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Performance of different rice and wheat varieties under alternate crop establishment techniques in rice-wheat rotation

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ABSTRACT

An experiment was conducted in rice-wheat system under eastern sub-Himalayan plains of West Bengal toevaluate the performance of predominant rice and wheat varieties under alternate crop establishment techniques. The experiment was laid out in a split-plot design having 20 treatment combinations in 3 replicates. Four different crop establishment methods [Direct seeded rice(DSR), bed planting(BP), unpuddled transplanting(UPTR) and puddled transplanting(PTR) for rice and surface seeding (SS), bed planting(BP), zero tillage(ZT) and conventional tillage(CT) for wheat] in main plots and five different varieties (Swarna sub 1, Pratiksha, IET 5656, Naveen and MTU 7029 for rice and PBW 343, K 0307, K 1006, DBW 39 and HD 2967 for wheat) in sub plots were allocated randomly for both rice and wheat. It was revealed from the results that the growth parameters of rice (plant height, number of tillers m^{-2}, dry matter accumulation and LAI) recorded at different stages of growth differed significantly with various crop establishment techniques and in all the stages of observation the values were superior in PTR in the first year and in UPTR in the second year. PTR produced significantly higher number of matured panicles m^{-2}(323 and 331 during 2015 and 2016, respectively),but there was no significant difference in number of matured panicles m^{-2} between PTR and UPTR in second year.In the first year PTR recorded significantly higher grain yield (4502kg ha^{-1}), while UPTR recorded maximum grain yield(4616 kg ha^{-1}) during second year of experimentation, being at par with PTR(4606 kg ha^{-1}) . Swarna Sub 1 (3779 kg ha^{-1}) in first year and Pratiksha (4215 kg ha^{-1}) in second year recorded maximum grain yield. In both the years of experimentation, BP in wheat resulted in maximum dry matter accumulation, tiller production, LAI as well as CGR, being at par with ZT in most of the growth parameters.BP (3713 and 3699 kg ha^{-1} during 2015-16 and 2016-17, respectively) recorded significantly higher grain yield in both the years of experimentation. This was followed by ZT (3454 and 3492 kg ha^{-1} during 2015-16 and 2016-17, respectively). The yield increase under BP was 8.12 and 14.52% over CT during 2015-16 and 2016-17, respectively.In the first year, HD 2967 recorded the highest grain yield (3580 kg ha^{-1}), while DBW 39 was the highest yielder (3392 kg ha^{-1}) in second year. Both the varieties were statistically at par in terms of grain yield in both the years of experimentation.Considering the above results, it can be concluded that Pratiksha and Swarna Sub 1 in rice and HD 2967 in wheat performed better in conservation agriculture (CA)-based management options.

Keywords: Alternate crop establishment techniques, rice, varieties, wheat and yield

The rice-wheat system, the world's largest agricultural production system, covers an area of 12.3 million hectare (Mha) in India with 0.5 Mha in Nepal, 2.2 Mha in Pakistan and 0.8 Mha in Bangladesh and around 85 per cent of this area falls in Indo-Gangetic plains (IGP) (Bhatt *et al.*, 2016). As a system, rice-wheat occupies about 24 m ha area worldwide (Ladha *et al.*, 2000) and in India it is the most popular and prevalent crop sequence. Agricultural production has been able to keep pace with population demand for food during the past few decades; this came about through significant area and yield expansion. It is estimated that about 2.5 per cent growth in cereal production will be required to meet food demands in the next decade (Hobbs and Morris, 1996).There is, therefore, a huge challenge ahead in the region to sustainably meet future food demands without damaging the natural resource base on which agriculture depends.A decline in land productivity, particularly of the rice-wheat (RW) system, has been observed over the past couple of years in the northern and north-western IGP despite the application of optimum levels of inputs under assured irrigation (Paroda, 1997).

