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# Influence of crop geometry and cultivars on growth, yield and production efficiency of dry direct-seeded rice (*Oryza sativa* L.)

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**Abstract:** A field experiment was conducted during *kharif* (summer) season of 2014, aim of the experiment was to investigate suitable crop geometry and cultivar and their influences on performance of dry direct-seeded rice (*Oryza sativa* L.), experimental treatments were consisting of 15 treatments, namely, main plots: five cultivars (MTU 7029, NDR 97, HUR 105, HUR 4-3 and PRH-10) and sub-plots: three crop geometry's (20 x 10, 20 x 20 and 25 x 25 $cm^2$). All the data recorded were statistically analyzed using the standard procedures of split-plot design. The results indicated that amongst cultivars, aromatic rice hybrid PRH-10 recorded significantly more grain yield (5582.32 kg/ha) than cultivar HUR 4-3 (4612.99 kg/ha) and NDR 97 (3397.82 kg/ha), whereas; it was statistically comparable with cultivar MTU 7029 (5489.24 kg/ha) and HUR 105 (5022.03 kg/ha). The cultivar PRH-10 also registered higher gross return (105771.9 ₹/ha), net return (66389.08 ₹/ha) and production efficiency (592.76 ₹/ha/day) than the remaining cultivars. The higher grain yield of PRH-10 over these cultivars was due to considerable improvement in most of its yield attributing characters like panicle length (27.92 cm), a number of grains/panicle (178.70) and test weight (26.35 g). In a case of crop geometry treatment, plant spacing of 25 x 25 $cm^2$ recorded higher grain yield as compared to remaining plant spacing while the plant spacing of 20 x 10 $cm^2$ recorded higher gross return, net return and production efficiency as compared to 20 x 20 and 25 x 25 $cm^2$. Plant geometry plays an imperative role towards improving the grain yield of cultivars in direct seeded rice by optimal utilization of natural resources. Therefore, for getting higher net return and production efficiency, cultivar PRH-10 at plant spacing 20 x 10 $cm^2$ can be raised in dry direct-seeded rice in Varanasi region of Eastern Uttar Pradesh.

**Keywords**: Crop geometry, Cultivar, Direct seeded rice, Economics, Production efficiency, Yield

## INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for over 50% of the world's population. It is grown in approximately 114 countries across the world on an area of 161.03 million hectares with annual production of 478.73 million tonnes having a productivity of 44.3 q/ha during 2014-15 (FAO, 2016) accounting about 11% of the world's cultivated land. Rice is the key crop in India's food security accounting about 44% of the total food grain production (Anonymous, 2010). It is the major source of energy providing 43% calorie requirement for over 70% of Indians and occupied 43.86 million hectares of cultivated area with annual production of 105.48 million tonnes having a productivity of 24.24 q/ha during 2014 -15 (Indiastat, 2016). Of this, more than 70% rice is grown under a rainfed condition, 9% under upland and 21% under partially or fully irrigated conditions.

According to estimation, by 2025, the world's farmers need to produce about 60% more rice than at present to meet the food demands of the expected world population at that time. Therefore, this extra rice production needed has to come from a productivity gain. The major challenge is to achieve this gain with less water, labor and energy, thereby ensuring long-term environmental sustainability along with two major challenges, first, it needs to enhance food production sustainably to feed a growing world population; at the same time, this increase needs to be accomplished under conditions of increasing scarcity of water resources (Dadhich and Meena, 2015; Meena *et al*., 2015). Therefore, under his situation, dry direct seeding is an appropriate alternative method of rice raising which offers such advantages as faster as easier planting, reduced labor, lesser water need, earlier crop maturity, less methane emission and often higher profitability (Thiyagarajan *et al.*, 2002; Uphoff, 2007; Krishna *et al*., 2008).

