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Productivity of aerobic rice hybrid under varying plant density: A review

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Abstract
Rice (*Oryza sativa* L.), one of most important food crops in the world, forms staple diet of 2.7 billion people. Globally it is cultivated in an around 150 million ha, producing 573 million tonnes paddy with an average productivity of 3.83 tonnes ha^{-1}. Its cultivation is of immense importance for food security of Asia, where more than 90% of global rice is produced and consumed. Rice provides 32-95% of the dietary energy and contributes 40% of food grain production, providing direct employment to 70% people in rural areas. Being the staple food for more than 65% of people, our national food security hinges on the growth and stability of its production. In India, rice is grown in an area of 44 million ha under four major eco systems i.e. irrigated (21 million ha), rainfed lowland (14.2 million ha) rainfed upland (6.3 million ha) and flood-prone (3.1 million ha) with total production of 105.24 million tonnes and average productivity of 2.4 t ha^{-1}. Whereas in Jharkhand Rice is cultivated in 17.4 lakh ha with total production of 31.6 lakh tonnes. Directorate of Economics and Statistics (2012-2013).
More than half of the rice area (55%) in India is under rainfed condition and distribution-wise 80% of the rainfed rice area is in eastern India, making its cultivation vulnerable to vagaries of monsoon. In the past four decades, our country has made spectacular progress in rice production and productivity. The increase was 4.5 times from 20.6 million tonnes in 1950-51 to 105 million tonnes paddy in 2012-13. Asia's food security depends largely on the irrigated rice fields, which produces three quarters of all rice harvested. But rice is a profligate user of water, consuming half of all developed fresh water resources. The increasing scarcity of water threatens the sustainability of the irrigated rice production system and hence the food security and livelihood of rice producers and consumers.

Keywords: Rice (*Oryza sativa* L.), aerobic rice weed dynamics, growth attributes, yield attributes, economics of aerobic rice

Introduction

Effect of seed rates on growth characters

Increasing seed rate from 50 to 75 kg per ha with single row hand drill in 22.5 cm spaced rows significantly increased dry matter per meter square and total number of effective tillers per meter row length under direct seeded rice condition (Khaliq *et al.*, 2012) [43].

Prasad *et al.* (1999) also reported that increasing seed rates from 60 to 80 kg ha^{-1} increased the plant height and the number of tillers meter square beyond which there is no further increase. Aerobic rice variety Han Dao 297 recorded the best population density with maximum number of total productive tillers, spikelet number per panicle and percentage of filled spikelets when seeded at 60 kg per ha seed rate (Yu Jun *et al.*, 2007) [90].

Especially under aerobic conditions, it is often felt that there is a higher risk of poor crop establishment associated with lower seeding rates. Guyer and Quadranti (1985) [32] advocated use of higher seeding rate only if no weed control or partial weed control is planned. Seed rate of 30 kg per ha, row spacing of 20cm, irrigation at150 percent CPE

(Cumulative Pan Evaporation), N_{120} $P_{6}o$ K_{50} kg per ha fertilization, and weed control through Pendimethalin @ 1 kg ai per ha (at 3-4 DAS) + two mechanical weedings at 15 and 30 days after sowing were found promising for significant performance of growth and development characters like number of tillers meter square and dry matter production meter square in aerobic rice (Kumar Mahender, 2012) [46].

Singh *et al.* (1998) [79] observed that the height of the rice plant increased with increasing seed rate from 80 to 120 kg per ha under flood prone condition. Similarly Sharma *et al.* (1998) [74] also reported that number of tillers increased with increasing seed rates (100-1000 seeds m^{-2}) under semi deep water

condition (0-100 cm.) at Cuttack, India with rice cv. Nalini.

Effect of seed rates on yield and yield attributing character

Seeding density of 80 kg per ha recorded significantly higher panicle bearing tillers per meter square, spikelets per panicle and 1000-grain weight (Akbar and Ehsanullah, 2004) [1]. Grain yield showed an increase of about 30 percent Kernel protein and amylase contents were also increased at the same seeding rate as compared to any other lower or higher seeding density.

Grain yield increased as seeding rate increased from 10 to 40 lb seed per acre but could not prove significant between the 30-lb and 40-lb seeding rates (Frizzell *et al.*, 2006) [25].

