Applied Biological Research 19 (2): 180-186; (2017)
DOI: 10.5958/0974-4517.2017.00025.8

GROWTH, YIELD AND WATER PRODUCTIVITY OF DRY DIRECT SEEDED RICE IN RELATION TO SOWING DATE, VARIETY AND WEED CONTROL

Harjeet Singh Brar* and M.S. Bhullar

Department of Agronomy, Punjab Agricultural University, Ludhiana 141 004, Punjab (India)
*e-mail: *hsbrar86@gmail.com*

(Received 22 December, 2016; accepted 13 August, 2017)

ABSTRACT

A field experiment was conducted to study effect of sowing dates, varieties and weed control methods on growth, yield and water productivity of direct seeded rice (DSR) in a split plot design. Crop growth rates were higher during 60-90 DAS and were positively correlated with grain yield. Grain yield of DSR sown on the day of nursery sowing was at par with transplanted rice. It saved 69 cm irrigation water and increased irrigation water use efficiency (IWUE) by 41.3%. Rice cv. 'PR 115' recorded higher IWUE than cv. 'PAU 201' but had a statistically similar grain yield. Higher IWUE, water expense efficiency (WEE) and grain yield was recorded in three hand-weedings as compared to the sequential application of pre- and post-emergence herbicides. DSR sown on day of nursery sowing, coupled with short duration variety (PR 115) and three hand weedings produced statistically similar grain yield with higher IWUE as compared to transplanted crop.

Key words: Direct seeded rice, date of sowing, growth rate, irrigation water saving, yield potential

INTRODUCTION

Rice (*Oryza sativa* L.), the most important cereal crop in Asia, is grown under varying hydrological conditions and about 90% of world rice is produced and consumed in Asia alone. Rice-wheat is the major cropping system covering 13.5 million-ha in the Indo-Gangetic Plains of India. In Punjab, rice is a major *kharif* crop with its cultivation mainly practiced through transplantation after puddling, followed by continuous pounding of water for first 15 days for seedling establishment. This practice leads to high water losses through surface evaporation, percolation and nutrient losses through leaching. In Punjab, rice is cultivated on 2.9 million ha area (Anonymous, 2016); while its water resources are sufficient only to sustain 1.6 million ha rice cultivation. Crop water requirement in Punjab is estimated to be 4.53 m ha-m as against the available 3.26 m ha-m, comprising 1.58 m ha-m of surface water and 1.68 m ha-m of ground water resources (Minhas *et al.,* 2010) thus indicating a deficit of 1.27 m ha-m water. To overcome the water needs of transplanted paddy, underground water is over-exploited by excessive pumping resulting in decline in water table. There is a steady fall in groundwater depth in Punjab (Hira *et al.,* 2004). The fall in groundwater was 1 m year^{-1} during 2002-2006 (Humphreys *et al.,* 2010). The high water-use in rice is mostly due to water requirements for puddling and the losses associated with continuous flooding (Hafeez *et al.,* 2007). All these operations are cumbersome and labour intensive. Direct seeded rice (DSR) is an option which may save water, energy and labour.

DSR is a resource conservation technology which makes paddy cultivation cost-effective. DSR, depending on season, location, and type of DSR followed, leads to the saving of 11-18% of irrigation water (Tabbal *et al.,* 2002) and reduces labour-needs by 11-66% as compared to transplanted rice (Kumar *et al.,* 2009). DSR also ensures timely sowing in a stipulated time-frame and the crop matures 7-10 days earlier than transplanted crop due to the absence of transplanting shock (Dhyani *et al.,* 2005) and allows timely planting of succeeding wheat crop. Planting time, location specific variety and weed control methods are major factors that trigger crop growth and productivity. Rice varieties vary in their growth habit, water requirement and productivity (Gill *et al.,* 2006). Heavy weed infestation is another yield limiting factor in DSR. Crop-weed competition due to early emergence of weeds along with crop seedling is major constraints in direct DSR (Singh *et al*., 2005). Yield losses due to weeds in DSR vary from 50-90% (Chauhan and Johnson, 2011; Chauhan and Opena, 2012) depending on the weed flora, their density and duration of competition and their effect on crop growth rates at different stages of crop growth. Kumar *et al*. (2014) reported that the application of herbicides controlled weeds effectively and boosted crop yield. The present study was planned with the hypothesis that DSR raised with a right combination of sowing time, variety and weed control method may be a better option than transplanted rice in terms of growth, yield and water use efficiency.