Among the available higher production technology

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selection of appropriate high yielding cultivar according to specific location and region at suitable crop geometry is imperative phenomena for boosting production of dry direct-seeded rice (DSR). As the seed of rice hybrids are expensive, therefore, selection of ideal crop geometry must to adopt for getting optimum plant stand in the field which results in higher growth and yield attributes. The same genotype do not perform equally good in all the growing ecosystem hence through selection of appropriate rice cultivar; the growth and yield potential, yield attributes as well as the economics and production efficiency of rice can be improved in direct seeded conditions (Meena *et al*., 2013; Meena and Yadav, 2015). Hybrid vigor in rice is profitably used to increase its productivity by 14-28% over the available best cultivars in India (Siddiqui, 1993). Crop geometry plays a significant role in optimization of rice yield due to efficient utilization of solar radiation as well as nutrients in direct seeded conditions (Siddiqui *et al.*, 1999). A planting density that can bring down the seed requirement without sacrificing productivity would go a long way in popularizing the direct seeded rice cultivation. The increase in plant population above optimum may decrease crop yield while on another side yield may also reduce due to lesser plant population below optimum due to inability to intercept maximum available light by poor plant stand (Mahajan *et al.*, 2010). Closer spacing hampers intercultural operations and as such more competition arises among the crop plants for nutrients, $CO_2$ and light. As a result, the plant becomes weaker and thinner producing lower growth and yield attributes. In contrast, at lower plant population these factors are not well utilized. Plant to plant and row to row spacing had a significant effect on growth, yield and yield attributing characters of direct seeded rice (Sultana *et al*., 2012). The plant geometry and spatial configuration exploit the initial vigor of the genotypes with enhanced soil aeration creating a congenial condition for better establishment (Shukla *et al.*, 2014). However, at present, the information of appropriate spacing and cultivar of rice is not well known in direct seeded condition. Keeping in mind, the present investigation was carried out to determine suitable cultivar and optimum crop geometry towards a profitable production of rice (*Oryza sativa* L.) under dry direct seeded conditions.

## MATERIALS AND METHODS

**Experimental site:** The present field experiment was conducted during *kharif* season of 2014 at Agronomy farm of Banaras Hindu University, Varanasi, Uttar Pradesh, which is situated at 25°18' N latitude, 83°03' E longitude and altitude of 81.71 m meters above mean sea level. This region comes under agro-climatic zone III A (Semi-Arid Eastern Plain Zone), and the region is mostly rainfed (Meena *et al.*, 2016).

**Treatments detail:** The experiment was laid out in split plot design with three replications. The different cultivars (5) were allocated in main plots and crop geometry (3) in subplots. The five cultivars used were Swarna (MTU 7029), Narendra Dhan 97 (NDR 97), Malviya Sugandhit Dhan 105 (HUR 105), HUR 4-3,Pusa Rice Hybrid 10 (PRH-10) and three crop geometry 20 x 10 $cm^2$ (50 hills/$m^2$), 20 x 20 $cm^2$ (25 hills/$m^2$) and 25 x 25 $cm^2$ (16 hills/$m^2$). Pusa Rice Hybrid-10 (PRH-10) is the first superfine grain aromatic hybrid with basmati like quality developed at IARI, New Delhi, in 1998 from the cross of Pusa 6A x PRR-78. The grains are fine and medium-long with a test weight of 22-24 g. It is a medium-duration hybrid which matures in 110-115 days. The cultivar MTU 7029 was released in 1982 from Acharya NG Ranga Agricultural University, Andhra Pradesh, India from the cross of Vasista x Mahsuri. It is a dwarf cultivar with medium slender grain, long duration cultivar which matures in about 140 days. The Narendra Dhan 97 (NDR 97) was produced by crossing Nagina 22 x Ratna in 1992 from Narendra Deva University of Agricultural & Technology, Faizabad, Uttar Pradesh, India. This is a short duration early maturing cultivar with medium slender grains. The cultivar HUR 4-3 and HUR 105 are mutant of Lanjhi and MPR7-2, respectively, released from Banaras Hindu University, Varanasi, Uttar Pradesh, India in 2009. These have long slender grain. Both of these (HUR 4-3 and HUR 105) are semi-dwarf cultivars with an average plant height of 90-100 cm and 100-102 cm, respectively and mature in 135-140 and 130-135 days, respectively.

**Physico-chemical properties of experimental soil:** The soil of the experimental field was 'sandy clay loam', neutral in reaction (pH 7.3), having 0.47% organic carbon (Walkley and Black method, 1947; Jackson, 1973), 207.5 kg/ha available N (Alkaline permanganate method, AOAC, 1967), medium levels of available phosphorus (21.5 kg/ha, Olsen's method, Jackson,1973) and available potassium (223.6 kg/ha, Flame Photometer method, Jackson, 1973) in 0–15 cm soil depth at the start of the experiment. Indian soils have been characterized into three classes, *i.e.* low, medium and high levels of a particular nutrient depending upon the fertility prestige (Prasad *et al*., 2006).