Grain yield of aerobic rice variety, Han Dao 297 (HD297) increased with increasing seed rates 60, 90 and 120 kg ha^{-1} to the tune of 3.8, 3.5 and 3.4 percent respectively (Yu Jun *et al.*, 2007) [90]

Farmers having difficulties in managing weeds should avoid lower seeding rates to improve the consistency of weed management. By the suitable weed management better yield of aerobic rice was obtained with optimum seed rate and increased the yield up to the maximum level. (Guillermo *et al.* 2009) [29], Seed rate and row spacing showed marked effect on yield attribute formation and ultimately the yield of aerobic rice (Directorate of Rice Research Report, 2012) [4, 46]. Aerobic rice yield increased significantly with increasing seed rate from the lowest of 20 kg per ha to 30 kg per ha at Kota and Ranchi (5.29 and 5.14 t ha^{-1}), to 35 kg per ha at Hathwara, Pantnagar, and Varanasi (3.52, 5.07 and 5.13 t ha^{-1}) and to the highest of 40 kg per ha at Nagina and Pusa (6.21 and 3.94 t ha^{-1}). Significantly higher panicle number and panicle weight with 30 kg seed rate and with slight decline or no change in panicle weight were recorded at 35 and 40 kg per ha seed rate resulted in the higher grain yields of aerobic rice. Ghosh *et al.* (1984) [27], studied on different seed rates and reported that increasing the seed rate from 60-90, 100 and 120 Kg per ha improved the number of panicles meter square.

Hybrid rice Feng-liang-you-xiang-1 sown directly at the rate of 22.5, 30, 37.5, 45, 52.5, 60 kg per ha influenced whole growth period, yield components, yield and relative economic output significantly (He Wen-jing *et al.*, 2013) [33]. It followed a quadratic curve relationship between seeding rate and whole growth period. However, where the seeding rates were less than 30 kg per ha or more than 52.5 kg per ha, the whole growth period was obviously shortened compared with that of other seeding rate. Among the yield components, panicles, grains per panicles, seed-setting rate and harvest index were affected significantly by the seeding rate, showing a linear relationship of quadratic curve; while the 1000 seed weight remained unaffected.

In a trial conducted by Jones and Snyder, (1987) [38] in Southern Florida with two contrasting plant types, tall (cv. Lebonnet) and semi-dwarf (cv. Bellemont and Lemont), were drill-seeded at rates of 50, 100, and 150 kg seed per ha with 0.15-m, 0.20-m, and 0.25-meter row spacings in three tests conducted on an organic soil revealed that increased seeding rates increased panicles per square meter in all tests for both plant types. However the increase in panicles was compensated by decrease in filled grain number per panicle, resulting in no significant variation in yield among seeding rates. It appears that seeding rates of 80 to 100 kg per ha are sufficient to obtain optimum yield in southern Florida. Kobayashi *et al.* (1971) [40] from Japan also reported that increasing the seeding rate in rice increased the panicle number per unit area.

In an experiment with three seed rates (60, 80 and 100 kg seed ha^{-1}) Prasad *et al.* (1999) found that panicles per meter square was maximum with a seeding rate of 80 kg seed per ha in line sowing, but with 100 kg per ha in broadcasting. In the same experiment it was observed that number of fertile spikelet per panicle recorded highest at lower seed rates i.e., 60 kg per ha. Similar result was noted in case of the test weight in which seeding rate with 60 kg per ha increased the 1000 grain weight than the higher seed rates.

A field experiment was concluded that high seeding rate and the subsequent high plant numbers were not required to obtain high yields but were used as insurance against factors affecting uniform plant establishment (Lewin *et al.*, 2005) [47].

Reddy *et al.* (1986) [69] reported that the number of panicles increased with the increasing seeding rates and also observed more panicle length.

In a field trial near Stuttgart, AR, Columbia, during 2002 to 2004 with the objective to study the effect of rice seeding rate on yield components of three modern, long-grain rice cultivars with seed rate lower-than recommended, Ottis and Talbert (2005) [55] concluded that lower seeding rates would produced yields similar to currently recommended rates. Rice seeding rates from 57 to 500 seeds meter square resulted in a rice density ranged from 37 to 373 plants meter and did not affect rice aboveground biomass production, panicle density, harvest index (HI), or rice yield, regardless of cultivar.