For growing rice, puddling may not be required as almost similar yield can be obtained under unpuddled transplanted conditions as reported by the scientists (Islam *et al.*, 2014; Sharma *et al.*, 1988).In Northern part of West Bengal, rice-wheat is also a common cropping sequence where rice is grown under rainfed puddled condition and wheat is grown after harvesting rice. Again due to high residual moisture even after harvesting medium-long duration varieties of rice, the sowing of subsequent rabicrops in the rotation gets delayed. Under such condition, the technologies like zero tillage, surface seeding or bed planting in wheat are supposed to be very promising. Substantial savings of time and fuel can be made by adopting these alternate tillage practices to make the production of rice and wheat more cost effective. Again in rice, bed planting or unpuddled transplanting may serve as alternative crop establishment techniques through which we can address the issue of profit maximization with conservation of natural resources.

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It is the need of the time to assess the performances of different high yielding varieties of both wheat and rice under these alternate crop establishment strategies. A single variety may not always perform better under all crop establishment techniques. The farmers always go for a single variety, Swarna (MTU 7029) almost in all land situation and under all establishment techniques. The variety prevalent in this zone for both rice and wheat has to be evaluated under various crop establishment techniques. With this backdrop, the experiment has been taken up.

MATERIALS AND METHODS

The experiment was conducted at the Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, located at 26°24′02.2′′N latitude, 89°23′21.7′′E longitude and at an elevation of 43 meters above mean sea level. It was carried out for two consecutive rice-wheat rotations, *i.e*., *kharif*, 2015 to rabi, 2016-17. The experimental site was bestowed with sub-tropical per humid climate. The annual precipitation varied from 2800-3000 mm of which 70-90 per cent used to be received during monsoon months (June – September). Temperature began to rise from February – March and reached its peak during April – May (30-35°C). The relative humidity remained very high (80-90%) almost throughout the year except during winter months (50-60%). The soil (0-15cm), on which the experiment was carried out, was sandy loam in texture (sand 69%, silt 21% ,clay 10%) with good drainage facility and pH 5.54, soil organic carbon 0.91, Mineralizable N 128.36 kg ha^{-1}, Available phosphorus 17.52 kg ha^{-1}, Available K_2O 122.09 kg ha^{-1}.

The experiment was laid out in a split-plot design having 20 treatments in 3 replicates. Four different crop establishment methods [Direct seeded rice (DSR), bed planting (BP), unpuddled transplanting (UPTR) and puddled transplanting (PTR) for rice and surface seeding (SS), bed planting(BP), zero tillage (ZT) and conventional tillage (CT) for wheat] in main plots and five different varieties (Swarna sub 1, Pratiksha, IET 5656, Naveen and MTU 7029 for rice and PBW 343, K 0307, K 1006, DBW 39 and HD 2967 for wheat) in sub plots were allocated randomly for both rice and wheat. The crop establishment methods were in long narrow strips with a size of each experimental plot of 50 m × 2m.

For UPTR, a mat type nursery bed was preparedand final land was prepared by ploughing with power tiller once.Conventional raised nursery bed were prepared under PTR with a width of 4 feetand final land preparation was done by 2 cultivator + 2 rotavator + harrowing with standing water. For UPTR, the seedlings were transplanted through 8 row transplanter, while transplanting was done manually for PTR.3-4 seedlings $hill^{-1}$ was set in transplanter for UPTR as well as under manual transplanting for PTR. Direct seeding in rice as well as zero tillage in wheat was performed with National make zero till drill (9-Tyne). Bed planting of riceand wheatwere done with 2 wheel drive RWC bed planter. The bed was formed with a single pass over the previous crop stubbles with a height of only 5-7 cm. Wheat seeds @ 125 kg ha^{-1} were broadcasted under surface seedingonto a saturated soil surface without any land preparation within rice stubbles. For conventional tillage of wheat the land was prepared by ploughing with 2 rotavator +1 power tiller + ladder with a seed rate of 100 kg ha^{-1}respectively. In DSR , ZT and BP plots for killing the existing weeds, a pre-plant glyphosate 41% S.L. @ 3.75 L ha^{-1} in 550 L water 7 days prior to sowing was applied. Bispyribac-Na @ 25 g a.i. ha^{-1} was applied at 20 days after transplanting in rice to control wide spectrum of weed flora, while 2,4-D Na salt 80% W.P. @ 1 kg a.i. ha^{-1} at 4-5 weeks after sowing was applied to kill the broad leaf weed flora in wheat. Boron was applied twice @ 0.20% with Solubor (B 20%), once at 35-40 days after sowing (DAS) and the next at 55-60 DAS. Check basin method of irrigation was followed keeping the depth of 4 to 5 cm.