MATERIALS AND METHODS

A field experiment was conducted at Research Farm, Department of Agronomy, PAU, Ludhiana located in the central plain region of Punjab under Trans-Gangetic agro-climatic zone of India, which is further described as cold winter and hot-dry summers. Winter season extends from December to January whereas summer season is encountered from April to June. The meteorological data for the crop season (May to October) was obtained from meteorological observatory of PAU (Table 1). The soil of experimental field was loamy sand with sand 81.4%, silt 7.7% and clay 10.9% as determined by international pipette method (Piper, 1966). Soil was slightly alkaline in reaction (pH 7.2), low in organic carbon (0.32%) and available N (244.5 kg N ha^{-1}), medium in available P (13.0 kg P ha^{-1}) and K (140.6 kg k ha^{-1}). The field experiment comprised of 24 treatment combinations *viz*., 6 sowing dates [direct seeding on 0 (June 5), 7, 14, 21 and 28 days after nursery sowing (DANS); transplanting 28 DANS], 2 rice varieties (PR 115 and PAU 201) and 2 weed control treatments (3 hand weedings at 20, 40, 60 days interval and pendimethalin application @ 0.75 kg ha^{-1} pre-emergence at 2 days after sowing followed by bispyribac-sodium 0.03 kg ha^{-1} as post emergence at 25-30 days after sowing). The experiment was laid in a split plot design with each treatment replicated three times.

Direct seeded plots were kept moist to avoid water stress to the crop and irrigations were given as per crop requirement and weather conditions. In transplanted treatment, water was kept standing for 2 weeks continuously for seedling establishment and thereafter irrigation was applied 2 days after the pounded water infiltrated into soil. Pendimethalin was applied immediately after seeding or transplanting. In direct seeded treatments, it was sprayed by dissolving in 500 L water ha^{-1}; in transplanted treatment, spread-uniformly in standing water by mixing in 150 kg sand ha^{-1}. Bispyribac-sodium was sprayed 25 days after seeding/transplanting by dissolving in 375 L water ha^{-1}. All the other production practices were followed as per recommended package of practices for *kharif* crops by PAU (Anonymous, 2016).

For growth analysis, the data on agronomic traits were noted at 30, 60 and 90 DAS and yield related traits recorded at harvest. Crop growth rate (CGR) was determined as per Hunt (1978) and expressed as g m^{-2} day^{-1}. Relative growth rate (RGR), estimated as per Wilson (1981), was expressed in g g^{-1} dry wt. day^{-1}. Net assimilation rate (NAR) was assessed as per Vernon and Allison (1963) and expressed as g m^{-2} day^{-1}. Water expense was assessed as per Dastana, (1967) using the formulae:

Water expense (cm) = irrigation water applied (cm) + effective rainfall (cm) ± profile water change (cm)

Water-use-efficiency (WUE) expressed as kg ha-cm^{-1} (Reddy and Reddi, 2009) was calculated as:

$$\text{WUE} = \frac{\text{Grain yield (kg)}}{\text{water applied to produce the yield (ha-cm)}}$$

Water-expense-efficiency (WEE) was calculated as:

$$\text{WEE (kg ha-cm)} = \frac{\text{Grain yield (kg)}}{\text{water expense (ha-cm)}}$$

The statistical analysis was performed as per Cochran and Cox (1967). Mean separation for various treatments was performed using least significant difference (LSD) test at 5% probability level.