In a study on effects of seeding and nitrogen rates on yield of some high yielding rice varieties growing on alluvial soils in the Mekong delta sown in the dry season 2002-2003, Phung *et al.* (2003) concluded that the general seed rate recommended for row seeding is about 100-120 kg per ha. Under the condition of good land levelling, seeding rate can be reduced further up to 60 kg per ha to increase economic efficiency in rice production.

Increased seeding rate may not be able to increase the weed competitiveness of a crop due to greater intra-specific competition between crop plants especially under stressful environmental conditions rather it may intensify the negative impact of higher intra-specific competition (Zimdahl, 1983; Krikland *et al.*, 2000) [92]. The circumstantial evidences suggest that, increased seeding rate of rice might have some positive effect on weed suppression.

Combination of a weed suppressive rice cultivar with proper seeding rate proved to be effective for weed control in aerobic rice (Zhao *et al.*, 2007) [91]. They also reported that, under aerobic condition, seeding rate as high as 500 seeds meter square reduced weed growth and increased crop yield to some extent compared with a low seeding rate of 300 seeds m^{-2}.

Effect of number of seedlings on economics

Dayal (1999) worked on rice hybrids 'VRH 704' and 'HRI 129' at Kanpur and concluded that maximum net income were found with 2 seedlings per hill (`15035.70 ha$^{-1}$) as compared to 1 seedling per hill (`13492.47 ha^{-1}).An field investigation carried out by Chauhan (2005) at C.S.A.U.A. & T. Kanpur and revealed that crop transplanted with 3 seedlings per hill recorded maximum net return (`6765.70 ha$^{-1}$) than the 1(`3503.60 ha^{-1}) and 2 seedlings per hill (`5823.40 Rs/ha^{-1}). However, 3 seedlings per hill also gave highest return per rupee (1.29) which was significantly higher than 1 and 2seedlings per hill, respectively.

Effect of spacing on growth characters

Sowing of aerobic rice at a spacing of 45 cm recorded significantly higher number of leaves per hill (187.3), leaf area per hill (4583 cm^2), number of tillers per hill (41.1), total dry matter production (79.4 g hill^{-1}) than other spacing (Basavaraja, 2010) [7]. Bridgit and Potty (2002) [12] also found significantly higher dry matter production of rice with 30 cm x 30 cm planting geometry (64.6 g hill^{-1}) compared 45 cm x 20 cm (55.8 g hill^{-1}). Higher yield in 30 cm x 30 cm spacing was due to less competition among the plants for nutrients, moisture and better aeration which encouraged better root development. Whereas Dhal and Mishra (1994) [20] observed that maximum dry matter yield from closer spacing of 10 x 10 cm as against wider spacing of 20 x 10 and 20 x 20 cm.

Maximum plant height (87.2 cm) was recorded with crop planted at 20 x 10 cm than the crop planted with 15 x 10 cm spacing (Dhal and Mishra, 1994) [20].

Maximum plant height (70.9 cm), effective tillers per hill (8.13), leaf area index (5.13), leaf area duration (252.9 days), dry matter production hill^{-1} (34.41 g hill^{-1}), root volume (26.1cc hill^{-1}), root weight (3.83 g hill^{-1}), crop growth rate (26.07 g m^{-2} day^{-1}), relative growth rate (64.79 mg g^{-1} day^{-1}), net assimilation rate (7.37 g m^{-2} leaf area day^{-1}) were recorded with 20cm spacing (Jena *et al.*, 2010) [37]. Uddin *et al.* (2010) [85] also observed improved plant height (cm), total tillers per hill, effective and non-effective tillers per hill with 15x15 cm spacing with Aman's rice cultivars under coastal high land ecosystem.

Dry matter production increased with higher plant population per unit area (Kabayashi *et al.*, 1989) [39]. Ikarashi *et al.* (1990) [34] noted greater number of effective tillers with denser planting under agro-ecological condition of Japan. Whereas Shinde *et al.* (2005) [75] concluded that wider spacing of 30 cm produced significantly higher tillers per m and total dry matter production.

Wider spacing of 20 x 15 cm with hybrid rice 'PA 6201' recorded maximum plant height, total and effective tillers hill^{-1} and dry matter accumulation per clump than that closer spacing of 20 x 10 and 15x15 cm (Nayak *et al.*, 2003) [51].