Periodic plant samples were taken for periodical biometrical observations (at 30, 60, 90 DAS and at harvest). Harvesting of the experimental plots was done manually and yield was estimated on net plot basis excluding the border rows. After harvesting, the produce was threshed and grains were dried to record yield.

Biometric observation including growth attributes *viz*. plant height, number of tiller m^{-2}, leaf area index (LAI) and biomass production (g m^{-2}) and yield componentsviz.number of mature panicles m^{-2}, number of filled grains $panicles^{-1}$,panicle length (cm) and 1000 grain weight(g) were worked out during maturity. Grain yield (kg ha^{-1}), Straw yield (kg ha^{-1}) and harvest index were worked out accordingly for both rice and wheat.

Analysis of variance method was used for statistical analyses and for drawing conclusions. The significance of various sources of variation was tested by error mean square by Fisher-Snedecorst “F” Test at probability levels 0.05 (Cochran and Cox, 1957; Panse and Sukhatme, 1967). For comparison of ‘F’ tables and for computation of critical differences, Fisher and Yates table was consulted.

RESULTS AND DISCUSSION

Growth performance of rice

There was no significant difference in plant height at all the stages of growth during both the years of experimentation (Table 1). The maximum plant height (107.9 and 105.9 cm during 2015 and 2016, respectively)

Table 1: Growth attributes of rice as influence by crop establishment techniques and varieties

Treatments	Plant height (cm) at harvest		Total number of tillers m^{-2}						LAI 90 DAT		Biomass production at harvest ($g\ m^{-2}$)	
			60 DAT		90 DAT		Harvest					
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Crop establishment techniques												
DSR	101.8	99.6	162	162	212	221	200	212	3.82	4.41	765.54	897.87
BP	101.9	98.5	176	172	241	231	234	221	3.87	4.72	990.22	975.91
UPTR	107.7	101.0	265	285	312	355	306	338	4.24	4.40	1244.69	1429.20
PTR	107.9	105.9	284	297	355	368	344	349	4.22	3.88	1472.35	1401.67
SEm (±)	**0.96**	**1.02**	**2.47**	**3.03**	**3037**	**3.86**	**4.01**	**3.84**	**0.01**	**0.01**	**17.24**	**13.29**
LSD (0.05)	**NS**	**NS**	**8.54**	**10.47**	**11.65**	**13.37**	**13.89**	**13.30**	**0.04**	**0.04**	**59.67**	**45.99**
Varieties												
Swarna Sub 1	94.3	93.9	231	214	306	284	294	271	4.22	4.28	1178.03	1126.64
Pratiksha	106.8	102.2	220	242	288	329	283	313	4.17	4.48	1149.43	1275.42
IET 5656	110.2	106.1	206	221	273	287	261	270	3.99	4.51	1090.20	1099.71
Naveen	118.0	110.3	226	234	239	260	236	252	3.58	3.81	1004.04	1160.37
MTU 7029	94.7	93.6	227	235	295	310	281	295	4.23	4.39	1169.31	1218.68
SEm (±)	**3.08**	**2.92**	**6.72**	**7.05**	**10.06**	**8.92**	**8.42**	**8.50**	**0.03**	**0.03**	**34.96**	**36.55**
LSD (0.05)	**8.88**	**8.40**	**19.37**	**20.31**	**28.99**	**25.69**	**24.24**	**24.49**	**0.07**	**0.08**	**100.73**	**105.29**