RESULTS AND DISCUSSION

Crop growth rate

At 30-60 DAS stage, the crop growth rate (CGR) of direct seeded rice sown on 21 and 28 DANS was significantly higher than the 1st three dates of sowing (0, 7 and 14 DANS) (Table 2). Low rainfall during establishment of early sown dates [6 mm during 23rd (3-6 June) and 80 mm during 24th (10-16 June) standard metrological week] was the reason for lower CGR than late planting dates which received 155 mm rainfall during 26th (24-30 June) standard metrological week. During 60-90 DAS, direct seeding on 0, 7 and 14 DANS recorded significantly higher CGR than 21 and 28 DANS sowing dates and the CGR under 1st two dates was at par with transplanted treatment. Higher rainfall during the month of August (Table 1), coincided with the tillering stage of early sown crop, lead to more tillering and leaf area, thereby enhanced CGR significantly at 60-90 DAS as compared to late sowing dates in which crop was still in its seedling stage and did not reach its tillering phase. The transplanted crop started vigorously, after coming out of transplanting shock and hence recorded higher CGR. Amongst varieties, PR 115 showed significantly higher CGR during 30-60 DAS while PAU 201 recorded significant higher CGR during 60-90 DAS. PR 115 is a short duration variety and has early quick growth while PAU 201 is medium duration variety and pick up active growth later than PR 115. Weed control treatments did not significantly affect CGR during 30-60 DAS, but during 60-90 DAS three hand weedings showed significantly higher CGR than herbicides. Because herbicides provided effective control of weeds during early growth stages and at later stage weeds re-emerged and competed with the crop and reduced crop growth rate. The repeated hand hoeing kept the field free of weeds throughout which increased CGR.

Relative growth rate

The relative growth rate (RGR) of direct seeded rice sown on 0, 7 and 14 DANS was statistically lower than those sown on 21 and 28 DANS during 30-60 DAS (Table 2). During 60-90 DAS trend reversed in favour early sowing, and direct seeding on 0, 7 and 14 DANS recorded statistically higher RGR than those of 21 and 28 DANS sowing dates. Transplanted crop was statistically higher RGR than those of direct seeding dates. The differential reflected in RGR are due to the differences in CGR

Table 1: Mean monthly meteorological data during crop season

Parameters		June	July	August	September	October
Air temperature (°C)	Maximum	34.3	34.1	32.9	32.3	31.7
	Minimum	25.5	27.1	25.7	22.7	19.3
	Mean	29.9	30.6	29.3	27.5	20.5
Relative humidity (%)	Morning	85.0	87.0	91.0	92.0	92.0
	Evening	66.0	69.0	73.0	61.0	47.0
	Mean	76.0	78.0	82.0	76.0	69.0
Sunshine (h)		5.7	6.1	7.1	8.9	7.0
Evapotranspiration (mm)		5.5	4.9	4.2	117.2	97.6
Rainfall (mm)		277.3	152.7	392.8	44.7	39.0

Table 2: Effect of sowing time, variety and weed control on crop growth rate, relative growth rate, net assimilation rate and yield in rice

Treatments	Crop growth rate ($g\ m^{-2}\ day^{-1}$)		Relative growth rate ($g\ g^{-1}\ day^{-1}$)		Net assimilation rate ($g\ m^{-2}\ day^{-1}$)		Grain yield ($q\ ha^{-1}$)
	30-60 DAS	60-90 DAS	30-60 DAS	60-90 DAS	30-60 DAS	60-90 DAS	
Date of sowing							
Direct sowing 0 DANS (June 5)	10.2 b	26.4 a	0.035 b	0.035 b	8.41 b	9.03 b	50.5 ab
Direct sowing7 DANS (June 12)	11.6 b	28.2 a	0.042 b	0.032 b	9.38 b	9.80 b	46.2 b
Direct sowing 14 DANS (June 19)	11.3 b	22.3 b	0.038 b	0.030 b	9.34 b	7.81 b	46.7 b
Direct sowing 21 DANS (June 26)	16.0 a	11.0 c	0.056 a	0.015 d	14.98 a	3.92 c	39.8 c
Direct sowing 28 DANS (July 3)	14.5 a	8.5 c	0.050 a	0.012 d	13.76 a	2.83 c	32.9 d
Transplanting 28 DANS (July 3)	-	26.9 a	-	0.042 a	-	16.09 a	56.3 a
LSD $_{0.05}$	2.8	3.0	0.007	0.005	4.23	2.08	6.0
Variety							
PR 115	14.3 a	17.0 b	0.047 a	0.023 b	12.26 a	7.11 b	44.7
PAU 201	11.2 b	24.0 a	0.042 b	0.033 a	10.08 b	9.38 a	46.2
LSD $_{0.05}$	1.4	1.5	0.003	0.002	1.15	0.45	ns
Weed control							
Pendimethalin 0.75 kg f.b. Bispyribac 0.03 kg ha^{-1}	12.9	19.5 b	0.047 a	0.027	11.59	7.99	43.6 b
Hand weeding (20, 40 & 60 DAS)	12.5	21.6 a	0.041 b	0.028	10.76	8.51	47.2 a
LSD $_{0.05}$	ns	1.5	0.003	ns	ns	ns	2.1
Interaction							
Date of sowing (S) × Variety (V)	S	S	S	S	S	S	S
S × Weed control (W)	S	S	S	S	ns	S	S
V × W	S	ns	S	ns	S	ns	ns
D × V × W	ns	S	ns	ns	S	S	S