Dry matter production, number of productive tillers per meter square plant stand were highest with 15 x 10 cm plant spacing with rice hybrids 'DRRH 1' and 'APHR 2' as compared to other plant spacing (20 x 10, 15 x 15 and 20 x 15 cm) under southern agro climatic zone of Andhra Pradesh (Obulamma and Reddeppa, 2002) [52].

Om *et al.* (1993) [54] in an experiments with rice cv. 'Basmati 370' at Rice Research Station, Kaul also noticed that closer spacing 15 x 15 cm produced maximum plant height (154.9 cm) than that of wider spacing of 22.5 x 15 cm (152.7 cm) and 30 x 15 cm (150.8 cm). Sultana *et al.* (2012) [82] observed that the row to row spacing had significant effect on number of effective tillers per hill, non-effective tillers per hill while plant height, number of total tillers, remained unaffected. Rice crop planted with 20 x 10 cm spacing produced significantly more effective tillers per hill (8.95) than the crop planted with 15x10 (7.41) and 10 x 10 cm (6.15) spacing (Patra and Nayak, 2001) [59].

Hybrid rice 'PA 6201' produced more effective tillers per hill with 20 x 20 cm (9.5) than the crop planted with 20 x 15 (9.0), 20 x (7.7) and 15 x 15 cm (8.7) plant geometry (Kewat *et al.*, 2002; Padmavati *et al.* 1998) [42].

Dry matter production per clump decreased with closer spacing. Wider spacing of 20 x 15 cm recorded 98.2 g dry matter per clump as against 87.2 g per clump with closer spacing of 10 x 10 cm (Raju *et al.*, 1984) [66]. Reddy and Reddy (1986) [69] recorded more plant height under closer spacing of 10 x 10 cm than under wider spacing. Banerjee *et al.* (2011) [6] observed that Hybrid rice variety 'Pro Agro 6201', with different planting geometry had a remarkable influence in increasing the number of effective tillers meter square and dry matter per meter square and was significantly higher with the closer spacing (15cm x 15cm) and produced significantly higher grain yield (6.00 t ha^{-1}).

Srinivasan (1990) [80] reported that closer spacing of 15 x 10 cm produced significantly higher productive tillers per meter square and dry matter accumulation per clump than the wider spacing of 20 x 10 and 25 x 10 cm in case of rice cv. 'Bhavani' at Madurai.

Rice crop planted with closer spacing of 15 x 15 cm produced more number of tillers per meter square and leaf area index than the crop planted with wider spacing (DRR, 1991). Similar results were also reported from the Central Rice Research Institute (CRM), Cuttack (CRRI, 1998) [18]. According to Miller (1991) [50], above ground vegetative biomass and tillers number were increased with increasing plant population.

Verma *et al.* (2002) studied the effect of spacing on rice hybrid 'PA 6201' and found that crop planted with 20 X 20 and 20 x 15 cm produced significantly more number of productive tillers per meter than the crop planted with 20 x 10 cm.

Effect of spacing on yield and yield attributing characters

Highest grain yield (6.73 t ha^{-1}), N uptake (124.8 kg ha^{-1}), P uptake (40.5 kg ha^{-1}), K uptake (84.3 kg ha^{-1}), water use efficiency (2.879 kg ha^{-1}-mm^{-1}), net return (72,750) and benefit: cost (2.09) were recorded at 20 cm x 20 cm spacing under SRI (Avasthe *et al.*, 2009). The optimum spacing under system of rice intensification for rice variety 'RCPL 1-87-8', 'RC Maniphou-7' and local cv 'Thulo Attey' was 20 cm x 20 cm. 'Pusa Sugandh-2' recorded a 2.0% yield decrease at 20 x 20 cm and 23.0% yield decrease at SRI with 10 x 10 cm spacing, as compared to conventional rice cultivation.

Increase in spacing of rice induced vigorous plant growth as well as increased the number of panicles per hill, grain yield per hill, filled grains per panicle and 1000 grain weight. The spacing 22.5 x 22.5 cm proved more appropriate because it produced better plant stand, gave more panicle density and higher grain yield than other two spacings (Baloch *et al.*, 2002) [5]. Banerjee *et al.* (2011) [6] reported that panicle length, filled grains per panicle and test weight of hybrid rice 'Pro Agro 6201' increased significantly with the closer spacing (15cm x 15cm) and produced significantly higher grain yield (6.001 ha^{-1}).