**General agronomic practices:** The crop was direct seeded under un-puddled un-ponded plots on 27 June 2014. One to two seeds were dropped in each hole of 4 -5 cm depth as per the spacing treatment. To maintain uniform plant population, thinning and gap filling was done after two weeks of sowing. Nitrogen was applied at two levels; *i.e.*,150 (for PRH-10) and 120 kg N/ha for remaining cultivars. Urea, an organic fertilizer containing 46% N was applied as per requirement of treatments in three splits, *viz*. (i) 50% N as a basal application at the time of sowing (ii) 25% N at tillering stage and (iii) 25% at panicle initiation stage of the crop. Phosphorus (80 kg $P_2O_5$/ha for PRH-10 and 60 kg $P_2O_5$/ha for remaining cultivars) as DAP, a complex fertilizer containing 46% $P_2O_5$ and 18% N and potash (60 kg $K_2O$/ha for PRH-10 and 40 kg $K_2O$/ha for remaining cultivars) as muriate of potash (contains 60% $K_2O$) were applied uniformly in all plots at the time of final land preparation. A foliar spray of zinc sulfate (contains 21% Zn) and lime mixture (un-slacked) prepared by mixing 5.0 kg $ZnSO4.7H_2O$ + 2.5 kg $CaCO_3$ with 500 liters water per ha was applied when Zn deficiency symptoms (brown spots on young leaves) appear at 35 DAS to protect the crop from *Khaira* disease. For management of weeds flora bispyribac Na @ 25 g/ha was foliar sprayed at 15 DAS followed by a manual weeding at 40 DAS when the soil moisture was sufficient for easy weed removal from the soil. The irrigation was given as per the crop requirement and rainfall pattern.

**The procedure of observations:** Leaf area index (LAI) values were taken at 30, 60 and 90 DAS (days after sowing) with the help of crop canopy analyzer. First, the total area of a leaf was measured by keeping the sensor of canopy analyzer over the crop canopy and then the ground area was recorded by keeping the sensor over the soil surface. Thus, an output of automatic LAI reading was obtained. From a plot, LAI reading was taken from five random places and their average leaf area index was worked out. Chlorophyll content in green functioning leaves was determined with SPAD meter at 60 and 90 DAS by selecting 15 healthy green leaves from different plants from each plot randomly, and an average of them was worked out. A number of tillers bearing panicle were counted in a meter square area with the help of 1 x 1 $m^2$ quadrate in each plot separately. Ten panicles were selected from randomly tagged plants from each plot at the time of harvest to determine the number of grains per panicle, panicle length and test weight (1000-grain weight). Since the duration of the five cultivars differed they were harvested at different periods. The cultivar NDR 97, PRH-10, HUR 105, HUR 4-3 and MTU 7029 were harvested on 30 September, 18 December, 4 November, 8 November and 20 November 2014, respectively. The net plots were harvested after removing the border rows and were tied, numbered and left out in the field to dry for 4-5 days. After proper cleaning and winnowing the grain weight of each plot at 14% moisture was recorded.

**Weather during experiment:** Rice is basically a crop of warm regions of the tropics and subtropics. The overall performance of crop was good; due to an optimum range of all parameters for favorable weather condition during the monsoon season of 2014. The mean maximum and minimum temperature during the whole crop growth period was 32.13 and 22.84°C while the mean maximum and minimum relative humidity were 84 and 60.4%, respectively (Fig. 1).

All the data recorded were statistically analyzed using the standard procedures of split-plot design (Gomez and Gomez, 1984). Analysis of variance (ANOVA) was used to determine the influence of all treatment. Once F ratio was significant, a multiple mean comparison was performed using Fisher's Least Significance Difference Test (0.05 probability level).