Table 2: Yield attributes and yields of rice as influenced by crop establishment techniques and varieties

Treatments	Number of mature panicles m^{-2}		Number of filled grains $panicles^{-1}$		Panicle length (cm)		1000 grain weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest index	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
Crop establishment techniques														
DSR	190	208	132	131	20.8	21.0	22.12	22.50	2254	2750	4136	4901	0.34	0.36
BP	219	218	138	135	21.5	21.3	22.32	22.66	3027	3026	5201	5327	0.37	0.36
UPTR	288	328	151	153	23.4	23.4	23.14	22.94	4141	4616	6291	6974	0.37	0.39
PTR	323	331	154	152	23.6	23.5	22.92	23.14	4502	4606	7014	7115	0.38	0.40
SEm (±)	**4.04**	**3.70**	**1.99**	**1.94**	**0.32**	**0.31**	**0.46**	**0.42**	**58.79**	**50.29**	**85.93**	**73.71**	**0.05**	**0.02**
LSD (0.05)	**13.99**	**12.81**	**6.89**	**6.71**	**1.11**	**1.07**	**NS**	**NS**	**203.45**	**174.05**	**297.37**	**255.10**	**NS**	**NS**
Varieties														
Swarna Sub 1	272	262	147	141	22.6	22.2	23.05	23.15	3779	3575	5853	5795	0.37	0.38
Pratiksha	264	299	149	151	22.5	22.8	22.50	23.20	3599	4215	5776	6408	0.37	0.40
IET 5656	243	264	138	142	22.2	22.5	22.92	22.83	3325	3545	5588	5698	0.36	0.38
Naveen	226	247	137	135	21.3	21.5	21.45	21.50	2995	3370	5270	6315	0.33	0.36
MTU 7029	271	285	148	145	23.1	22.8	23.20	23.38	3708	4043	5816	6181	0.37	0.39
SEm (±)	**8.21**	**8.81**	**4.57**	**4.53**	**0.71**	**0.70**	**0.51**	**0.52**	**115.53**	**125.70**	**186.80**	**200.34**	**0.03**	**0.04**
LSD (0.05)	**23.65**	**25.39**	**NS**	**NS**	**NS**	**NS**	**1.46**	**1.50**	**332.82**	**362.13**	**NS**	**NS**	**NS**	**NS**

Table 3: Growth attributes of wheat as influenced by crop establishment techniques and varieties

Treatments	Plant height(cm) at harvest		Total number of tillers m^{-2}						LAI 90 DAS		Biomass production at harvest($g\ m^{-2}$)	
			60 DAS		90 DAS		Harvest					
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Crop establishment techniques												
ZT	96.02	95.44	232	239	309	315	294	300	4.14	4.19	890.41	922.50
BP	92.94	90.72	248	256	317	338	322	323	4.11	4.17	972.15	953.43
SS	79.06	75.49	150	153	191	195	174	180	4.07	4.10	651.91	594.21
CT	87.86	85.23	250	230	317	302	303	285	4.14	4.20	864.47	852.34
SEm (±)	**1.23**	**1.31**	**3.06**	**2.61**	**4.23**	**3.71**	**4.01**	**3.04**	**0.05**	**0.06**	**15.38**	**14.34**
LSD (0.05)	**4.27**	**4.55**	**10.59**	**9.04**	**14.65**	**12.84**	**13.89**	**10.51**	**NS**	**NS**	**53.23**	**48.46**
Varieties												
PBW 343	86.19	83.18	201	212	266	277	249	263	4.02	4.08	852.51	857.88
K 0307	88.51	85.56	209	224	277	289	261	273	4.36	4.38	867.68	829.21
K 1006	90.23	89.78	222	206	279	271	262	255	3.97	4.01	681.05	797.70
DBW 39	87.18	85.22	227	232	274	297	286	280	3.93	4.01	886.20	826.52
HD 2967	92.75	89.85	241	225	323	303	308	289	4.30	4.31	936.25	841.75
SEm (±)	**2.76**	**2.72**	**6.99**	**7.16**	**9.13**	**9.24**	**8.88**	**8.84**	**0.13**	**0.13**	**25.70**	**24.90**
LSD (0.05)	**NS**	**NS**	**20.13**	**20.63**	**26.29**	**26.64**	**25.59**	**25.47**	**0.37**	**0.37**	**74.05**	**71.71**