A experiment during Kharif at Agronomy Field Unit, University of Agricultural Sciences, G.K.V.K., Bangalore, to study the effect of spacing and genotypes on growth and yield of aerobic rice. The results revealed that sowing of Aerobic rice at a spacing of 45 cm has recorded significantly more panicle length (22.1 cm), number of grains per panicle (195.8) and grain yield (57.3 q ha^{-1}) compared to other spacing (Basavaraja, 2010) [7]. Similarly, Sultana *et al.* (2012) [82] also reported higher grain yield (4.35 t ha^{-1}) from 25 cm row spacing due to the increased number of effective tillers per hill (13.11) (Sultana *et al.,* 2012) [82].

No significant variation due to spacing on harvest index was observed by (Chaudhury, 1991) [14]. However, the highest harvest index (39.4%) was obtained with the wider spacing of 20 x 15 cm.

Chopra and Chopra (2004) [16] reported that wider spacing of 20 x 15 cm, 30 x 15 cm and paired row 20: 40: 20 cm recorded significantly higher number of panicles per plant than the closer spacing of 15 x 15 cm. However, the seed yield was not affected due to different spacing. Similarly Clarete, (1977) [17] observed that row spacing did not markedly affect the yield components but showed significant variation on grain yield. Highest grain yield of 2642 Kg per ha was obtained from plots with row spacing of 30 cm. Lowest grain yield of 1764 Kg per ha was recorded due to row spacing of 45 cm. Close spacing can result in severe competition for nutrients, water and solar radiation leaving very little for use by each plant to grow normally. Reduced plant per unit area and increased interval between rows facilated weeds to grow and thus wider spacing resulted in low yield. Whereas, Dongarwar *et al.* (2002) [22] conducted a field experiment with hybrid rice 'Sahyadri' and reported that plant spacing (20 x 10, 20 x 15 and 20 x 20 cm) did not influence grain yield significantly.

Gunri *et al.* (2004) [30] found that closer spacing of 15 x 15 cm gave maximum length of panicle, number of panicle per meter, number of filled grains per panicle and grain yield as compared to wider spacing of 20 x 15 cm.

Closer spacing of 20 x 10 cm and 15 x 15 $_C$m with rice hybrid 'PA 6201' produced significantly more grain yield 63 and 60 q per ha, respectively over the wider spacing of 20 x 20 (47 q ha^{-1}) and 20 x 15 cm (53 q ha^{-1}). However, panicle length and test weight remained unaffected due to different spacing (Kewat *et al.,* 2002) [42]. Whereas while working with two rice hybrids 'DRRH 1' and 'APHR 2' Obulamma and Reddeppa (2002) [52] reported that crop planted with 20 x 10 cm spacing recorded significantly higher grain yield than that crop planted with 15 x 15 and 20 x 15 cm spacing but there was no significant difference with 15 x 10 cm spacing. Contrary to that Gupta and Sharma (1991) [31] reported from Jabalpur that plant spacing of 10 x 10 and 15 x 15 cm produced greater grain yield (2.86 and 2.82 t ha^{-1}, respectively) than the plant spacing of 15 x 10 and 20 x 10 cm (2.67 and 2.59 t ha^{-1}, respectively).

Jalil (2008) [36] reported that the crop (cv. BRRI dhan 29) with 25 cm row to rowspacing produced the highest grain yield (5.87 t ha^{-1}) under aerobic system of cultivation. Lower grain yield (4.3t ha^{-1}) was obtained from 20 cm row spacing due to fewer effective tillers per hill (12.8) and spikelets per panicle (108.41). Lower straw yield (5.451 ha^{-1}) and biological yield (9.82 t ha^{-1}) were obtained from 25 cm row spacing.

Significantly higher panicle length (26.1 cm), fertile spikelets per panicle (106.7), 1000 grain weight (23.07 g) and finally grain yield 5.87 tonnes per ha were recorded at spacing of 15x15 cm (Jena *et al.,* 2010) [37]. The highest net monetary return (`14432.00 ha^{-1}) and B:C ratio (1.63) were obtained irrespective of varieties planted at 15 xl 5 cm plant spacing.