## RESULTS AND DISCUSSION

**Effect of cultivars:** The present study showed that the superfine grain aromatic hybrid Pusa Rice Hybrid 10 (PRH-10) maintained its significant superiority in morphological parameters i.e. plant height (119.73cm), number of leaves/$m^2$ (305.89 and 2058.11 at 30 and 60 DAS, respectively) (except at 90 DAS), and leaf area index (0.36 and 4.31 at 30 and 60 DAS) (except at 90 DAS) as compared to other rice cultivars under direct seeded conditions (Table 1). MTU 7029 recorded significantly higher number of leaves/$m^2$ (1715.78) at 90 DAS than remaining cultivars. However, the LAI at 90 DAS in PRH-10 (4.64) was higher than other cultivars, but it was at par with MTU 7029 (4.22). In contrast, the number of leaves/$m^2$ continued to increase up to 60 DAS after that decreased in all the cultivars except in MTU 7029, in which from 60 DAS (1650.22) to 90 DAS (1715.78) slight increment was noticed. All the cultivars in the study recorded maximum LAI value during flowering stage (90 DAS). However, at 90 DAS, the cultivar NDR 97 registered lower LAI indicating its physiological maturity at this stage. MTU 7029 (42.71 and 42.04) mentioned significantly higher chlorophyll content in functioning leaves during the entire period of observations than the HUR 105 (36.36 and 34.38), HUR 4-3 (38.69 and 35.44) and NDR 97 (36.98at 90 DAS) at 30 and 60 DAS, respectively while NDR 97 at 60 DAS (40.53) and PRH-10 at 60 (41.37) and 90 DAS (40.88) had statistically comparable chlorophyll content with MTU 7029 (Table 1). The plant height, number of leaves (at 30 and 90 DAS) and LAI of rice hybrid PRH-10 was more than inbred cultivars due to more number of tillers/$m^2$ as well as wider and longer leaves or might be due to better utilization of available natural resources like photoperiod and temperature for growth and development which may result in more nitrogen absorption for the synthesis of protoplasm responsible for rapid cell division which may increase the plant in shape and size or may be due to genetical characters of the cultivar (Kumar *et al*., 2002; Adhikari *et al*., 2004; Gautam *et al*., 2008; Meena *et al*., 2015). Rice hybrids show hetero-biltios is for leaves production due to higher tillers per plant. The same higher value of LAI was also reported in rice hybrid at heading stage by Yang *et al.* (2001). The higher chlorophyll content in cultivar MTU 7029 was due to the genetic character of the cultivar. Statistically similar chlorophyll content in hybrid cultivar PRH-10 and MTU 7029 may be due to the fact that cultivar PRH-10 accumulate higher nitrogen from the soil than the other cultivars and chlorophyll content in leaves is directly associated with nitrogen uptake.

The rice hybrid PRH-10 registered significantly longer panicles (27.92 cm), more number of grains/panicle (178.70), test weight (26.35 g) and harvest index (53.25) than the remaining tested cultivars (Table 2a). Furthermore, the number of grains/panicle was statistically comparable in PRH-10 (178.70), HUR 4-3 (157.50) and MTU 7029 (153.50). The differences in test weight among HUR 105 (23.05 g), HUR 4-3 (22.15 g), NDR 97 (19.91 g) and MTU 7029 (18.62 g) were also significant, and it was in decreasing order. The cultivar MTU 7029 had more number of effective tillers/m$^2$ (289.67) than the rest of the cultivars. The higher values of yield attributes recorded by hybrid PRH-10 over inbred cultivars was associated with its higher number of tillers per unit area, better crop growth and development, higher photosynthetic efficiency due to higher LAI at flowering and also towards physiological maturity. Significantly higher harvest index in PRH-10 than the rest of the tested cultivars was due to the higher dry matter accumulation and consequently higher total biological yield. Similarly, grain yield in PRH-10 (5582.32 kg/ha) was significantly higher over cultivar HUR 4-3 (4612.99 kg/ha) and NDR 97 (3397.82 kg/ha) whereas; it was statistically comparable with MTU 7029 (5489.24 kg/ha) and HUR 105 (5022.03 kg/ha). The straw yield of cultivar HUR 4-3 (5589.20 kg/ha) was significantly more over the cultivar PRH-10 (4924.01 kg/ha) and NDR 97 (4473.53 kg/ha), although; HUR 4-3 (5589.20 kg/ha), HUR 105 (5402.74 kg/ha) and MTU 7029 (5176.16 kg/ha) had non-significant straw yield. The higher grain yield of a hybrid over conventional cultivar was perceived mainly due to the heterosis effect (Virmani, 1996) or it was also due to the better formation of yield attributes *i.e.* test weight, panicle length and number of grains/panicle. The statistically comparable grain yield in MTU 7029 with PRH-10 was due to its significantly higher number of effective tillers per unit area over other cultivars.