DANS: Days after nursery sowing; S: Significant interaction effect; ns: Non-significant interaction effect

during different growth stages among sowing dates as explained earlier. The transplanted crop grew vigorously as compared to direct sown rice during 60-90 DAS lead to higher RGR. Amongst varieties, RGR followed similar trend as were recorded for CGR; cv. PR 115 recorded significantly higher RGR during 30-60 DAS, while cv. PAU 201 gave significant higher RGR during 60-90 DAS. Differential growth habit of short (cv. PR 115) and medium (cv. PAU 201) duration varieties was the reason for differential growth rates at different growth stages. Among the weed control treatments, herbicide treatment controls the weeds effectively at earlier stage (before 60 DAS) and led to significantly higher RGR than that of three hand weedings. At later stage (60-90 DAS), RGR in herbicide treatment reduced and was at par with three hand weedings due to emergence of weeds at that stage.

Net assimilation rate

The net assimilation rate (NAR) is function of plant health and directly related to crop and RGR (Table 2). At 30-60 DAS, lower NAR of DSR sown on earlier dates than late sowing dates. Similar to CGR and RGR trend reversed at 60-90 DAS, the NAR for early sowing dates was statistically higher than late sowing dates. Transplanted crop showed highest NAR during both the stages and proved better than all direct sown dates. The differences in NAR may be attributed to differences in CGR and RGR. Short duration rice cv. PR 115 recorded significantly higher NAR during 30-60 DAS, while medium duration variety PAU 201 showed significantly higher RGR during 60-90 DAS. The NAR did not vary among weed control treatments.

Grain yield

Direct seeding of rice on the day of nursery sowing (June 5) recorded significantly higher grain yield than direct seeding on 21 and 28 DANS and was at par to direct seeding on 7 and 14 DANS (Table 2). Transplanted crop produced the statistically highest grain yield that was at par with direct seeding on 0 DANS. Higher CGR, RGR and NAR during the grand growth period in transplanted and early direct seeding treatments increased the grain yield. Gill *et al.* (2006) also reported that direct seeding on June 10, recorded the highest rice grain yield. The reproductive phase of late planted crop coincided with low temperature during end September which led to increased spikelet sterility and poor grain filling. Padhi (1995) reported that delay in rice seeding by 15 days from the optimum reduced the grain yield by 12.3-17.7%. The two rice varieties recorded statistically similar grain yield. Three hand weedings produced significantly higher grain yield as compared to sequential application of pendimethalin 0.75 kg ha^{-1} and bispyribac 0.03 kg ha^{-1}. Frequent weeding keeps field free from weeds, while in case of herbicide application weeds re-emerged at later stage. All these lead to higher CGR, RGR and NAR in the hand weeded crop which further improves grain yield.