More panicle length was observed with wider spacing of 20 x 10 cm than the closer spacing of 15 x 10cm (Krishnan *et al.,* 1994) [45]. Where as, Reddy and Reddy (1994) showed that adoption of lower plant density gave significantly higher 1000 grain weight (23.39g). Similar results were also obtained by Kanungo and Roul (1994) [41], Trivedi and Kwatra (1983) [83] and Raju *et al.* (1984) [66].

Under agro climatic condition of China Liu *et al.* (1997) found that 16.5 x 19.8 cm plant spacing proved optimum for hybrid rice. Similarly Padmaja and Reddy (1998) [56] reported that hybrid rice 'APHR 2' had significantly higher grain yield (4.57 t ha^{-1}) with 15 x 15 cm spacing than that with 20 x 15 cm spacing. They also found significantly more filled spikelets per panicle (102) with wider spacing of 20 x 15 cm as compared to that closer spacing of 15 x 15 $_C$m. Similar result was also obtained from CRRI, Cuttack with hybrid rice 'PA 6201' (CRRI, 1998) [18].

In a coordinated trial on different spacings (15 x 15, 20 x 15, 20 x 10 and 25 x 15 $_C$m) conducted at Kapurthala, Karnal and Mandya with promising rice hybrids indicated no significant difference in yield due to spacing. However, 15 x 15 cm in Kapurthala, 20 x 15 cm in Karnal and 20 x 10 cm in Mandya were found to be optimum (DRR, 1995a) [23]. Whereas, Pandey and Tripathi (1995) reported that closer spacing of 15 x 10 cm resulted more grain yield than the wider spacing of 20 x 10 cm.

Increased rice plant density, beyond the optimal, might lead to high dilution effect resulting in lower yield. On the other hand, lower yield at less-than optimal densities is probably due to the inability to intercept maximum available light due to poor stand establishment (Mahajan *et al.,* 2010) [49]. In fact, intra-specific competition due to different seeding densities may vary in their intensity and compensatory growth of individual plant, when grown at lower densities and resulted in similar grain yield over a broad range of densities, a phenomenon known as the law of constant for yield (Bond *et al.,* 2005) [9].

Wider spacing of 30 cm produced significantly higher grain (9.53 t ha^{-1}) straw yield (12.79 t ha^{-1}) of rice attributed mainly due to significantly higher value of number of panicle per meter square (292), length of panicle (25.78 cm) and 1000-grain weight (26.94g) over the closer spacing of 25 cm (Shinde *et al.,* 2005) [75]. Wider spacing recorded 5.77 and 6.80 per cent higher grain and straw yield, respectively over the closer spacing. Similar findings were reported by Dhal and Mishra (1994) [20].

Significantly higher panicle per meter square (615), grain yield (5734 kg ha^{-1}) and straw yield (6528 kg ha^{-1}) were recorded with closer spacing of 15 x 10 cm as compared to with wider spacing of 15 x 10 and 20 x 10 cm (Patra and Nayak, 2001) [59]. However, panicle length, weight per panicle and 1000-grain weight did not varied significantly due to the spacing. The result confirms the findings of Gupta and Sharma (1991) [31].

A field experiment at Dapoli reported that rice crop transplanted with 20 x 20 cm spacing produced significantly more number of panicle per hill (12.25) and weight of panicle per hill (34.13g) than the 15 x 10, 20 x 15 and 20 x 10 cm spacing (Pol *et al.,* 2005) [61]. Wider spacing of 20 x 20 cm recorded significantly higher grain yield to the tone of 11.86, 7.96, and 3.40 percent over 15 x 10, 20 x 10 and 20 x 15 cm spacing, respectively. Similar findings were reported by Chandraker and Chandravanshi (1998) [13] and Dongarwar *et al.* (2002) [22].

Under coastal high land ecosystem Aman's rice cultivar BRRI dhan 44. produced the highest grain yield (4.83 t ha^{-1}) at the spacing of 15 cm x 15 cm (Uddin *et al.,* 2010) [85]. Hybrid rice 'Sahyadri' with closer spacing of 20 x 10 cm produced significantly more grain (63q ha^{-1}) and straw yield (162 q ha^{-1}) than the wider spacing 20 x 20 and 20 x 15 cm, but was at par with 15 x 15 cm (Powar and Deshpande, 2001) [62].