**Effect of crop geometry:** Plant population as a consequence of different spacing treatment led to variation in growth attributes, yield attributes and finally grain yield due to inter and intra-plant competition for solar radiation, space, and nutrients (Gautam *et al.*, 2008). Amongst different crop geometry, critical difference (CD) values at $p$=0.05 were used to determine the significance. Three plant spacing – 20 x 10, 20 x 20 and 25 x 25 cm$^2$ – revealed that closer spacing of 20 x 10 cm$^2$ maintained it's significant superiority in producing relatively higher number of leaves/m$^2$ (320.87 and 2132.40 at 30 and 60 DAS, respectively) and leaf area index (0.35, 3.58 and 3.89 at 30, 60 and 90 DAS, re-

**Table 1.** Effect of crop geometry on plant height, number of leaves/m$^2$, leaf area index and chlorophyll content on dry direct seeded rice cultivars at different growth stages

| **Treatment** | **Plant height (cm)** | **Number of leaves/m$^2$** | | | **Leaf area index (LAI)** | | | **Chlorophyll content** | |
|---|---|---|---|---|---|---|---|---|---|
| | **At harvest** | **30 DAS** | **60 DAS** | **90 DAS** | **30 DAS** | **60 DAS** | **90 DAS** | **60 DAS** | **90 DAS** |
| Cultivar | | | | | | | | | |
| MTU 7029 | 110.52 | 238.89 | 1650.22 | 1715.78 | 0.29 | 3.08 | 4.22 | 42.71 | 42.04 |
| NDR 97 | 84.48 | 249.22 | 1890.89 | 1143.11 | 0.29 | 3.28 | 1.39 | 40.53 | 36.98 |
| HUR 105 | 111.99 | 267.67 | 1721.11 | 1448.56 | 0.31 | 3.17 | 3.84 | 36.36 | 34.38 |
| HUR 4-3 | 101.15 | 255.89 | 1599.56 | 1373.00 | 0.30 | 2.82 | 3.46 | 38.69 | 35.44 |
| PRH-10 | 119.73 | 305.89 | 2058.11 | 1401.00 | 0.36 | 4.31 | 4.64 | 41.37 | 40.88 |
| SEm± | 1.30 | 4.27 | 35.82 | 20.22 | 0.005 | 0.14 | 0.20 | 0.84 | 0.41 |
| CD ($P$=0.05) | 4.24 | 13.92 | 116.80 | 65.95 | 0.017 | 0.44 | 0.66 | 2.74 | 1.35 |
| Crop geometry (cm$^2$) | | | | | | | | | |
| 20 x 10 | 107.11 | 320.87 | 2132.40 | 1420.13 | 0.35 | 3.58 | 3.89 | 38.64 | 36.21 |
| 20 x 20 | 105.24 | 257.13 | 1720.87 | 1301.53 | 0.30 | 3.35 | 3.41 | 40.19 | 38.44 |
| 25 x 25 | 104.37 | 212.53 | 1498.67 | 1527.20 | 0.28 | 3.03 | 3.22 | 40.96 | 39.19 |
| SEm± | 0.77 | 2.74 | 23.44 | 22.00 | 0.003 | 0.07 | 0.07 | 0.50 | 0.26 |
| CD ($P$=0.05) | NS | 8.10 | 69.13 | 64.90 | 0.011 | 0.20 | 0.21 | 1.49 | 0.77 |

**Table 2a** Effect of crop geometry on yield attributing characters, biological yield and harvest index (%) of dry direct seeded rice cultivars

