation (PAR) in SRI method. Leaf elongation also increases significantly when soil is kept just saturated and not flooded. Significantly ($P < 0.05$) higher root dry weight and root volume were observed under SRI condition. DSR was next best in order followed by RM and FP, which were at par with each other. Among the varieties, 'SR-2' accumulated higher root dry weight and volume compared to other varieties. Root dry weight of 'SR-1' was significantly higher than 'SR-3' and 'Jhelum'. Significant differences were not observed in root volume among the varieties. Maintenance of soil in moist, non-flooded condition in SRI resulted in sufficient aeration and offers an opportunity for rice plant to develop larger root systems. This improves the access of roots to nutrients and moisture and also enhances their resilience against biotic and abiotic stresses (Kassam *et al.,* 2011). Huge competition in DSR and RM methods owing to crowded environment both below and above ground resulted in overall poor performance of all the varieties as compared to SRI method. In FP method because of random planting and higher number of seedlings/hill and irrigation through flooding produced

Table 1. Effect of crop establishment methods and varieties on growth parameters of rice (pooled data over 2 years)

Treatment	Plant height (cm) at harvest	Tillers/m^2 at max. tillering	LAI at flowering	PAR intercepted (%) at flowering	Root dry weight (g/ m^2) at flowering	Root volume (mL/m^2) at flowering
Establishment methods						
SRI	131.3	447	4.85	94.7	299	1,264
DSR	126.3	417	4.66	92.0	276	1,171
RM	124.2	397	4.37	88.4	264	1,123
FP	122.3	368	4.19	86.4	260	1,081
SEm±	1.25	4.60	0.13	0.95	4.21	23.81
CD (P= 0.05)	3.67	14.65	0.52	3.29	9.85	56.79
Varieties						
'SR-1'	129.2	418	4.58	89.9	269	1,109
'SR-2'	133.9	437	4.62	93.3	284	1,187
'SR-3'	123.3	386	4.51	89.6	254	1,153
'Jhelum'	122.4	394	4.56	88.5	257	1,142
SEm±	1.26	4.04	0.18	1.27	4.68	26.86
CD (P= 0.05)	4.26	15.03	NS	3.29	8.55	49.07

SRI, System of rice intensification; DSR, direct seeded rice; LAI, leaf-area index; PAR, photosynthetic active radiation; RM, recommended management practices; FP, farmer's practices

least favourable growth conditions, which suppressed the growth and tillering and caused the highest yield penalty compared to other 3 methods of establishment.

Physiological parameters

The rate of photosynthesis was significantly (P≤0.05) higher in SRI method followed by DSR. RM and FP methods showed statistically similar photosynthetic rate. Photosynthetic rate among the varieties was in the order of 'SR-2' > 'SR-1' > 'SR-3'='Jhelum'. The transpiration rate under RM and FP methods was significantly (P≤0.05) higher than DSR and SRI methods. Varietal effect on rate of transpiration was non-significant. Chlorophyll 'a' content under SRI method was the highest followed by DSR. RM and FP had statistically similar content of chlorophyll 'a'. Variety 'SR-1' had a significantly (P≤0.05) higher chlorophyll 'a' content than other 3 varieties which were at par with each other. Vis-à-vis SRI method was also superior to other 3 cultivation methods with respect to chlorophyll 'b' content. Significantly higher chlorophyll 'b' content was observed in 'SR-1' as compared to other 3 varieties. Chlorophyll 'b' content in 'SR-3' and 'Jhelum' was statistically similar and significantly (P≤0.05) lower than 'SR-2' (Table 2). The higher photosynthetic rate in SRI conditions as compared to other methods could be due to higher chlorophyll content as chlorophyll forms the photosynthetic apparatus of plants and its content is closely related to photosynthetic rate (Porra *et al*., 1993). Higher rate of photosynthesis in SRI method may also be due to higher nitrogen and phosphorus uptake. Nitrogen is an important component of both chlorophyll and RuBisCo; therefore its high content promotes the photosynthetic rate (Hidayati *et al*., 2016). Phosphorus is directly involved in photosynthetic process and affects quantum efficiency and dark reaction of photosynthesis. Among the crop establishment methods in SRI maturity got slightly delayed possibly due to the moderate temperature and prolonged tillering and extension of the vegetative phase. Delayed maturity of rice under SRI has been observed in earlier studies conducted at the centre. In DSR maturity of the crop was early and close to the RM and FP. Among the varieties, 'SR-2' and 'SR-1' took 4–7 days extra to attain maturity. SRI method of crop establishment recorded the highest water-use efficiency and water productivity, which was almost double than that of DSR, RM and FP. Among the varieties the physiological water-use efficiency was similar significantly higher water productivity was recorded in rice variety 'SR-2'.