Table 4: Yield attributes and yields of wheat under different crop establishment techniques

Treatments	Number of mature panicles m^{-2}		Number of filled grains $spike^{-1}$		Spike length (cm)		1000 grain weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest index	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Crop establishment techniques														
ZT	267	277	40	40	10.40	10.46	39.98	39.72	3454	3492	5577	5729	0.38	0.38
BP	296	299	37	39	10.42	10.48	40.28	39.72	3713	3699	6131	5835	0.38	0.39
SS	124	130	35	32	9.38	9.34	39.32	39.62	2127	2066	4066	4081	0.34	0.32
CT	277	261	38	37	10.18	10.24	41.12	39.98	3434	3230	5360	5281	0.39	0.39
SEm (±)	**2.99**	**2.96**	**0.48**	**0.49**	**0.13**	**0.12**	**0.10**	**0.09**	**43.62**	**32.77**	**80.90**	**73.35**	**0.05**	**0.03**
LSD (0.05)	**10.34**	**10.25**	**165**	**1.70**	**0.46**	**0.41**	**0.34**	**0.32**	**150.93**	**113.41**	**279.95**	**253.82**	**NS**	**NS**
Varieties														
PBW 343	221	234	35	35	9.65	9.78	39.30	38.38	2826	2907	5225	5671	0.35	0.33
K 0307	226	244	36	37	9.83	10.05	41.08	41.33	3065	3073	5379	5208	0.37	0.37
K 1006	225	222	36	36	9.78	9.78	38.73	38.00	3086	2895	4976	5038	0.36	0.36
DBW 39	255	249	40	37	10.48	10.35	40.93	40.60	3353	3392	5339	5107	0.38	0.39
HD 2967	275	259	41	40	10.75	10.70	40.85	40.50	3580	3342	5500	5134	0.39	0.38
SEm (±)	**8.35**	**8.21**	**1.19**	**1.17**	**0.32**	**0.32**	**0.26**	**0.25**	**103.11**	**105.37**	**172.47**	**167.36**	**0.08**	**0.05**
LSD (0.05)	**24.05**	**23.65**	**3.43**	**3.38**	**0.92**	**0.92**	**0.74**	**0.73**	**297.03**	**303.55**	**496.81**	**482.10**	**NS**	**NS**