| **Treatment** | **Yield attributing characters** | | | | **Biological yield** | | **HI (%)** |
|---|---|---|---|---|---|---|---|
| | **Panicle length (cm)** | **No. of effective tillers/$m^2$** | **No. of grains/ panicle** | **Test weight (g)** | **Grain yield (kg/ha)** | **Straw yield (kg/ha)** | |
| Cultivar | | | | | | | |
| MTU 7029 | 22.12 | 289.67 | 153.50 | 18.62 | 5489.24 | 5176.16 | 51.51 |
| NDR 97 | 22.45 | 234.22 | 96.40 | 19.91 | 3397.82 | 4473.53 | 43.13 |
| HUR 105 | 22.14 | 246.33 | 144.70 | 23.05 | 5022.03 | 5402.74 | 48.17 |
| HUR 4-3 | 24.75 | 227.33 | 157.50 | 22.15 | 4612.99 | 5589.20 | 45.20 |
| PRH-10 | 27.92 | 254.89 | 178.70 | 26.35 | 5582.32 | 4924.01 | 53.25 |
| SEm± | 0.36 | 3.64 | 9.08 | 0.21 | 218.79 | 200.01 | 0.17 |
| CD ($P=0.05$) | 1.17 | 11.87 | 29.62 | 0.69 | 713.51 | 652.28 | 0.56 |
| Crop geometry ($cm^2$) | | | | | | | |
| 20 x 10 | 23.63 | 255.53 | 136.10 | 21.92 | 4895.10 | 5161.76 | 48.45 |
| 20 x 20 | 23.71 | 234.33 | 148.80 | 22.06 | 4601.74 | 5209.02 | 46.48 |
| 25 x 25 | 24.28 | 261.60 | 153.60 | 22.07 | 4965.79 | 4968.60 | 49.77 |
| SEm± | 0.09 | 2.30 | 3.05 | 0.20 | 100.42 | 131.24 | 0.20 |
| CD ($P=0.05$) | 0.29 | 6.78 | 9.01 | NS | 296.23 | NS | 0.60 |

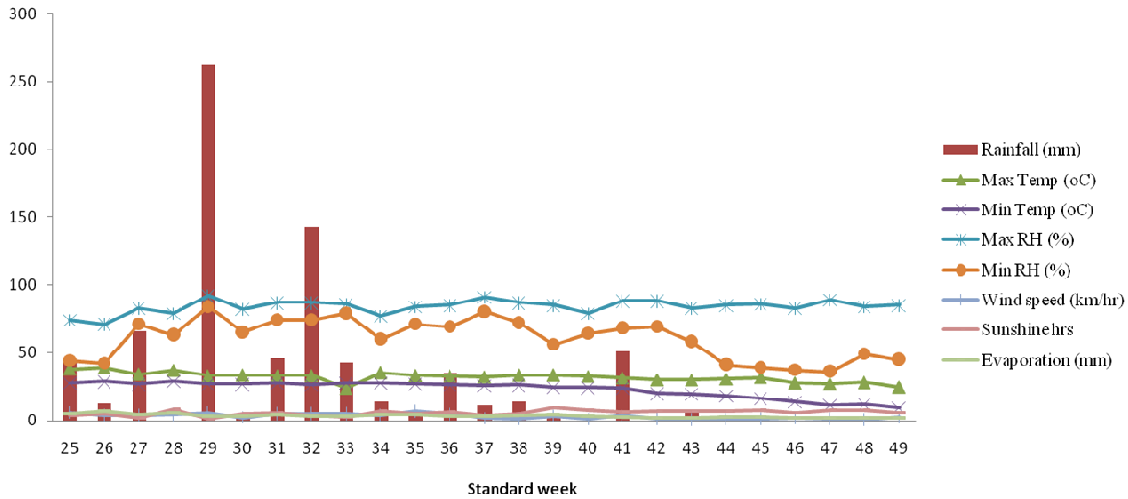


**Fig. 1.** *Standard week wise Meterological observations recorded during the period of experimentation (June, 2014—Dec., 2014).*

**Table 2b.** Interaction effect of crop geometry and cultivars on panicle length in dry direct seeded rice.

| **Treatment** | **Cultivars** | | | | |
|---|---|---|---|---|---|
| **Crop geometry (cm$^2$)** | **MTU 7029** | **NDR 97** | **HUR 105** | **HUR 4-3** | **PRH-10** |
| 20 x 10 | 21.72 | 21.55 | 22.13 | 24.98 | 27.75 |
| 20 x 20 | 22.50 | 22.13 | 21.93 | 24.35 | 27.65 |
| 25 x 25 | 22.13 | 23.67 | 22.35 | 24.92 | 28.35 |
| | | | | SEm± | CD(P=0.05) |
| Two plant geometry at the same cultivar | | | | 0.22 | 0.64 |
| Two cultivar means at the same or different plant geometry | | | | 0.44 | 0.87 |