Yield attribute and yield

The overall increase in panicles/m^2 under SRI, DSR and RM was about 22%, 14% and 8.0% over FP (Table 3). Among the varieties, 'SR-2' produced significantly higher (P≤0.05) panicles/m^2 over all other varieties. 'SR-1' was the second best and 'SR-3' and 'Jhelum' were at par with each other. SRI and DSR produced significantly higher filled grains/panicle as compared to RM and FP. 'SR-2' produced the highest filled grains/panicle, which was significantly higher than that of 'SR-1'. Filled grains/panicle in 'SR-1' was significantly higher as compared to 'SR-3'

Table 2. Effect of crop establishment methods and varieties on physiological parameters and chlorophyll content of rice (pooled data over 2 years)

Treatment	Photosynthetic rate (Pn) (μ mol/m^2/s)	Transpiration rate (TR) (mmol/m^2/s)	Water-use efficiency (Pn/TR)	Average water productivity (kg/m^3)	Chlorophyll 'a' (mg/g)	Chlorophyll 'b' (mg/g)
Establishment methods						
SRI	24.51	6.22	3.94	1.02	2.29	1.08
DSR	21.12	6.94	3.04	0.58	2.08	0.87
RM	19.38	7.15	2.71	0.52	1.76	0.82
FP	18.65	7.03	2.65	0.49	1.71	0.85
SEm±	0.67	0.14	0.07	0.03	0.10	0.03
CD (P= 0.05)	1.72	0.36	0.18	0.08	0.17	0.09
Varieties						
'SR-1	20.43	6.58	3.10	0.63	2.23	1.01
'SR-2'	21.87	6.41	3.41	0.67	1.96	0.92
'SR-3'	17.91	6.63	2.70	0.57	1.83	0.81
'Jhelum'	17.52	6.49	2.70	0.58	1.92	0.76
SEm±	0.53	0.13	0.06	0.03	0.06	0.02
CD (P= 0.05)	1.36	NS	0.15	0.07	0.13	0.07

SRI, System of rice intensification; DSR, direct seeded rice; LAI, leaf-area index; PAR, photosynthetic active radiation; RM, recommended management practices; FP, farmer's practices

and 'Jhelum'. SRI and DSR produced 1,000-grain weight at par with each other but significantly higher than RM and FP. Grain yield among the establishment practices ranged between 5.9 to 7.20 t/ha. SRI, DSR and RM recorded 22%, 14% and 6.0% increase in grain yield over FP. Among varieties 'SR-1' and 'SR-2' produced 9.5% and 16.8% higher grain over 'Jhelum' which was at par with 'SR-3'. Likewise the straw yield also recorded a significant increase in SRI method over the other establishment methods. The increase in straw yield was 17%, 12.5% and 2.4% in SRI, DSR and RM over FP, respectively. Higher photosynthetic rate, chlorophyll content and nutrient uptake, larger root system, larger leaves with wide spread canopy for greater light interception under SRI conditions resulted in most of the tillers to convert into productive ones (Thakur *et al*., 2009). Higher yield attributes and yield under SRI have been reported in India by many workers (Singh *et al*., 2015; Priyanka *et al*., 2015). Yoshida (1981) remarked that yield of rice is determined by number of productive tillers per unit area, 1,000-grain weight and filled grain/panicle. Yield superiority of SRI over traditional methods of establishment has also been reported by Hosain *et al.* (2018) and Rozen *et al.,* (2018). The improvement in all these yield parameters resulted in significantly higher grain yield in SRI compared to other methods. The greater remobilization of carbon reserves from vegetative parts to grains could also be a reason for higher grain yield under SRI condition. The significantly greater straw weight under SRI conditions was due to improved growth parameters like plant height, tiller count and LAI.