was recorded under PTR closely followed by UPTR (107.7 and 101.0 cm during 2015 and 2016, respectively). Naveen was the tallest (118 and 110.3 cm during 2015 and 2016, respectively), being at par with IET 5656 (110.2 and 106.1 cm during 2015 and 2016, respectively) and Pratiksha (106.8 and 102.2 cm during 2015 and 2016, respectively). Number of tillers m^{-2} at different stages of growth was found to differ significantly with various crop establishment techniques. PTR recorded the maximum number of tillers m^{-2} at 90 days after transplanting (DAT) (355 and 368 during 2015 and 2016, respectively), followed by UPTR (312 and 355 during 2015 and 2016, respectively) (Table 1). Islam *et al.*(2014) reported similar tiller production in puddle transplanted rice and single pass unpuddled transplanted rice under high Barind tracts of Bangladesh. The number of tillers was reduced during harvest as compared to 90 DAT under all crop establishment techniques due to tiller mortality at later stages. At 90 DAT, maximum tiller number was recorded with Swarna Sub 1 in first year (306 m^{-2}) and Pratiksha (329 m^{-2}) in second year. Among the different crop establishment techniques, UPTR recorded the highest LAI at 90 DAT(4.24)closely followed by PTR (4.22) in the first year;while BP recorded the maximum LAI at 90 DAT (4.72) in the second year. Higher LAI at 90 DAT was probably due to higher rate of leaf emergence resulted from greater interception of light under PTR and UPTR. LAI decreased sharply at harvest due to leaf senescence under all the crop establishment techniques.Among the varieties, the highest LAI was recorded with MTU 7029 (4.23 at 90 DAT) closely followed by Swarna Sub 1(4.22 at 90 DAT) in first year; while IET 5656 recorded maximum LAI at 90 DAT (4.51) in the second year.LAI values were statistically at par amongst Swarna Sub 1, Pratiksha and MTU 7029 in the first year, while IET 5656 and Pratiksha were statistically at par in terms of LAI in the second year. The values indicated similar leaf types in Pratiksha, MTU 7029, IET 5656 and Swarna Sub 1.It was noted that Naveen recorded maximum LAI at 60 DAT as compared to other varieties as Naveen reached the flowering stage earlier than the other varieties due to its shorter duration of growth. The growth tendency of different varieties was not similar for which there was variation in LAI among the varieties. The total biomass production at harvest was maximum irrespective of crop establishment techniques. The maximum dry matter accumulation was recorded with PTR in first year (1472.35 g m^{-2}) and under UPTR (1429.20 g m^{-2}) in second year. In the first year, Swarna Sub 1 recorded the highest biomass production (1178.03 g m^{-2}), closely followedby MTU 7029 (1169.31 g m^{-2}), being at par with Pratiksha (1149.43 g m^{-2}). However, in the second year, the variety Pratiksha produced maximum dry matter (1275.42 g m^{-2}), being at par with MTU7029 (1218.68 g m^{-2}).

Yield performance of rice

Number of matured panicles m^{-2} was found varying significantly under various crop establishment techniques during the years of experimentation (Table 2). PTR recorded the highest number of matured panicles m^{-2} (323 and 331 during 2015 and 2016, respectively). There was no significant difference in number of matured panicles m^{-2} between PTR and UPTR in second year. Among the varieties, Swarna Sub 1 produced the highest number of matured panicles m^{-2} (272) in the first year and Pratiksha (299) in the second year of experimentation. The number of filled grains panicle^{-1} was found to differ significantly under various crop establishment techniques. The highest number of filled grains pancle^{-1} (154) was achieved with PTR in first year and with UPTR (153) in second year. Varieties had no significant effect on the number of filled grains panicle^{-1}. Among the varieties,Pratiksha recorded the highest number of filled grains panicle^{-1} (149 and 151 during 2015 and 2016, respectively), closely followed by MTU 7029(148 and 145 during 2015 and 2016, respectively) and Swarna Sub 1(147 and 141 during 2015 and 2016, respectively). PTR recorded significantly higher length of panicle (23.6 and 23.5 cm during 2015 and 2016, respectively) during both the years of experimentation(Table 3). However, there was no significant difference in panicle length between PTR and UPTR during both the years of experimentation.Varieties showed no significant difference on panicle length during both the years of experimentation. The highest panicle length was obtained with the variety MTU 7029 (23.1 and 22.8 cm during 2015 and 2016, respectively). However, 1000-grain weight did not vary significantly under various crop establishment techniques in both the years of experimentation. However, maximum 1000-grain weight (23.14 g) was obtained under UPTR in first year and PTR in second year of experimentation. 1000-grain weight of rice with respect to varieties varied significantly during both the years of experimentation.

PTR recorded significantly higher grain yield (4502kg ha^{-1}) in first year (Table 2), while UPTR in the second year recorded maximum grain yield (4616 kg ha^{-1}), being at par with PTR (4606 kg ha^{-1}). Under PTR, the crop exposed to more water availability throughout the growing period and weed controlled manually indicating maximum weed control efficiency leading to higher yields. Sidhu *et al.* (2014) reported higher grain yield in rice under puddle transplanting than other crop establishment methods. However, in UPTR, weeds were controlled through herbicides including pre-emergence as well as post-emergence herbicides.