spectively) over the square planting of 20 x 20 cm$^2$ and 25 x 25 cm$^2$ except the number of leaves/m$^2$ at 90 DAS (1527.20) as in wider spacing of 25 x 25 cm$^2$. The variations in plant height at harvest stage due to different crop geometry were non-significant. The maintenance of a significantly higher number of leaves/m$^2$ at 20 x 10 cm$^2$ over other spacing was due to higher plant population per unit area. An increase in a number of plants per unit area at a spacing of 20 x 10 cm$^2$ led to maintenance of a higher number of leaves as well as LAI than the wider spacing. The significant increase in number of leaves/m$^2$ at 90 DAS in wider spacing over remaining two spacing might be due to the higher mortality of tillers/m$^2$ associated with higher plant population that led to higher below and above ground competition for space, nutrient, water, air and light for performing normal physiological activities of the plant. Chlorophyll content in plant leaves increased with increase in plant geometry as in wider plant spacing of 25 x 25 cm$^2$ (40.96 and 39.19) and 20 x 20 cm$^2$(40.19 and 38.44) over narrow spacing of 20 x 10 cm$^2$ (38.64 and 36.21) at 60 and 90 DAS, respectively; this might be due to the fact that with increase in plant spacing the inter and intra-plant competition for nutrients decreases and as a consequence plant accumulated more nitrogen as compared to closer plant spacing.

The significant increase in number of effective tillers/ m$^{-2}$ at plant spacing 25 x 25 cm$^2$ (261.60) and 20 x 10 cm$^2$ (255.53) was observed over spacing of 20 x 20 cm$^2$ (234.33). However, a number of effective tillers/m $^{-2}$ was at par between plant spacing of 25 x 25 cm$^2$ and 20 x 10 cm$^2$. The higher number of effective tillers/m$^2$ at 25 x 25 cm$^2$ spacing was due to lesser inter- and intra-plant competition for water, nutrient, light, and space. Direct seeding of rice cultivars at a wider spacing of 25 x 25 cm$^2$ resulted in significantly higher panicle length (24.28 cm), and a number of grains/ panicle(153.60) as compared to narrow plant spacing 20 x 10 cm$^2$ (Table 2a). Interaction effect of cultivars and spacing revealed the significantly longer panicles with cultivar PRH-10 at 25 x 25 cm$^2$ (28.35 cm) plant geometry over other cultivar and plant geometry interaction except for cultivar PRH-10 at 20 x 10 cm$^2$ (27.75 cm) with which it was not significant (Table 2b). The appreciable augmentation in yield ascribing characters of dry direct-seeded rice cultivars at wider spacing was due to better utilization of space, solar radiation and other inputs resulting in more panicle length and number of grains/panicle as compared to closer spacing. Furthermore, at closer plant spacing higher dry matter accumulation might have limited the

**Table 3.** Effect of crop geometry on economics and production efficiency of dry direct seeded rice cultivars

| Treatment | Economics | | | | Production efficiency (₹/ha/day) |
|---|---|---|---|---|---|
| | Cost of cultivation (₹/ha) | Gross return (₹/ha) | Net return (₹/ha) | B:C ratio | |
| MTU 7029 + 20 x 10 $cm^2$ | 35466.53 | 84368.36 | 48901.83 | 1.38 | 346.82 |
| MTU 7029 + 20 x 20 $cm^2$ | 35361.53 | 96100.36 | 60738.83 | 1.72 | 426.74 |
| MTU 7029 + 25 x 25 $cm^2$ | 35291.53 | 97841.84 | 62550.31 | 1.77 | 436.40 |
| NDR 97 + 20 x 10 $cm^2$ | 35211.53 | 66294.33 | 31082.80 | 0.88 | 335.43 |
| NDR 97 + 20 x 20 $cm^2$ | 35136.53 | 53847.96 | 18711.43 | 0.53 | 199.77 |
| NDR 97 + 25 x 25 $cm^2$ | 35086.53 | 65460.91 | 30374.38 | 0.87 | 321.99 |
| HUR 105 + 20 x 10 $cm^2$ | 35361.53 | 96336.93 | 60975.40 | 1.72 | 482.65 |
| HUR 105 + 20 x 20 $cm^2$ | 35256.53 | 84175.32 | 48918.79 | 1.39 | 386.20 |
| HUR 105 + 25 x 25 $cm^2$ | 35186.53 | 87141.88 | 51955.35 | 1.48 | 408.03 |
| HUR 4-3 + 20 x 10 $cm^2$ | 35361.53 | 80797.81 | 45436.28 | 1.28 | 348.62 |
| HUR 4-3 + 20 x 20 $cm^2$ | 35256.53 | 80285.48 | 45028.95 | 1.28 | 342.86 |
| HUR 4-3 + 25 x 25 $cm^2$ | 35186.53 | 85813.18 | 50626.65 | 1.44 | 384.51 |
| PRH-10 + 20 x 10 $cm^2$ | 39382.86 | 105771.9 | 66389.08 | 1.69 | 592.76 |
| PRH-10 + 20 x 20 $cm^2$ | 38782.86 | 99118.40 | 60335.54 | 1.56 | 535.52 |
| PRH-10 + 25 x 25 $cm^2$ | 38382.86 | 98016.09 | 59633.23 | 1.55 | 529.29 |