Nutrient uptake

Nutrient uptake was significantly influenced by crop establishment methods and varieties. The order of N uptake was SRI>DSR> RM> FP among different cultivation

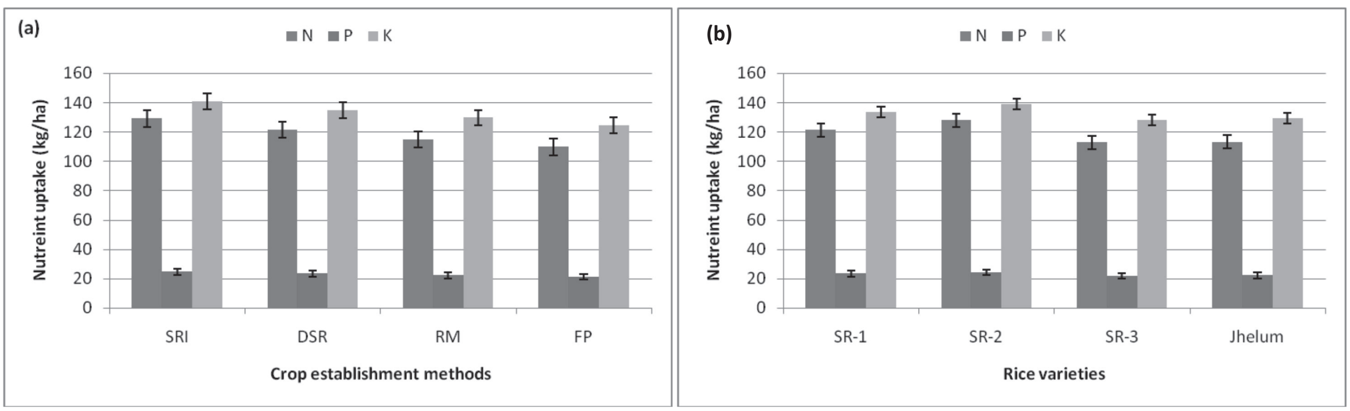

Fig. 2. Effect of crop establishment methods (a) and varieties (b) on N, P and K uptake of rice (data pooled over 2 years).

Table 3. Effect of crop establishment methods and varieties on yield attributes, yield and nutrient uptake of rice (pooled data over 2 years)

Treatment	Panicles/ m^2	Filled grains/ panicle	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Net returns (×10^3 ₹/ha)	Benefit: cost ratio
Establishment methods							
SRI	396	93.8	26.92	7.20	8.8	74.83	1.32
DSR	372	90.8	25.65	6.71	8.47	77.77	1.70
RM	351	88.4	25.33	6.26	7.72	55.78	0.95
FP	326	84.2	25.11	5.90	7.54	53.19	0.96
SEm±	5.90	2.20	0.41	0.10	0.13	0.81	0.08
CD (P= 0.05)	15.07	5.60	1.05	0.25	0.32	2.08	0.20
Varieties							
'SR-1'	365	93.4	26.12	6.71	8.23	68.38	1.26
'SR-2'	392	109.2	26.45	7.16	8.87	76.88	1.42
'SR-3'	341	76.9	25.57	6.08	7.61	57.45	1.06
'Jhelum'	346	77.5	25.63	6.13	7.53	57.82	1.07
SEm±	5.33	1.40	0.40	0.13	0.16	0.82	0.05
CD (P= 0.05)	12.31	5.01	0.73	0.27	0.32	2.10	0.14

SRI, System of rice intensification; DSR, direct seeded rice; LAI, leaf-area index; PAR, photosynthetic active radiation; RM, recommended management practices; FP, farmer's practices

methods and 'SR-2' > 'SR-1' > 'SR-3'='Jhelum' among varieties (Fig 2.). P uptake was also significantly influenced by the crop establishment methods. P uptake in SRI was significantly higher than DSR, RM and FP. Higher grain and straw yield mainly contributed to higher N, P and K uptake in SRI. Among the varieties 'SR-2' maintained its superiority in P uptake also. SRI had significantly higher K uptake values among the crop establishment methods. The K uptake recorded in different varieties was of the order of 'SR-2' > 'SR-1' > 'SR-3' ='Jhelum'.

Relative economics

Highest net returns (₹77.77× 10$^{3)}$ and B: C ratio were recorded in DSR. This was owing to reduction in the cost of cultivation. In varieties, the highest net returns and B:C ratio was realised from 'SR-2' due to its higher yield.

This study showed that SRI method significantly improved the performance of different varieties which was evident by its positive impact on their growth, yield and physiological parameters. However, DSR was economically more rewarding.

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