Water use efficiency

The direct seeded rice saved 69 to 84 cm of irrigation water as compared to puddled transplanted crop. The saving in irrigation water increased with every delay in direct seeding. The savings in total water expense with direct seeding of rice on 0, 7, 14, 21 and 28 DANS were 41, 49, 57, 68 and 83 cm, respectively, as compared to puddled transplanted crop (Table 3). Direct seeding on the day of nursery raising reduced the total water expense by 17%, while this figure rose to 35% when rice was direct seeded on the day of transplanting as compared to the transplanted treatment. The irrigation water used for nursery raising, puddling and pounding increased the water expense in transplanted treatment. In case of varieties, longer duration of PAU 201 led to an increase in irrigation water and total water expense as compared to short duration variety PR 115. Because of two extra irrigations were applied to PAU 201 to complete its life cycle as compared to PR 115. Mahajan *et al.* (2009) also reported that the amount of irrigation water increased with the duration of cultivars. Irrigation water and total water expense did not vary among weed control treatments. Direct seeding of rice on 0, 7, 14, 21 and 28 DANS recorded 41.3, 37.9, 39.3, 27.2 and 5.4% higher irrigation water-use-efficiency (IWUE) than transplanted crop. Bhuiyan *et al.*, (1995) also reported that DSR has higher WUE than puddle transplanted rice. Higher IWUE and water-expense-efficiency (WEE) was recorded in early sown DSR and efficiencies decreased with delay in sowing. Because of decrease

Table 3: Effect of sowing time, variety and weed control on irrigation water applied and water use efficiencies in rice

Treatments	No. of irriga-tions	Irrigation water applied (cm)	Effective rainfall (cm)	Water left in soil profile at harvest (cm)	Total water expense (cm)	IWUE (kg ha^{-1} cm^{-1})	WEE (kg ha^{-1} cm^{-1})
<u>Date of direct sowing</u>							
0 DANS (June 5)	16	120	88.7	12.4	196	42.1^a	25.7^a
7 DANS (June 12)	15	113	88.0	12.3	188	41.1^a	24.6^{ab}
14 DANS (June 19)	15	113	80.0	12.3	180	41.5^a	25.9^a
21 DANS (June 26)	14	105	76.5	12.6	169	37.9^a	23.6^{ab}
28 DANS (July 3)	14	105	61.0	12.5	154	31.4^b	21.5^b
Transplanting 28 DANS (July 3)	22	$24^{\#}$ + 165	61.0	12.9	237	29.8^b	23.8^{ab}
LSD $_{0.05}$						5.1	3.1
<u>Variety</u>							
PR 115	15	117	75.9	12.5	180	38.3^a	24.8^a
PAU 201	17	132	75.9	12.5	195	35.1^b	23.6^b
LSD $_{0.05}$						1.8	1.1
<u>Weed control</u>							
Pendimethalin 0.75kg f.b. Bispyribac 0.03 kg ha^{-1}	16	124	75.9	12.5	187	35.2^b	23.3^b
Hand weeding	16	124	75.9	12.5	187	38.0^a	25.2^a
LSD $_{0.05}$						1.8	11.0

DANS: Days after nursery sowing; IWUE = Irrigation water-use-efficiency; WEE = Water expense efficiency;
[#]Irrigation water applied for nursery rise and puddling for transplanted crop.