Application of glyphosate before land preparation might be helpful to control the initial flushes. The present experiment showed that grain yield in UPTR of rice was similar to PTR indicating that tillage intensity can be reduced to a significant extent to establish transplanted rice without sacrificing yield. Islam *et al.* (2014) reported that tillage intensity could be reduced to establish transplanted rice without sacrificing yield. Higher grain yield under unpuddled mechanical transplanting was also reported by Kumar (2011). Grain yield varied significantly among the varieties in both the years of experimentation (Table 2). Swarna Sub 1 (3779 kg ha^{-1}) in 1st year and Pratiksha (4215kg ha^{-1}) in 2nd year recorded maximum grain yield. Straw yield showed similar trends unlike grain yield. However, harvest index of rice varieties did not vary significantly in relation to crop establishment techniques. Better environment exhibited under PTR and UPTR might be helpful in exploring higher grain:straw ratio.

Growth performance of wheat

There was significant difference in plant height at all the stages of growth during both the years of experimentation (Table 3). The tallest plant (96.02 and 95.44 cm during 2015-16 and 2016-17, respectively) was recorded under ZT closely followed by BP (92.94 and 90.72 cm during 2015-16 and 2016-17, respectively). Noorka *et al.* (2009) reported higher plant height in wheat under alternate crop establishment techniques like zero tillage (ZT) over conventional tillage. At harvest, HD 2967 was the tallest (92.75 and 89.85 cm during 2015-16 and 2016-17, respectively). The highest number of tillers (317 and 338 m^{-2} during 2015-16 and 2016-17, respectively) was recorded under BP at 90 days after sowing (DAS), being statistically at par with ZT (309 and 315 m^{-2} during 2015-16 and 2016-17, respectively) and CT (317 and 302 m^{-2} during 2015-16 and 2016-17, respectively) during both the years of experimentation. The number of tillers was reduced during harvest due to mortality of tiller at later stages under all crop establishment techniques. Maximum tiller number was recorded with HD 2967 (323 and 303 m^{-2} during 2015-16 and 2016-17, respectively) at 90 DAS during both the years of experimentation. Irrespective of establishment techniques, LAI was maximum at 90 DAS, which coincided with the flowering stage, the stage in which the crop showed highest LAI (Table 3). Bed planting resulted in a favourable synthesis of growth favouring constituents in plant system due to better supply of nutrients as well as moisture which led to increased number of leaves per unit area and resulting in enlargement in leaf area also. This was in conformity with the findings of Alam (2013).The highest LAI at 90 DAS was recorded with the variety K 0307 (4.36 during 2015-16 and 4.38 during 2016-17) closely followed by HD 2967 (4.30 during 2015-16 and 4.31 during 2016-17). Green leaf area is the source of food production of green plants and significant variation was observed in respect to leaf area index among the varieties. In both the years of experimentation, BP recorded maximum dry matter accumulation (972.15g m^{-2} during 2015-16 and 953.43g m^{-2} during 2016-17), being at par with ZT in second year. Significantly higher dry matter accumulation was noticed in bed planting system as compared to conventional one probably due to better utilization of CO_2 and solar radiation as the plants were spaced-planted in bed planting system.In all the varieties taken in the experiment, dry matter went on increasing up to maturity of the crop. Except the variety K 1006, other four varieties exhibited higher production of dry matter. The cause of rapid increase of dry matter at later stages was possibly due to emergence of considerable number of new tillers $plant^{-1}$ and fertile spike $plant^{-1}$ (Balyan, 1992).Similar results were obtained by Ahmed *et al.* (2005) in wheat showing that variety had significantly different effect on dry matter production.