Rajesh and Thanunathan (2003) [65] reported that crop planted with wider spacing of 20 x 15 cm recorded significantly higher grain yield as compared to crop planted with closer spacing of 20 x 10 and 15x15 cm. By skipping one row after every three rows at 15 cm x 15 cm spacing proved to be more effective in producing highest grain yield of 4.51 tonne per ha during the wet season and 5.27 tonne per ha during the dry season (Rautaray S.K., 2007) [68].

Closer spacing of 15 x 15 cm gave higher grain yield than the wider spacing of 20 x 20 cm because of exposer of large number of plants and leaf area to sunlight during the growth period resulting in better photosynthesis and consequently higher yield (Rao and Moorthy, 2003) [67].

Rice hybrid 'PA 6201' and cv 'Lalat' recorded no significant effect of spacing (20 x 10, 15 x 15 and 20 x 15 cm) on harvest index. However, maximum harvest index (42%) was obtained with wider spacing of 20 x 15 cm (Samdhia, 1996).

With rice hybrids TR 6465H', 'IR 68284H', 'IR 68877H,' and 'IR 72' under different plant spacing (20 x 20, 20 x 30, 15 x 30 and 10 x 30 cm) produced no significant variation on yield (Sanico *et al.,* 1998) [72].

According to the Directorate of Rice Research Report, 2012 [4, 46], seed rate and row spacing influence yield attribute formation and ultimately the yield of aerobic rice. Results of the coordinated trial from twelve locations (Bankura, Ghaghraghat, Hathwara, Kota, Ludhiana, Nagina, Pantnagar, Parbhani, Pusa, Ranchi, Varanasi and Hazaribagh) revealed that among the row spacings tested, aerobic rice sown in rows 20 cm apart proved promising for realizing significantly higher productivity at Ranchi (5.48 t ha^{-1}), Varanasi (4.97 t ha^{-1}), Pusa (3.67 t ha^{-1}), Pantnagar (4.74 t ha^{-1}), Kota (5.33 t ha^{-1}), Ludhiana (8.84 t ha^{-1}) and Bankura (3.45 t ha^{-1}), however at Nagina (5.76 t ha^{-1}) 30 cm row spacing proved most productive. Significantly higher panicle number and panicle weight at 20 cm row spacing and higher panicle numbers at 30 cm row spacing are the reasons for higher grain yields.

In hybrid rice 'PA 6201', number of fertile grain per panicle increased with closer spacing of 15 *x* 10 cm than with wider spacing of 20 x 15 cm (Srivastav and Tripathi, 1995).

Maximum plant height (90.2 cm) of rice cv. 'K 39' with closer spacing of 10 x 10 cm and minimum plant height (83.9 cm) with wider spacing of 20 x 20 cm was reported by Shah *et al.* (2008). They also observed more tillers per meter square production with closer spacing of 10 x 10 cm than with wider spacing of 15 x 15 cm. Similar results was also recorded by Kanungo and Roul (1999).

Shivay and Singh (2003) [76] worked with hybrid rice 'PRH 10', planting geometry of 20 x 15, 25 x 12 and 30 x 10 cm did not influenced significantly number of panicle per hill, panicle length, filled grains per panicle, grain weight per panicle, 1000-grain weight, grain and straw yield. This might be due to equal area was provided in each planting geometry per hill. These results confirm the findings of Chopra and Chopra (2000) [15].

An experiment in rice hybrid PA 6201 and local check 'Krant', more panicle length (24.97 cm), filled grains per panicle (100.77), 1000-grain weight (29.24 g) and grain yield (3.98 t ha^{-1}) were recorded with closer spacing of 15 x 10 cm as compared with wider spacing of 20 x 10 and 20 xl5 cm (Shrivastava *et al.,* 1999) [77].

Spacing of 25 x 25 cm resulted in higher grain and straw yields and better economic returns than 30 x 30 cm under SRI system for aromatic rice (Singh *et al.,* 2012) [78]. Averaged over two years, the increase in grain yield with 25 x 25 cm over 30 x 30 cm was to the tune of 19.5 percent.

While working on hybrid rice at Thailand Ferraris *et al.* (1973) [24] found that plant spacing (25 x 25, 25 x 12.5 and 25 x 6.25 cm) did not influence grain yield significantly. Whereas, Trivedi and Kwatra (1983) [83] observed that length of panicle increased with wider spacing. Similarly Sukla *et al.* (1984) recorded more fertile grains per panicle and length of panicle with wider spacing (30 x 10 cm) as compared to that with closer spacing. Similar result was also obtained by Verma *et al.* (1991) [88]. Venugopal and Singh (1985) [87] on other hand observed that there was no significant differences in panicle length due to spacing of 15 x 15, 20 15 and 20 x 20 cm in rice cv. 'DR 92'.