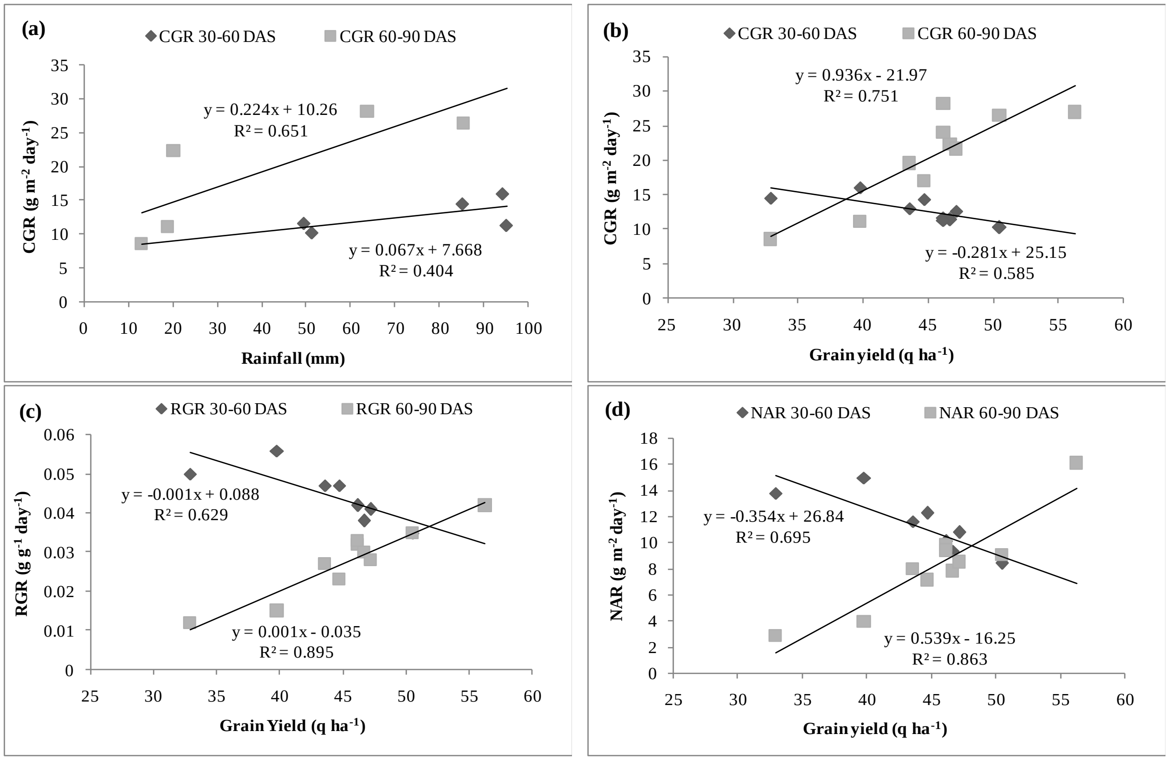

Fig. 1: Relationships between a) rainfall and CGR; b) CGR and grain yield; (c) RGR and grain yield; and (d) NAR and grain yield

in yield with delay in sowing. Among the varieties, PR 115 recorded 9.1 and 4.6% higher IWUE and WEE than PAU 201; two extra irrigations to PAU 201 reduced its efficiency. Mahajan *et al.* (2009) reported higher WUE in short duration cultivars. The three-hand weeding recorded 8.0% higher IWUE and 8.2% higher WEE as compared to herbicidal treatment, owing to higher grain yield under hand weedings and similar irrigation water expense under both the treatments.

Relationships between rainfall, crop growth parameters and grain yield

Crop growth is directly correlated with rainfall, but it varies with the time of rainfall and stage of crop growth. CGR of direct seeded rice was positively correlated with rainfall (Fig. 1a). Correlation was higher during 60-90 DAS ($R^2 = 0.651$) than during 30-60 DAS ($R^2 = 0.404$). During 30-60 DAS, crop under early tillering phase respond comparatively less to rainfall, while during 60-90 DAS crop under profuse tillering followed by panicle initiation phase respond more to rainfall. So, rainfall in August coincided with peak tillering followed by panicle initiation phase which led higher CGR at 60-90 DAS.

Grain yield of direct seeded rice responded variably to crop growth parameters at different growth stages (Fig. 1b-d). During 30-60 DAS, crop growth parameters (CGR, RGR and NAR) did not contribute to grain yield, moreover CGR, RGR and NAR were negatively correlated with grain yield at this stage with R^2 values of 0.585, 0.629 and 0.695, respectively. However, during 60-90 DAS, crop growth parameters were positively correlated with grain yield. During this stage CGR, RGR and NAR were positively correlated with grain yield with R^2 values of 0.751, 0.895 and 0.863, respectively. Since all these growth rates and assimilates coincided with panicle initiation and early grain development phase, therefore they contributed to a higher grain yield.

The present study concluded that timely sown (1st week of June) DSR coupled with short duration variety and proper weed control measure was at par with transplanted rice in terms of growth rate and grain yield. DSR was much better in water saving and water use efficiency than transplanted rice.

REFERENCES

Anonymous. 2016. *Package and Practices for Kharif Crops*. Punjab Agricultural University, Ludhiana, Punjab (India).

Bhuiyan, S.I., Sattar, M.A. and Tabbal, D.F. 1995. Wet seeded rice: Water use efficiency and productivity constraints to wider adoption. pp. 143-147. **In**: *Constraints, Opportunities and Innovations for Wet Seeded Rice* (ed. K. Moody). IRRI, Manila, Philippines.