Yield performance of wheat

Number of matured spike m^{-2} was found to differ significantly under various crop establishment techniques during both the year of experimentation (Table 4). BP recorded the maximum number of matured spike m^{-2} (296 and 299 during 2015-16 and 2016-17, respectively). Among the varieties, HD 2967 produced maximum number of matured spike m^{-2} (275 and 259 during 2015-16 and 2016-17, respectively) in both the years of experimentation. Number of filled grains $spike^{-1}$ was found to differ significantly under various crop establishment techniques. The highest number of filled grains $spike^{-1}$ was achieved with ZT (40 $spike^{-1}$ during both the years). Number of filled grains $spike^{-1}$ was found to differ significantly among the varieties during both the year of experimentation. HD 2967 recorded the highest number of grains $spike^{-1}$ (41 and 40 during 2015-16 and 2016-17, respectively), closely followed by DBW 39 (40 and 37 during 2015-16 and 2016-17, respectively), being at par with each other. Spike length under various crop establishment techniques had a significant difference during both the years of experimentation. The highest spike length was recorded with BP (10.42 and 10.48 cm during 2015-2016 and 2016-17, respectively), closely followed by ZT (10.40 and 10.46 cm during 2015-16 and 2016-17, respectively), being at par with each other. The highest spike length was obtained with the variety HD 2967 (10.75 and 10.70 cm during 2015-16 and 2016-17, respectively) closely followed by DBW 39 (10.48 and 10.35 cm during 2015-16 and 2016-17, respectively).

Maximum 1000 grain weight (41.12 and 39.98 g during 2015-16 and 2016-17, respectively) was obtained under CT during both the years of experimentation. BP also recorded a higher 1000 grain weight (40.28 and 39.72 g during 2015-16 and 2016-17, respectively). K 0307 recorded maximum 1000 grain weight (41.08 and 41.33 g during 2015-16 and 2016-17, respectively) during both the years.

Perusal of data (Table 4) indicated the superiority of BP in terms of grain yield. BP (3713 and 3699 kg ha^{-1} during 2015-16 and 2016-17, respectively) recorded significantly higher grain yield in both the years of experimentation. This was followed by ZT (3454 and 3492 kg ha^{-1} during 2015-16 and 2016-17, respectively). The yield increase under BP was 8.12 and 14.52 per cent over CT during 2015-16 and 2016-17, respectively. ZT also recorded significantly higher yield(3454 and 3492 kg ha^{-1}during 2015-16 and 2016-17, respectively) over CT. The better yield performances under bed planting might be attributed to the higher response of crops towards nutrients and its efficient use by the plants, significantly resulting in the maximum number of tillers $plant^{-1}$, highest 1000 grain weight and higher number of grains $spike^{-1}$. Bed planting showed improved water use efficiency, fertilizer use efficiency as well as reduced infestation of weeds. Moreover, the bed planted crops were less prone to lodging, which was in conformity with the findings of Hobbs *et al.* (2000). Higher grain yields from BP and ZT mightalso be attributed to advancement of sowing time, soil moisture conservation for a longer period, appropriate seed rate and seeding depth, uniform distribution of seedsin lines, less leaching of nutrients due to localized placement of fertilizers, free exchange of gases and more plant photosynthesis as suggested by Gupta *et al*. (2002). Higher yields under BP over CT was also reported by a number of scientists (Yadav *et al.* , 2009; Alamgir *et al.*,2015). In the first year, HD 2967 recorded the highest grain yield (3580 kg ha^{-1}), while DBW 39 was the highest yielder (3392 kg ha^{-1}) in second year. Both the varieties were statistically at par in terms of grain yield in both the years of experimentation. The highest straw yield (6131 and 5835 kg ha^{-1} during year I and II, respectively) was also achieved under BP, which was statistically at par with ZT in second year. Harvest index (HI) value did not vary significantly under various crop establishment techniques and varieties during both the years of experimentation (Table 4).

Considering the above results, it can be concluded that rice under unpuddled transplanting followed by wheat under zero tillage would be the most viable option in rice-wheat cropping system in terms of the productivity. Pratiksha and Swarna Sub 1 in rice and HD 2967 in wheat performed better in CA-based management options than the other existing varieties of eastern sub-Himalayan plains.

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