The row to row spacing produced significant effect on yield and yield contributing characters of rice. Number of effective tillers per hill, non-effective tillers per hill and sterile spikelet per hill were affected significantly by row to row spacing while plant height, number of total tillers, panicle length, 1000-grain weight and harvest index remained unaffected (Sultana *et al*,. 2012) [82]. Higher grain yield (4.35 t ha^{-1}) was obtained from 25 cm row spacing due to the increased number of effective tillers per hill (13.11). Higher straw yield (5.56 t ha^{-1}) and biological yield (9.89 t ha^{-1}) were obtained from 20 cm row spacing.

Spacing of 15 x 20 cm performed better for grain yield (3.66 t ha^{-1}), number of productive tillers $hill^{-1}$ (5.13), number of total grains per panicle (91.80), number of filled grains per panicle (84.40) and harvest index (45.50%), (Uddin *et al.* 2010) [85].

Higher grain and straw yield with closer spacing (6.66 lakh hills ha^{-1}) than that with wider spacing (3.33 lakh hills ha^{-1}) was reported by Wagh and Thorat (1987) [89]. They further concluded that crop planted with 15 x 10 cm recorded significantly higher test weight than that with crop planted with 20 x 15 cm spacing.

Effect of spacing on economics

Wider plant spacing of 20 x 20 cm gave the highest net monetary return (23895 ha^{-1}) as compared to closer spacing of 20 x 10 and 20 x 15 cm of hybrid rice 'Sahyadri' (Powar and Deshpande, 2001) [62]. Whereas, Kewat *et al.* (2002) [42] working with rice hybrid 'PA 6201' reported that 20 x 10 cm spacing recorded maximum gross return (42750 ha^{-1}) and net monetary return (27665 ha^{-1}), as well as benefit: cost ratio (2.8) over the 15 x 15, 20 x 15 and 20 x 20 cm spacing.

Growth characters of hybrid rice

Rice hybrids ‘PHB 71’ recorded maximum and significantly higher plant height, productive tillers per m^2 and dry matter accumulation than ‘PMS2A/IR 31802’, ‘PMS10A/PR 106’ and ‘HKR 126’ (Om *et al.* 1997).

Rice hybrid ‘PA 6201’ produced significantly higher productive tillers per hill, dry matter accumulation per plant (Pandey *et al.* 2001) [57] and leaf area index than other rice hybrid tested Obulamma and Reddeppa (2002) [52] also observed that rice hybrids ‘DRRH 1’ and ‘APHR 2’ maintained higher dry matter production, number of productive tillers per meter square, plant stand and leaf area index than other varieties tested.

Yield and yield attributing character of hybrid rice

Rice hybrid'PA 6201' recorded maximum and significantly higher harvest index (42%) than cv 'Lalata' (Samdhia,1996) [71].

Rice hybrid CORH-1fertilized on the basis of soil test crop response based nitrogen (256.7 kg ha^{-1}) in four equal split recorded maximum dry matter, productive tiller per hill, grain per panicle, 1000 grain weight, panicle weight, grain yeld and ultimately gave maximum benefit: cost ratio (Balasubramanium, 2002. Whereas Samrat *et al.* (2002) repored that rice hybrid 'PA 6207' fertilized with 200 kg N ha^{-1}, produced maximum effective tiller, filled grains per panicle, 1000 grain weight, grain and straw yield.

Rice hybrid 'Sahyadri' produced significantly higher grain yield (53.22 q/ha) than other variety tested (Dixit *et al.*,2004).

Gandhi *et al.* (2011) while conducting a multi locational trial observed that new aerobic rice variety MAS 946-1 performed superior to the existing check variety Rasi at all the locations with an average grain yield advantage of 24.91 per cent under South Eastern Dry Zone (Zone-5) in Karnataka.

Upland rice variety 'PMK 3' produced significantly higher grain yield (3684 kg/ha) than other rice variety HD 297, HD 277, HD 502 (Marti *et al.,* 2011).

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