Chauhan, B.S. and Johnson, D.E. 2011. Growth response of direct seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. *Weed Science*, **59:** 119-122.

Chauhan, B.S. and Opena, J. 2012. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. *Field Crops Research*, **137:** 56-69.

Cochran, W.G. and Cox, G.M. 1967. *Experimental Designs*. John Wiley, New York, USA.

Dastana, N.G. 1967. *A Practical Manual for Water Use Research*. Navabharat Parkashans, Pune (India).

Dhyani, V.C., Singh, V.P. and Singh, G. 2005. Response of rice to crop establishment and weed management. *Indian Journal of Weed Science,* **37:** 260-262.

Gill, M.S., Kumar, A. and Kumar, P. 2006. Growth and yield of rice (*Oryza sativa* L.) cultivars under various methods and time of sowing. *Indian Journal of Agronomy,* **51:** 123-127.

Hafeez, M.M., Bouman, B.A.M., Van De Giesen, N. and Vlek, P. 2007. Scale effects on water use and water productivity in a rice-based irrigation system (UPRIIS) in Philippines. *Agricultural Water Management,* **92:** 81-89.

Hira, G.S., Jalota, S.K. and Arora, V.K. 2004. *Efficient Management of Water Resources for Sustainable Cropping in Punjab.* Department of Soils, PAU, Ludhiana, Punjab (India).

Humphreys, E., Kukal, S.S., Christen, E.W., Hira, G.S., Singh, B., Yadav, S. and Sharma, R.K. 2010. Halting the groundwater decline in north-west India which crop technologies will be winners? *Advances in Agronomy,* **109:**155-170.

Hunt, R. 1978. *Plant Growth Analysis*. Edward Arnold, London, UK.

Kumar, K., Shukla, U.N., Singh, M., Singh, S., Singh, R. and Pant, A.K. 2014. Yield potential of direct seeded rice (*Oryza sativa* L.) as influenced by different seeding technique and weed management practices. *The Bioscan,* **9:** 981-984.

Kumar, V., Ladha, J.K. and Gathala, M.K. 2009. Direct drill-seeded rice: A need of the day. **In**: *Annual Meeting of Agronomy Society of America*, November 1-5, 2009, Pittsburgh. Pennsylvania, USA.

Mahajan, G., Baharaj, T.S. and Timsina, J. 2009. Yield and water productivity of rice as affected by time of transplanting in Punjab India. *Agricultural Water Management,* **96:** 525-532.

Minhas, P.S., Jalota, S.K., Arora, V.K., Jain, A.K., Vashist, K.K., Choudhary, O.P., Kukkal, S.S. and Vashist, B.B. 2010. *Managing Water Resources for Ensuing Sustainable Agriculture: Situational Analysis and Options for Punjab.* Research Bulletin No. 2/2010. PAU, Ludhiana.

Padhi, A.K. 1995. Response of rainfed rice to sowing time. *Oryza*, **32:** 124-126.

Piper, C.S. 1966. *Soil and Plant Analysis*. Hans Publishers, Bombay (India).

Reddy, T.Y. and Reddi, G.H.S. 2009. *Principles of Agronomy*. Kalyani Publishers, Ludhiana, India.

Singh, R.P., Singh, C.M. and Singh, A.K. 2005. Effect of crop establishment methods, weed management and split nitrogen application on weed and yield of rice (*Oryza sativa* L.). *Indian Journal of Agricultural Science,* **75:** 285-287.

Tabbal, D.F., Bouman, B.A.M., Bhuiyan, S.I., Sibayan, E.B. and Sattar, M.A. 2002. On farm strategies for reducing water input in irrigated rice: case studies in Philippines. *Agricultural Water Management,* **56:** 93-112.

Vernon, A.J. and Allison J.C.S. 1963. A method of calculating net assimilation rate. *Nature,* **200:** 814 (23 November 1963) [doi:10.1038/200814a0].

Wilson, W.J. 1981. Analysis of growth, photosynthesis and light interception for single plants and stands. *Annals Botany,* **8:** 507-512.