diversion of photosynthates to grains (Gautam *et al.*, 2008; Sihag *et al.*, 2015). Direct seeding of rice at a spacing of 25 x 25 $cm^2$ proved significantly superior regarding grain yield (4965.79 kg/ha) and harvested index (49.77) over other spacing. It was mainly attributed to greater number of grains/panicle, panicle length and 1000-grain weight in 25 x 25 $cm^2$ plant spacing. However, the spacing 25 x 25 $cm^2$ (4965.79 kg/ha) and 20 x 10 $cm^2$ (4895.10 kg/ha) had statistically comparable grain yield. Similarly, significantly higher harvest index at wider plant spacing (25 x 25 $cm^2$) over two other spacing was due to higher grain yield.

**Effect of cultivar and crop geometry on economics:** The higher gross return (105771.9 ₹/ha) and net return (66389.08 ₹/ha) was obtained in rice hybrid PRH-10 at closer plant spacing of 20 x 10 $cm^2$ over other cultivars and plant spacing combinations (Table 3). However, the maximum benefit-cost ratio (1.77) was found with growing of cultivar MTU 7029 at plant spacing of 25 x 25 $cm^2$; this was due to the lesser cost of cultivation in association with comparatively higher grain yield.

**Effect of cultivar and crop geometry on production efficiency:** The production efficiency significantly influenced due to the cultivars and plant spacing combinations (Table 3). PRH-10 at closer plant spacing 20 x 10 $cm^2$ obtained the maximum production efficiency (592.76 ₹/ha/day) over rest of the cultivars and plant spacing combinations which decrease towards increasing plant spacing. The fact behind this result was higher grain yield in PRH-10 in association with short growth cycle as compared other high yielding cultivars MTU 7029, HUR 105 and HUR 4-3.

## Conclusion

The present study demonstrated that the cultivar PRH-10 improved plant height (119.73 cm), LAI (4.64), panicle length (27.92 cm), a number of grains/panicle (178.70), test weight (26.35 g), grain yield (5582.32 kg/ha) and harvest index (53.25). Similarly, cultivar MTU 7029 performed better in a number of leaves/$m^2$ (1715.78) and number of effective tillers/$m^2$ (289.67). Amongst crop geometry 25 x 25 $cm^2$ improved number of leaves/$m^2$ (1527.20) at 90 DAS, panicle length (24.28 cm), number of effective tillers/$m^2$ (261.60), number of grains/panicle (153.60), test weight (22.07 g), grain yield (4965.79 kg/ha) and harvest index (49.77) whereas; in 20 x 10 $cm^2$ LAI (3.22) was improved at 90 DAS. The cultivar PRH-10 at 20 x 10 $cm^2$ was superior regarding gross return (105771.9 ₹/ha), net return (66389.08 ₹/ha) and production efficiency (592.76 ₹/ha/day) and the cultivar MTU 7029 at 25 x 25 $cm^2$ had higher benefit cost ratio. Therefore, for getting higher net return and production efficiency cultivar PRH-10 at plant spacing 20 x 10 $cm^2$ can be raised in dry direct-seeded rice in Varanasi region of Eastern Uttar Pradesh.

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